Insights From the Columbia Accident Investigation Process

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The undersigned participated in conducting interviews with Columbia accident investigation participants, developing the content and identifying opportunities to consider for improving mishap preparedness, contingency action planning and execution of major mishap investigations.

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Executive Summary

Putting aside the tragic circumstance, the investigation into the 2003 STS-107 Columbia accident provides an opportunity to review the preparedness and procedures that NASA has in place for future accidents. The intent of this monograph is not to reopen the investigation or to review or challenge any of the findings or recommendations of the Columbia Accident Investigation Board (CAIB). Rather, it provides an opportunity to document vignettes and observations from many of the participants and stakeholders of the investigation for both posterity and insight for future leaders.

As might be expected from events of this magnitude, there were some trials and tribulations across the investigation. Unsurprisingly, leadership played a key role in successfully standing up the investigation. In particular, retired Admiral Harold W. "Hal" Gehman Jr. was singled out by many of the interviewees for his keen insight and relaxed management style. His ability to organize the major investigative body, foster relationships with other organizations and put to rest concerns expressed in Congress and the press allowed the investigation teams to concentrate on the matters at hand and allowed leadership to address the external concerns. It demonstrates that finding the right leader is of critical importance to any endeavor.

Many interviewees compared the Columbia effort to the 1986 Challenger investigation, and almost everybody agreed that NASA had made great strides in conducting a more forthcoming investigation, with greater emphasis on communications and openness. In particular, the early involvement of public affairs and the readability of the CAIB final report provide a solid framework for any future accident investigation.

Despite the overwhelming opinion that the overall process worked well, everybody also believed some processes could be accomplished better or differently given the Columbia investigation experience. Nearly 50 individual opportunities were identified and organized using a seven-element framework to assist in collating and communicating the interview survey results. Framework elements included 1) Leadership and Independence,

2) Contingency Action Planning, 3) Preparation and Training, 4) Investigation and Recovery, 5) Legal, 6) Communications and 7) Administrative.

Selected key actionable opportunities included:

- Update NPR 8621.1 NASA Procedures and Guidelines for Mishap and Closecall Reporting, Investigating and Recordkeeping.
- Update Contingency Action Plans (CAPs) at the NASA Headquarters, center, and program levels.
- Conduct additional training with prospective mishap board and support organization personnel.
- Create a start-up checklist for the inter-agency contingency board

The authors and those interviewed for this monograph agree that each documented opportunity is worth considering. Applicability may not be clear in every accident investigation, but NASA and any future accident investigation board should understand the points of view and weigh the potential benefits and costs of implementation.

1.0 Introduction

On February 1, 2003, Columbia broke apart during entry, resulting in the loss of its crew of seven and the tragic end of mission STS-107. In compliance with the Agency Contingency Action Plan in effect at the time, NASA Administrator Sean O'Keefe immediately appointed an accident investigation board and grounded the space shuttle fleet pending the outcome of the investigation.

The Columbia debris search quickly exceeded any previous NASA experience, and the search rivaled or surpassed the National Transportation Safety Board's (NTSB's) recovery experiences with Pan American (Pan Am) World Airways flight 103 and Trans World Airlines (TWA) flight 800. Since investigators initially had little idea of exactly what had claimed Columbia, it was important to collect as much debris as possible, resulting in an undertaking that ultimately consumed some 1.5 million hours to cover 2.3 million acres. Unlike the Challenger accident 17 years prior, where the proximate cause of the accident was almost immediately apparent, it would take several months of intense analysis before investigators could reasonably describe how a piece of foam from the External Tank (ET) could bring down Columbia.

As the agency approached the 10-year anniversary of the accident, the Human Exploration and Operations Mission Directorate (HEOMD) initiated an effort to document the lessons learned from the accident investigation process, particularly standing up the investigative team. This monograph is one of the outputs of this effort, the other being a Web site with video interviews and other material. The intent of this lessons learned activity is *not* to reopen or evaluate the accident investigation or the findings and recommendations of the Columbia Accident Investigation Board (CAIB). Rather, it is to document observations from various participants that included members of the Columbia Accident Investigation Board, the Columbia Task Force (CTF), the NASA Accident Investigation Team (NAIT), and supporting agencies such as the NTSB, the press and congressional staff.

One of the things that became apparent during the interviews conducted for this monograph was the importance of selecting the right person to lead the investigation. Unanimously — from the administrative assistants that kept everything running, to the investigators on the CAIB and NAIT, to senior management across the various agencies — everybody agreed that Gehman was the right person. This was not a surprise to anybody who served under him during the CAIB, but it is a tribute that, even a decade later, every person mentioned his leadership style as a critical part of the success of the investigation.

No two accidents are the same, and accident investigators and the agencies that employ them frequently prepare for an investigation based on the familiarity of the circumstances and experience from the last accident. It is unlikely any of the *specific* lessons learned from Columbia will be directly applicable to the next accident. In fact, some of what was learned from Columbia has been overcome by events; in 2005, Congress enacted legislation prescribing that a Presidential Commission will investigate any future similar accident. But the general flow and feel of the investigation, and the questions and answers the participants faced, are probably similar to the quandaries some future set of investigators will face. Hopefully this monograph will provide insight for the next team.

It is true of most things in life, but one participant from Columbia reminded us to let "common sense prevail, but be prepared … even in the back of your mind … for a major contingency."[1]

One of the NASA participants in the investigation issued this final takeaway: "Spaceflight is difficult. It works in extreme environments and, with our current state of technology, it stresses the capabilities of the materials that we use to build the spacecraft. We all need to understand how difficult it is and any kind of hubris is unwarranted. We ought to be humble about spaceflight and remember there is no such thing as routine spaceflight." It is good advice.[2]

2.0 Document Layout

Section 3.0, "Activating the CAIB," provides the initial context and discussion leading to the formation and implementation of the CAIB immediately after the accident on the morning of February 1, 2003.

Section 4.0, "Opportunities," the bulk of the report, provides specific opportunities for improving the process to stand-up an accident investigation, along with supporting observations and discussion.

Section 5.0, "Preparing for the Next Accident," discusses the current state of contingency action planning and readiness within HEOMD.

Section 6.0, "Implications for Commercial Space," explores the complexity of investigating a potential mishap with a commercial space transportation provider.

Appendix A provides a summary of interviews and sources; Appendix B provides a summary of historical human spaceflight accident investigations; and Appendix C provides a discussion of the Columbia accident, largely excerpted from the published CAIB report.

3.0 Activating the CAIB

Shortly after the planned landing time of 9:16 a.m. Eastern time, NASA declared a Space Shuttle Contingency and executed the Contingency Action Plan for Space Flight Operations. As part of that plan, the Office of Space Flight also established a Headquarters (HQ) Contingency Action Team in Washington, DC, to oversee data collection and administrative matters. NASA also deployed the Mishap Investigation Team (MIT), which immediately began coordinating debris recovery efforts with federal, state and local agencies. The MIT initially operated out of Barksdale Air Force Base (AFB) in Louisiana, and soon after in Lufkin, Texas, and Joint Reserve Base (JRB), in Carswell, Texas.[3]

At 10:30 a.m., NASA activated the International Space Station (ISS) and Space Shuttle Mishap Interagency Investigation Board designated in the Contingency Action Plan. The plan in effect at the time of the Columbia accident listed, by name or title, the initial seven members of the Board:[4]

- U.S. Air Force (USAF) Chief of Safety, Major General Kenneth W. Hess
- Federal Aviation Administration (FAA) Office of Accident Investigation, Steven B. Wallace
- Commander, 14th Air Force, Major General Michael A. Hamel
- Commander, Naval Safety Center, Rear Admiral. Stephen A. Turcotte
- Department of Transportation (DOT) Chief of Aviation Safety Division, Dr. James N. Hallock
- Commander, Air Force Flight Test Center, Brigadier General Wilbert D. Pearson
- NASA Field Center Director or NASA Program Associate Administrator, TBD

Deputy Administrator Frederick D. Gregory, who was in Washington, DC, while Administrator Sean O'Keefe was at Kennedy Space Center (KSC) for the landing, called upon each of these individuals to report for duty. Major General Hamel nominated Brigadier General Duane W. Deal, the commander of the subordinate 21st Space Wing,

in his stead, based largely upon Deal's accident investigation background. Major General John L. Barry, Director of Program and Plans for the Air Force Materiel Command, replaced Brigadier General Pearson.

O'Keefe selected the Director of the Ames Research Center (ARC), G. Scott Hubbard, as the NASA Field Center Director since Ames had a comparatively minor role in the Space Shuttle Program. Hubbard remembered: "My cell phone rang, and it was Fred Gregory phoning me. He said that Sean is down at KSC and it's clear that we have had a serious accident. We don't quite know exactly what's going on but we have activated the contingency plan, which calls for formation of a board mostly by title or function, and there is a spot on there for one NASA person and the Administrator would like you to fill that role." Hubbard agreed.

Interestingly, some in NASA did not welcome Scott Hubbard back into the fold when the investigation ended, feeling he had been "too hard" on NASA. Fortunately, the feeling was not universal; for instance, the crew office personnel at Johnson Space Center (JSC) presented Hubbard with a token of their appreciation for a difficult job well done. Gestures such as this made coming home easier.[5]

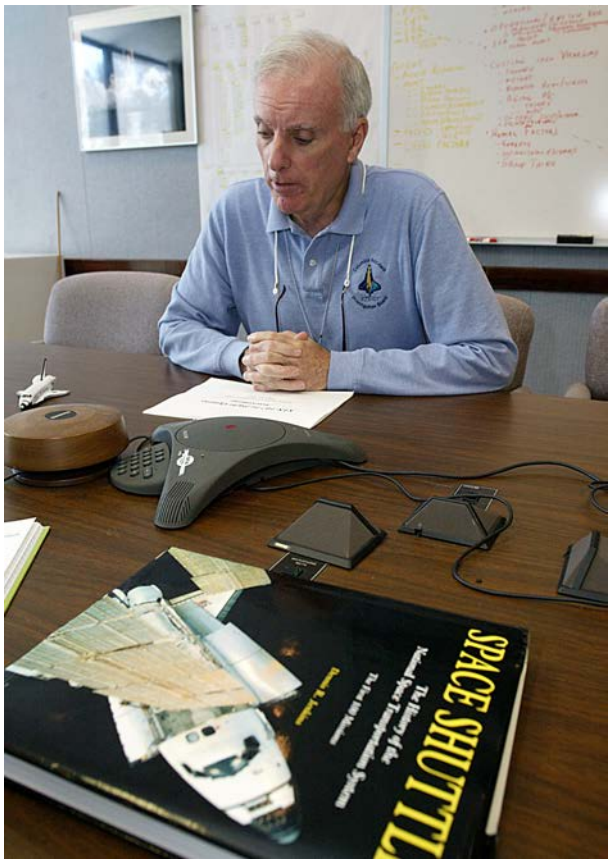
By design, the Contingency Action Plan did not specify the Board chairperson, so Gregory called O'Keefe to discuss possible candidates. Gregory remembered: "He gave me three or four names, one was Air Force, one was Army, one was Navy, and there may have been more than that. He said, 'Choose one and get a leader.' I looked at the list and Admiral Gehman looked like the best one. I called Admiral Gehman, who was in his car down in Virginia Beach — I told him what the situation was and asked him if he would chair this investigation panel and without hesitation he said yes." Later that day, O'Keefe officially named Gehman as the chairman.[6] The following day, February 2, O'Keefe formally appointed the other initial Board members.[7]

In addition to the eight voting members, two non-voting NASA representatives helped establish the Board. These included Bryan D. O'Connor, NASA Associate Administrator

for Safety and Mission Assurance, who served as an ex officio member, and Theron M. Bradley Jr., NASA Chief Engineer, who served as the Executive Secretary. Soon, two NASA officials, David M. Lengyel and Steven G. Schmidt, both from O'Keefe's staff, replaced Bradley. NASA also assigned J. William Sikora, Chief Counsel of the Glenn Research Center (GRC) in Cleveland, Ohio, as legal counsel to the Board.[8]

Almost immediately, pundits criticized the Board for a perceived lack of independence. In response to the 1986 Challenger accident, Ronald Reagan established a Presidential Commission led by William Rogers, completely independent of NASA. For Columbia, George W. Bush left it to the NASA Administrator to investigate his own agency. By appearances, it was not an ideal situation, but anybody who thought the Board was not independent had never met Admiral Gehman.

Gehman retired from the U.S. Navy (USN) on November 1, 2000, as a four-star admiral after 35 years of active duty. His last assignments were as NATO Supreme Allied Commander, Atlantic; the Commander of the United States Joint Forces Command; and Vice Chief of Naval Operations. He was, arguably, the most powerful man in the U.S. military.[9] Gehman brought his relaxed, friendly, decisive management style to the Board. This was essential to meld the widely divergent capabilities and personalities of the academic, industry, government, and military members of the Board and their support staffs during a long, intense investigation. Gehman made every member of the staff feel they were an important part of the organization, but there was never any doubt who was in charge.



Gehman — NASA Administrator Sean O'Keefe appointed Gehman to chair the CAIB. Gehman proved to be the ideal choice, able to manage a diverse set of Board members while simultaneously assuring Congress and the press that the results of the investigation would be impartial and comprehensive. (CAIB)

On Sunday, February 2, Gehman and the initial Board members convened at Barksdale AFB and conducted their first official meeting at 6 p.m. Central time. Afterward, Gehman gave his first press conference, later remembering, "I was trying to prove a point … I had a message that I was trying to deliver." The message was simple: Gehman, not NASA, was in control of the investigation.[10]

The Board initiated its investigation at 8 a.m. on February 3. On Tuesday, the Board toured the debris field around Nacogdoches, Texas, and formally relieved the Headquarters Contingency Action Team of its interim responsibilities. The Board also assumed operational control of the debris search and recovery efforts from the MIT.

During the first week, the Board received briefings on the Space Shuttle Program (called "Shuttle 101 training") and the STS-107 mission. The Board also reviewed the methodology of the Rogers Commission, the International Civil Aviation Organization standards adopted by the NTSB and the FAA, and the accident investigation models used by the Air Force and Navy. Rather than assign formal blame or determine legal liability for the accident, the Board intended to conduct both an accident and a safety investigation. As part of the safety investigation, the Board intended to delve into NASA's organizational structure and culture.[11]

Gehman remembered: "Once we went through the Shuttle 101 training at Barksdale AFB — not only external tanks and rocket boosters and all that kind of stuff but also the program — I immediately realized that the money, the power, the schedule, the influence, the decisions were all made at the Johnson Space Center. Right then I said that we're in the wrong place. We're not in the business of picking up debris. This is a program investigation and we have to go where the program is."[12] On February 6, the Board relocated to Houston, eventually settling into a facility at the Regents Park III office complex, just outside JSC. Staff and Board members were also located at KSC, Michoud Assembly Facility (MAF), the Southwest Research Institute (SwRI), Washington, DC, and elsewhere.[13]

Significantly, the Board soon changed its name to the Columbia Accident Investigation Board and rewrote its charter. Gehman said: "The thing that we did in the first 2 or 3 days was to try and visualize our output. This visualization was not completely compatible with the words of the charter. So we were questioning the charter in the first 72 hours."[14] The original charter, derived from Appendix D of the Contingency Action Plan, had a number of provisions members felt would impede a comprehensive and impartial investigation. Additionally, the Board was not satisfied that its initial charter adequately ensured independence from NASA. Sean O'Keefe signed the new charter on February 18, 2003, waiving the original requirements that the Board use standard NASA mishap investigation procedures. Instead, O'Keefe authorized Gehman to pursue "whatever avenue you deem appropriate" to conduct the investigation.[15]

The Board resolved to have its own administrative and technical staff that could conduct an independent investigation. Nevertheless, the Board would have to rely largely upon NASA for most testing and analysis since that was where the equipment and expertise resided. In addition, Gehman wanted control of his own budget and would establish and maintain records independent from NASA. O'Keefe also agreed to let the Board appoint new members.

It did not take long. On February 6, the Board appointed Roger E. Tetrault, retired Chairman and Chief Executive Officer of McDermott International. On February 15, the Board added Sheila E. Widnall, Ph.D., Professor of Aeronautics and Astronautics at the Massachusetts Institute of Technology and former Secretary of the Air Force. On March 5, the Board appointed Douglas D. Osheroff, Ph.D., the 1996 Nobel Laureate in Physics and Chair of the Stanford Physics Department; Sally K. Ride, Ph.D., Professor of Space Science at the University of California at San Diego and the first American woman in space; and John M. Logsdon, Ph.D., Director of the Space Policy Institute at the George Washington University. This brought the total number of Board members to 13, coincidentally the same as the Rogers Commission.[16]

Columbia Accident Investigation Board Members — A portrait of the members of the CAIB. Standing (from left): Dr. Douglas D. Osheroff, Major General John L. Barry, Rear Admiral Stephen A. Turcotte, Brigadier General Duane W. Deal, Major General Kenneth W. Hess, and Roger E. Tetrault. Seated (from left): G. Scott Hubbard, Dr. James N. Hallock, Dr. Sally K. Ride, Admiral Harold W. Gehman Jr., Steven B. Wallace, Dr. John M. Logsdon, and Dr. Sheila E. Widnall. (CAIB)

Several individuals involved with the investigation later remembered that adding Ride was fortunate. Not only did she bring her astronaut experience and was able to relate it well to the other Board members, but she brought experience from the Challenger investigation, allowing the CAIB to learn from those who had conducted a shuttle accident investigation before. Ken Hess later commented, "She brought some very good flavor to our investigation that would have been sorely missed had she not been there." Similarly, one person responsible for reporting on the CAIB's performance to Congress believed it was ideal to bring in an expert, such as Logsdon, on space policy since it lent credibility to the Board's investigation of the Space Shuttle Program as a whole.[17]

NASA Interfaces

In addition to the initial Headquarters Contingency Action Team, the Office of Space Flight activated the standing NASA Mishap Investigation Team to conduct the initial activities, including securing evidence and organizing the tactical response to the accident. The MIT reported to the Mishap Response Team (MRT), which served as the leadership for the NASA investigation. Both teams used standard NASA procedures for mishap investigations, including the impounding of all relevant data and hardware, taking witness statements, releasing information to the public, and conducting data and wreckage recovery and analysis. The majority of these tasks were subsequently subsumed by the CAIB.[18]

As the investigation progressed, Associate Administrator William F. Readdy reorganized the MRT to more closely align with the CAIB's structure and investigative paths. He furthered this decision by changing the name and charter of the MRT into the NASA Accident Investigation Team on March 18, 2003. Brock R. "Randy" Stone, the JSC Deputy Center Director, was the chairman of the NAIT, which comprised three groups that closely paralleled those of the CAIB. Group I, Materials, was led by James W. "Jim" Kennedy, the KSC Deputy Center Director; Group II, Operations, was led by Randy Stone, the JSC Deputy Center Director; and Group III, Engineering, was led by Frank J. Benz, the JSC director of Engineering. Each major space shuttle organization and NASA

center had membership in the NAIT, which was responsible for testing and analysis activities and controlled the debris within guidelines issued by the CAIB. This included the testing conducted at the SwRI in San Antonio.[19]

In addition, the NASA Task Force Team, later redesignated the Columbia Task Force, served as the formal interface between the CAIB and NASA, although the MRT/NAIT also had a direct interface to the CAIB members. The task force was established within the first few days after the accident under authority of Major General Michael C. Kostelnik, the Deputy Associate Administrator for the International Space Station and Space Shuttle, and was led by Frank T. Buzzard, the former ISS Chief Engineer who was scheduled to retire the week after the Columbia accident but stayed on as a NASA employee until the CAIB delivered its report. The CTF was responsible for action tracking and configuration management of all products delivered to the CAIB.

The CAIB Investigation

On March 28, 2003, the CAIB released a document that contained the procedures and guidelines that the Board would follow during its investigation. This document described the functions and responsibilities of the Board, described the required support staff, and contained the charters for the CAIB, CTF, and NAIT.[20]

The CAIB broke up into four groups, each led by several Board members. These groups were: Group I, Management and Treatment of Materials; Group II, Training, Operations, and In-Flight Performance; Group III, Engineering and Technical Analysis; and Group IV, Organization and Policy. There was also an Independent Assessment Team (IAT) that checked critical analysis. Each group took a different investigative path to ensure that all possible angles were covered.[21] Ken Hess remembered: "Gehman was 'follow the money,' Hubbard was 'follow the foam,' and the ops group [led by Hess] was, if you were looking for a bumper sticker, 'look at the bumper stickers' — everything we heard, was it true or not true? From our initial briefings we heard things like, it's a badge-less organization, anyone could stop a launch, the communication up and down is seamless, it

doesn't make any difference if you're a contractor or a government guy or an engineer, or not — and all those bumper stickers served as investigative angles that the operations team started poring into."[22]

Gehman created the Independent Assessment Team to make certain that the investigation was impartial and complete. Jim Mosquera, the head of the team, remembered, "it was kind of more like a special operations team, if you will: keep tabs on what was going on in the major areas of the investigation and look for the ones where things were not necessarily going too well or fast enough or taking some tangent that Board members felt really ought to be steered in another direction, or just frankly just keep tabs of what was going on." Although it ultimately did not find anything major to report, the concept proved useful and should be evaluated by any future investigation board.[23]

Although the CAIB ultimately investigated the accident for more than 6 months, and took several additional months to finish the report volumes and data archiving, this was not the initial hope. Gehman remembered that the Board members felt that "if we could find out what nut broke or what system failed, and if there was a fix to that, we could get the shuttle flying again. Consequently, for about the first 2 weeks we worked 7 days a week and we worked long hours trying to assimilate the videography that we had, the debris that was getting picked up, and interviews with the key managers. I had a relatively short-term goal that if we could find the Challenger-like smoking gun, maybe we could get this thing flying again. After about 10 or 14 days it was apparent that that was not the case — there was no simple, easy answer."[24]

Admiral Gehman worked with O'Keefe to ensure a smooth appearance to the rest of the world. Gehman recalled: "There's a tiny little story there — the story of my relationship with Sean O'Keefe. The reason I say that is because whether the issue was rewriting the charter, adding more members, spending money or whatever it was, I consulted or informed Sean O'Keefe. I wasn't into looking for battles where it wasn't necessary to have battles. I didn't know Sean before this … I didn't know him and didn't have any relationship with him. By informing and explaining what I wanted … to Sean, in

advance, like rewriting the charter or expanding the size of the Board or moving from Barksdale AFB to Houston, none of those became issues. There was no hidden conflict there because I liaisoned the issues away in advance."[25]

CAIB Public Hearing — In an effort to keep the public and press informed, the CAIB conducted numerous public hearings. Here, the CAIB holds a press briefing at the NTSB headquarters in Washington, DC, on June 24, 2003. From left: Roger Tetrault, Steve Wallace, Steve Turcotte, Admiral Gehman, and Laura Brown, CAIB Public Affairs Officer. (CAIB)

At least initially, there was a great deal of concern from Congress and the media about a perceived conflict of interest of a NASA-appointed board investigating a NASA accident. Gehman remembered: "One of the biggest lessons this Board had was that we started off with two strikes against us. The two strikes were the press was against us and Congress was against us because we weren't a Secretary of State Rogers–level commission. So the press criticized us for not being truly independent and Congress criticized us for not being senior enough." In response, Gehman spent a lot of time getting to know the chairpersons and ranking minority members of all four NASA oversight congressional

committees. He established a rapport with them and emphasized that the Board was going to do a good job and was independent. Gehman said: "That gets back to my standing out in the front of the gates at Barksdale AFB at 8 o'clock on Sunday night. I was trying to establish that we were operating on our own timeline, we were going much faster than anyone would ever have dreamed, we're here, we're at work, we're independent, we can do anything that we want, and I don't have to call back to Washington for permission to hold a press conference. That was part of a game plan to establish independence." To his credit, Sean O'Keefe understood that some things the Board did were theater so they could demonstrate their independence.[26]

Knowing that keeping the public informed was a critical issue, Gehman vowed to provide detailed updates on the progress of its investigation through frequent public hearings, press briefings, and by immediately releasing all significant information, with the exception of details relating to the death of the crewmembers and privileged witness statements taken under the condition of confidentiality. Showing no favoritism, the CAIB would simultaneously release its report to Congress, the White House, NASA, the public, and the astronauts' families. Throughout the investigation, Gehman consulted regularly with the administration and members of Congress to ensure that the Board provided the national leadership and public with a full and open accounting of the Columbia accident.

Unlike the previous NASA accident boards, the CAIB decided it needed to run a test program to thoroughly understand the cause of the Columbia accident. Scott Hubbard recalled, "It was probably in March where several of us, including myself, felt like that we really needed a test program to validate what we were thinking might have been the cause." There was, of course, video evidence of the foam strike, and some computational fluid dynamics and transport analysis had been run to understand how the foam impacted the orbiter. NASA set up a test program at SwRI, under the direction of the CAIB, that ultimately showed a piece of insulating foam could punch a hole through the wing leading edge RCC [Reinforced Carbon-Carbon panel]."[27]

At the request of congressional oversight committees, the Board significantly expanded the scope of its investigation to include a broad review of the Space Shuttle Program. In addition to establishing the accident's probable and contributing causes, the Board expected its report to serve as the basis for an extended public policy debate over the future course of the human spaceflight program. While striving for consensus, Gehman encouraged all Board members to voice any disagreements in minority reports.[28]

CAIB Public Hearing — The CAIB conducted a public hearing at the National Transportation Safety Board on June 12, 2003. Board members in attendance included (from left) Sally Ride, Steve Turcotte, Steve Wallace, Admiral Gehman, Doug Osheroff, John Barry, and John Logsdon. (CAIB)

Unlike many high-level boards and commissions, where the senior staff has the real power, there was little doubt with the CAIB that Gehman and the other Board members were running the show. Staff conducted the day-to-day investigative activities, but they did so under the direction of a Board member. Similarly, although the finished report was assembled by a group of professional writers and graphic artists, the Board drafted the content with little ghostwriting by staff. Everybody involved in the investigation took his or her responsibility seriously, and long days with few weekends were the norm for much

of the time. Ultimately, the CAIB staff numbered more than 100 mostly full-time people, with many others doing consultations or short-term analysis work. Although most of the Board members and staff were released after the first volume of the final report was released in August 2003, several members and the senior staff worked until just before the new year, assembling the remaining volumes and archiving data.[29]

As the investigative activities wound down and the efforts turned to analysis, report writing, and briefing the White House and members of Congress, the Board and staff moved to Analytic Services Inc.'s ANSER facility in Arlington, Va., just outside Washington, DC.[30]

The Columbia investigation lasted 6 months, with the CAIB issuing the first volume of its report on August 25, 2003. The CAIB concluded that the piece of foam debris from the External Tank's left bipod was the cause of the Columbia accident: "The physical cause of the loss of *Columbia* and its crew was a breach in the Thermal Protection System on the leading edge of the left wing. The breach was initiated by a piece of insulating foam that separated from the left bipod ramp of the External Tank and struck the wing in the vicinity of the lower half of Reinforced Carbon-Carbon panel 8 at 81.9 seconds after launch. During re-entry, this breach in the Thermal Protection System allowed superheated air to penetrate 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 breakup of the Orbiter."[31]

O'Keefe and Gehman — Admiral Hal Gehman (right) delivers the first volume of the CAIB report to NASA Administrator Sean O'Keefe on August 25, 2003. (NASA/Bill Ingalls)

As had been the case after the Challenger accident, it took almost 31 months before the Space Shuttle Program was ready to return to flight with the launch of STS-114 on July 26, 2005. There would be 22 more flights before the program ended with the landing of STS-135 on July 21, 2011. The last of the four remaining orbiters was transferred to its display site on November 2, 2012, marking the visible end of the Space Shuttle Program.

4.0 Opportunities

Introduction

This monograph documents opportunities for NASA to consider when updating mishap preparedness and contingency action plans and improving the execution of major mishap investigations.

The bulk of the opportunities and supporting discussions are based on a unique dataset represented by the experiences of participants in the Columbia accident investigation. The authors believe that critically examining the participants' points of view will aid future investigation boards.

Data Gathering

The authors conducted 30 interviews with 34 individuals ranging from members of the CAIB to representatives of the NAIT, CTF, and NTSB, as well as public affairs officers, congressional staff, and the press. Each interview, usually conducted by telephone, lasted between 60 and 90 minutes. Interviews followed a standard format that began by asking where the individuals were when they heard about Columbia; what worked well from their perspective; what could be improved; what caused delay or conflict or inefficiencies; what accelerated the investigation process; what was their key takeaway from the accident investigation experience. As might be expected, the answers varied greatly.

Framework for Analysis

The team has devised a seven-element framework consisting of the following elements:
1) Leadership and Independence, 2) Contingency Action Planning, 3) Preparation and Training, 4) Investigation and Recovery, 5) Legal, 6) Communications and 7) Administrative.

Opportunity Structure

Each opportunity is presented with an action statement (title) and has one or more observations and a supporting discussion section.

Opportunity Summary Table

Forty-seven individual opportunities have been identified for consideration and are summarized in the following table.

A	**Leadership and Independence**
A.1	Select a Strong Leader
A.2	Quickly Establish Independence
A.3	Eliminate Conflict of Interest
A.4	Identify Knowledgeable but Independent Support Staff
B	**Agency Contingency Action Plan**
B.1	Validate Alignment with Congressional and White House Expectations
B.2	Conduct Senior Management Review of Contingency Action Plans
B.3	Ensure that the Agency Contingency Action Plan is Flexible
B.4	Ensure that Center Contingency Action Plans Are Detailed
B.5	Ensure Office of General Counsel Support for the Investigation
B.6	Address Board Member Hiring Process and Legal Status
B.7	Develop Organizational Start-up Template/Checklist
B.8	Develop Data and Configuration Management Templates
B.9	Define the NASA Public Affairs Office's Roles and Responsibilities
B.10	Address Interfaces with Inspector General
B.11	Address Management of Local Volunteer and Government Support
B.12	Address Pathology Support
B.13	Address Debris Recovery Processes, Organization, Roles and Responsibilities
C	**Preparation and Training**
C.1	Train Accident Investigation Personnel

C.2	Consider Memorandums of Understanding
C.3	Identify Potential Center Support Personnel and Contractors
D	**Investigation and Recovery**
D.1	Implement an Open, Data-Driven Accident Investigation Process
D.2	Establish a Policy for Disposition of Crew Module Debris
D.3	Ensure Crew Performance is Accurately Assessed in the Investigation
D.4	Develop Debris Recovery Guidance Material
D.5	Establish Secure Communications for Recovery Teams
D.6	Determine Crew Office Role in Debris Recovery
E	**Legal**
E.1	Establish Legal Counsel Early On
E.2	Empower Legal Staff in the Field
E.3	Resolve Jurisdictional Issues in Advance
E.4	Pre-Coordinate Roles with the NASA Office of Inspector General
E.5	Proactively Manage the Witness Statement Process
E.6	Be Prepared to Address FOIA, FACA, ITAR/EAR Issues
E.7	Establish a Relationship with the Department of Justice for Evidence and Records Management
F	**Communication**
F.1	Establish Public Affairs Officers' Support Early On
F.2	Provide Media Training for the Board
F.3	Develop Compliance Approach for Federal Advisory Committee Act
F.4	Leverage Social Media and Implement a Call Center
F.5	Carefully Coordinate Communication with the Crew's Families
F.6	Develop a Quick-Response, Independent Public Affairs Office Support Strategy
F.7	Communicate Both What You Know and What You Don't Know
F.8	Be Prepared to Educate the Media
G	**Administrative**
G.1	Implement a Rigorous Records Management Process
G.2	Establish a Quick-Response Procurement Process for Major Agency Mishaps
G.3	Establish and Document Flexible Rules and Guidelines for Travel
G.4	Plan Ahead for Printing Support
G.5	Leverage Public Affairs Support for Release of the Report

A. LEADERSHIP AND INDEPENDENCE

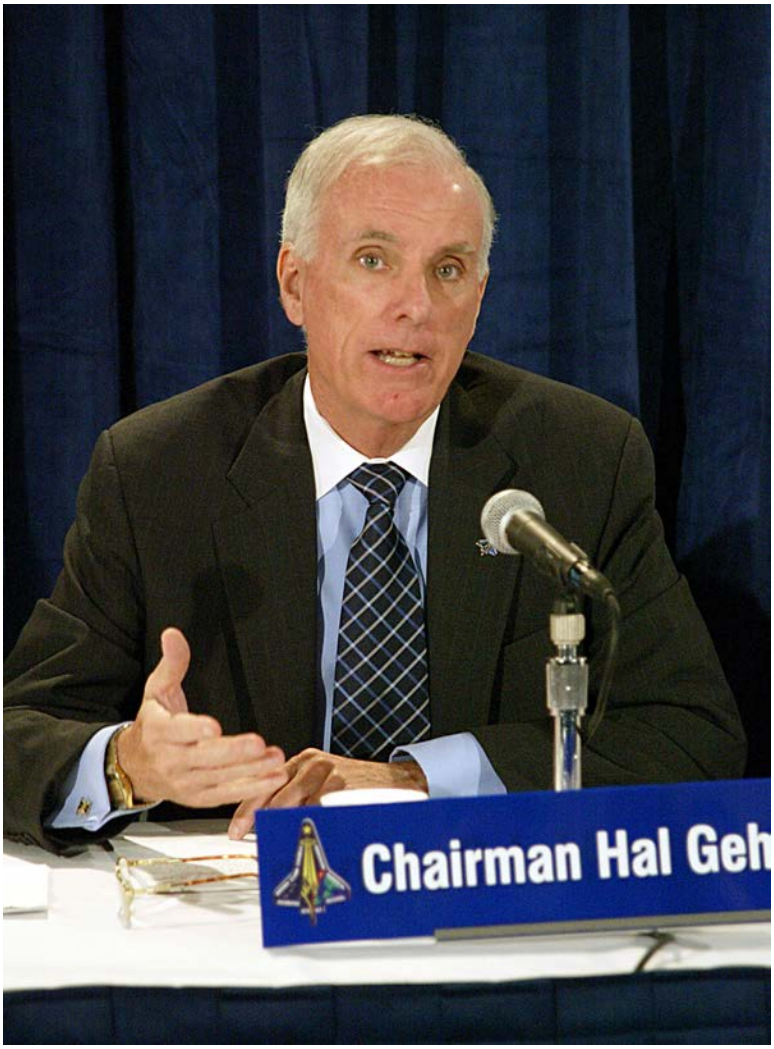
A.1 Select a Strong Leader

Observation: *Choosing a strong leader is important; the leader must be respected, independent from any aspect of the accident being investigated, and willing to take charge and face criticism. In the words of one of the participants, "Whoever leads [the next] board, if there is to be another one, has to be politically savvy because it's going to involve Congress and the public. It will be a very public operation and you need somebody that can speak to the press, speak to Congress and understand how those circles work in order to make sure that they don't get overrun by all the outside interests."*

Discussion: One of the things that became apparent during the interviews conducted for this monograph was the importance of selecting the right person to lead an accident investigation. Unanimously — from the administrative assistants that kept everything running, to the investigators on the CAIB and NAIT, to senior officials across the various agencies — everybody agreed that Gehman was the right person. This was not a surprise to anybody who served under him during the CAIB, but it is a tribute that, even a decade later, every person mentioned his leadership style as a critical part of the success of the investigation.

And it wasn't just his dealings inside the CAIB that people remember. One participant mentioned, "He had great public relations skills, he had great political skills — there's a reason he was a four star." Another remembered: "Admiral Gehman was an exceptional leader. He stayed above the investigation because he was experienced with large and capable teams."

One congressional staffer agreed, remembering: "I was extremely impressed with Gehman's ability to lead and cut through the bull. I think Gehman was a brilliant psychologist in terms of how he managed the Board itself and also NASA. I think he did an outstanding job." The staffer also believed that Gehman's conduct of the investigation ultimately eliminated any question regarding the independence of the CAIB.



Admiral Gehman — The proper chairperson can make or break a board, especially its credibility with the public, press and Congress. Even a decade later, every person interviewed for this monograph mentioned Admiral Gehman's leadership as being critical to the success of the Columbia investigation. (CAIB)

Admiral Gehman was equally respected on the NASA side: "First thing I would say about Admiral Harold Gehman was he was a gifted leader, highly intelligent, and as an organizational leader I learned a lot from him just watching him and interfacing with him on a daily basis. He was adept at what I would call 'herding cats'; there were a lot of personalities on the accident investigation board that would go in different directions for their own reasons, like cats. Admiral Gehman was extremely capable and able to keep the Board focused, move it forward when it needed to move forward, reorganize it when it needed to be reorganized. So I have a great admiration and respect for Admiral Gehman; he was a wonderful choice to do that job."

Another aspect of leadership is knowing how to divide and conquer. From the beginning, the CAIB ran three independent lines of investigation in an attempt to ensure whatever answer they came up with could be validated. This was particularly important before the Modular Auxiliary Data System (MADS) recorder was recovered since it seemed the final answer would be driven most by circumstantial evidence. One CAIB member recalled, "I take my hat off and really salute Gehman in this process because he kept the various lines of investigation different, so that if they all came up with the same answer, you knew that you had a consistent response that you would need to withstand the scrutiny not only of the NASA engineering family and NASA leadership but also from the Congress and American people standpoint."

A.2 Quickly Establish Independence

Observation: *An accident investigation board needs to establish its independence quickly and convincingly. This point has largely been overcome by Congress's 2005 mandate requiring a Presidential Commission to investigate any future NASA accident that results in loss of life or vehicle. Nevertheless, it is another example of the importance of choosing a Board that has the ability to convince the politicians, public and media of the Board's independence and integrity.*

Discussion: The question of independence came early and often. Unlike Challenger, where the President appointed a commission to investigate the accident, for Columbia the NASA Administrator appointed the CAIB. One participant remembered, "As you know, there are a lot of political issues around NASA investigating itself, and so there was a lot of discussion about how the Board needed to act independently of NASA and how … to do that with the funding coming from NASA." Members worried, "How were we going to be able to convince Congress and the public, primarily, that this was a sufficiently independent Board and that the conclusions it came to were going to be accepted?" Part of the solution was to draft a new charter, "and not work off just an NASA Procedural Requirement [NPR] or something from NASA."

One CAIB member recalled: "We had a lot of problems with that [perception of independence] at the very beginning of our work. I mean Congress and other people were saying 'we don't want this Board we want somebody else,' they wanted to do just like the Challenger and get someone like Rogers to form an 'independent' board at that point." In fact, during the first couple of weeks, several participants worried that the White House or Congress would not believe the CAIB was independent and would charter their own commission. One member remembered, "There was discussion of whether we would be either shunted aside as not relevant by the commission or whether the politics would be such that Congress would establish a commission and simply pluck Admiral Gehman and a few other people out and stick them on a Blue Ribbon panel." The same individual continued, "They could have done it for Columbia and that was one of the great things about Admiral Gehman personally, I think — he's the one that carried that load politically and convinced the oversight committees that there was no need for a commission."

Indeed, Congress initially questioned the independence of the CAIB, and one congressional staffer remembered: "There was something about the way that O'Keefe was picking the chairman that caused everybody on the committee to pause and question their independence. I remember there being a back and forth discussion. It may have been because Gehman was a Navy guy … and obviously O'Keefe was Secretary of the Navy

for a brief period. I definitely believe there was a concern about independence." As it turned out, once Congress met Admiral Gehman, the situation resolved itself: "What happened to kill that [concern] was that [Congress] met Gehman — and he is a pretty impressive guy — and they became comfortable with that idea with having him at the helm. I think ultimately everyone was very impressed with his performance, and the members really put a lot of faith in his abilities."

Similarly, one reporter that covered the Columbia accident remembered: "It became clear once I got to know Gehman and his personality that this guy was going to be independent of anybody. He was not going to be beholden or kowtow or write any sort of report that was anything less than what he thought should be in it, no matter what."

One of the participants on the NASA investigation observed: "From my perspective, the CAIB functioned very, very well and I'm hard pressed to see how that would improve by having a presidentially appointed commission. I don't know that having a presidentially appointed CAIB would have made the CAIB better. I think it might have introduced an additional element in the chain of command. It could have made things a little difficult for us to get the work done."

A.3 Eliminate Conflict of Interest

Observation: *Any future accident investigation board should ensure that none of the members or supporting staff are in any way connected to the accident.*

Discussion: Independence goes further than just the investigation board itself. No board or commission could possibly muster the resources to conduct all of the technical evaluations, analysis and testing required in an accident the scope of Columbia. Despite being independent, the CAIB relied upon NASA to do most of the work. The major support groups (the CTF and NAIT, in the case of CAIB) within NASA also need to be independent and distant from the organizations directly involved in the accident. One member of the NAIT opined: "The first item is having nothing to do with the accident. Not being in the management chain and not having anything to do with the accident. This

allows unbiased support and advice to the accident board and avoids any appearance of a conflict of interest." Based on participating in the Challenger and Columbia investigations, another participant observed, "People involved in the accident cannot investigate themselves. They have an automatic bias."

Initially, several high-ranking NASA officials, with positions directly related to the accident, were appointed as ex officio members or support staff to the CAIB or MRT/NAIT. Members of the CAIB believed this was inappropriate: "You may remember that the next step was to ask Sean O'Keefe to remove certain people from the investigation. They were devastated by being removed because they assumed that it impugned their integrity, and I understood their feelings; I would probably feel the same way. But it just had to be. We couldn't have people that were part of the accident be part of the investigation team."

Sometimes, you do not even realize you have baggage. As one CAIB member recalled his key takeaway from the accident: "Organizations like NASA, highly professional engineering organizations, that were used to dealing with great unknowns and great risk, had become numb to it after a while. The process becomes, 'Can I get to launch on time?' And that was really the only measure of merit after a while. Everything else was just risk we had to deal with and we were used to that." The same member believed that "you can never stand far enough away from whatever it is that you are doing to get a fresh perspective," and that, sometimes, somebody else has to do that for you.

A.4 Identify Knowledgeable but Independent Support Staff

Observation: *Obviously, there will not be any future Space Shuttle accidents, but the lesson is equally appropriate for any human spaceflight program. The NASA task force leader should be sufficiently intimate with the program and NASA operations to know who, what, and where to draw support from during the early days of an investigation. However, they must also be sufficiently removed from the accident so as to avoid any perception of a conflict of interest.*

Discussion: Another function of NASA is to educate the accident board since most of the members will not be familiar with the vehicle they are investigating. One member of the CTF recalled: "One of the primary responsibilities of the Columbia Task Force was to educate the CAIB members and their support staff on 'Shuttle 101,' the basic operation and management of the shuttle system…. The key lesson learned is to recognize that they will not have detailed knowledge of the shuttle operations, its configuration, its engineering design, some of its early engineering design traits and how we got to the configuration, how we operated, how we did the program management, how the principle centers would interact. So recognize that this task force for any major investigation of a NASA incident will have to educate the board."

The participant continued: "The leader of the task force must have significant knowledge of the shuttle systems, its operation, and its interface at the multiple centers that support the shuttle program. The primary function or requirement for a task force director is that they've had nothing to do with the accident itself, either operations or management; they must be independent and must be outside."

B. AGENCY CONTINGENCY ACTION PLAN

B.1 Validate Alignment with Congressional and White House Expectations

Observation: *Regardless of how the formal accident board is chartered, or who is selected as its chairperson, planning for a contingency is important. Whatever entity ultimately investigates an accident will need support from the entire range of NASA organizations since that is where the technical expertise lies. Senior NASA leadership should begin a dialog with the White House and Congress to ensure that the Agency Contingency Action Plan matches their expectations.*

Discussion: Since Robert Seamans wrote the first mishap investigation policy in the aftermath of the Gemini 8 in-flight anomaly, NASA has been planning its response to a major accident. One participant on the NAIT remembered, "The Space Shuttle Program had originally set it up with a mishap investigation team chaired by the JSC safety division chief." That did not happen on Challenger since a Presidential Commission quickly usurped the entire investigation. Afterward, the Space Shuttle Program Contingency Action Plan was formalized as Appendix R of the NSTS-07700 document and stated, "This plan will be implemented in concert with the Contingency Action Plan for Space Flight Operations and NASA Center contingency plans." These plans allowed NASA to charter the investigation board and left it to the NASA Administrator to select a chairperson. Although the CAIB rose above the criticisms of this approach, in 2005, Congress mandated that a Presidential Commission investigate any future human space flight accident.

B.2 Conduct Senior Management Review of Contingency Action Plans

Observation: *Senior NASA leadership should regularly review the Agency Contingency Action Plan with the participation of the people and organizations called out in the plan. This should include the technical organizations, the general counsel, and public affairs. External organizations that will likely be called upon to support any investigation, such as the military, the FAA, and the NTSB, should be included in the reviews. Independent*

reviewers (for example, from the military aviation safety centers, Naval Reactors, or other safety-critical organizations) should also periodically review the plan.

Discussion: Another official remembered the impetus for the Columbia contingency action plan: "We were much better prepared for this mishap than we were for Challenger. I don't think we had any contingency plan for Challenger and that is why I think there was an immediate call for a Presidential investigation — an independent panel." Afterward, "One of the things that Dan [Goldin] and Sean [O'Keefe] wanted to assure was that we never appeared to be inadequately prepared to handle our own accidents." A senior official noted: "It's clear that knowledge of the plan by all applicable people is mandatory. I would suggest that there be a review of it every 6 months." The same official advised: "Make sure the principle players are aware of the plan and what it involves, and even though it may seem unrealistic, the plan has been built based on the experience of a couple of major accidents. It has to be updated to reflect lessons from the past." The authors note that this monograph is part of the continuous improvement process and that the HEOMD and external organizations do review their plan in conjunction with mission simulations.

B.3 Ensure that the Agency Contingency Action Plan is Flexible

Observation 1: *This argues against trying to be too specific in the Agency Contingency Action Plan since the exact circumstances of the accident cannot be known in advance. Some accidents may be technical in nature while others may be procedural. Some may focus on culture or other intangibles. The Agency Contingency Action Plan needs to be sufficiently flexible to allow the investigation board to follow the best path toward their goal. That being said, the plan needs to contain sufficient detail to assist the board during the initial start-up activities.*

Discussion: Despite the need for pre-planning to smooth the initial start-up of an investigation, several participants advised against too much planning or defining too stringent a procedure within the Agency Contingency Action Plan. One CAIB member

recalled: "The Board heard from the FAA on how they do accident investigations. NASA, NTSB, USAF, USN and each of the constituents wanted the internal processes and procedures to look like theirs. What we did was attempt to visualize what the output would be. In other words, were we going to fix blame, were we going to come up with fixes that you have to implement before you can fly again, was this going to be a lessons learned kind of a thing? We attempted to visualize what the output would be and then worked backwards to determine what processes we needed to get to that. It was not clear. We were hand wringing over the Navy way of doing it or the NTSB way of doing it, and we spent a lot of time on this as we tried to understand the merits of each." This member suggested: "In investigations like this, you don't know where it's going to go when you start. You don't really have any idea what's going to happen, so don't lock yourself into some preset, prescribed process because you don't know where it's going to go."

Observation 2: *Be flexible, but responsive. Each accident board will eventually develop its own organizational structure, rhythm, and process, but the Agency Contingency Action Plan should contain a boilerplate that can be used during the start-up phase.*

Discussion: Having a flexible Agency Contingency Action Plan will help minimize start-up transients, but everybody on both sides of the Columbia investigation cautioned that, no matter how well you plan, you will not execute that way, at least for long. One NASA representative advised: "Every accident investigation is different; every accident investigation board, its leadership, roles and responsibilities, will be different. So you can write down the principle functions that you will need, but then you need to work with them on a daily basis, be flexible, and expect your organization to change. As the accident investigation board changes their roles and responsibilities, be ready to change with it; add and subtract from your team with strong people who can support them."

Observation 3: *Any future accident board has choices. They can, like the CAIB, be intimately involved in the investigative process, or they can elect to be more of a review board that evaluates the results of others. The Agency Contingency Action Plan and NASA task force need to be sufficiently flexible to allow the accident board (especially if*

it is a Presidential Commission) to operate the way it determines best suits its role and members.

Discussion: During the first weeks of the investigation, members of the CAIB decided how they would tackle the investigation. One recalled: "I have served on many project review boards and various other advisory committees and whatnot. And there you sit for a day and people bring in presentations and you look at them and you ask questions and then you write a report." That is, by all accounts, largely how the Rogers Commission investigated the Challenger accident. Continuing: "[Because of] the magnitude of this and the visibility of this — and I think frankly that a growing concern, and its very hard for an agency to investigate itself, led the board somewhere between the first day and by mid March, to gravitate to being much more hands on. I think that if you have something similar, a true national tragedy of very large scope and scale, that thinking about what you might have to do, not just in a review board kind of capacity but in a hands-on capacity, was certainly a lesson learned. I don't know if we'll ever have something else of this scale but you have to prepare for the possibility." The hands-on approach taken by the CAIB was a significant structural difference from the Rogers Commission, and the Columbia report delved deeply into areas that would likely not have been uncovered if the CAIB members had been less involved in the process.

B.4 Ensure that Center Contingency Action Plans Are Detailed

Observation: *Each of the programs and NASA centers should have a contingency action plan that includes detailed procedures that will be executed in the event of an accident, such as securing all data and hardware. In addition, other organizations, including public affairs and legislative affairs, should have Contingency Action Plans that are subordinate to the Agency plan and guide their initial activities. Plans at this level can, and should, be much more detailed than the Agency Contingency Action Plan since the process at the working level is not, generally, as dependent on the type of accident.*

Discussion: The Mission Operations Directorate mishap plan, the one used by the flight

controllers in the Mission Control Center at JSC, seemed to work well. One participant remembered, "We have a plan, and with our organization, being an ops [operations] organization, one of the things we are really good at is executing per the plan." The flight directors "started talking to the team on the voice loops and making sure they all had that plan out and were going down the list and taking care of everything they were supposed to be taking care of, and it all went exactly per the plan. It was pretty much just following the procedure."

B.5 Ensure Office of General Counsel Support for the Investigation

Observation: *The importance of legal representation cannot be underestimated and should be accommodated in the Agency Contingency Action Plan and the interagency contingency board start-up checklist.*

Discussion: NASA legal counsel was assigned to both the CAIB and the NASA investigative groups. Given the small nature of the NASA legal team, most of the attorneys knew each other, and it did not take long for them to begin having regular tag-up calls. This ensured that they were giving consistent advise to the investigators, and it also allowed them to learn from each other.

Initially, the NAIT did not understand the need for an attorney, and, in fact, greeted the counsel, "okay you're a lawyer — what am I supposed to do with you?" This attitude promptly changed. The attorneys quickly showed that "there's a lot of stuff that has to be considered in rules and regulations that we don't need the technical folks bogged down trying to figure out." Despite the somewhat cold initial reception, one NASA official later opined that although "I couldn't figure out why in the world someone was trying to put an attorney on his team, I would never again establish a team without an attorney on it."

The counsel assigned to the CAIB had a warmer reception, for no other reason than there was a directive that the Board have a staff attorney. Despite this directive, contact information for the assigned counsel was lacking, and it took almost 24 hours before the attorney was notified that he needed to report to Barksdale.

B.6 Address Board Member Hiring Process and Legal Status

Observation: *The Agency Contingency Action Plan should describe the process of selecting additional accident board members, as well as how the members will be compensated. If they are to be hired, as was the case with nongovernment members of the CAIB, then procedures should be developed ahead of time to expedite this process.*

Discussion: The CAIB was a mixture of government individuals — military officers and federal civilian employees — and nongovernment individuals. This presented some potential for personal liability for the nongovernment members. The ultimate answer was "to hire all of the Board members as federal employees to bring them under the umbrella the Federal Tort Claims Act." This also required the Board members to file disclosure statements that dealt with potential conflicts of interest. The CAIB members were not, however, hired as Special Government Employees (a special classification relating to members of advisory panels), but were instead hired by NASA as regular employees under the authority of the Space Act. Since this had not been thought of ahead of time, it took extraordinary measures to make it happen in a timely manner.

B.7 Develop Organizational Start-up Template/Checklist

Observation 1: *The Agency Contingency Action Plan should contain a concise initial organizational structure that identifies a "best guess" of the roles and responsibilities of each group, understanding that this will likely change once the accident board is stood up and functioning. This organizational structure should consider NASA Headquarters, NASA centers, the NASA Engineering and Safety Center, the NASA Safety Center, performing organizations, the Department of Defense (DOD), the NTSB, the FAA, the Department of Justice (DOJ), the Federal Bureau of Investigation (FBI) and other federal agencies.*

Discussion: Perhaps one of the more confusing areas of the Columbia investigation was, "Who does what?" An NTSB participant recalled, "I never really figured out the chain of command." One of the attorneys assigned to the NASA investigation remembered: "I had

never been in a situation where you have [the CAIB] that was appointed and you had to understand the difference between the [CAIB's] role, which was the investigation, and then you had the mishap investigation team [CTF/NAIT, whose] job really was to just gather the evidence that the CAIB needed in order to do its job. So the mishap investigation team, it wasn't so much they were investigating it, except that they were having to follow up to locate all the evidence and gather as much information as they could about what was on the ground." This was different than the typical NASA mishap investigation, where a single team gathered the evidence, conducted the investigation and wrote the final report.

Observation 2: *NASA was established along technical and geographic boundaries of expertise, reflecting a stovepipe organization. Each NASA center is largely independent, and each program is largely independent. Merging the diverse organizations and personalities into a coherent whole proved to be difficult during the Columbia accident investigation. The Agency Contingency Action Plan should include a straw-man organization that can be put into place quickly in the early days of an accident. The development of this organization should be coordinated within NASA and with outside organizations that have accident investigation experience, such as the FAA, NTSB and military.*

Discussion: During the early days of the investigation, NASA showed an unfortunate "not invented here mentality." One participant from the NTSB recalled: "If I were in charge I would have set it up like we set up a large aircraft accident — very well-defined groups of experts in structures and systems and aero and human performance and things like that…. We would have been prepared with a set plan. It didn't seem like NASA had a well-defined plan of what to do immediately…. I'll caveat that by saying that our groups are never as big as they had to handle. If there had been a little bit clearer plan on paper from the get-go it might have helped."

B.8 Develop Data and Configuration Management Templates

Observation: *Develop templates for data and support request forms and include them in the Agency Contingency Action Plan, along with a one-paragraph procedure for requesting, executing and tracking the request. Include brief procedures for configuration management and secure data storage. NASA should also define how an accident board will acquire a secure IT system for data management and storage. The template and procedure may be modified as required once the investigation board is up and running.*

Discussion: For any significant accident, the investigation board will require a large amount of data, documentation and other support from NASA. One participant on the CTF remembered, "There were so many requests coming in from the Board and you just couldn't react to all of them." The solution was to develop a formal method to request support (using a specific form in this case) and to limit the requesters to CAIB members, not staff. This allowed the CAIB members to filter the requests going to NASA. Similarly, only a Board member could officially close a request for information. The Board and the task force tracked each request to ensure that it was answered in a timely manner. Configuration management of the requests and resulting data was important. In any future investigation, screening the data for International Traffic in Arms (ITAR), proprietary and sensitive information will be of even greater importance (and marking it as such, but not restricting Board access to it).

Similarly, another CTF member advised: "One lesson we learned that wasn't discussed in the Contingency Action Plan is that you will be overwhelmed with data analysis and information requests. Early in the process it will be [technical and management] briefings about the shuttle program. The task force must be able to archive; this is a very visible investigation so you must be prepared to, one, log every question; two, log every answer; and three, provide a configuration management system that will save that and preserve it for future use."

Another issue during the investigation was secure data storage. Any future investigation should immediately acquire a secure IT solution for data management and storage, with emphasis on controlling and separating Personally Identifiable Information (PII), Sensitive But Unclassified (SBU), proprietary and privileged data.

B.9 Define the NASA Public Affairs Office's Roles and Responsibilities

Observation: *The Agency Contingency Action Plan should define the initial role of public affairs in the aftermath of an accident. The NASA Public Affairs Office (PAO) will be responsible for the initial interactions with the press until the accident board can be established and take on that responsibility. The Agency Contingency Action Plan should also define, at least in preliminary form, how NASA PAO will interact and assist the accident board after it is established until the time when the board's independent PAO support comes online.*

Discussion: The NASA public affairs staff was cognizant, and supportive, of the need for the CAIB to be independent. Once the CAIB public affairs organization was established, NASA largely ceased releasing information on the investigation itself, leaving that to the CAIB. One NASA participant recalled: "We were perfectly fine with that. There was no reason for us to have any control or any input into that. So any release of formal information, for the most part, came out of the CAIB."

B.10 Address Interfaces with Inspector General

Observation: *The Agency Contingency Action Plan should address how the investigation board, and the supporting NASA task force, will interface with the NASA Office of Inspector General (OIG) with regards to criminal prosecutions. In all likelihood, this type of crime does not address the accident per se, but rather actions such as theft of debris or destruction of evidence. The Agency Contingency Action Plan should describe a clear handoff between the investigation board and the criminal authorities (OIG, FBI, U.S. Attorneys' Office, etc.).*

Discussion: The CAIB decided early that it would conduct a safety investigation and not attempt to assign fault or blame on any individual. However, if a criminal act were discovered during the NASA investigation, it would be up to the NASA OIG to investigate, in cooperation with other federal agencies such as the FBI. One participant cautioned, "Whoever is conducting the investigation should know that there is a direct line to criminal investigators that can be executed on a moment's notice … if there is a crime that has been committed, the IG will work with the U.S. attorney's office in terms of prosecution of the crime."

B.11 Address Management of Local Volunteer and Government Support

Observation 1: *Agency management, mishap planners and interim response personnel should be aware that in accident scenarios like Columbia, NASA can be overcome with offers of support from local volunteers and agencies. Some of this support may require remuneration by NASA. These issues should be addressed in the* NASA Safety Center Mishap Handbook *and training courseware.*

Discussion: Despite all of the federal agencies' involvement in Columbia debris recovery, ultimately a search of this magnitude "rises and falls on the local emergency services, local fire departments, police departments, sheriffs' departments, and state troopers." These first responders understand that the local citizens know the countryside, the roads and towns, and are familiar with the weather and local hazards. It is a depth of knowledge that no outside organization can hope to match, at least not in a timely manner. A participant confirmed, "The federal government has enormous resources to bear on some of these things, but you can't focus it, you can't direct it and you can't organize it well without the local knowledge."

Observation 2: *Other agencies, such as the American Red Cross, have also found that well-meaning volunteers are not always the answer to a major crisis. The Agency Contingency Action Plan should have a process to collect volunteer names and contact information, as well as instructions for the investigation team on how to coordinate*

volunteer efforts while operating under public scrutiny. The Public Affairs Office should participate in defining these instructions, perhaps with advice from disaster organizations (such as the Red Cross) that routinely face similar situations.

Discussion: In fact, at times there was too much support. One participant remembered, "We had too many volunteers that we couldn't organize, and we had to just tell people, 'please let us do this at our pace, we've got to preserve evidence, we've got to go about this the right way.'" The on-site coordinators began collecting names and contact information and asking about skills that could be used as needed. But it was all very emotional because "we had so many people wanting to volunteer, and a big part of that was clearly, they were hurt — I couldn't imagine being on the outside of this, not being able to help." Ultimately, "we did our best to communicate what we could to the folks, but just to tell them 'thanks we really do appreciate your offer,' but trying to get people to search the woods who haven't been trained to do so is not a good proposition."

B.12 Address Pathology Support

Observation: *The NASA Chief Medical Officer should determine the level of pathological support required after an accident and make arrangements with the appropriate agencies for this support. Since the Columbia accident, NASA has signed a Space Act Agreement (SAA) with the Department of Defense Armed Forces Medical Examiner System (AFMES), providing the expertise of AFMES to NASA in the event of another accident. This SAA is sufficient to manage the issues and concerns raised in the discussion below.*

Discussion: Determining the cause of death, and evaluating vehicle systems relating to the deaths, is also of critical importance for any investigation and subsequent return-to-flight activities. One participant closely involved in this effort advised, "You want somebody with an aerospace medical background and preferably someone who has had accident investigation experience as well as good systems knowledge." Determining the cause and circumstances surrounding the death of the crew is critical: "Understanding how the crew died was important to understand the countermeasures to mitigate that risk in the future."

During the Challenger investigation, the Washington, DC–based Armed Forces Institute of Pathology (AFIP) handled the crew's remains, although most of the work was conducted at KSC. The AFIP was founded in 1862 as the Army Medical Museum and was located on the grounds of the Walter Reed Army Medical Center. It primarily provided second-opinion diagnostic consultations on pathologic specimens such as biopsies. The unique character of the AFIP rested in the expertise of its civilian and military staff of diagnostic pathologists whose daily work consisted of the study of cases that are difficult to diagnose owing to their rarity or their variation from the ordinary. One of the primary participants remembered, "From everything I know, it was very well done. It was everything we had come to expect from AFIP."

One participant suggested, "It might be good for a flight surgeon to go visit AFIP every year or so and just talk to them — how do you investigate aircraft accidents … to understand what their capability is."

Another participant remembered: "Keep in mind that they had no requirement to do anything for us. … I will say that, from my perspective, I would not characterize their support as anything less than impressive. That's my opinion and of course opinions are going to vary, but those folks did so much for us with only our promise that we would get something in place to make this a lawful provision…. [They were] basically expending taxpayer dollars to do something that their agency is typically not supposed to be doing." A different flight surgeon involved in the investigation also had no criticisms of AFIP and thought they did a professional job.

As it happens, the AFIP was disestablished on September 15, 2011, although some of its functions were transferred to the newly founded Joint Pathology Center in Silver Spring, Md. Nevertheless, it is important to "have people that you know ahead of time that are on-call in the event of an accident investigation. In Challenger and Columbia we had to cobble it together at the time. We should make sure that we know who has the appropriate background or if they don't have that background get them trained up in accident investigations so you have a cadre of two or three people at least."

B.13 Address Debris Recovery Processes, Organization, Roles and Responsibilities

Observation 1: *A significant effort was required by NASA, the Federal Emergency Management Agency (FEMA), the Environmental Protection Agency (EPA), the U.S. Forest Service and other local authorities to activate debris search teams and develop debris recovery procedures in real time. Procedures for documenting the debris' geographic location, handling possible biological and chemical hazards, photographing the debris and transporting debris had to be developed and promulgated to search teams in the field. The NASA Safety Center, which is developing both a handbook and mishap investigation training for the agency, should consider incorporating this information in these products.*

Discussion: Of the debris search, one participant recalled: "It was a tough time of year, it was cold, the conditions were harsh, we had snow on the ground a number of times and we needed people who were trained to deal with that kind of thing. We used the National Guard for a week or two to try to help us find the crew and then we went more with the Forest Service to help us with the search for debris. Had I to do it over again I might have the Forest Service involved even sooner. One of the biggest issues we had was how are we going to feed people, how are we going to keep them from freezing to death and all that kind of thing." Succinctly: "the National Forest Service has these teams that come in and they are totally self-sufficient. They come in and feed, house and clothe these folks and give them medical care 24/7…. They had a tent that they put the boots in at night to get them dried out, raise the temperature and have blowers blowing through, and I mean those guys know what they're doing. It's their business and they're professionals at it."

Searchers — When the Forest Service deploys firefighters, they do so with all of the infrastructure necessary to care for them, including food service and medical care. This was important given the relative isolation of many of the debris search areas. (NASA)

Of the Forest Service, another official remembered: "There were 1,500 people in each one of the camps sleeping in tents. It was raining. It was cold. It was terrible, and they would just all be standing there ready to go…. Out of the 3 months that we [were searching for debris] people were working 12 to 15 hours a day, 7 days a week. I never heard one foul word, never heard one complaint."

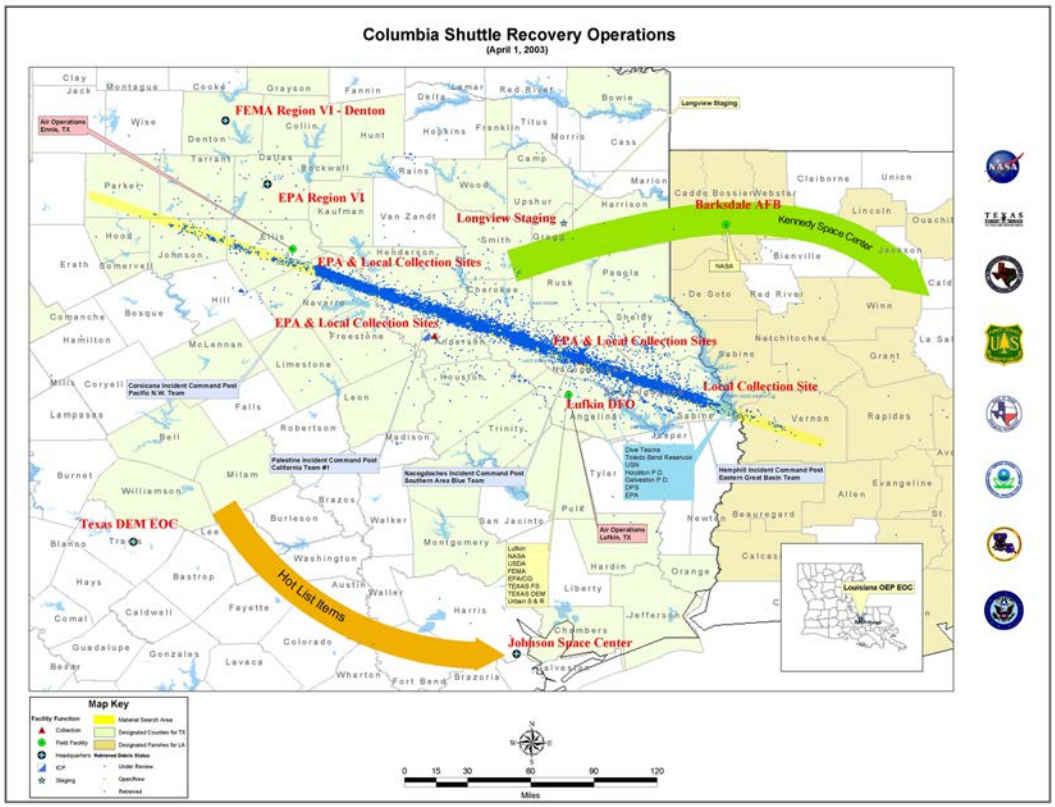
How to search for debris also evolved relatively quickly. Satellites proved worthless looking for small, randomly shaped debris. Aircraft and helicopters were only marginally better. One participant remembered: "We did use helicopters on the outer edges to look for bigger pieces, but most of the time it was walking shoulder to shoulder. We had ATVs (all-terrain vehicles) to help get people around if someone got hurt or something like that, but it was all shoulder-to-shoulder, 3 feet apart, walking through brush, woods, thickets, the whole nine yards."

Searchers — Sleeping arrangements and food service were never fancy, but everything was remarkably organized. For instance, heated tents were provided where searchers could dry their boots overnight. (NASA)

Shipping the debris back to KSC also presented some early challenges. These were resolved when senior NASA officials at the site realized, "the KSC guys know how to do that. They handle hardware all day every day."

Observation 2: *It is impossible to plan for all possible accidents, so the agency needs the flexibility to quickly call upon any NASA or other federal resources that might be needed. The NASA Safety Center, which is developing mishap investigation training for the agency, should consider incorporating these lessons into their courseware.*

Discussion: The Columbia debris recovery effort quickly exceeded any previous NASA experience and rivaled the NTSB's experience during the investigations of Pan Am 103 and TWA 800.[32] Since investigators initially had little idea of exactly what had claimed Columbia, it was of vital importance to collect as much debris as possible, resulting in a massive undertaking that ultimately involved some 1.5 million hours to cover 2.3 million acres.



Debris Map — The Columbia debris recovery effort ultimately involved more than 1.5 million hours and covered 2.3 million acres. At the time, some 84,900 pounds, representing 38 percent of the orbiter, was recovered. (CAIB)

One of the first people on the scene remembered: "We landed in Lufkin. Security guys had set up for us to meet with the local sheriff, a secret service agent and the FBI agent in charge, and it went from there…. We didn't have a plan for how to recover in that type of

scenario. We had plans to recover a launch problem or a crash near the landing site kind of thing, but this was all new." None of the various mishap or contingency action plans discussed debris recovery since there had been little thought of an accident happening off a federal reservation (KSC, Edwards AFB, or the Eastern Range).

Observation 3: The NASA Safety Center Mishap Handbook *and training course should cover the topic of handling debris after an accident. This should include how to transport the debris, where to assemble it, document it and reconstruct it. The NTSB procedures, and Columbia investigation effort, offer a valuable starting place.*

Discussion: NASA had little experience in reconstructing a major aircraft accident. Perhaps unfortunately, the NTSB is expert at it. One of the NASA participants remembered: "We didn't really have an idea of two dimensional, three dimensional, virtually with scanned-in parts, and we didn't know exactly what to do or how to do it. There were two groups. The NTSB came down and they kind of gave us a sense of focus. The other group was Boeing aircraft safety folks." Both groups agreed, "the two-dimensional grid will be good enough, and very rarely do they go into a three dimensional kind of reconstruction." In the end, NASA prepared a three-dimensional reconstruction of the left wing leading edge since that was the most important part of the puzzle.

Debris Hangar — A little-used hangar at the Kennedy Space Center became the central point for collecting Columbia debris. A grid on the floor helped technicians place the debris in the correct area. Note the table for the left wing. (NASA)

After debris was recovered, it was shipped to the Reusable Launch Vehicle Hangar at KSC. Within the first 2 weeks, NASA, with help from the NTSB, had laid out a grid pattern on the hangar floor that corresponded to the shape of the orbiter. A participant remembered setting up the grid with typical NASA precision: "Here we are setting up lasers and trying to do things with the precision of spaceflight and they're, like, 'Just put some tape on the floor, you go 110% of scale because you're going to spread this thing out, that's about the right grid.' So we laid out the grid with their help and they said, 'Look, you rough it out, put the pieces there and you'll focus in; as you start to look at the debris, you'll focus in.'"

Nose Gear — All of Columbia's debris was carefully identified and tagged before it was placed on the hangar floor. This is the nose landing gear. After the investigation was finished, the debris was moved to a secure location in the Vehicle Assembly Building (VAB) at the Kennedy Space Center. (NASA)

As debris was identified, it was placed in the appropriate location on the grid. This helped engineers and others visualize how much debris had been recovered from various parts of Columbia. One early theory was that something happened to carrier panel 6 on the left wing that allowed hot gases to enter the wing. One member of the reconstruction team remembered: "It was kind of ironic that we're on the phone talking about it and there we are standing in the hangar and at our feet is carrier panel 6. So we had it recovered and we're like, nope don't think that's the right answer."

However, as the recovery and reconstruction effort continued, even without the MADS recorder data, it was quickly becoming evident that the problem was with the wing lead edge around RCC-8L — pieces of all the other panels had been recovered, but 8L was missing in its entirety.

Debris — The only part of Columbia that was truly reconstructed was the leading edge of the left wing. Here, Steve Altemus (right), the lead of the Columbia Reconstruction Project Team, explains the fixture that contained recovered pieces of the Reinforced Carbon-Carbon to NASA Administrator Sean O'Keefe. (NASA)

C. PREPARATION AND TRAINING

C.1 Train Accident Investigation Personnel

Train Prospective Board Members on Basic NASA Operations

Observation: *NASA needs to make every effort to ensure that the individuals identified in the Agency Contingency Action Plan make themselves available for mishap training and simulations. This training should also be provided to legal counsel, public affairs and other senior staff that can be identified ahead of time. At a minimum, the training should be completed once per year, perhaps concentrating on a different program or NASA center each year.*

Discussion: Each of the six Board members identified by name in the Agency Contingency Action Plan was aware of the potential for serving on an accident board. NASA made training available to familiarize the individuals with the general operations of NASA, and specifically the International Space Station and Space Shuttle Programs. This training included opportunities to visit various NASA centers (JSC, KSC, etc.) and to participate in simulations and mission rehearsals. One CAIB member who participated in the training remembered, "The training was barely scratching the surface, I would say, as compared to the drinking from a fire hose learning curve that we had when the CAIB really convened." However, everybody agrees there is no realistic way of providing comprehensive training in a short period of time.

Unfortunately, many members on the list did not have the opportunity to participate in even this limited training. One CAIB member that did attend remembered that "only two people had actually been to a training session down at … Cape [Canaveral]; I had been three times and he had been once." One of the consequences of missing this training was that many members "didn't really understand the whole way NASA operated at KSC and during launches and things like that, and that's probably something they would have learned if they'd gone to the sims [simulations]."

Another CAIB member, in particular, regretted missing the training, recalling, "If I had had the contingency training that NASA had planned for me before the mishap had occurred, it would have made a world of difference in my ability to be more effective early on." This member recommended that NASA be more forceful in training the people identified in the Agency Contingency Action Plan.

Identify and Train Prospective Accident Investigators

Observation: *Specific engineers and operations personnel, both NASA employees and contractors, should undergo periodic accident investigation training provided by the NASA Safety Center. Even if these individuals never need to investigate an accident, knowing the process can help shape day-to-day operations (record keeping, etc.) to facilitate any future accident investigation.*

Discussion: In addition to the specific training and simulations offered to the potential members of the accident board, the accident investigators also need training. The FAA and NTSB, as well as the military, offer accident investigation training, but very few within NASA have been through this training. There was more than one comment along the lines of, "I wished I had gone to one of those major accident investigation training exercises; would have probably saved me two or three nights of not sleeping trying to figure out how to get started."

Train Support Organizations on Accident Investigation Processes

Observation: *More support organizations, such as legislative affairs and public affairs, should arrange accident investigation training for the personnel who are likely to be required in any future investigation. Although these organizations will not be assigned as investigators, understanding the basic investigative process can assist them in their duties. These support organizations should also be included in the training and simulations provided to potential board participants.*

Discussion: Unlike many of the organizations — and perhaps surprisingly — the general counsels at the various NASA centers were well-prepared for a mishap. One remembered taking "aircraft mishap investigation courses … to become familiar with the regulations and policies." It was only a half-day course, but it provided the attorneys with a running start when they needed to support the Columbia investigation.

C.2 Consider Memorandums of Understanding

Observation 1: *Although it is impossible to determine ahead of time the type of outside agency assistance that will be required, having agreements for support with FEMA, the EPA, the NTSB, the FAA, and the military is prudent. Ideally, members of these organizations would be able to participate in the annual training and simulations provided to potential board members. The Agency Mishap Manager is currently working on putting in place Memorandums of Understanding (MOUs) to facilitate this coordination.*

Discussion: Regardless of the desire to plan for an accident, one participant put it succinctly, "The first thing you learn is you never have an accident that's planned for." For instance: "We had a much larger accident than had ever been thought of or planned for. The FEMA folks were absolutely critical and they did a great job, but never in the foggiest world have we ever thought … that we were going to be working with FEMA or the EPA or the Forest Service or any of that."

Observation 2: *For both Challenger and Columbia, military support was critical to the investigation. With the end of the Space Shuttle Program, the former agreements with Defense Manned Spaceflight Support (DDMS) Office have largely lapsed and should be replaced by new agreements between NASA and the military that are tailored to the ISS and commercial space transportation efforts.*

Discussion: Given the scope of the accident, the investigation got off to a quick start. As one NTSB participant recalled: "It didn't seem like NASA had a well-defined plan of what to do immediately. But again, this was unprecedented since nothing like this had

happened before, so that's kind of understandable…. I don't think we [the NTSB] could have done much better." Nevertheless, having been through two major and very different accidents, NASA needs to develop a more thorough plan for the future.

One of the members of the JSC Mishap Investigation Team was from the department of DDMS that provided a variety of support services to the Space Shuttle Program. In the case of Columbia, everybody quickly realized that the investigation would require a base of operations, and one member of the NAIT remembered: "We thought about Fort Polk, we thought about JRB Carswell, we thought about a lot of places, but we ended up at Barksdale AFB. Later on, we figured out that Barksdale was a little bit off the debris path, but they had the ability to put us on the ground running in just a matter of hours." Like most large military facilities, Barksdale had facilities, infrastructure, security and a morgue — all-important considerations at the beginning of the investigation. Another participant believed that "locating in a different place that was a little more central probably would have helped a little; however, the facility [Barksdale] was good and we had computers up and running and Air Force support before nightfall." One thing the military is particularly good at is logistics.

C.3 Identify Potential Center Support Personnel and Contractors

Observation: *The Agency Contingency Action Plan requires sufficient detail to minimize start-up transients. Mishap managers and administrative and technical leads should be identified at each of the human spaceflight centers and headquarters to support any future accident board or commission. Select civil service and contractor personnel at each center should participate in the annual training and simulations offered to the potential board members.*

Discussion: Another participant, responsible for the initial support to the CAIB, wanted "more detail in the NASA contingency plan. You need administrative and technical leads at the human spaceflight centers, KSC, MSFC [Marshall Space Flight Center], JSC and HQ … [and they] need to have a daily coordination teleconference," before the investigation board convenes each day.

D. INVESTIGATION AND RECOVERY

D.1 Implement an Open, Data-Driven Accident Investigation Process

Keep an Open Mind — Evaluate Underlying Causes

Observation: *As Gehman has said, complex systems fail in complex ways. The proximate cause (i.e., the widget that failed) is frequently easy to determine, but the underlying root (often called the ultimate or distal) causes are often harder to discern and more important to ascertain. As part of any meaningful safety investigation, a board should consider looking at the organizational, institutional and cultural aspects of the accident.*

Discussion: You cannot go into an investigation assuming you know the answer, regardless of how obvious it might appear. As one CAIB member later said: "When you go into an accident investigation, you can't have a presumption of any kind of cause. You can't zoom in too quickly until you got the right forensics. I've seen examples of other accident investigations — which really weighed heavily on my mind as we went through this investigation — that emphasize you can't presume anything from the beginning. Specifically, I had seen three investigations go down the wrong path of having an initial presumption of what the cause was — and it turned out to be 180 degrees from the real cause. You cannot presume."

Another CAIB member recalled: "The lessons that I keep wanting to come back to are that complex organizations fail in complex ways. Gehman makes that point in his review — you're not going to be able to come up there and say something silly like 'the foam did it' and you're done. I think that was the fundamental point that he was making. When you fail on a scale like Columbia or Challenger, there are myriad factors that you have to be willing to look into."

Another senior participant in the Columbia investigation stressed the need to keep an open mind after an accident, knowing full well that it may clash with the culture or commercial interests of those involved. "I would tell them to be very careful about

circling the wagons and pulling a team together to prove what you already suspect are all of the answers. In fact, that did get in our way some during the Columbia investigation. There were some senior managers, well-intended senior managers by the way … that went into the investigation already absolutely confident that that foam strike could not have damaged the wing. It is not possible for that to have caused this problem…. They were well intended when they did it, but it got in the way of us finding the right answers. In fact, when the CAIB shot that piece of foam through the leading edge in San Antonio, the guys that had been leading the discussion in that way — that was their first realization that holy cow, maybe we were wrong. That would be my message to a commercial company when and if, well not if but when, they have their first in-flight emergency or catastrophe. Do not pull a team together to prove what you already know the answer to be. Put a team together to look through the data objectively and listen to what the data is really telling you."

Former astronaut and Associate Administrator for the Office of Safety and Mission Assurance Bryan O'Conner said it well in a 2009 article: "The proximate causes of an accident and the changes needed to avoid repetition are usually clearer and more readily dealt with than the associated root causes. As a team of engineers, we usually find a way to modify the design, change the software, or develop an operational workaround that adequately mitigates the proximate and near proximate causes of our mishaps. But root causes are different kinds of problems. Root causes tend to be related to the broader, sometimes squishier aspects of what we do: such things as the what-versus-how of our procedures and requirements and the appropriate volume and frequency of organizational communications up and down and left and right. Sometimes they involve organizational and authority relationships, the effectiveness of checks and balances, and other cultural aspects of program and operational management."[33]

Given his experiences on the Cole investigation, Gehman was determined to include an investigation into the NASA organization and culture, and the Board heard from leading experts in organizational theory to provide a framework for this inquiry. As it turned out, this line of investigation revealed serious issues within NASA and resulted in several findings and recommendations.

Follow the Data

Observation: *Check your baggage at the door. Do not approach an investigation assuming you know anything. Let the data take you where you need to go, and do so with your eyes fully open. This applies to technical, organizational and cultural issues.*

Discussion: Beliefs are a part of the normal human thought process, although scientists and engineers attempt to minimize them as much as possible. But it is a cultural and sociological norm that everybody believes in certain things, even when there is no rational reason for the belief. Such was the case with Reinforced Carbon-Carbon. Essentially everybody associated with the Space Shuttle Program believed RCC was tough; worries about the Thermal Protection System (TPS) had always centered on the fragile ceramic tiles, not on the RCC.

During the early parts of the Columbia investigation, one engineer recalled that "the first surprise was that everyone thought that the RCC was tough; the weak area was the tile." Because of this line of reasoning, the original test program at SwRI concentrated on tiles, especially ones around the main landing gear doors, not the leading edge of the wing that was protected by RCC. Some of this was based on earlier "testing that we [JSC] did against tile and RCC, and RCC survived pretty good against ice as opposed to the tile." Another NASA engineer remembered, "It wasn't just the Space Shuttle Program that was in denial [about RCC] … most of us thought [foam] could not do that."

Air Cannon — This air cannon at the Southwest Research Institute in San Antonio was used by NASA and CAIB investigators to evaluate how foam could damage tiles and RCC. (CAIB)

The discovery of the MADS recorder changed all of this. Confronted with sensor readings that pointed to a breach in the leading edge, the CAIB and NAIT both changed tactics and began to look more closely at the RCC. One of the NAIT members recalled: "As soon as we got the MADS data all of a sudden there was this mad scramble to go build a wing so that we could test RCC panels. Since it was hard to get RCC panels we grabbed the fiberglass panels off of Enterprise. We started shooting and checking out our instrumentation and photography so we could go forward." The initial testing was not particularly revealing: "We shot at the apex, and what we saw — and we had to look really hard — was just a tiny little crack. There was no hole or anything. It was a tiny crack with just a slight separation." Analysis of the videos suggested the impact was further under the panel, so the next test shot foam at the underside of the RCC panel. Success, if you want to call it that. The supposedly tough RCC had a large hole in it, caused by a piece of foam.

Before Air Cannon — Investigators constructed a reproduction of the wing leading edge and shot pieces of foam at it using an air cannon at SwRI. This is the leading edge before the eighth test. Note the scuffmarks from an earlier shot on fiberglass panels borrowed from Enterprise. Those panels were subsequently reinstalled on Enterprise, and the scuffmarks can still be seen. (CAIB)

After Air Cannon — The same panel after the eighth test. Note the large hole in the RCC panel. This conclusively demonstrated that foam traveling at high speeds could breach the RCC and cause a Columbia-type accident. (CAIB)

Temper Speculation

Observation: *Immediately after the Columbia accident, some NASA officials were speculating on the cause of the accident and also ruling things out as a cause. All NASA and contractor employees should receive a short, annual briefing on how to conduct themselves after an accident, including not speculating in public or talking to members of the press.*

Discussion: Another important point, noted by a participant from the NTSB: "One of the basic tenets which is driven into our heads is to avoid speculation. That is rule number one for the entire on-scene phase of an investigation. Only later in the entire drill do we start analyzing things…. I think the basic tenet is not to speculate and to be incredibly thorough."

Consider All Views

Observation: *There are no unimportant views on an accident board. Minority, dissenting and additional opinions — identified as such — should be published by any accident investigation board.*

Discussion: From the beginning, Admiral Gehman encouraged dissenting opinions, even when it came to the final report. In the end, there were no real dissenting opinions, but several CAIB members felt compelled to write an addendum to the report that further explained some areas that they felt strongly about. One remembered: "When we were writing that report, and [we] stand by the report 110%, we had to limit what went in there — and [we] do not disagree with that. There were some items that [we] felt strongly enough about because of the interviews, and because of the facts that had been brought forward to [us] through those interviews. While it was okay that something wasn't going to become part of the core report, [we] believed it needed to become an appendix of some type — so [we] wrote one. It was not a dissenting opinion whatsoever. It is an addendum to the report stating that these are some things we needed to look at."

Consider All Data Sources

Observation: *Evaluate all of the data at your disposal, but determine what data is of the greatest use and concentrate your resources where they will provide the greatest return. NASA should consider establishing agreements with the military to codify methods of pulling classified data related to any future accident, as well as name points of contact (by organization and title) for any future accident investigation.*

Discussion: The Early Sightings team at JSC used every technique at their disposal in the effort to track down debris from Columbia. In addition to the public comments and videos, a team consisting of JSC, FAA, and NTSB investigators pored through FAA and military radar tracks. Unfortunately, many of the materials used on the orbiter, such as tiles and RCC, have very small radar signatures and seldom showed up on the recorded data. Initially, people were dispatched to search areas based on what was later determined to be noise in the radar data. The Air Force Research Laboratory at Wright-Patterson AFB quickly determined that "the air traffic control radars were not capable of tracking the materials." One of the team members recalled, "The reason that is important is we were concerned here that Lufkin — in thinking they had actual, usable data from the guys who were providing them information — [that we] were sending out people to search areas that we couldn't reliably say was shuttle debris when they could have been used somewhere else."

The Air Force also volunteered that they had an infrasound system that listened for explosions around the world, and they provided the raw data to NASA for analysis, although it did not prove particularly useful. Interestingly, however, the system did record the ground impact of major pieces. Engineers also reached out to the Department of the Interior for seismic data. One participant remembered, "We could correlate it to the sonic booms as the orbiter dropped through the atmosphere, but it didn't tell us anything that we didn't already know."

Unsurprisingly, much of these data were classified. The Air Force provided a knowledgeable liaison to work with the Early Sightings Team to pull data out of the classified world that NASA could use. By all accounts, this interface worked very well. One participant remembered, "This guy had every clearance known to man; he had been in the black world in the Air Force on the space side for so long that he knew everybody, he knew where everything was…. He was able to reach directly into that world and get us directly to the guy to provide the data and provide the clearances to allow data to flow over to our side."

Leverage Public Input

Observation: *It is important to pay attention to public reports, even if they are not from professional observers. Useful information can be gained from multiple sources, so do not discount any source of information, especially early in the investigation.*

Discussion: As the accident unfolded, phone calls began pouring into the Emergency Operations Center (EOC) at JSC, which happens to be in the same building as the Mission Control Center (MCC), although it has no relationship to the MCC. The people that operate the EOC interact with local law enforcement, fire protection and ambulances for emergency response in the case of a hurricane, tornado or big fire; but lacking a better idea, the JSC operators were patching all of these phone calls to the EOC. Many of the calls related to people seeing something "fall off" Columbia as it streaked overhead. One person remembered, "I walked in on February 2nd and the conference room table was overflowing with individual pieces of paper, and there were maps on a different table, and on the maps people had started using post-its and sticking post-its on the maps to indicate where the person was that called for each one of those little pieces of paper."

This was the beginning of the Early Sightings Team that attempted to track down debris and worked until mid-May 2003. NASA personnel "sifted through all of the public reports and identified any of the ones where there was a witness that said they actually saw something that came off shuttle and saw where it fell number one, and number two

— the folks that actually had imagery where they either had a still camera or a video camera looking at the sky. We made sure we identified each one of those, and then we reached out and got copies of that imagery from those folks."

Although not professionally recorded, much of this imagery provided an understanding of what happened to Columbia. One participant remembered: "Exactly one week after the accident we had looked at the imagery enough that we had this kind of epiphany that in one of the video images we were able to synchronize the image itself exactly in time and in inertial space just because we saw the orbiter flying in front of Venus. We knew where the photographer was standing when that particular photographer took the video — that photographer had a GPS on him and snapped his location. This is before the days when cameras would do that for you. Because of that, we were able to know the exact time and location of the shuttle in the sky when that image was taken. That then allowed us to make various ballistic analyses just off that one video. Then we were able to piece together all the other images and all the other videos that we had. We were able to link back to this one both going forward and backward in time. So in the end, the videos you may have seen where you see the white dots flying across the sky and you see little dots coming off of them, those came out of our team. We were able to time correlate and do ballistic analysis on every single one of those videos, which pretty much took us from the California coast all the way into west Texas with only a small break in coverage. That allowed us to then generate footprints on the ground where the high-likelihood areas were so that if we were going to send people out west and put boots on the ground to look for whatever that object was that came off shuttle we could tell them, 'here are the areas you should look.' We had all that figured out by February 8th."

After the MADS recorder was located in March, the early sightings became less important, and most debris reports were not investigated extensively. However, if the MADS recorder had not been located, a great deal more effort would have been expended attempting to locate debris in California or Utah to better understand what had happened to the orbiter.

Modular Auxiliary Data System — Recovering the MADS recorder was a turning point in the investigation, although the CAIB continued to pursue other avenues to confirm that all the science led to the same cause. Nevertheless, finding additional debris was less important after the MADS recorder was recovered. (CAIB)

Resist External Pressure

Observation: *Any large-scale accident investigation must resist pressure from the White House, Congress and the press for a quick judgment on the cause of the accident. The investigation must take as much time as is necessary to understand the true scope and cause of the problem, as well as to report that understanding in a concise and meaningful manner. Note: The existing NASA procedural requirements document identifies a nominal 75-day target for completion of accident investigations.*

Discussion: You can also not go into an investigation like Columbia with a predetermined schedule. One CAIB member recalled: "You cannot have a time limit on a full investigation. You can certainly aim for a time target, but you must first aim to get it right. I think that's what we did, but we also knew it couldn't be open-ended. Knowing we'd have to have some type of target date, when we got to the point we knew what the physical cause was, we started working backward from that toward a target date by defining the milestones we would have to accomplish…. From those milestones, you could then approximate a completion timeframe, and set the gears in place to complete the report's writing, editing, review, publication and release."

D.2 Establish a Policy for Disposition of Crew Module Debris

Observation: *The Agency Mishap Manager should consider establishing a policy for handling crew module debris that is consistent with other accident investigation organizations (FAA, NTSB, military) policies.*

Discussion: During the Columbia investigation, including the debris reconstruction, the crew module was always handled separately and only a few select people had access to the debris. Even today, the crew module debris is stored separately from the rest of the orbiter. One NTSB participant found this odd: "I was a little surprised about the sensitivity regarding the front end of the shuttle, the cockpit for instance. Only because I have been in charge of accidents where hundreds of people died, and although we were grieving, it wasn't like you folks. Perhaps, there may have been some oversensitivity there that may have slowed things down. By way of example, our rebuild of [TWA] 800, we have about 120 seats installed in the fuselage and you can walk up and down the aisles. People died in those seats and I had just a little trouble understanding why the entire front end of the shuttle was so sacred."

D.3 Ensure Crew Performance is Accurately Assessed in the Investigation

Observation: *Considerations for the crew and their families cannot, ultimately, stand in the way of reporting causes or effects that the accident board considers significant. Each*

accident will be different, but the accident board will ultimately need to decide how to handle unpleasant truths to ensure future crew safety.

Discussion: Although keeping the families involved is a noble concept, it is fraught with other considerations. How, for instance, do you tell the families their loved one did not do everything they should have: "The front-seaters did it just like you should, better than you have to. And yet you see other crewmembers that don't have their gloves on. We had already found them, and we knew that people came in without their gloves and helmets on, which shows a lack of discipline…. That was one of the findings in the report." Ultimately, the investigation determined that "the crew's death was caused by hypobaria and blunt trauma."

D.4 Develop Debris Recovery Guidance Material

Observation: *Recognizing the complexity of debris recovery and analysis, consider developing concise procedure and/or checklists for searchers that describe how to document and handle debris. This information could be incorporated into the NASA Safety Center's mishap investigation handbook and training course.*

Discussion: Thousands of digital photographs were taken during the debris reconstruction. Unfortunately, as one NTSB participant recalled: "We forgot to tell them to put a ruler in there and identify the pictures a little better. All it would have taken would have been a one-page memorandum, but we didn't think of that."

D.5 Establish Secure Communications for Recovery Teams

Observation: *Debris searchers should be issued secure communications equipment as soon as possible after an accident. Center-level Contingency Action Plans should detail where such equipment is located and how it may be obtained.*

Discussion: An issue that became obvious during the initial search for the crew's remains was the need for secure communications. One participant remembered: "There are some conversations, and not just about remains, that you don't want everybody to listen to —

even from a souvenir hunting standpoint — people who get in the way of an investigation and screw up the evidence. You don't want them hearing what you are doing and why — it's not helpful." This seems particularly important when discussing the search for the crew's remains, considering the potential for individuals who might consider publicizing this aspect of an accident.

D.6 Consider Crew Office Role in Debris Recovery

Observation: *There was a disagreement between the flight medical operations community's and the crew office's opinions on using members of the crew office to search for the crew's remains after an accident. Arguments both for and against should be discussed and resolved between the NASA flight surgeons and Flight Crew Operations Directorate on how to handle such future actions.*

Suits — The David Clark Company S1035 Advanced Crew Escape Suits (ACES) for the STS-107 crew. The suits were not intended to protect the crew from a Columbia-type accident. (NASA)

Discussion: During the early weeks of the search effort, members of the crew office were involved in looking for the crew remains. In retrospect, at least one participant believed that that was ill advised: "Having the crew office involved in remains recovery is a mistake. We virtually never, in any other accident investigation, have people with direct relationships … recover the remains and be involved in that. It's just not healthy." He continued: "We talked to the psychiatrists later on other stuff not related to this, they were incredulous that NASA would have crew members that were going to continue to be potential candidates for flying do that — it's just not a good idea. We would be foolish to do this again."

Another participant was not so sure: "I don't know. I guess I would leave that to the experts to decide if that's a good thing or not. I do know that the [crew office] people who were out helping to locate the crew remains were very motivated to do it quickly and do it in a way that was considered decent — I'm not saying that other people wouldn't do that, but the crew was highly motivated." And there were some advantages: "Many times in life when you have on a blue suit … you can get a lot of things done just by saying 'Hey, my name is —, and I'm with the astronaut office, and I want you to fly this helicopter to there or we need a plane to get to wherever.' A lot of times people will accommodate that request quickly because the term astronaut is still well respected and allows you to get things done quickly."

E. LEGAL

E.1 Establish Legal Counsel Early On

Observation: *Having legal counsel available to the accident board from its inception can have a major impact on how the board is formed and the procedures under which it operates. The Office of General Counsel should identify counsel to the board and make that counsel available immediately after an accident.*

Discussion: For the CAIB, the NASA counsel began early and had a major impact on the formation of the Board from a legal perspective. One attorney remembered, "The first thing was what we talked about, the FACA [Federal Advisory Committee Act] issue, which went to the identity of the Board members, the employment of the Board members, how they'd be compensated, the liability issues, all those things."

The relationship between the various investigative entities also presented opportunities and challenges for the attorneys. One attorney remembered: "The MIT was weird because they were based out of Barksdale with FEMA support, while FEMA was based out of Lufkin with NASA support. Part of my job out there ended up being trying to bridge the gap between the roles and responsibilities of FEMA and NASA to help everybody understand how they worked together and anytime we needed to look at what was the authority of either of the entities. Who was in charge of leading a particular effort?" The answer differed with each circumstance, so this was sometimes a subtle, but critical effort.

For instance, NASA had no legal authority to direct local law enforcement or to pay claims from local governments for out-of-pocket costs, such as searching for and protecting debris. One of the attorneys remembered, "If we hadn't had FEMA in the middle of this activity I don't know how we would have done a lot of that because FEMA had a claims process and [NASA didn't] have any authority for that." This had not been an issue during Challenger since the accident occurred over federal land (or water).

E.2 Empower Legal Staff in the Field

Observation: *Any person assigned to the accident investigation needs to be empowered by their management to take any reasonable actions necessary to accomplish their roles. However, everybody assigned to the accident needs to coordinate their activities such that there is a clear and consistent course of action across the investigation.*

Discussion: Fortunately, the attorneys that were dispatched to assist the various investigative groups were fully empowered by their management. One remembered: "I didn't have to go through my boss or go through [the Office of General Counsel at Headquarters] to do that. We talked about what needed to be done on the daily telecons, but I was very much empowered. If I was in the moment and I needed an answer for something from somebody, I was empowered to go call whomever I felt I needed to, to get that answer. Along the same lines, unless it was a new matter that no one had seen, so a case of first impression, we could make decisions at any level regarding the legal issues going with our particular groups. I didn't come back and ask permission to make any decisions. We just made the correct legal decisions." Nevertheless, the attorneys remember spending a lot of time talking to one another so that their advice was consistent across all of the investigative groups, with a particular emphasis on the CAIB and NAIT marching to the same tune.

E.3 Resolve Jurisdictional Issues in Advance

Observation 1: *Any future debris recovery efforts should have a prearranged chain of command with the NTSB, DOD, FAA and the other federal agencies that are likely to respond to the accident. This chain of command should be formalized within Program Contingency Action Plans and trained to during mission simulations. Representatives from these agencies should attend the annual training offered to board members.*

Discussion: In the United States, the National Transportation Safety Board is responsible for investigating nonmilitary aircraft accidents as well as certain types of highway crashes, ship and marine accidents, pipeline incidents and railroad accidents. Space

shuttle accidents, however, were a special case. One NAIT participant remembered "two or three years before this happened. I went up and took the NTSB course that they give their accident investigators, and while I was there I talked to one of those guys, and it became pretty obvious that there wasn't a lot of communications between NASA and the NTSB on who was in charge, and NASA was pretty certain that they were in charge of any shuttle accidents, and NTSB was pretty sure that they were in charge of any shuttle accidents."

FEMA presented another jurisdictional quandary. President Bush declared the debris area a national disaster area, which allowed FEMA to operate, and they are usually in charge once that occurs. Another participant remembered: "The president announced that FEMA was going to be in charge of the operation. Big mistake. FEMA didn't know anything about [the] space shuttle." Even within FEMA, there was no clear chain of command. Eventually, the White House Situation Room resolved the issue by making the senior NASA representative on the ground the overall coordinator, with FEMA responding to his requests. This worked, and one participant recalled, "We could not have done it without FEMA, and it was so massive, and it took us a little bit of time to get our hands around where things were and the magnitude of what really needed to be done."

Observation 2: *Congressional legislation subsequent to the Columbia accident has clarified jurisdictional issues regarding the crew, but NASA legal counsel should continue to be prepared to resolve any disputes quickly with minimal publicity or impact to the crew's families.*

Discussion: There were also some initial concerns over jurisdiction of the remains of the Columbia crew. After Challenger, there had been a minor dispute between NASA and the Brevard County medical examiner; most local medical examiners feel they are responsible for anybody killed in their jurisdiction. NASA made a point that the space agency, with assistance from the Armed Forces Institute of Pathology (AFIP) in Maryland, was in charge of all flight crew remains. After this, nobody objected; at least not publicly.

For Columbia, "there's a whole bunch of different counties involved, some of them have coroners, some of them have medical examiners, but the deaths happened in the air space over Texas." One of the legal counsels remembered that "we didn't at the time of the accident have authority for the Administrator to say those are NASA employees" and that NASA would deal with the remains. Fortunately, there were no serious objections from the local officials to NASA running the show. Subsequently, Congress has passed legislation that grants NASA authority over flight crew remains after a human spaceflight accident.

This is another area where the legal counsels came into play. One counsel remembered, "One of my responsibilities was to help make sure we could complete the death certificate for the crew so that they could get those to the families and the families could be able to handle their business." The death certificates ultimately showed the location of death was "in the air space over Texas." Oddly, the original death certificates had to be completed using an actual, old-fashioned typewriter.

E.4 Pre-Coordinate Roles with the NASA Office of Inspector General

Observation: *The NASA Office of Inspector General and the various security offices at the NASA field centers should coordinate roles and responsibilities in advance. Since the Columbia accident, the NASA OIG and NASA Security have established a Memorandum of Understanding to better clarify their respective authorities, roles and responsibilities.*

Discussion*:* During the early days of the investigation there were some coordination mistakes among various NASA security organizations and the NASA Office of Inspector General. One participant remembered: "We had difficulty at times having our [OIG] investigators playing nicely with [the] security apparatus at NASA. There was a lot of ill will for a lot of different reasons, [and] having the folks play nice together was a little bit of a challenge. It was very frustrating because it was intolerable that there was any conflict there [in Lufkin]. It was like who got to ride in the truck — it was really silly stuff but nonetheless real because of different perceptions of roles and responsibilities of

[the] security apparatus at NASA versus the criminal investigators in the NASA OIG."

E.5 Proactively Manage the Witness Statement Process

Advise Witnesses of Rights and Obligations

Observation: *All witnesses called by a board need to be informed of their rights and obligations under the law. NASA counsel needs to be available at any time to work with civil servants, and contractor employees should be advised to consult with their employer concerning the availability of employer-furnished legal counsel or of the advisability of retaining their own attorney to understand their rights and obligations.*

Discussion: One member of the CTF remembered: "The accident board will call witnesses; you'll need strong legal representation. JSC legal provided [counsel] to our team. She was able to brief witnesses on their roles and responsibilities, what their rights are. All of the critical players who were interviewed by the accident investigation board who were part of the decision making of the Columbia flight were formal witnesses and were formally interviewed. So you need a legal team to help them understand their rights, to assist them on what they should say or cannot and the details of what the accident investigation board is allowed to ask. They also protected and documented the witness statements because they tend to be restricted information, so you'll need a legal team or legal representative to put those in the right place and understand the rules and roles and obligations."

Codify Rules Regarding Privileged Witness Statements

Observation: *The ability of a NASA investigation board (or a Presidential Commission) to take privileged witness statements and guarantee their confidentiality should be codified as appropriate. This should include the conditions placed on Congress and other oversight organizations to access the transcripts, as well as how the interviews will be archived for the future.*

Discussion: How the interviews were handled within the Board was telling of the professionalism of the members. Since they were confidential, the contents of the interviews could not be openly discussed in the daily stand-up meetings that were attended by staff. But they were discussed openly at the Board-only meetings. One CAIB member recalled, "We'd provide information that we got from an interview, and suggest another group might want to pursue or address this or that area." These discussions frequently led to more people being interviewed to find specific answers, or to initiate specific investigative paths. One CAIB member realized: "If you start with a set list of interviewees and that's all you're going to talk to, you're going to miss something. You need to open it up to others that may have more to offer. Also understand that can be a double-edged sword; for example, we had a lot of interviews that ended up being not really worthwhile, but even those interviews let people know that the CAIB was out there and that we were interested in hearing from them. I believe that also helped more people to come forward with valuable information for the investigation."

As some had expected, many of the witness statements contained information that needed to be kept confidential. One CAIB member recalled, "The biggest things that came out were tangible examples of complacency that had happened across the program." In conclusion, "the bottom line is that the interviews provided an abundance of tangible examples that helped every single group on the investigation through what they were pursuing."

The CAIB felt that maintaining the confidentiality of witness statements was imperative to convince the witnesses that whatever they said could not be used by NASA or their employer against them. This was generally similar to how the military handles witness statements during aircraft accidents. Initially, the intent was that only CAIB members and select staff investigators could view the witness statements. However, this intent was ignored by Congress. It quickly became apparent "that there was a history of Congress having access to those kinds of witness statements pursuant to an agreement with the investigative board." The CAIB attorneys reviewed "letters from the Air Force, and we patterned our negotiated agreement between us and the [Congressional] staff as to who

was going to actually be able to see the witness statements; they could review them but they couldn't take notes on them, and they couldn't bring any kind of recording device." In response, the Department of Justice contractor put the witness statements into a searchable database that allowed searching across transcripts by subject.

After prolonged, and oft-times heated, discussions, the CAIB and Congress reached an agreement. One CAIB member remembered: "We agreed upon a Congressional reading room, which is a solution that has happened many, many times before in many other types of disclosure types of things. You put all your stuff in there and let members come and read all they want." However, no notes or recording devices were allowed.

Archiving the witness statements also required negotiations between CAIB, the National Archives and Records Administration (NARA) and Congress. CAIB was determined to keep its promise of confidentiality but recognized the historical need to archive as much as possible. Ultimately, the witness statements were transferred to the National Archives, but they will not be released for 50 years. The exception was to Congress, which continued to have access to them through the end of the term under the same conditions as they did during the investigation.

At least one person still questions the legal authority surrounding the assertion of executive privilege to protect the confidentiality of the witness statements, believing that "there is no statutory safety investigation or statutory privilege. The privilege that was extended, while it makes perfect sense, was created out of thin air. In other words, there are real legal privileges, medical privileges, lawyer-client privileges and spousal privileges — there are real privileges in law, but this was one that was not legally based."

Court Reporters for Witness Statements

Observation: *Use professional court reporters to take witness statements. You will end up with a much better product. As one counsel explained, a court reporter "will tell people to be quiet when more than one person is speaking. I can't capture multiple people talking at the same time, you need to speak one at a time. The court reporter*

would identify the individual speaking." Employing a court reporter would not have compromised the convenience or confidentiality of the interviews: "There are court reporting firms everywhere. They could go to some informal location wherever they needed to go and do this. Their machines are portable."

***Discussion**:* During the first week of the investigation, and after much deliberation, the CAIB members decided they would conduct the investigation generally along the lines of a military aircraft accident. This resulted in a safety investigation where no specific person was ever directly quoted. The idea was to uncover the causes, direct and indirect, of the accident so that they could be addressed; the goal was not to assess blame on any particular person or persons. A Board member noted that "we became convinced that offering people anonymity in order to answer questions was going to get us such an important body of knowledge that it was worth the heat [the Board] was going to take."

One CAIB member recalled: "The part about it that was important to me was to try to get a decision whether we were going to do a safety investigation that would allow us to get at the root causes of what may have happened and still release the information but protect the people who talked to us. There was a very protracted conversation about whether or not testimony would be protected. That finally carried the day even though that cost us a few bumps and bruises with the Congress when they figured out that we weren't going to release names to them. In the whole, I think that decision was a very important one to make because it got us insight and it got people talking to us that probably otherwise would not have."

Only Board members and select senior investigators were authorized to conduct privileged interviews. The interviews themselves proved to be a frustrating experience. In order to obtain as many statements as possible, and to make the witnesses feel at ease, the CAIB was willing to meet with witnesses in public places. This often resulted in a great deal of background noise. Coupled with the use of administrative support to transcribe the tapes, the result was often nearly unusable. This ran against the advice of legal counsel and was an unusual misstep for the CAIB.

One participant suggested that "we should have used court reporters to take their statements and got a real transcript." At the time, the CAIB was concerned about using a third-party court reporter for fear they would release data, but professional court reporters routinely support confidential proceedings, so that should not have been a concern. In retrospect, "if you really do want to record witness statements and make a transcript of it for [historical] purposes you should really get a court reporter to do it or a high-quality recording and use a professional transcriber."

One of the attorneys remembered, "You can't go to a temporary administrative support service company, bring in people who have never been exposed to our jargon and expect you will wind up with a useable product." In addition: "I have never before seen so many senior NASA employees so incredibly frustrated as when they got their transcripts back and took a look at them and said there's no way I ever would have said this. These aren't my words. They spent hours and hours reviewing their transcripts trying to get something useful on paper."

E.6 Be Prepared to Address FOIA, FACA, ITAR/EAR Issues

Observation*: The legal counsel for an accident investigation board needs to be conversant in the requirements of the Freedom of Information Act (FOIA) and FACA, as well as being able to handle the International Traffic in Arms Regulations, the Export Administration Regulations (EAR) and other federal regulations regarding the release of data from the board.*

Discussion*:* The Freedom of Information Act is a federal law that allows for the full or partial disclosure of previously unreleased information and documents controlled by the U.S. government. The Act defines agency records subject to disclosure, outlines mandatory disclosure procedures and grants nine exemptions to the statute. It was originally signed into law by President Lyndon Johnson on July 4, 1966, as Title 5 of the Untied States Code, Section 552 (5 USC §552) and went into effect the following year. NASA's implementation of the FOIA is contained in 14 Code of Federal Regulations

(CFR) Part 1206, "Availability of Agency Records to Members of the Public," and the CAIB conformed to these requirements and processes.

One of the NASA attorneys remembered that FOIA compliance was "really, really high on the list because one of the lessons that we learned after Challenger was that we weren't communicating well, and the CAIB made an early on determination that we were going to put as much information out as quickly as possible."

Because the CAIB held little original technical data — it was primarily produced by NASA and provided to the CAIB — FOIA was not a major issue. Most of the CAIB-developed data was pre-decisional and therefore exempted from FOIA. Most of the rest was released in the final reports. The only information that did not fall into those categories was the privileged interviews, which were ultimately exempted from release for 50 years to protect the participants.

One CAIB participant remembered that "most of the data resided with NASA, so FOIA was not a major issue for us. We knew that we would be responsive to FOIA, but in reality I think I did maybe half a dozen FOIA requests. We did get Admiral Gehman delegated authority to make determinations for the Board information, but that was more along the lines of making us appear to be independent. NASA did, in parallel, set up a very transparent and very expedited FOIA process, and NASA got great marks for how it dealt with requests for information, and that aura flowed over to the Board." Nevertheless, the CAIB produced minutes of the public hearings and the nonpublic Board meetings. Obviously, the nonpublic meetings were pre-decisional and the minutes could not be released, "but we wrote them to be releasable at some point, and they were. Those went over to the archives unrestricted." Anybody who wants can now read those minutes in the National Archives.

E.7 Establish a Relationship with the Department of Justice for Evidence and Records Management

Observation: *Any accident board will require assistance handling and archiving data. The Department of Justice provided this support to the Rogers Commission and the CAIB. Consideration should be given to codifying this relationship in the Agency Contingency Action Plan.*

Discussion: It became obvious early during the investigation that the CAIB would accumulate a large quantity of records and evidence. One participant recommended using the Department of Justice to control these items based on that organization's experience with the 9/11 terrorist attacks and tobacco litigation efforts. The DOJ also had experience saving and sorting through e-mail traffic, which was a prime source of evidence for the CAIB. Using DOJ also "had all the appearances and could convey to Congress and the public that the Board was in control and it wasn't being led around by NASA." At the same time, the Board also began considering how to archive the records in compliance with the National Archiving Records Act. The DOJ and its contractor Aspen were key to this effort as well.

F. COMMUNICATION

F.1 Establish Public Affairs Officers' Support Early On

Observation: *Establish a process that supports bringing in independent public affairs officers that represent the Board as soon as possible during an investigation. The NASA Public Affairs Office will still have an important role to play for releasing information from the NASA side, but all communications from the Board should come from a non-NASA source. This process should be documented in the Agency Contingency Action Plan and routinely exercised so that all of the players are familiar with it.*

Discussion: Immediately following the Columbia accident, NASA Headquarters established a team of public affairs officers to deal with inquiries and conduct daily teleconferences with all the human spaceflight centers. As many as 15 to 20 people were responding to media inquiries, and no fewer than 10 were available at any one time.

Soon after the CAIB was established, there was a plan to bring in myriad public affairs officers from all of the organizations involved, including the Air Force, Navy, FAA, and NTSB. This was thwarted when the DOD declined to participate since their public affairs staff was already overwhelmed with preparations for the invasion of Iraq. The FAA stood up and took charge, with assistance from the NTSB and, eventually, one Air Force public affairs officer. In some respects this actually worked to the CAIB's advantage. One participant remembers that reporters were questioning, "Here's a board investigating NASA and the public affairs guy is from NASA — how does that work?" Continuing: "Clearly, one of the early challenges for the Board was to establish itself as an independent entity, and that was what the broadening of the membership and all that was designed to ensure everybody that that was in fact the case. I think the perception of having somebody from NASA speaking to the press on the Board's behalf was just as much of a problem as the limited membership of the Board in terms of the optics of independence."

Hearing — The CAIB conducts a press briefing in Washington, DC, on July 11, 2003. The CAIB Public Affairs Officer, Laura Brown (left), facilitated the briefing. Board members included Admiral Gehman, Duane Deal, Ken Hess, Jim Hallock, and John Logsdon. (CAIB)

The same participant concluded by saying, "I think it would give it instantly more credibility if it was a team of people and I think they would have to know that they would be called upon to do this and know what their plan would be, just like you do with the Board." Another participant believes it would be beneficial for this part of the plan to be exercised with the board members listed in the Agency Contingency Action Plan, so that potential kinks in the system could be ironed out prior to a board being activated.

F.2 Provide Media Training for the Board

Observation: *Board members and selected staff should receive training on how to interface with members of the public and press who might be involved in the investigation. This requirement should be documented in the Agency Contingency Action Plan.*

Discussion: Teaching people, particularly Board members and others authorized to speak to the media, how to deal with interviews is important. One CAIB member recalled: "Dealing with the media, that's vital. Those of us in the military get media training, and that's something that's invaluable for understanding and dealing with the media. If you're not familiar with that training, that's where you go through mock interviews, you go through mock morning shows, and they videotape what you do. You are walking the hallway or entering a conference room, and all of a sudden you get an ambush interview. So what this training drives home to you is making sure you can convey your message in talking to your various constituencies so that you're relatively comfortable with the media. I would suggest that maybe such training is not a bad idea for any future board members—to take a day out for accelerated media training."

F.3 Develop Compliance Approach for Federal Advisory Committee Act

Observation: *The FACA rules were established to allow public insight into the hundreds of panels that advise government agencies. However, these rules can hinder an accident investigation. Members of any future accident board need to consider their position on FACA rules and attempt to reach a compromise similar to that enacted by the CAIB, which allowed the Board the privacy to investigate the accident while keeping the public informed of their actions.*

Discussion: The Federal Advisory Committee Act was enacted in 1972, as Public Law 92-463, to ensure that advice provided by the various federal advisory committees is objective and accessible to the public. The act formalized a process for establishing, operating, overseeing and terminating these advisory bodies. Executive orders and congressional revisions in 1993, 1997 and 1998 have further refined the act.[34]

In theory, the CAIB initially fell under the FACA regulations. Although well-intentioned, with generally good guidelines, certain aspects of the FACA rules do not lend themselves to an accident investigation — particularly the requirement to conduct all deliberations in public forums. Early on, while still at Barksdale AFB, the CAIB discussed "whether we

were going to be a FACA board or not." The members generally agreed that the FACA rules would place too many restrictions on Board activities. Simultaneously, legal counsel worried how to protect Board members from liability. The ultimate answer to both issues was "to hire all of the Board members as federal employees and bring them under the umbrella the Federal Tort Claims Act." This also required the Board members to file disclosure statements that dealt with potential conflicts of interest. Since all of the members were hired as federal employees, the FACA requirements did not apply.

However, Gehman and the other Board members agreed, from the start, to conduct the Board in the spirit of the FACA rules regarding the public dissemination of information. The CAIB Procedures and Guidelines document states, "The Columbia Accident Investigation Board (CAIB) is keenly aware of the public's interest in its activities, and of the Board's responsibility to the American people for objectively, promptly, and efficiently completing the mishap investigation of the loss of the Space Shuttle *Columbia*…. In doing so, the Board intends to open certain of its activities to the public consistent with conducting an efficient safety investigation."[35]

One CAIB member remembers that the "public hearings will reflect everything that we're doing offline." The public hearings were scheduled and announced in general conformance to the FACA requirements, and minutes from the public hearings were posted to the CAIB Web site.

In addition, the CAIB maintained a Web site and a toll-free number where the public could provide input to the Board, again in the spirit of the FACA rules.

Hearing — The CAIB press conference on May 28, 2003, at the Lunar and Planetary Institute in Houston. From left: Lieutenant Colonel Woody Woodyard, CAIB Public Affairs Officer; Admiral Gehman; Duane Deal; Ken Hess; and Sheila Widnall. (CAIB)

F.4 Leverage Social Media and Implement a Call Center

Observation: *The Agency Contingency Action Plan should include in the board start-up checklist actions to consider establishing a toll-free number, a dedicated Web site, and the use of social media outlets to allow the public to contact the agency in the event of an accident.*

Discussion: An important lesson learned from the Columbia accident investigation process was to engage the local population. "The people of east Texas were unbelievably cooperative. They were unbelievably helpful. We only had one or two people refuse to let us on their property." To make it easier, "we set up an 800 number, and we had a team of people who did nothing but respond to those calls, and we went out and picked up a lot of stuff where somebody said, 'Hey I found this in my backyard,' and we'd pick it up —

whether it was a piece of shrub or not — and we'd thank them for it. My goal was that we would respond to everybody who called, and we would treat them as if what they had was important. We wanted everyone to leave with a good taste in their mouth about NASA."

Several social media platforms have emerged since the Columbia accident, such as Facebook and Twitter. These will pose additional challenges for the next investigation. However, one FAA representative does not believe it will be a major concern within the investigation itself: "We haven't had any large commercial aviation accidents in a while, but I don't see investigators tweeting what they find at a wreckage site or something like that. I think they're all, by training, a lot more cautious than that." Although this is probably true, it does not account for the thousands of debris searchers, members of the public and other individuals that might have access to evidence before it becomes controlled by the investigation.

F.5 Carefully Coordinate Communication with the Crew's Families

Observation: *A major difference between a spacecraft accident and an aircraft accident is the amount of publicity surrounding the accident and the families of the crew. NASA should ensure that the Agency Contingency Action Plan, the public affairs office contingency action plan and the crew office contingency action plan are coordinated and provide adequate processes for the accident investigation team to follow in the immediate aftermath of an accident.*

Discussion: Dealing with the crew's remains and families is always a sensitive subject and deserves particular consideration. Fortunately, the Flight Crew Operations Directorate (aka the crew office) had a contingency plan. One participant recalled: "[Our] immediate concern was the families and another concern was that we recovered the remains of the astronauts. We set up a command center. We had family representatives who were responsible for meeting with the crew's families to ensure that they had contact with each other." Continuing: "The crew office has been through this twice now, and they

have established that the most important thing for the crew office is to immediately … take care of the families. That is based off the military model of having [casualty officers]."

Another individual emphasized that it is important to keep the families informed. He remembered, "There were things in Challenger they were not telling the crew's families." This burden was eased somewhat during the Columbia accident investigation by the makeup of the families; one crewmember's spouse happened to be a flight surgeon and was familiar to members of the investigation team. This spouse agreed to act as the point of contact for the families, making the effort to keep them informed easier. The families were also given the opportunity to review the crew-related portions of the report prior to publication. As one participant recalled: "We were careful about writing our recommendations. We wrote the things we thought needed to be done before the next flight and stuff to think about for the future. We had very strong recommendations about the crew discipline and not wearing protective gear." The families were not given veto power, but the writers were willing to entertain comments; there were no requests to change or remove anything.

F.6 Develop a Quick-Response, Independent Public Affairs Office Support Strategy

Observation: *Every accident investigation board should have a professional public affairs staff to handle the press. The Agency Contingency Action Plan should include providing initial public affairs support until the accident investigation board can establish its own support. To support the appearance of independence, it might be appropriate to coordinate with another federal agency (FAA or NTSB) to provide this temporary support. However the support is provided, the represented agency public affairs staff should participate in the annual simulation training.*

Discussion: Attempting to communicate to dozens, or hundreds, of reporters one at a time is not possible. The CAIB public affairs staff took a play out of the FAA manual and

set up daily telecons. One participant remembered: "You can answer a whole bunch of questions just by talking to everyone at one time. You give out the information you can…. Everybody's getting the same information and can stay on the line to get updates. We created a system where there's one person on the phone and then there's a runner who can go get additional information from people who are nearby."

The daily teleconferences turned into weekly status briefings that continued through the first half of the investigation. A participant remembered that "it worked for a while because we had enough to say at each one; we were finding out enough. I don't think we ever struggled to say something new at the press briefings; a week was just enough time and we were making enough progress that we could come up with something to say at each of them." After the Board moved to Washington, DC, and the pace of the investigation slowed, the weekly conferences ended and were replaced by as-needed events.

As is often the case, reporters themselves revealed an interesting perspective during the investigation because of the different knowledge levels of the various groups. Media organizations threw all kinds of resources, including investigative reporters, all of whom were focused on finding a "smoking gun." And many of the reporters, while experienced journalists, were not well educated in the basics of the Space Shuttle Program.

One participant remembered: "It was really fascinating to me when I got there because I knew all the aviation reporters and they were used to covering accidents but they weren't used to covering space accidents. There was a whole set of reporters who were space reporters who were used to covering space but they weren't used to covering accidents. So they had no idea what the process was or how an investigation unfolded. Then you had general science reporters who knew a little bit about both but weren't really used to covering anything like this." This required the CAIB public affairs staff, as well as their NASA counterparts, to educate many reporters on the space shuttle, accident procedures and myriad other details.

NASA's organizational structure also caused some issues for the CAIB public affairs staff. Unlike many federal agencies, there was no centralized control over the NASA public affairs efforts. Each NASA center acted independently, as did Headquarters. This frequently required the CAIB public affairs officers to coordinate with multiple locations concerning a single subject. One reporter remembered that, initially, "it took me a while to figure that out, that when I talked to one center I was talking to one center, not talking to all of NASA public affairs." Any future board should be aware of this and handle the issue accordingly.

F.7 Communicate Both What You Know and What You Don't Know

Observation: *The observation here is best expressed by one of the participants: "Insofar as you can tell people what's going on and make people available to talk about it and put it in context even in an investigation that is ongoing, when you don't have all the answers, but you can put as much out there at any given time as you feel comfortable with, I just think it always helps your case and I think anybody who doubts that for a second should go back and look at the media coverage of the Challenger accident and the media coverage of the Columbia accident and it is vastly different in its tone. It's vastly different in its accuracy and I think in almost every respect the press coverage of the Columbia accident was far better because the public affairs support around the Columbia accident was much better."*

Discussion: During the Columbia accident investigation, NASA public affairs made a conscious effort "to provide whatever information we could and as timely a fashion we could." To facilitate this approach, public affairs "found it of value if we drive the media to specific briefings. They know that they're going to get the latest information at such and such time … we divided up responsibilities and committed to two briefings a day. We did a morning briefing and an afternoon briefing."

One of the NASA public affairs officers remarked, "NASA did not have the best of reputations for being forthcoming with information following Challenger and … I wanted

to have a different outcome as a result of Columbia." Accommodating this idea, the same official continued, "Sean [O'Keefe] did a very smart and wise thing by publicly announcing in the war room at that time that we were going to provide and release all factual information up until the loss of the orbiter and anything after that … was going to be the purview of the accident investigation board." In fact, one NASA participant remembered that when the CAIB public affairs officer "came onboard as the person who was going to launch the public affairs effort for the CAIB, things changed almost immediately and for the better; that's not a reflection on anybody on the NASA side who was offering public affairs support or anything like that, but I think it gave some clarity to the organizational relationship."

One member of the press who reported on Challenger remembered: "I covered the presidential commission hearings and I'm not sure that I recall, back then, them having as much press interaction as the CAIB did on this case. I think the CAIB, maybe it was attributable to the chairman, and maybe the public affairs team overall, but I think that they did the same thing in terms of involving the press. Even when they did the public hearings, they seemed to always block out time, even if it was a short period of time, for some press availability to answer a few questions, and it seemed to be that that's where I saw a big difference between the two commissions. One seemed much more open, and I don't know, the Presidential Commission on Challenger seemed much, and I don't know if formal is the right word, but they certainly did not seem as accessible and more relaxed. The CAIB handled all of its activities, it seemed, in more of a public fashion."

Another participant remembered, "It's very difficult for me to have any sort of criticism of the way NASA public affairs and the CAIB were handled…. I was really impressed at the time and I can tell you that people, who I respect, people like Bill Harwood of CBS who did cover the Challenger accident will tell you it was like night and day, the difference between the treatment and the support and the openness that they got from NASA public affairs following Columbia as opposed to what happened in 1986."

F.8 Be Prepared to Educate the Media

Observation: *In the day of instantaneous worldwide communication, it is important for NASA and the accident board to fully interact with the press and be willing to educate the media, in whatever form, which is critical for accurate reporting. The Internet, especially social media, allows anybody to be heard, so establishing a commitment to be as open and forthcoming as possible, within the limits required to conduct a comprehensive investigation, is critical.*

Discussion: Another major change that has taken place in the media will make NASA's job harder in the future. The era of "beat" reporters, those specifically assigned to a particular subject such as aviation or space, has largely disappeared. In the past, the beat reporters had spent years covering a subject, and they were well versed with the terminology and science associated with aviation and space. As one public affairs officer opined: "I think one of the things we have to be prepared to do in a way we didn't have to do in the past with beat reporters is you have to be really ready to educate people. You have to really take it to the lowest common denominator and start out with, okay this is a rocket, and the pointy end goes up."

However, defining exactly what NASA's role might be in any future accident might be more difficult than in the past. For the space shuttle and ISS, NASA was obviously the controlling agency. For commercial launches, even if they are carrying a NASA payload or crew, this may not be true. One NASA official observed that the public affairs contingency action plan for commercial launches differed substantially from previous efforts. The good news is that NASA PAO is actively working with the commercial providers to develop contingency action plans and to participate in simulations to familiarize the participants with the plan.

G. ADMINISTRATIVE

G.1 Implement a Rigorous Records Management Process

Observations: *Every program/project should have adequate records management processes in place that associate a retention schedule and a custodian with the active records. NASA records management personnel developed a series of suggestions based on their CAIB and CTF experiences.*

- Program/project records management should include security and access limitations that are clearly marked on documents (e.g., EAR, ITAR, PII, Proprietary) from the beginning of the document development process.
- Program/project records management should indicate the "official version" of documents, marking all others "reference copies."
- Program/project records management should "clean house" along the way or before turning collections over to records management personnel, eliminating duplicative "copies" of official accident investigation board or associated task force records.
- The accident investigation board and associated task forces should:
    - Meet with National Archives and Records Administration early in the investigation to work out records management and retention issues.
    - Establish a single repository for data and records.
    - Understand the records that they are creating and save them in a format acceptable by NARA.
    - Use common language naming conventions and create an indexing aid (filing system) for their repository to make it easier to find documents.
    - Transfer to the National Archives an acronym list containing acronyms common to compiled documents.
    - Back up all electronic records along the way (Regents Park III fire incident).

Discussion: As could be expected, accumulating and preserving records was a major function for the CAIB and NASA. Early on, the NASA records manager worked with the CAIB, the various NASA centers and NARA to determine how best to handle investigation records. One of the first key topics was defining the best format for preserving the electronic records; this was eventually defined as PDF. Representatives from NARA worked with the CAIB to develop a retention schedule for the CAIB records. The confidential witness statements proved a particularly sensitive area, with NARA eventually agreeing to hold them for 50 years prior to releasing them to the public.

The two largest issues surrounding records were ITAR and proprietary markings. Most CAIB and CTF records were not marked with any export control information, mostly because the Space Shuttle Program did not have the resources to review the documents. At the end of the investigation, some 95 percent of the CAIB records were marked "ITAR Not Reviewed," although most were reviewed over the course of the following year. NARA policy prohibits the archives from accepting hardcopies of ITAR documents, although they can accept softcopies.

A more difficult subject was that the primary space shuttle contractor, United Space Alliance (USA), marked almost all data as proprietary, although this was often an inappropriate marking.

G.2 Establish a Quick-Response Procurement Process for Major Agency Mishaps

Observation: *The Agency Contingency Action Plan, or a supplemental document, should contain information that allows an investigation board to "hit the ground running" by providing a procurement process, points-of-contacts, charge numbers and other administrative details. This should include methods of obtaining IT support (smartphones, computers, e-mail, encryption, etc.), office supplies, time cards, etc.*

Discussion: As the Board stood up at Regents Park III, the administrative staff discovered they had no method of requisitioning office supplies. The Board did not have

a "charge number" and neither NASA/JSC nor United Space Alliance could provide logistics support without one.

G.3 Establish and Document Flexible Rules and Guidelines for Travel

Observation: *NASA should allow any accident investigation board some flexibility with travel regulations. This should be pre-coordinated with the appropriate agencies (General Services Administration [GSA], OIG, etc.) and guidelines issued to assist the board chairperson during implementation. The resulting travel regulations need to be propagated to the board members and staff to ensure compliance.*

Discussion: Any accident investigation will require the board and support staff to travel extensively. This presented some issues during the Columbia investigation. For instance, most of the Board and staff were on extended temporary duty (TDY) in Houston, meaning they lived in hotels. However, occasionally, a Board member or staff person would need to travel to another site. Under the NASA implementation of the Joint Travel Regulations, this meant the person had to checkout of their Houston hotel, since the regulations do not allow a person to have a hotel room in two cities at the same time. This was an unnecessary burden on the person to save a small amount of money. In addition, many Board members and staff did not understand the Joint Travel Regulations (JTR).

Provide the Board "Press Production" Report Production Capability

Observation: *Any future accident board should have an internal staff capable of producing the final report in a press-production form. This allows the board to tightly control the security of the report and also to place the appropriate priority on its development.*

Discussion: As is the case with all endeavors of this sort, writing and producing the final report was compressed into a remarkably short time since the Board members, naturally, wanted to use all available time to refine their findings and recommendations. Fortunately, Gehman had allowed staff members to hire writers and graphic artists that

could work on the report internally, rather than farming it out to the NASA Headquarters staff or an outside organization. This allowed the proper emphasis (and overtime) to be placed on producing the report quickly and accurately; it also simplified the security surrounding the final findings and recommendations.

G.4 Plan Ahead for Printing Support

Observation: *Any future accident investigation board should make arrangements well in advance for printing the final report. Given that it is difficult, if not impossible, to determine ahead of time exactly when the report will be ready for printing, the board needs to ensure that its printer, whether it be the Government Printing Office (GPO) or another provider, is sufficiently flexible to meet any deadlines.*

Discussion: Printing the report in a timely manner proved critical. Once they decided that they were finished generating original material, the Board set a date for the release of the report. Normally, the NASA Headquarters printing office is used for NASA publications, but the CAIB did not want to use this route for the final report because it might give the impression of a lack of independence. Since the printing office uses GPO, which is responsible for printing all government documents, the CAIB contacted GPO directly. However, GPO indicated that they could not accommodate the deadline set by the Board. Therefore, CAIB elected to have the initial print run produced by a non-GPO printer, who successfully met the deadline. This subsequently caused some consternation within GPO, but resulted in a quality product, delivered on time.

G.5 Leverage Public Affairs Support for Release of the Report

Observation: *Any accident board needs a professional public affairs staff to coordinate releasing the report to the press. Although the goal is normally to release the report to all constituents simultaneously, some consideration needs to be afforded to the press so that they can prepare meaningful stories to support the release.*

Discussion: Releasing the final report required a great deal of coordination by the public affairs officers. Reporters were concerned that "something is going to leak out; my colleague over there is going to get it before I do." One participant remembered, "In a group like the CAIB, the group is pretty tight, and I am so happy that none of them leaked out the information in the report because I had a lot of personal fear about that and I was making promises to people that I would do everything I could to prevent that."

In order to prepare meaningful stories for release at the same time as the report, the reporters needed a certain amount of advanced access to the final report. As one public affairs officer remembered, this involved "setting up a process that would allow us to let them read certain portions of it in an embargo basis before we had the press conference so that they had enough information to ask intelligent questions." The answer was to have each reporter come in at 6 a.m. on the day the report was going to be released. One public affairs officer remembered, that as they arrived: "I had a folder prepared for everyone that had a copy of the report in it; when I handed them the folder with the report I asked them to give me all of their electronic devices and I put them in a folder. The place we had it, the NTSB boardroom, actually has no cell phone coverage, so even if they had them I don't think they could have used them. But laptops, cell phones, anything, they had to give me before they went in there or they had to leave them outside where we were reading them. Then I gave them the cliff note version; I know you guys think you're speed readers, you think you've done this a million times, but I guarantee you cannot read through this report in the next 3 hours, so I'm going to tell you where the juicy bits are. So I went through and told them where to focus their reading."

Releasing the report to all constituents simultaneously proved a challenge. However, one reporter that covered the investigation remembered that the CAIB "did a terrific job of letting people know in advance how they could receive it — you could do everything from download images to the text, and they made it available on DVDs, or CDs, as well as paper copies — and I think they managed that pretty darn well."

5.0 Preparing for the Next Accident

The April 30, 2012, version of the HEOMD Implementation Plan for Mishap Preparedness and Contingency Management (HIPMPCM) describes the roles and responsibilities of the various NASA organizations following a major accident. However, the majority of mishap preparedness and contingency plan responsibilities are delineated within individual program and project Mishap Preparedness and Contingency Plans (MPCP) and, appropriately, are implemented within HEOMD project-level and center-level Safety and Mission Assurance organizations. In addition, NPR 8621.1, NASA Procedural Requirements for Mishap and Close Call Reporting, Investigating, and Recordkeeping, delineates a number of important functions to be carried out at the mission directorate level.[36]

In essence, there are three type of accidents covered in the HIPMPCM. For NASA mishaps, with the exception of "serious, high visibility" accidents, the appropriate NASA program office or NASA center is responsible for the investigation. For commercial space mishaps, the NTSB, FAA or Air Force would most likely investigate. For a major accident, along the lines of Challenger or Columbia, the investigation will be the responsibility of either a Presidential Commission (as directed in the NASA Authorization Act of 2005) or an interagency mishap board empanelled by the NASA Administrator. Either of these cases will lead to activation of the Headquarters Contingency Action Team (HCAT).

The HEOMD Associate Administrator ensures that agreements for joint programs with international partners and other federal agencies incorporate elements of NPR 8621.1 to ensure that joint mishap investigating and reporting complies with NASA requirements. Contingency responsibilities of the ISS international partners are defined in the Memorandum of Understanding and other agreements but, in general, each international partner is responsible for establishing and implementing contingency procedures for its vehicles and elements.

In case of a mishap involving an ISS visiting vehicle provided by an international partner (e.g., Progress, Soyuz, ATV, H-II Transfer Vehicle [HTV]), the vehicle owner is responsible for the contingency response and mishap investigation related to the vehicle. However, if the ISS or the ISS crew is impacted by the mishap, then the NASA contingency procedures may also be invoked, per the HIPMPCM. Mishaps that only impact the visiting vehicle (i.e., do not impact the ISS or crew) are not considered to be NASA mishaps.

If a mishap involving an international astronaut occurs on board a NASA/U.S. vehicle, NASA will establish and lead all investigations in accordance with the HIPMPCM and other applicable NASA mishap plans and interagency agreements.

Representatives of the other international space agency(s) may be invited to participate, as appropriate, within existing agreements. In the case of a mishap involving a NASA astronaut aboard a Russian vehicle, Roscosmos will establish and lead the investigation. The HEOMD Associate Administrator or designated agent will be responsible for designating NASA representatives to participate in the investigation.

Space Act Agreements with a NASA center or program include a clause regarding mishap and closecall investigations based on the Office of the General Counsel's NASA Advisory Implementing Instruction (NAII) 1050-1B Space Act Agreements Guide. The specific terms are negotiated and agreed to prior to agreement signature and any work performed.

The most striking change in accident investigation policy came with the NASA Authorization Act of 2005 (Public Law 109-155). This law established a process where "any incident that results in the loss of (1) a Space Shuttle; (2) the ISS or its operational viability; (3) any other United States space vehicle carrying humans that is owned by the Federal Government or that is being used pursuant to a contract with the Federal Government; or (4) a crew member or passenger of any space vehicle described in this subsection …" would be investigated by a Presidential Commission, similar to the Rogers Commission during the Challenger accident.[37]

This Presidential Commission would (1) investigate the incident; (2) determine the cause of the incident; (3) identify all contributing factors to the cause of the incident; (4) make recommendations for corrective actions; (5) provide any additional findings or recommendations deemed by the commission to be important, whether or not they are related to the specific incident under investigation; and (6) prepare a report to Congress, the President and the public.

The law makes available any federal employee the commission believes can assist with the investigation, while protecting that employee's existing job. The law also specifies that the NASA Engineering and Safety Center (NESC) will provide data and technical support as requested by the commission.

One of the attorneys who worked on the Columbia investigation brought up an extremely important point. A great deal of the initial support for the investigative teams came from the Department of Defense through the standing agreements between NASA and the DDMS. For the most part, those agreements were space shuttle–specific and have expired with the completion of the shuttle program. The attorney worried, "Without having a standing agreement in place with DOD at least to be able to leverage their resources since they have secure bases all across the country that you're able to kind of get in there to do that investigation — that was key for starting up the mishap investigation team activity right away."[38]

6.0 Implications for Commercial Space

NASA has adapted to the new rules and regulations governing the commercial space cargo resupply services environment including mishap planning and preparation. The observations from this report will be used to update the Agency Contingency Action Plan and supporting documents and will be codified into updated training courseware for the Inter-Agency Contingency Board. Lessons learned and best practices in mishap planning and preparation developed for the commercial cargo resupply missions will be applied to commercial crew services in the future. The information below was excerpted from the current Agency Contingency Action Plan and is intended to illustrate the integration between NASA, the FAA, the NTSB and the USAF for commercial cargo mishap planning.

There are two types of commercial launch services that are managed and/or procured within HEOMD:

1) The ISS Commercial Orbital Transportation Service demonstration and the Commercial Resupply Service (CRS) missions licensed and regulated by the FAA, and

2) The commercial launch services procured and managed by NASA's Launch Services Program (LSP) for NASA-sponsored robotic missions that include substantial involvement by NASA and are therefore not licensed and regulated by the Federal Aviation Administration. Mishap procedures for this domain are well-documented and will not be covered here.

For commercial resupply services to the International Space Station, the general guidelines include the following:[39]

- The launch operation and entry is licensed and regulated by the FAA.
    - The commercial space provider is ultimately responsible for public safety.
    - The FAA and Air Force Range are responsible for ensuring public safety.
- The NTSB or FAA is responsible for investigating any mishaps that are regulated by the license.
- If a mishap happens on the launch pad, the commercial space provider and possibly the Air Force would investigate. If a pad mishap involves the failure of a flight safety system, the NTSB/FAA would investigate.
- If there is a mishap during ascent or entry, the FAA will investigate with assistance from the commercial space provider. The NTSB may take the lead role in the investigation, depending on the nature of the mishap.
- Loss of NASA cargo on the test flight does not trigger a NASA investigation.
- If NASA facilities are damaged or NASA personnel are injured, the appropriate NASA center would investigate that aspect in accordance with NPR 8621.1 and the appropriate NASA center mishap preparedness and contingency plan with respect to facility damage.
- If a mishap occurs during ISS integrated operations, the ISS program will investigate in accordance with NPR 8621.1 and SSP 50190 (ISS Contingency Action Plan).
    - Integrated operations start at 90 minutes prior to approach initiation and last until the vehicle leaves the approach ellipsoid on a nonreturn trajectory.
    - The ISS program assumes mishap responsibility at the Go/No Go for approach to 1.4 kilometers.

The NTSB is the lead agency to investigate any launch or reentry accident resulting in a serious injury/fatality or significant property damage not associated with the launch. The current NTSB/FAA/USAF memorandum of understanding defines an accident as:

- Vehicle/payload components impacting outside the impact limit lines,
- A fatality or serious injury (as defined in 49 CFR 830.2) to any person not located on the launch range facility, or as
- Third-party property damage greater than $25,000.

However, the NTSB may also investigate other mishaps depending on the (potential) severity. Any investigation will be conducted in accordance with current rules and practices and be led by the NTSB Investigator in Charge. Depending on accident circumstances, NASA could be a party to the NTSB investigation or be an observer.

To familiarize the participants with the new procedures, NASA, in conjunction with the NTSB, FAA, and the Air Force, has been conducting launch mishap tabletop exercises (TTE) to better understand each participant's roles and responsibilities. This is seen as an effort to develop an understanding and effective method for managing a launch, orbital or reentry mishap. TTEs have been conducted with both the Eastern Range (November 2010) and Western Range (November 2011), and future TTEs are being planned with the Wallops range at Wallops Flight Facility (WFF). NASA's HEOMD also conducted a commercial cargo mission mishap TTE in April of 2012 with the FAA, the NTSB, KSC and ISS management support. A key learning point, particularly for NASA personnel accustomed to shuttle operations, was the dynamic nature of mishap responsibilities at the boundaries of mission profiles.

7.0 Appendix A: Interviews and Sources

All interviews were conducted by David M. Lengyel.

Interview, Harold W. Gehman, CAIB, July 11, 2012.

Interview, Frank T. Buzzard, CTF, July 20, 2012.

Interview, Frederick D. Gregory, NASA Headquarters, August 2, 2012.

Interview, Kenneth W. Hess, CAIB, August 9, 2012.

Interview, G. Scott Hubbard, CAIB, August 10, 2012.

Interview, Laura J. Brown, CAIB PAO, August 10, 2012.

Interview, Frank J. Benz, NAIT, August 24, 2012.

Interview, James P. Bagian, CAIB flight surgeon, September 4, 2012.

Interview, James N. Hallock, CAIB, September 4, 2012.

Interview, Anna K. "Kitty" Rogers, Jana T. Schultz, and Christine F. Cole, CAIB staff, September 4, 2012.

Interview, Duane W. Deal, CAIB, September 7, 2012.

Interview, Amy Xenofos and Donna M. Shafer, NASA, September 7, 2012.

Interview, David W. Whittle, NAIT, September 10, 2012.

Interview, David A. King, NAIT, September 11, 2012.

Interview, J. William Sikora, CAIB Counsel, September 12, 2012.

Interview, Brock R. "Randy" Stone, NAIT, September 17, 2012.

Interview, Patti F. Stockman, NASA Headquarters, September 17, 2012.

Interview, William F. Readdy, NASA Headquarters, September 24, 2012.

Interview, Ralph R. Roe, NAIT, September 28, 2012.

Interview, John R. "Bob" Lang, USA, September 28, 2012.

Interview, Stephen J. Altemus, NAIT, September 28, 2012.

Interview, Robert W. Cobb, NASA IG, October 2, 2012.

Interview, Paul S. Hill, NAIT, October 2, 2012.

Interview, Kyle J. Herring, NASA PAO, October 5, 2012.

Interview, Michael J. Bloomfield, NASA astronaut, October 17, 2012.

Interview, Michael D. Cabbage and Robert N. Jacobs, NASA PAO, October 19, 2012.

Interview, Marcia S. Smith, Congressional Research Service, October 22, 2012.

Interview, James P. Mosquera, CAIB Staff, October 26, 2012.

Interview, William B. Adkins, House Science Committee staff, October 31, 2012.

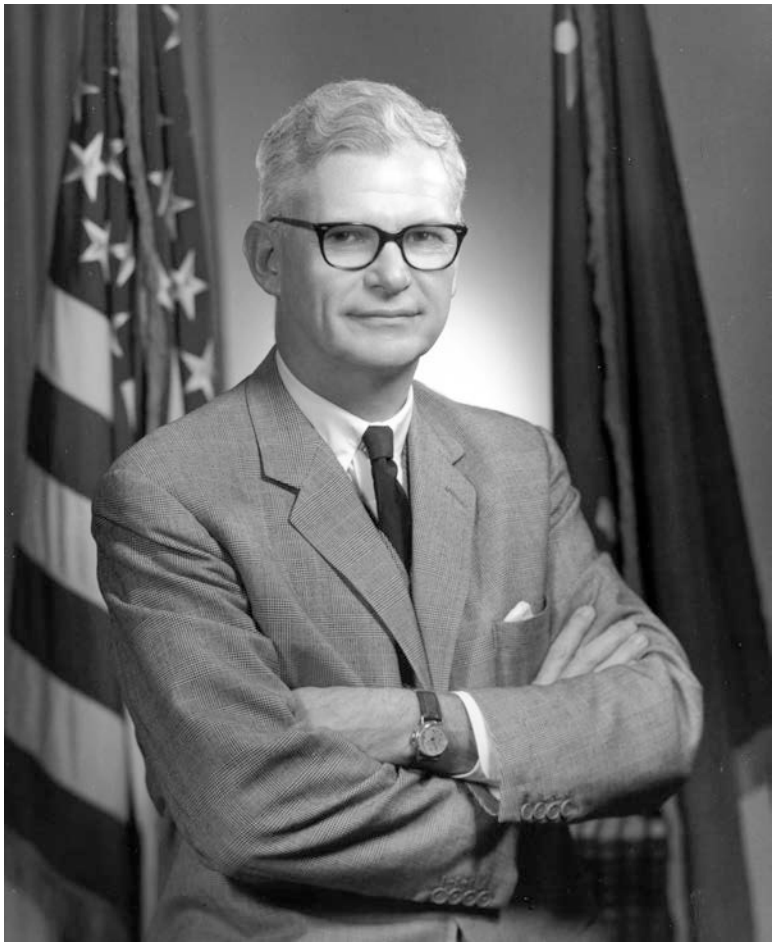
Interview, Steven B. Wallace, CAIB, October 31, 2012.

Interview, Robert P. Benzon, NTSB, November 6, 2012.

8.0 Appendix B: Human Spaceflight Accident Investigations

Over the course of the past 51 years, the American human spaceflight program has suffered three fatal accidents: AS-204 (Apollo 1) in 1967, Challenger (STS-51L) in 1986, and Columbia (STS-107) in 2003. Each accident was significantly different in cause and scope, although each ultimately showed disturbing similarities in thought process and management practice. The investigation into each accident also differed. For AS-204, NASA investigated itself; for Challenger, the President established an independent commission; and for Columbia, an independent board operated under NASA auspices.

As a result of an in-flight anomaly during Gemini 8, on April 14, 1966, Deputy Administrator Robert C. Seamans Jr. issued NASA Management Instruction 8621.1, Mission Failure Investigation Policy and Procedures. Based partly on military aircraft accident investigation procedures, this document gave the Administrator the option to conduct an independent investigation of "major failures" instead of leaving it to the responsible program office. In essence, Seamans was attempting to eliminate the inherent conflict of interest that results from a program investigating itself. Regardless of what organization conducted the investigation, Seamans stated, "It is NASA policy to investigate and document the causes of all major mission failures which occur in the conduct of its space and aeronautical activities and to take appropriate corrective actions as a result of the findings and recommendations." This philosophy has never waivered.[40]



Seamans — NASA Deputy Administrator Robert C. Seamans Jr. (October 30, 1918–June 28, 2008). (U.S. Air Force)

The new procedure was put to the test within the year. Immediately after the AS-204 (later called Apollo 1) fire on January 27, 1967, Seamans established the Apollo 204 Review Board chaired by Langley Research Center Director Dr. Floyd L. Thompson. Initially, the board also included Colonel Frank F. Borman II, Dr. Maxime A. Faget, E. Barton Geer, George W. Jeffs, Dr. Frank A. Long, Colonel Charles F. Strang, George C. White Jr., John J. Williams, and legal counsel George T. Malley. All of these members, except Malley, were somehow involved in Apollo because, in Seaman's judgment, the complexity of Apollo required board members familiar with the program and NASA management procedures.[41]

Apollo 1 Crew — The crew of AS-204 (Apollo 1): Edward H. White II, Virgil I. "Gus" Grissom and Roger B. Chaffee. (NASA)

Presaging the scope of the later Columbia investigation, the Apollo 204 Review Board charter included a mandate to "Consider all other factors relating to the accident, including design, procedures, organization, and management."[42] To assist in the investigation, the board established 21 working panels to review spacecraft subsystems, components and materials. These panels provided the main source of information from which the board formulated its findings and recommendations.[43] It was quickly apparent that North American Aviation would garner significant criticism, so on February 3, Seamans replaced George Jeffs, the North American Aviation chief engineer for Apollo, with Dr. Robert W. Van Dolah, from the U.S. Bureau of Mines. At the same time, Frank Long left the board for undisclosed reasons.[44]

Seamans immediately ordered all Apollo 204 hardware and software impounded, to be released only under control of the board. After taking photographic documentation of the CM-012 (Command Module 012) interior, the board ordered the capsule disassembled using procedures tested on the identical CM-014. Engineers conducted an evaluation of every part, and board members interviewed witnesses and reviewed the autopsy results. The board found the documentation for CM-012 so lacking that they were at times unable to determine the configuration of the spacecraft at the time of the accident.

Even during the race to the moon, having NASA investigate itself appeared suspect, so NASA Administrator James E. Webb sought, and received, approval from President Lyndon Johnson for the internal NASA investigation. Webb subsequently notified appropriate members of the House and Senate. According to his biography: "Webb went to President Lyndon Johnson and asked that NASA be allowed to handle the accident investigation and direct the recovery from the accident. He promised to be truthful in assessing blame and pledged to assign it to himself and NASA management as appropriate."[45]

On April 5, 1967, the board issued its final report to the NASA Administrator. The report presented the results of the investigation and made specific recommendations that led to major design and engineering modifications, changes to test planning and discipline, revisions to manufacturing processes and procedures, and increased quality control. Despite open criticism of many aspects of the government-contractor relationship and management procedures, and a mandate to consider "organization and management," all of the findings and recommendations were technical or procedural in nature.

This concentration on the technical aspects of the accident could have been because the board worried about the impact of criticism on the human space program as a whole. The report stated: "the Board is very concerned that its description of the defects in the Apollo Program that led to the condition existing at the time of the Apollo 204 accident will be interpreted as an indictment of the entire manned space flight program and a castigation of the many people associated with that program. Nothing is further from the Board's

intent. The function of the Board has been to search for error in the largest and most complex research and development program ever undertaken. This report, rather than presenting a total picture of that program, is concerned with the deficiencies uncovered."[46]

In addition, the United States Senate also investigated the accident. Senator Clinton P. Anderson was chairman of a committee that included 15 additional senators, including W. Stuart Symington (former Secretary of the Air Force) and John C. Stennis. The preface to the Senate report indicated: "It is the committee's view that, when an event such as the tragic Apollo 204 accident occurs, it is necessary for the appropriate congressional committees to review the event thoroughly. The Congress has a duty to be fully informed and to provide an information flow to the people. Further, the committee has a responsibility to satisfy itself that a strong NASA management is exercising vigilance over the safety of the people working on the space programs."[47]

In addition to the technical causes of the accident, the Senate investigation also examined the "stewardship of the National Aeronautics and Space Administration in the Apollo Program" and the "performance of North American Aviation, Inc. as the prime contractor for the Apollo command module." The committee found that the Apollo 204 Review Board conducted an exhaustive, thorough, and objective investigation of the accident and added little to the overall discussion.[48]

It would be 19 years before the next fatal accident.

The Space Shuttle Program was, by far, the longest of the American human spaceflight programs, ultimately spanning a period of 40 years with a flight campaign that lasted 30 years. Formal studies began in 1969 and President Richard Nixon approved the development effort on January 5, 1972. After an intense competition, North American Rockwell (now part of Boeing) won the contract to develop and manufacture the orbiter; the Solid Rocket Booster (SRB) contract went to Thiokol (now Alliant Techsystems [ATK]) while Rocketdyne (now Pratt & Whitney) developed the Space Shuttle Main

Engines (SSMEs) and Martin Marietta (now Lockheed Martin) developed the External Tank (ET).

Only 30 months after program approval, on June 4, 1974, workers at Air Force Plant 42 in Palmdale, Calif., started structural assembly of Orbiter Vehicle 101 (OV-101). On September 17, 1976, Enterprise was rolled out amid much pomp and circumstance. NASA used the vehicle for a series of atmospheric test flights in 1977 that validated the orbiter could successfully fly and land on a concrete runway. At the same time, the development of the SRB and ET continued at facilities around the country. The SSMEs, the most advanced rocket engines ever developed, were proving troublesome.

Somewhat behind the original schedule, the first orbital test flight took place on April 12, 1981, with John W. Young and Robert L. Crippen aboard Columbia. By 1984, three additional Orbiters — Challenger, Discovery and Atlantis — had joined the fleet at the Kennedy Space Center in Florida. Between 1981 and mid-January 1986, the program launched 24 successful missions, including 11 in the previous 12 months. The space shuttle seemed to be hitting its stride.

Things changed abruptly on the morning of January 28, 1986, when Challenger was lost 73 seconds after lift-off. A combined Coast Guard/NASA/Air Force/Navy search team spent the next 3 months searching the Atlantic for the remains of the orbiter and its crew. The search teams found the wreckage in water up to 1,200 feet deep and ultimately recovered approximately 30 percent of the orbiter.[49]

Challenger Crew — The crew of STS-51L pose for their official portrait on November 15, 1985. Back row (from left): Ellison S. Onizuka, Sharon Christa McAuliffe, Gregory B. Jarvis and Judith A. Resnik. Front row (from left): Michael J. Smith, Francis R. "Dick" Scobee and Ronald E. McNair. (NASA)

Perhaps because national television carried the accident live, Ronald Reagan formed a Presidential Commission to investigate the accident with the issuance of Executive Order 12546 on February 3, 1986. William P. Rogers, a former Secretary of State under Richard Nixon, chaired the commission that included David C. Acheson, Neil A. Armstrong, Dr. Richard P. Feynman, Robert B. Hotz, Dr. Alton G. Keel Jr., Lieutenant General Donald J. Kutyna, Sally K. Ride, Robert W. Rummel, Joseph F. Sutter, Arthur B. C. Walker Jr., Dr. Albert D. Wheelon, and Brigadier General Charles E. Yeager.[50]

Given the stature of many of the members of the commission, it was not surprising that

subordinate investigators did most of the fieldwork, with the commission itself serving more as an executive review board for most of the effort. Nevertheless, the commission held 35 formal panel sessions that generated almost 12,000 pages of transcript. Investigators interviewed more than 160 individuals and examined nearly 6,300 documents that totaled more than 122,000 pages, as well as hundreds of photographs and hours of video footage.[51]

The final report was released on June 6, 1986, and concluded: "The consensus of the Commission and participating investigative agencies is that the loss of the Space Shuttle *Challenger* was caused by a failure in the joint between the two lower segments of the right Solid Rocket Motor. The specific failure was the destruction of the seals that are intended to prevent hot gases from leaking through the joint during the propellant burn of the rocket motor. The evidence assembled by the Commission indicates that no other element of the Space Shuttle system contributed to this failure."[52]

The Challenger investigation delved more deeply into culture and organization than had the Apollo 204 Review Board and concluded that neither NASA nor Thiokol responded adequately to internal warnings about the faulty SRB seal (O-ring) design. Furthermore, NASA and Thiokol did not make a timely attempt to develop and verify a new seal after the initial design was shown to be deficient. Neither organization developed a solution to the unexpected occurrences of O-ring erosion and blow-by despite this problem being experienced frequently during earlier flights. Instead, NASA and Thiokol management came to accept erosion and blow-by as unavoidable and an acceptable flight risk.[53]

The commission made observations that ultimately came back to haunt the agency during the Columbia investigation. For instance, NASA and Thiokol accepted escalating risk apparently because they "got away with it last time." As Richard Feynman observed, the decision-making was "a kind of Russian roulette…. [The shuttle] flies [with O-ring erosion] and nothing happens. Then it is suggested, therefore, that the risk is no longer so high for the next flights. We can lower our standards a little bit because we got away with it last time…. You got away with it, but it shouldn't be done over and over again like

that." Columbia University sociologist Diane Vaughn later characterized this as a "normalization of deviance" that became a major topic during the Columbia investigation.[54]

Although the commission concluded that the Challenger accident was a direct result of the Solid Rocket Motor seal failure, it also uncovered numerous other areas of concern, everything from the orbiter braking system to a decision-making process described as "flawed." The Commission found that, in its efforts to produce an "operational" system, NASA had abandoned many of the procedures that had made it successful during its first 25 years.[55]

In addition to its technical recommendations, the Rogers Commission believed that NASA should establish an Office of Safety, Reliability, and Quality Assurance reporting directly to the NASA Administrator and improve communications between centers. In particular, NASA should undertake an effort to consolidate decision-making and review processes into a Space Shuttle Program organization instead of as an individual center effort.[56]

During the 32-month stand-down after the Challenger accident, NASA made great strides toward meeting most of these recommendations. By the beginning of September 1988 (just prior to return-to-flight STS-26R), 76 mandatory orbiter modifications included devising a crew escape system, increasing the thermal protection on the chin panel, installing new brakes, and recertifying the 17-inch propellant disconnects between the orbiter and the ET. In addition, workers at KSC had completed more than 185 ground system modifications. By far, the most extensive work had been to the Solid Rocket Motors, which were now called Redesigned Solid Rocket Motors (RSRMs, although the "R" eventually became "Reusable"). A new Safety Risk & Quality Assurance (SR&QA) officer was in place, and NASA had overhauled its overall decision-making process.

After Challenger, NASA Headquarters developed a more detailed Contingency Action Plan that listed specific members of any future accident board, identified by the positions

they held within NASA, the FAA and the military. Interestingly, the plan did not identify a board chairperson, leaving this appointment up to the NASA Administrator. In addition to the Agency Contingency Action Plan, a similar plan was incorporated into the NSTS-07700 Space Shuttle Requirements Document, and each of the human spaceflight centers and major contractors had documents that identified how they would react to a major accident.

Including the return-to-flight launch of STS-26R on September 29, 1988, the Space Shuttle Program flew 87 successful missions through the landing of STS-113 on December 7, 2002. Although there were technical issues on some missions, and concerns with hydrogen leaks grounded the fleet on several occasions, the space shuttle proved its mettle. During this period, the program launched three Great Observatories and two planetary probes, performed several classified military missions, contributed numerous scientific flights using Spacelab and SPACEHAB, made four servicing missions to the Hubble Space Telescope, visited the Mir space station seven times, and conducted the first 15 International Space Station assembly flights.

STS-26R Launch — Discovery flew the first return-to-flight mission at 11:37 a.m. on September 29, 1988, the first of 87 successful flights before the Columbia accident. (NASA)

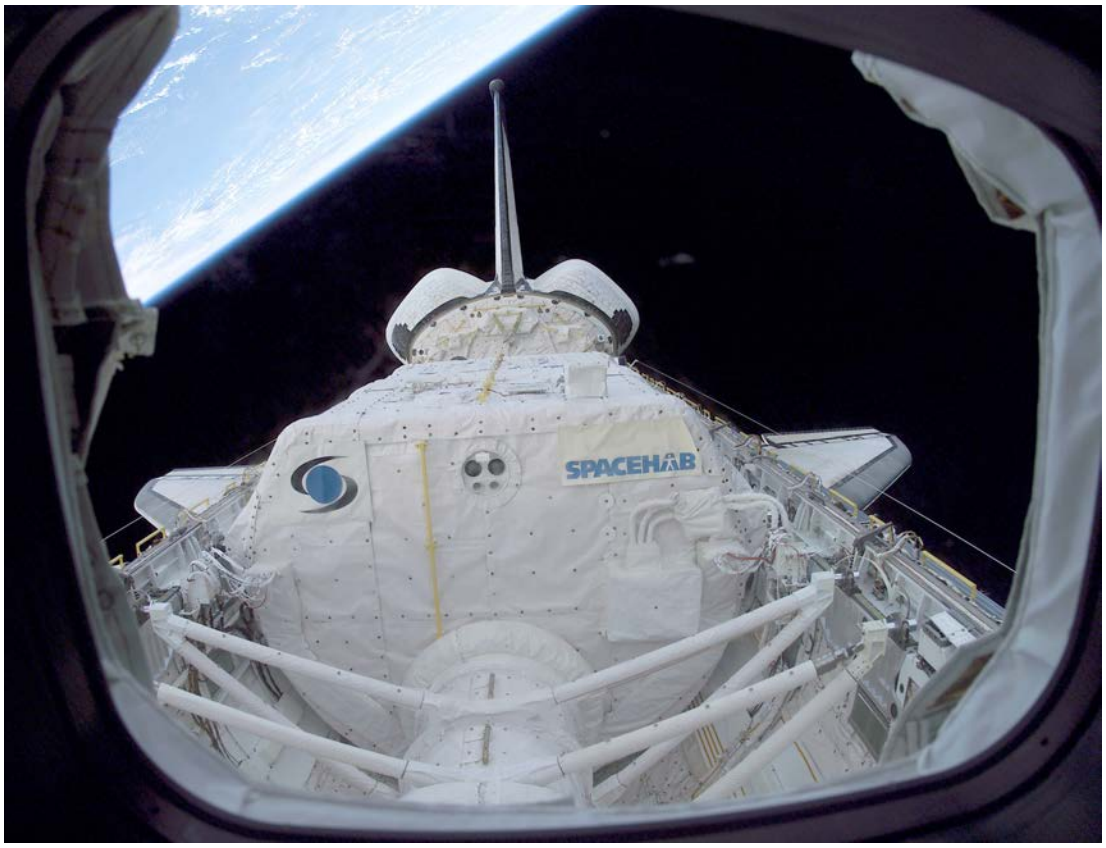
By the beginning of the 21st century, NASA was making plans to continue flying the space shuttle until the year 2020, well past its expected 10-year lifetime when the program began. The vehicles had been well-maintained, underwent frequent inspections, and were in the process of being updated with glass cockpits and other modern systems. Everything appeared to be going so well.

9.0 Appendix C: Columbia and STS-107

Much of the following narrative is excerpted from the Columbia Accident Investigation Board (CAIB) final report.

Almost from the beginning, NASA used the space shuttle for dedicated science missions, often aboard Columbia because it was equipped for extended-duration missions. Many of these science missions carried pressurized Spacelab or SPACEHAB modules to accommodate life sciences or microgravity research.[57] In March 1998, NASA Administrator Daniel S. Goldin announced that STS-107, tentatively scheduled for May 2000, would be a multidisciplinary science mission generally similar to the STS-90 Neurolab mission.[58]

The primary payload for STS-107 was the SPACEHAB Research Double Module. Other payloads included Israel's Mediterranean-Israeli Dust Experiment (MEIDEX) accompanied by the first Israeli astronaut. In addition, NASA wanted to carry Triana, a deployable Earth-observation satellite. Political disagreements between Congress and the White House delayed Triana, which NASA replaced with the cobbled-together Fast Reaction Experiments Enabling Science, Technology, Applications, and Research (FREESTAR) payload.[59]



SPACEHAB — The SPACEHAB Research Double Module as seen from the aft flight deck of Columbia on January 22, 2003, during STS-107. (NASA)

As the manifesting process continued, NASA selected January 11, 2001, as the launch date for STS-107. This, however, was not to happen, and the mission would ultimately be delayed more than 2 years. Contrary to popular perception, most space shuttle mission delays took place long before a vehicle was stacked or moved to the launch pad. In the case of STS-107, only a few of the eventual 13 delays took place after the orbiter was configured for flight.[60]

In addition to the normal shuffling of the manifest to accommodate the availability of crews, hardware and changing priorities, a series of events caused delays for STS-107. The first was replacing Triana with FREESTAR. Next was a problem with Kapton wiring in the orbiter fleet that extended the OV-102 Orbiter Maintenance Down Period (OMDP)

for 6 months. The first Columbia flight following the OMDP was supposed to be STS-107, followed by the fourth Hubble servicing mission (SM3B) on STS-109. However, NASA considered the Hubble servicing more critical than the science mission, and it was ultimately flown first.[61]

Another delay came a month before the planned July 19, 2002, launch when concerns about cracks in the main propulsion system (MPS) flowliners caused a 4-month grounding of the orbiter fleet. The flowliner in each main propellant feed line mitigated turbulence across the flexible bellows as propellants flowed to the SSME low-pressure turbopumps and protected the bellows from flow-induced vibration. First discovered on Atlantis, NASA subsequently discovered cracks on each orbiter. Technicians at KSC fixed the cracks through a tedious process of welding and polishing. To maintain the ISS assembly sequence while minimizing the delay in returning the Expedition 5 crew, both STS-112 and STS-113 were launched before STS-107.[62]

Launch

Shortly after 07:30 EST on January 16, 2003, the STS-107 crew was driven from the astronaut quarters in the Operations and Checkout Building to Launch Complex 39A. Rick Husband was the first crewmember to enter Columbia, at 07:53, and Kalpana Chawla was the last, at 08:45. The closeout crew secured the hatch at 09:17 and all nonessential personnel cleared the launch pad at 10:16. Fifteen minutes later, the countdown clock came out of the planned T–9-minute hold and the SSMEs ignited at 10:38:55. The final flight of Columbia began at 10:39:00.000 when the two SRBs ignited.[63]

Columbia Crew — Taken in October 2001. Seated in front (from left) are Rick D. Husband, Kalpana Chawla and William C. McCool. Standing (from left) are David M. Brown, Laurel B. Clark, Michael P. Anderson and Ilan Ramon. (NASA)

As expected, 2 minutes and 7 seconds after launch, the SRBs separated from the ET and made a routine splashdown in the Atlantic Ocean. Approximately 6 minutes and 23 seconds later, the three SSMEs shut down normally, followed by ET separation. At 11:20, a 2-minute Orbital Maneuvering System (OMS) burn positioned Columbia in a 175-mile orbit. It all seemed so normal.[64]

As was done for every launch, within 2 hours of liftoff the Intercenter Photo Working Group performed a cursory evaluation of the video from tracking cameras around the launch site. This initial review did not reveal any unusual events. However, when the analysts received higher resolution film that had been processed overnight, they noted a debris strike at T+81.9 seconds.[65]

During launch, three cameras around the launch site saw "a large light-colored piece of debris … originate from an area near the ET/Orbiter forward attach bipod." The quick-look analysis indicated, "The debris appeared to move outward in a –Y direction, then fell aft along the left Orbiter fuselage and struck the underside (–Z) of the leading edge of the left wing." Based on the available imagery, analysts determined that one large piece and at least two smaller pieces of insulating foam separated from the left bipod (–Y) ramp area of the ET at T+81.7 seconds. Further analysis showed the large piece was 21 to 27 inches long and 12 to 18 inches wide, tumbling at approximately 18 revolutions per minute (rpm).[66]

Columbia on Launch Pad — OV-102 waiting for launch as STS-107. The left ET bipod ramp is clearly visible at the bottom of the intertank, just above the orbiter crew hatch. (NASA)

ET Bipod Close-up – A close-up image of the ET bipod ramp (top left) that separated during launch and struck the underside of the wing leading edge 81.9 seconds after launch. (NASA)

Just prior to separating from the ET, the foam was traveling at the same 1,568 miles per hour (mph) (2,300 feet per second [fps]) as the rest of the vehicle. Visual evidence showed that the large foam debris impacted somewhere on the underside of the wing approximately 0.161 seconds after separation. During that time, air resistance caused the foam to slow to 1,022 mph (1,500 fps) while the rest of the vehicle continued to accelerate toward orbit. Therefore, the orbiter hit the foam with a relative velocity slightly greater than 545 mph (800 fps).[67]

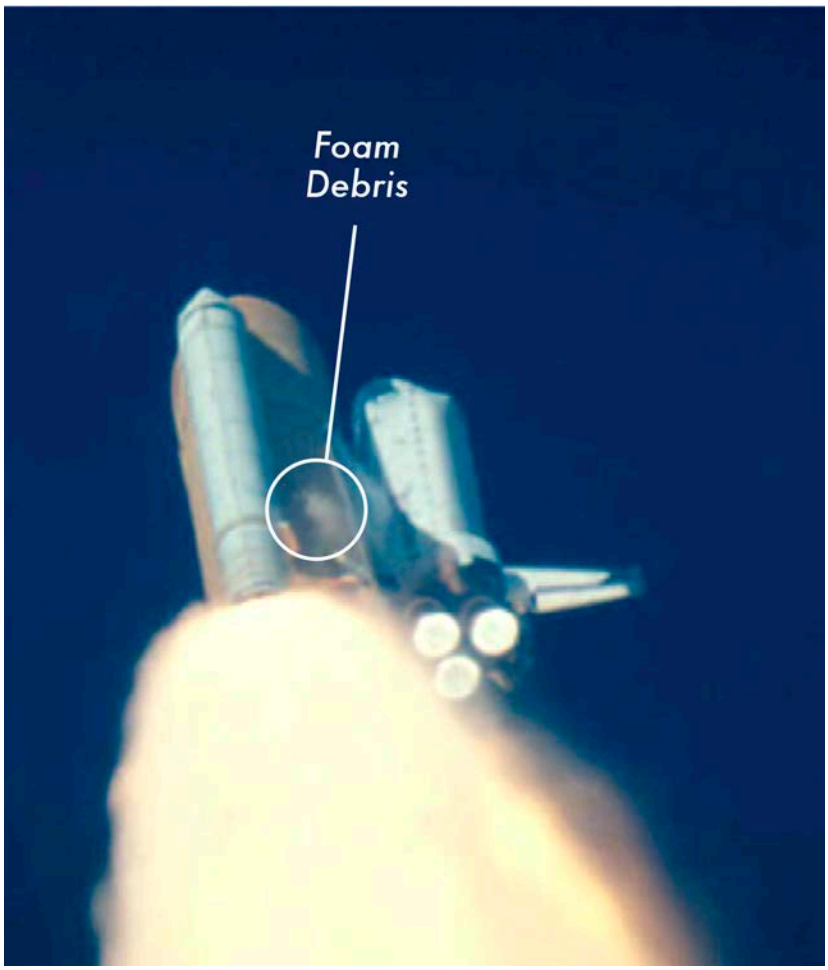
The large size of the foam and the momentum transfer concerned the Intercenter Photo Working Group, which worried Columbia had been damaged. The analysts requested that a high-resolution on-orbit image of Columbia be obtained by the Department of Defense. Unsurprisingly, the DOD has several methods to image objects in orbit around Earth.

Ground-based telescopes are the most common and the Space Shuttle Program had used this type of imagery on several previous missions.[68]

After discovering the debris strike, the analysts prepared a report with a video clip of the impact and sent it to the Mission Management Team (MMT), the Mission Evaluation Room (MER) and engineers at Boeing and United Space Alliance. NASA convened a Debris Assessment Team on January 21 and the first meeting ended with the highest-ranking NASA engineer on the team bringing forward a request for on-orbit imagery.[69]

Without on-orbit images of Columbia, the Debris Assessment Team could use only analytical tools that had not been designed for this type of impact. Over the next 6 days, the team concluded that some localized heating damage would occur during entry, but they could not definitively state that this would result in structural damage. On January 24, the Debris Assessment Team presented these results to the MER, whose manager gave a verbal summary to the MMT later the same day. The MMT decided the debris strike was a "turnaround" (maintenance) issue and did not pursue the request for imagery.[70]

Even after this decision, engineers throughout the program continued to exchange e-mails and discuss possible damage. Many of these messages were shared with others over coffee or drinks at local gathering places around Johnson Space Center and Kennedy Space Center, and there was a great deal of formal and informal discussion at all levels of engineering — except, apparently, where it counted. Almost everybody assumed that the MMT and MER were taking the threat seriously and would provide all necessary assistance to the groups working the issue at JSC. Sadly, that was not the case.[71]



Debris Strike — The day after the launch, the Intercenter Photo Working Group detected a possible debris strike to the left wing of Columbia. (NASA)

Entry

Saturday, February 1, 2003, dawned cool and foggy in Central Florida. The heavy fog burned off quickly as the sun rose above the Atlantic, revealing a bright winter day that was perfect for Columbia to come home. Mission Control was not working any technical or procedural issues, and forecasters in Houston and Florida found the weather within the flight rules. This was confirmed by astronauts Kent V. "Rommel" Rominger and Barbara R. Morgan, who had been Christa McAuliffe's backup in the NASA Teacher in Space Program, flying in a Shuttle Training Aircraft above the Shuttle Landing Facility.

At 13:15:30 UTC (08:15:30 EST), as Columbia flew upside down and tail-first 175 miles above the Indian Ocean, the crew executed a 158-second de-orbit burn that slowed the orbiter approximately 176 mph. Although a small percentage of the 17,500 mph orbital speed, it was enough to nudge the vehicle into the atmosphere. After the burn, the crew maneuvered Columbia right-side-up and forward-facing with the nose pitched up 40 degrees. A little more than 28 minutes after the de-orbit burn, somewhere over the Pacific Ocean, the orbiter reached Entry Interface, arbitrarily defined as an altitude of 400,000 feet (written EI+000, meaning Entry Interface plus 000 seconds).

As the vehicle descended, atmospheric friction began to heat the surface of the orbiter, with the nose and wing leading edges experiencing temperatures greater than 2,800 degrees Fahrenheit (degF). It is precisely this environment that the thousands of tiles and blankets on the orbiter were designed to endure.

The orbiter descended through the increasingly dense atmosphere, creating shock waves at the nose and along the wing leading edges. The interaction between these shock waves generated extreme temperatures, especially around Reinforced Carbon-Carbon panel 9, where the wing displays its classic double-delta shape. The flow behind these shock waves is hot enough to cause air molecules to tear apart, or "dissociate." Although physicists and aerodynamicists are quick to point out that this superheated air is not plasma, it is a purely technical distinction and the air immediately around the leading edge of the wing can reach 10,000 degF. Fortunately, the boundary layer acts as a shield so the wing leading edge experiences temperatures of only 3,000 degF. As designed, the leading edge RCC panels direct the air around the wing, and internal insulation protects the aluminum leading edge spar. Unknown to flight controllers or the crew, a breach in RCC-8L (the eighth panel on the left wing) was exposing the internal wing structure to temperatures well above the 350 degF point, where aluminum loses its structural strength, and, soon, above its 1,200 degF melting point.

During entry, sensors aboard Columbia collected temperature, pressure and stress data. Because of the limited 128-kilobyte bandwidth of the 1970s-vintage Operational Flight

Instrumentation (OFI) telemetry system, only a portion of the data was transmitted to the ground, with the remainder stored on the Modular Auxiliary Data System recorder on the orbiter. This recorder was located in the crew module and was unique to OV-102, a leftover from the Orbiter Experiments (OEX) system used on many early flights. Although the experiments had long since concluded, the instrumentation remained on Columbia and was still providing flight data for ongoing analysis. Almost unbelievably, on March 20, 2003, the MADS recorder was found intact, and its data proved invaluable to investigators reconstructing the aerodynamic, aerothermal and mechanical condition of the orbiter.

Finding the MADS recorder was one of the turning points of the investigation. Frank Benz, the JSC Director of Engineering, remembered: "At that point in time a lot of the focus of the analysis was a hit somewhere around the chine area or at the [main landing gear] door, or on one of the carrier panels. Everything was focused on how heat got into the wheel well. When we found the MADS recorder we had 2 minutes of earlier data and all of a sudden we saw that the first indication was a thermal-couple behind RCC panel 8. The whole focus changed. All of our testing changed. We had been focusing on shooting tile at SwRI. Now we realized that we didn't get hit on the tile, we got hit on the RCC."[72]

At 13:48:39 (EI+270), while the Orbiter was over the Pacific Ocean, MADS recorded the first unusual condition. Four sensors, on either side of the wing leading edge spar near RCC-8L, began producing abnormal readings. Since engineers did not consider these data particularly useful during flight, it was not displayed to the crew or telemetered to the ground, but was dutifully sent to the MADS recorder.

The orbiter began yawing to the left at 13:51:46 (EI+457), although the angle remained within previous flight experience for almost 2 minutes. At 13:52:05 (EI+476), the yaw changed due to increased drag from the damaged left wing and the flight control system commanded elevon trim to compensate. Neither the yaw moment change nor the elevon trim change was obvious to the flight controllers or the crew as an off-nominal condition, although post-accident analysis concluded that this was the first indication to the changing aerodynamic properties brought about by the damage to the left wing.

Columbia crossed the California coast west of Sacramento at 13:53:26 (EI+557), traveling east at Mach 23 and 231,600 feet. At this point, the wing leading edge was experiencing 2,800 degF, the same as every other space shuttle entry. During the next 15 seconds, however, temperatures on the fuselage sidewall and the left OMS pod began to rise. Investigators later used flight data to reconstruct the aerodynamic forces acting on the orbiter and subsequent hypersonic wind tunnel tests indicated that damage to the wing leading edge near RCC-8L caused the increased heating of the OMS pods. Wind tunnel tests also demonstrated that increasing damage to leading edge RCC panels resulted in increasing drag and decreasing lift on the left wing, explaining the roll and yaw forces acting on the orbiter.

The orbiter crossed from California into Nevada at 13:54:23 (EI+614) traveling at Mach 22.5 and 227,400 feet. Witnesses observed 18 debris-shedding events in the next 4 minutes as Columbia streaked over Utah, Arizona, New Mexico and Texas. All of this was unknown to the crew and flight controllers. Over Arizona, at 13:56:30 (EI+741), Columbia entered the first planned roll reversal, turning from right wing down to left wing down. Traveling at Mach 20.9 and 219,000 feet, at EI+756 the orbiter crossed from Arizona into New Mexico, passing just north of Albuquerque. The orbiter completed the roll reversal at EI+766 and the guidance and flight control systems were continuing to compensate for the compromised aerodynamics of the left wing.

The orbiter passed into Texas at 13:58:20 (EI+851), traveling at Mach 19.5 and 209,800 feet. Ballistic analysis later showed that the westernmost piece of recovered Columbia

debris was released at EI+852. This debris, a tile from the upper left wing just behind RCC-8L, was found in Littlefield, Texas. Aboard Columbia, changing drag on the left wing was beginning to develop into a recognizable problem as the flight control system commanded another abrupt change in elevon trim at 13:59:26 (EI+917).

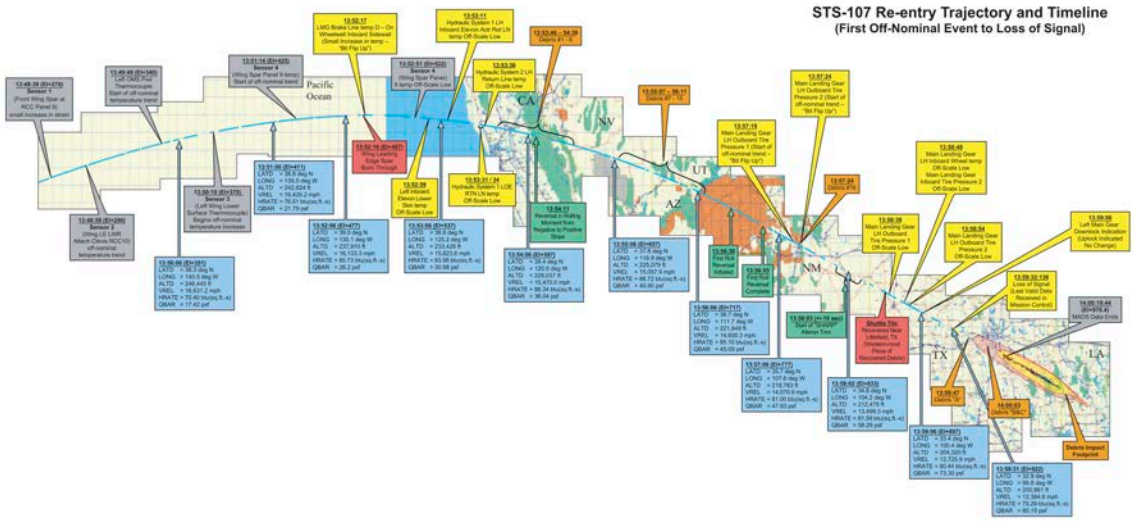
The last valid data received by the Mission Control Center computer system was at 13:59:32.136 (EI+923) while Columbia was approaching Dallas at Mach 18.1 and 200,700 feet. This coincided with an expected short-duration loss of signal as the onboard communication system automatically reconfigured from the west Tracking Data and Relay Satellite (TDRS) to the east TDRS satellite or to the Merritt Island Launch Annex (MILA) Spaceflight Tracking and Data Network ground station at KSC. Contact would never be restored.

Video imagery showed a dynamically changing orbiter trail after 13:59:37 (EI+928) with a braided or corkscrew appearance, implying a similar motion of the vehicle. At 13:59:46 (EI+937), ground-based video indicated a bright piece of debris was released, followed by a second piece 2 seconds later. This second piece separated from the orbiter's trail and decelerated slowly, remaining visible for more than 37 seconds before dispersing into significantly fainter pieces. Ballistic analyses of ground debris indicate that pieces of the left OMS pod were being shed starting at about EI+940.

Breakup — Four images from the CAIB report showing Columbia breaking up during entry. The ability to time correlate images from various sources helped investigators determine how the orbiter broke apart. (lower left: Robert McCullough/The Dallas Morning News; others: CAIB)

There is debate among the investigators about exactly when orbiter loss of control occurred. In the Columbia Crew Survival Investigation Report, the Spacecraft Crew Survival Integration Investigation Team (SCSIIT) concluded that loss of control (LOC) occurred at 13:59:37 (EI+928), which is approximately 42 seconds earlier than the time provided in Columbia Accident Investigation Board Report. The SCSIIT concluded that loss of control coincided with the loss of hydraulics since it was then no longer possible to control the orbiter, while the CAIB concluded that the event coincided with the loss of electrical power to the MADS and video recorders at EI+970. It is an irrelevant difference of opinion between the authors of the reports. In any case, videos from ground observers at 14:00:18 (EI+969) showed Columbia disintegrating.

By 14:00:25 (EI+976), there were visual indications that the obiter was in multiple pieces. An engineering analysis conducted during the investigation showed the breakup started with the compromise of the payload bay doors, exposing the payload bay longeron sills to high heating. The skin splice between the mid-body and the forward bulkhead failed due to mechanical and thermal loads. The forebody rotated away from starboard to port, and as the forebody separated from the mid-body, various power, data and fluid lines failed. At this point, the crew module was free to move forward and strike the inside of the forward fuselage. Engineers estimate that at the time of the breakup, Columbia was traveling Mach 15 at 181,000 feet, corresponding to 228 knots equivalent airspeed (KEAS) and a dynamic pressure of 83 pounds per square foot (psf).



CAIB Timeline — This timeline, reproduced from the CAIB final report, shows the sequence of events that led to the destruction of Columbia during entry, including the size of the main debris footprint across eastern Texas and Louisiana. (CAIB)

Because the loss of signal occurred 28 seconds earlier, and nobody in Mission Control monitored outside mass media (such as CNN), flight controllers had no insight into these events. At 14:02:21 (EI+1092), the Mission Control Center commentator reported: “Fourteen minutes to touchdown for Columbia at the Kennedy Space Center. Flight controllers are continuing to stand by to regain communications with the spacecraft.” By this time, television had already showed the vehicle breaking up.

At 14:12:39 (EI+1710), the orbiter should have been banking on the heading alignment circle to line up with KSC Runway 33. About this time, a member of the Mission Control team received a call on his cell phone from a friend who had just seen live television coverage of Columbia breaking up. Upon hearing the news, LeRoy E. Cain issued the first order from the Mission Operations Directorate (MOD) Contingency Action Plan, "Lock the doors." At KSC, all related facilities were put under guard. Officials took similar actions at the Marshall Space Flight Center and the Michoud Assembly Facility.

Memorial — The loss of Columbia and its crew brought an outpouring of grief and sympathy from the American public. This is an impromptu memorial outside the Johnson Space Center in Houston. (NASA)

Debris

Just before 08:00 on February 1, the residents of East Texas heard a low-pitched rumble generated by pieces of Columbia traveling nearly 12,000 mph. A fisherman on Toledo Bend reservoir saw a piece splash down in the water, while debris smashed into the

windshield of a woman driving near Lufkin. Cattle stampeded in Eastern Nacogdoches County and 911 dispatchers were overwhelmed with calls reporting sonic booms and smoking debris.[73]

Quickly, NASA officials notified emergency response personnel in Texas that Columbia had broken up and began explaining the dangers to the public. The initial concern was that debris would strike people or structures, but the early hour on a weekend minimized these events. Almost miraculously, no one on the ground was injured and little property damage resulted from the debris. Nevertheless, there were close calls, such as the 600-pound SSME piece that dug a 6-foot-wide hole in the Fort Polk golf course and a piece of debris that landed between two natural gas storage tanks near Nacogdoches. Ultimately, NASA paid approximately $50,000 to property owners who made claims resulting from falling debris or collateral damage from the search efforts.[74]

Debris — Finding the remains of Columbia was critical to the investigation, but not an easy task in the heavily wooded areas where most of the debris fell. (NASA)

To reinforce the message that debris was government property as well as essential evidence, NASA officials and local media repeatedly urged local residents to report all debris immediately. For those who might have been keeping debris as souvenirs, NASA offered an amnesty that ran for several days, and in the end, only a handful of people were prosecuted for theft and all known debris was recovered.[75]

Local fire and police departments began responding to debris reports coming in at a rate of 18 per minute. Within hours of the accident, President George W. Bush declared East Texas a federal disaster area and dispatched response teams from the Federal Emergency

Management Agency and Environmental Protection Agency. The President activated FEMA under the terms of the Robert T. Stafford Disaster Relief and Emergency Assistance Act (Stafford Act), designed to bring an orderly and systemic means of federal disaster assistance for state and local governments. One of the NASA attorneys assigned to the investigation remembered that NASA "didn't have authority to do a lot of what we needed to do without FEMA, so it was good they were there."[76]

As the day progressed, county constables, volunteers on horseback and local residents began searching for debris while National Guard units and NASA contractors mobilized. The military dispatched explosive ordnance disposal teams to deal with the pyrotechnics. To aid in the eventual investigation, the Stephen F. Austin State University sent seven teams into the field with Global Positioning System (GPS) units to mark the exact location of debris on detailed Geographic Information System (GIS) maps.[77]

The efforts of the National Guard, Texas Department of Public Safety and local emergency response personnel were soon overwhelmed by the expanding bounds of the debris field, the densest region of which ran from just south of Fort Worth, Texas, to Fort Polk, La. Faced with a debris field several orders of magnitude larger than any previous accident site, the federal government activated Forest Service wildland firefighters as the primary search teams. Walking in lines 10 feet apart, a distance calculated to provide a 75 percent probability of detecting a 6-inch-square object, 20-person teams scoured snake-infested swamps, mud-filled creek beds and brush so thick that one team advanced less than 100 feet per hour. Once the wildland firefighters entered the field, they located more than 1,000 pieces of debris per day. Within a month, more than 4,000 searchers were at base camps in Corsicana, Palestine, Nacogdoches and Hemphill, Texas. These searchers, drawn from across the United States and Puerto Rico, worked 12-hour days on 14-, 21-, or 30-day rotations and were accompanied by GPS-equipped NASA and EPA personnel trained to identify and handle debris.[78]

Searchers — The U.S. Forest Service wildland firefighters were a critical element of finding the Columbia debris. More than 4,000 firefighters were based at camps in Corsicana, Palestine, Nacogdoches, and Hemphill, Texas, and searched some 700,000 acres on foot. (NASA)

Hyper-spectral and forward-looking infrared data from two satellites proved of little value because their sensors were unable to differentiate orbiter debris from other objects. As a result, the air search fell to spotters from the Civil Air Patrol (CAP) using 37 helicopters, 7 fixed-wing aircraft and various ultra-lights. On March 27, 2003, during the air search, a Bell 407 helicopter crashed in Angelina National Forest in San Augustine County after a mechanical failure. Tragically, the accident took the lives of Jules F. "Buzz" Mier Jr., a contract pilot, and Charles Krenek, a Texas Forest Service employee, and injured three others.[79]

The Office of the Navy Supervisor of Diving and Salvage organized 60 divers into 8 dive teams to search Toledo Bend Reservoir and Lake Nacogdoches. Sonar mapping of more than 31 square miles identified more than 3,100 targets in Toledo Bend and 326 targets in

Lake Nacogdoches. The murky water and many submerged hazards resulted in only a single object being recovered from Toledo Bend and none from Lake Nacogdoches.[80]

The public continued to report debris, and the NASA Mishap Investigation Team addressed each of the 1,459 reports it received. So eager was the public to turn in pieces of potential debris that NASA received reports from 37 U.S. states that Columbia did not pass over, as well as from Canada, Jamaica and the Bahamas.[81] One enterprising individual in Europe was selling a piece of "debris" that landed in his backyard. Given the impossibility of the claim, NASA did not even investigate the incident.[82]

Ultimately, more than 25,000 people from 270 organizations took part in debris recovery operations. Searchers expended more than 1.5 million hours and covered 2.3 million acres, an area approaching the size of Connecticut. Some 700,000 acres were searched by foot, and more than 84,000 pieces of debris weighing more than 84,900 pounds, representing 38 percent of the Orbiter, were recovered. (By the end of 2012, roughly 5,000 pounds of additional debris had been located, bringing the total to approximately 40 percent of the orbiter.) Although radar and video recordings indicate Columbia shed debris as it crossed California, Nevada and New Mexico, the most westerly piece of confirmed debris was a single tile found in Littlefield, Texas. The most easterly debris, turbo pumps from the three SSMEs, was found near Fort Polk, La., some 500 miles away.[83]

Searchers — The searchers came from across the country, and many of the base camps had boards similar to this one, where people could place a pin annotating where they were from. It was a massive effort that ultimately involved more than 25,000 people from 270 organizations. (NASA)

In all, FEMA, which directed the overall effort, expended more than $305 million on the search. This does not include the wages of hundreds of civil servants, NASA contractors and the military. It was the largest and most expensive debris search in history.[84]

10.0 Appendix D: Acronyms

Acronym	Meaning
ACES	Advanced Crew Escape Suits
AFB	Air Force Base
AFIP	Armed Forces Institute of Pathology
AFMES	Armed Forced Medical Examiner System
AMES	Ames Research Center
ATK	Alliant Techsystems
ATV	all-terrain vehicle
CAIB	Columbia Accident Investigation Board
CAP	Civil Air Patrol
CAP	Contingency Action Plan
CFS	Code of Federal Regulations
CFS	Commercial Resupply Service
CRS	Congressional Research Service
CTF	Columbia Task Force
DDMS	Defense Manned Spaceflight Support Office
degF	degrees Fahrenheit
DOD	Department of Defense
DOJ	Department of Justice
DOT	Department of Transportation
EAR	Export Administration Regulations
EOC	Emergency Operations Center
EPA	Environmental Protection Agency
ET	External Tank
FAA	Federal Aviation Administration
FACA	Federal Advisory Committee Act
FBI	Federal Bureau of Investigation
FEMA	Federal Emergency Management Agency
FOIA	Freedom of Information Act
FPS	feet per second
FREESTAR	Fast Reaction Experiments Enabling Science, Technology, Applications, and Research
GIS	Geographic Information System
GPO	Government Printing Office
GPS	Global Positioning System
GSA	General Services Administration
HCAT	Headquarters Contingency Action Team
HEOMD	Human Exploration and Operations Mission Directorate
HIPMPCM	HEOMD Implementation Plan for Mishap Preparedness and Contingency Management

HQ	Headquarters
HTV	H-II Transfer Vehicle
IAT	Independent Assessment Team
ISS	International Space Station
ITAR	International Traffic in Arms
JRB	Joint Reserve Base
JSC	Johnson Space Center
JTR	Joint Travel Regulations
KEAS	knots equivalent airspeed
KSC	Kennedy Space Center
LOC	loss of control
MADS	Modular Auxiliary Data System
MAF	Michoud Assembly Facility
MCC	Mission Control Center
MEIDEX	Mediterranean-Israeli Dust Experiment
MER	Mission Evaluation Room
MILA	Merritt Island Launch Annex
MIT	Mishap Investigation Team
MMT	Mission Management Team
MOD	Mission Operations Directorate
MOU	Memorandum of Understanding
MPCP	Mishap Preparedness and Contingency Plan
MPH	miles per hour
MPS	main propulsion system
MRT	Mishap Response Team
MSFC	Marshall Space Flight Center
NAII	NASA Advisory Implementing Instruction
NAIT	NASA Accident Investigation Team
NARA	National Archives and Records Administration
NESC	NASA Engineering and Safety Center
NPR	NASA Procedural Requirement
NTSB	National Transportation Safety Board
OEX	Orbiter Experiments
OFI	Operational Flight Instrumentation
OGC	Office of General Counsel
OIG	Office of Inspector General
OMDP	Orbiter Maintenance Down Period
OMS	Orbital Maneuvering System
OV	Orbiter Vehicle
PAO	Public Affairs Office (or Officer)

PII	Personally Identifiable Information
psf	pounds per square foot
RCC	Reinforced Carbon-Carbon
rpm	revolutions per minute
RSRM	Redesigned Solid Rocket Motor (Later, “Reusable” Solid Rocket Motor)
SAA	Space Act Agreements
SBU	Sensitive But Unclassified
SCSIIT	Spacecraft Crew Survival Integration Investigation Team
SR&QA	Safety Risk & Quality Assurance
SRB	Solid Rocket Booster
SSME	Space Shuttle Main Engine
STS	Space Transportation System
SwRI	Southwest Research Institute
TDRS	Tracking Data and Relay Satellite
TDY	temporary duty
TPS	Thermal Protection System
TTE	tabletop exercise
TWA	Trans World Airlines
USA	United Space Alliance
USAF	U.S. Air Force
USC	U.S. Code
USN	U.S. Navy
VAB	Vehicle Assembly Building
WFF	Wallops Flight Facility

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[1] Interview, Kyle J. Herring, by David M. Lengyel, October 5, 2012. All interviews were conducted by Lengyel.

[2] Interview, Stephen J. Altemus, October 1, 2012.

[3] "Agency Contingency Action Plan for Space Flight Operations," January 2003, p. D-2; *Columbia Accident Investigation Board—Final Report, vol. I* (Washington, DC: CAIB, August 2003), p. 39.

[4] "Agency Contingency Action Plan for Space Flight Operations," p. D-1.

[5] Interview, G. Scott Hubbard, August 10, 2012.

[6] Interview, Frederick D. Gregory, August 2, 2012. The Admiral may go by "Hal" to his friends, but on the accident Board, he was always "the Admiral" — as much a sign of respect as for any other reason. Almost all of us who served under the Admiral felt we came away better for the experience, the tragic circumstances notwithstanding.

[7] Letters from O'Keefe to the eight Board members, all dated February 2, 2003.

[8] *CAIB Final Report*, p. 231. Although Gehman welcomed the assistance of Lengyel and Schmidt, they were excluded from much of the investigative and deliberative actions since they were NASA employees. Lengyel was reassigned fairly early to organize the Stafford-Covey Return-to-Flight Task Group in Houston.

[9] Contrary to popular belief, the Chairman of the Joint Chiefs of Staff is not the ranking military commander. Following the Goldwater-Nichols Act in 1986 the Joint Chiefs of Staff do not have operational command authority, neither individually nor collectively, as the chain of command goes from the President to the Secretary of Defense to the Commanders of the Combatant Commands. While Gehman was its commander, the Joint Forces Command was the primary central command for all U.S. combat forces.

[10] Interview, Admiral Harold W. "Hal" Gehman, July 11, 2012.

[11] Gehman interview; *CAIB Final Report*, p. 231.

[12] Gehman interview.

[13] *CAIB Final Report*, pp. 231–232.

[14] Gehman interview.

[15] *CAIB Final Report*, pp. 231–232.

[16] *CAIB Final Report*, p. 232.

[17] Interview, Dr. James N. Hallock, September 4, 2012; Interview, Michael J. Bloomfield, October 17, 2012; Interview, Marcia Smith, October 22, 2012; Interview, Major General Kenneth W. Hess, August 9, 2012.

[18] "Columbia Accident Investigation Board: Procedures and Guidelines," (Washington, DC: March 28, 2003).

[19] "Columbia Accident Investigation Board: Procedures and Guidelines," March 28, 2003; Interview, Brock R. Stone, September 17, 2012; Interview, Frank J. Benz, JSC Director of Engineering 2003, August 24, 2012.

[20] "Columbia Accident Investigation Board: Procedures and Guidelines," March 28, 2003.

[21] *CAIB Final Report*, pp. 243–245.

[22] Hess interview.

[23] Interview, James P. Mosquera, October 26, 2012.

[24] Gehman interview.

[25] Ibid.

[26] Ibid.

[27] Hubbard interview.

[28] *CAIB Final Report*, p. 234.

[29] Ibid.; personal experience of the authors.

[30] Personal experience of the authors.

[31] *CAIB Final Report*, p. 49.

[32] The British were responsible for recovering Pan Am 103, but one NTSB representative remembered that debris was spread from "coast to coast" and "blew all across the peninsula." During the TWA 800 investigation, the NTSB reported that nearly 1 million pieces of the Boeing 747 (some 90 percent of the aircraft) were recovered from the ocean during a debris search that took 2 years.

[33] Bryan O'Conner, "Some Safety Lessons Learned," *ASK Magazine* no. 35 (Summer 2009): 5–6.

[34] "The Federal Advisory Committee Act (FACA) Brochure," located at *http://www.gsa.gov/portal/content/101010*, accessed October 28, 2012.

[35] "Columbia Accident Investigation Board: Procedures and Guidelines," March 28, 2003, Appendix R.

[36] HEOMD Implementation Plan for Mishap Preparedness and Contingency Management Plan. April 30, 2012.

[37] NASA Authorization Act of 2005, Pub. L. No. 109-155, 119 Stat. 2941 (2005).

[38] Interview, Karen A. Ault and Donna M. Shafer, September 7, 2012.

[39] HEOMD Implementation Plan for Mishap Preparedness and Contingency Management Plan. April 30, 2012.

[40] Robert C. Seamans Jr., NASA Management Instruction 8621.1, April 14, 1966. Published in *Report of Apollo 204 Review Board to the Administrator, National Aeronautics and Space Administration*, April 5, 1967. Located at *http://www.hq.nasa.gov/office/pao/History/Apollo204/13.html*, retrieved March 7, 2012.

[41] *Apollo 204 Accident*, Report of the Committee on Aeronautical and Space Sciences (Washington, DC: U.S. Senate, January 30, 1968).

[42] *Report of Apollo 204 Review Board*, pp. 1–5.

[43] *Apollo 204 Accident*, U.S. Senate report.

[44] Memorandum for the Apollo 204 Review Board, from Robert C. Seamans Jr., February 3, 1967. (There were actually four memos, all with the same title and date; one reappointed all the members of the board and contained a revised charter, and then three individual memos relieved Jeffs and Long and appointed Van Dolah. Both Jeffs and Long were subsequently listed as consultants to the board.)

[45] "James E. Webb—NASA Administrator," located at *http://history.nasa.gov/Biographies/webb.html*, retrieved October 19, 2012.

[46] *Report of Apollo 204 Review Board*, p. iii.

[47] *Apollo 204 Accident*, U.S. Senate report, p. iii.

[48] *Apollo 204 Accident*, U.S. Senate report, p. 3.

[49] William P. Rogers, Chairman, *Presidential Commission on the Space Shuttle Challenger Accident, Final Report* (Washington, DC: June 6, 1986), p. 17; Memorandum, Jesse W. Moore, Code M/Associate Administrator for Space Flight, "Space Shuttle Mission 51-L Flight Readiness Review Assessment," January 17, 1986, pp. 66–69.

[50] *Presidential Commission Final Report*, pp. 202–203, 206, and 212–213.

[51] *Presidential Commission Final Report*, p. 208.

[52] *Presidential Commission Final Report*, p. 40.

[53] *Presidential Commission Final Report*, p. 148.

[54] Diane Vaughan, *The Challenger Launch Decision: Risky Technology, Culture, and Deviance at NASA* (Chicago: University of Chicago Press, 1996); *CAIB Final Report*, pp. 195–201.

[55] *Presidential Commission Final Report*, passim.

[56] *Presidential Commission Final Report*, pp. 198–201.

[57] *CAIB Final Report*, p. 27.

[58] Statement of Daniel S. Goldin, NASA Administrator, before the Subcommittee on VA-HUD-Independent Agencies, Committee on Appropriations, House of Representatives, March 31, 1998.

[59] Roberta L. Gross, NASA Inspector General, to Daniel S. Goldin, NASA Administrator, *Assessment of the Triana Mission, G-99-013, Final Report* (Washington, DC: OIG, September 10, 1999). See in particular footnote 3, concerning Triana and the requirements of the Commercial Space Act, and Appendix C, "Accounting for Shuttle Costs."

[60] *CAIB Final Report*, p. 28.

[61] Ibid.

[62] Ibid.

[63] *CAIB Final Report*, p. 33; "STS-107 Launch Film Screening Report," JSC Image Science and Analysis Group (Houston, Texas: JSC, January 20, 2003).

[64] *CAIB Final Report*, p. 34.

[65] *CAIB Final Report*, p. 37.

[66] "STS-107 Launch Film Screening Report."

[67] *CAIB Final Report*, p. 62.

[68] *CAIB Final Report*, p. 37.

[69] *CAIB Final Report*, pp. 37–38.

[70] *CAIB Final Report*, p. 38.

[71] *CAIB Final Report*, p. 38; personal experience based on several emails to the author during the STS-107 mission.

[72] Interview, Frank J. Benz, JSC Director of Engineering 2003, August 24, 2012.

[73] *CAIB Final Report*, p. 39.

[74] *CAIB Final Report*, pp. 44–45 and 87.

[75] *CAIB Final Report*, p. 47.

[76] Interview, Amy Xenofos and Donna M. Shafer, September 7, 2012.

[77] *CAIB Final Report*, p. 44.

[78] *CAIB Final Report*, pp. 45–46.

[79] *CAIB Final Report*, p. 46.

[80] Ibid. p. 46.

[81] *CAIB Final Report*, pp. 46–47.

[82] *CAIB Final Report*, p. 47.

[83] Ibid. Additional debris figures provided by Michael A. Ciannilli, NASA/KSC-GP030, in an e-mail to the author on October 9, 2012.

[84] *CAIB Final Report*, p. 47.

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