Columbia's Final Mission

Case Study

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The Space Shuttle Program

In the early 1970s NASA had devised a plan to construct an outpost to serve as a base for further space exploration, ultimately allowing humans to travel to Mars. The plan required NASA to develop a fleet of vehicles that could transport crew and materials between Earth and the Space Station. Ultimately, neither President Lyndon Johnson nor his successor, Richard Nixon, approved the development of a costly space station. Nevertheless, NASA clung to the concept of a new reusable vehicle for manned space flight. Without a space station, the vehicle needed a new purpose. Facing budget cutbacks, NASA chose to justify the Shuttle on economic grounds. The agency argued that it could employ a reusable vehicle to place satellites into orbit for scientific, commercial, and national security purposes. When compared to alternative means of transporting satellites into space, a fleet of shuttles offered the promise of substantial cost savings. To justify the massive investment required to develop and build a fleet of shuttles, NASA used a projected rate of 50 flights per year.

In exchange for additional funding from the White House and Congress, NASA agreed to meet challenging Department of Defense specifications. The Department of Defense requirements altered and further complicated the design of the vehicle, as the orbiter incorporated such revolutionary features as delta-shaped wings, engines that used both solid and liquid fuels, and a reusable thermal protection system (TPS) that consisted of tiles designed to protect the shuttle from the heat of reentry into the Earth's atmosphere. Designers intended for these features to minimize the per-flight cost.

Development of the Shuttle proved difficult given NASA's tight budget and complex design specifications. Despite these challenges, NASA believed that the Shuttle would be safer than any other spacecraft, and NASA did not develop an escape system in the orbiter for the crew. The Shuttle contained 230 miles of wiring and more than 2.5 million parts, including 24,305 TPS tiles applied by hand to the exterior of the orbiter.

NASA delayed the first Shuttle mission from March 1978 to April 1981 because development of the Shuttle proved to be more complicated than expected.

Foam Strike History

Foam debris strikes caused damage to every mission in the history of the Space Shuttle Program. NASA originally considered foam strikes on ascent particularly dangerous, due to the fragile nature of the TPS. NASA engineers assumed that only small pieces of debris would strike the Orbiter. Therefore, they designed the TPS, composed of tiles and Reinforced Carbon-Carbon (RCC) panels, to withstand minor impacts. Prior to the final *Columbia* flight, debris had struck but never penetrated the RCC panels.

After the *Columbia's* 1981 inaugural flight, NASA replaced more than 300 tiles. Foam strikes became a concern during the investigation of the *Challenger* disaster as well. Despite concerns raised by the Rogers Commission regarding NASA's safety procedures and repeated instances of foam separating from the External Tank during ascent, the agency pushed forward with its flight schedule.

Over time, as the shuttles continued to land safely, agency engineers and managers began to focus increasingly on the turnaround schedule implications of foam strikes rather than the flight-safety effects. According to Columbia Accident Investigation Board member and top-ranking U.S. Department of Transportation aviation safety expert James Hallock, "[Shedding foam] became sort of expected. Not only was it expected, it eventually became accepted." While originally considered a serious threat, foam loss eventually came to be categorized as an "in-family" event—a problem within NASA's experience base that was not considered a safety-of-flight issue.

In 1990, agency managers classified foam loss as an "in-flight anomaly." This designation meant that NASA should resolve the problem before the next flight or else prove it did not threaten the lives of the crew. Over the years, agency engineers never determined the cause of the foam loss, nor did they discover a means to prevent it.

Instead, the agency moved incrementally to lessen the severity of its classification of foam losses. In 1992, the Integration Office at Johnson Space Center (JSC) terminated the in-flight anomaly status for foam strikes and classified them as an "accepted flight risk." Meanwhile, the External Tank Project at Marshall Space Flight Center concluded that debris strikes did not constitute "a safety-of-flight issue."

On October 7, 2002, the *Atlantis* (STS-112) sustained a debris strike 33 seconds after launch. The damage sustained by *Atlantis* was the "most severe of any mission yet flown." Again, the External Tank Project down played the significance of the foam strike, categorizing it as an "action" item rather than an "in-flight anomaly"—the more serious classification used in all prior events. This designation still meant that engineers should determine the cause of foam loss and propose corrective action. However, with the agency facing schedule delays for subsequent missions, the Shuttle Program decided to fly two missions, STS-113 (November 23, 2002) and STS-107 (the *Columbia*, to be launched January 16, 2003), without resolution of the foam problem.

The Final Columbia Mission: Launch Day

On January 16, 81.7 seconds into launch, a chunk of insulating foam fell off the External Fuel Tank and struck the Orbiter's left wing. The Intercenter Photo Working Group, a team of NASA engineers charged with reviewing liftoff imagery from tracking cameras, did not detect the strike until 9:30 a.m. the next day.

Flight Day 1

When the Intercenter Photo Working Group identified the strike on the left wing, they found that a restrictive camera angle and a blurry image did not clarify the size, shape, or momentum of the foam or the location of impact while the photographs were unclear, the group did have the distinct impression that the piece of foam was unusually large—larger than any they had seen.

The Intercenter Photo Working Group determined that they needed better imagery to assess potential Shuttle damage accurately. The group's chair contacted Wayne Hale, the Shuttle Program Manager for Launch Integration at Kennedy Space Center, to request imagery of *Columbia's* left wing on-orbit. The group hoped that NASA could use military spy satellites to capture better images. Hale, who held top-secret clearance and was familiar with the process of requesting military assistance, agreed to look into it, which he did five days later. Hale also informed Ron Dittemore, Space Shuttle Program Manager, and Linda Ham, chair of the Mission Management Team (MMT), of the debris strike.

Meanwhile, the Intercenter Photo Working Group distributed a report, including a digitized clip of the strike, to many others within NASA and its contractors. NASA engineer Rodney Rocha viewed the clip and recalled that he "gasped audibly" due to the debris' size. Boeing began performing an analysis to determine the velocity and angle of and potential damage from the debris strike.

Due to the size of the foam loss, concerned analysts at JSC classified the event as "out of family." In the Mission Evaluation Room (MER), managers entered in their log that the strike was of "low concern." However, at NASA, when an "out-of-family" event occurred, written guidelines mandated that engineers work with agency contractors to analyze the situation. This group, according to procedure, should have become a Tiger Team, as in the case of *Apollo 13*. In the case of STS-107, Boeing analysts did team up with NASA engineers to evaluate the debris strike, but they were not classified as a Tiger Team.

Instead, this adhoc group became known as the Debris Assessment Team (DAT). NASA engineer Rocha and United Space Alliance engineering manager Pam Madera chaired the DAT. CAIB member Widnall commented that the DAT's "charter was very vague. It wasn't really clear who they reported to…I think they were probably unsure as to how to make their requests to get additional data." Tetrault also stressed that the DAT "did not report to the Mission Management Team." Moreover, he pointed out that, "When these issues (foam strikes) were discussed, there was never any direct communication between the Debris Assessment Team and the Mission Management Team. It was generally through other parties."

Flight Days 2, 3, and 4

Boeing analysts worked through the weekend to complete their analysis of possible damage to the orbiter. They used a mathematical tool called Crater that employed an algorithm to predict the depth to which debris might penetrate the tiles. Historically, engineers found that Crater predicted more severe damage than what actually occurred. Engineers had never utilized Crater to assess debris impacts while a mission was on-orbit, however, and the estimated size of the debris was 600 times larger than the pieces used to calibrate Crater. Moreover, a Crater-certified engineer at Boeing offices in Texas, who had used the program only twice, performed the analysis for STS-107. The engineer did not consult with more experienced engineers at Boeing's California facility who had used the model on prior occasions.

Crater predicted that the debris created a gaping hole in the TPS tile. However, the DAT members discounted this conclusion because Crater did not take into account the denser bottom level of the tile, only the more fragile top layer. The DAT focused their attention on the TPS tiles and not the RCC panels on the wing's leading edge due to a long-standing belief that foam did not pose a danger to the RCC panels.

Rocha, co-chair of the DAT, e-mailed a JSC manager to determine whether *Columbia's* crew could perform a space walk to inspect the wing, but he never received an answer. After the disaster, Dittemore told reporters that a space walk was not feasible, but other experts disagreed with his conclusion, though acknowledging the risky nature of the maneuver.

On Flight Day 4, the DAT met informally, and it expanded to include debris, tile, RCC panel, and safety specialists from NASA, Boeing, and United Space Alliance. The team decided that they could not draw firm conclusions without additional imagery.

Flight Day 5

Early in the morning, the DAT briefed MER manager Don McCormack on the results of the Crater analysis while pointing out that they had not completed their analysis. McCormack later relayed this information to the MMT during its second meeting. Space Shuttle procedures directed that the MMT should meet daily during a mission. However, during the 16-day STS-107 mission, the MMT met only five times (Flight Days 1, 5, 8, 11, and 15).

After McCormack briefed the MMT on the debris issue, Ham, the team's chairperson, reminded everyone that foam losses had occurred often on previous flights. She also commented that foam was "not really a factor during the flight because there is not much we can do about it."

Both Ham and Dittemore, the Shuttle Program Manager, attended the meeting in which agency officials concluded that it was safe to fly STS-113 despite the significant foam loss experienced by STS-112. After the MMT meeting on Flight Day 5, Ham revisited the documents presented at that meeting, and she sent an e-mail to Dittemore in which she commented that the flight rationale for STS-113 was "lousy." Ham, known for her domineering management style, knew that she was to serve as Launch Integration manager for the next shuttle mission, STS-114. She recognized that she would have to address this flawed past rationale or face a delay of that upcoming mission.

Ham also knew that a delay in STS-114 would jeopardize a major management goal—to launch Node 2 of the International Space Station by February 19, 2004. Management considered that target date critical for two reasons. First, Node 2 would complete the U.S. core of the Space Station. Second, NASA and the Space Station Program had faced increased scrutiny in recent years from the White House Office of Management and Budget.

On the same day as this MMT meeting, engineer Calvin Schomburg distributed an e-mail discounting the risk of damage from the debris. He wrote, "FYI—TPS took a hit—should not be a problem—status by end of week." Schomburg, an engineer closely connected to senior Shuttle Program managers, was considered an expert on TPS. However, he did not have expertise regarding the RCC panels, which the foam may have struck. Following this e-mail, Paul Shack, manager of the Shuttle Engineering office at JSC, informed Rocha that foam loss had been classified as not "a 'Safety-of-Flight' issue" during prior Flight Readiness Reviews.

Meanwhile, United Space Alliance manager Bob White, in response to concerns from his employees serving on the DAT, called Lambert Austin in the Space Shuttle Integration Office. White asked Austin how to request imagery of the Columbia while it was on-orbit. Austin called the Department of Defense to determine how to obtain such imagery, but he insisted that he was not making a formal request. Austin was not familiar with NASA's imagery request procedures.

That same day, the DAT held its first formal meeting. After agreeing on the need for additional visual data, team members asked Rocha to seek new imagery. The DAT concluded that Rocha should pursue this request through his own engineering division rather than following the Shuttle Program's chain of command (i.e., from Rocha to the MER to the MMT). Rocha e-mailed Shack, his superior, asking if NASA could "petition (beg) for outside agency assistance?" In an attempt to stress the importance of his request, Rocha put this sentence in boldface type.

Flight Day 6

Wayne Hale responded to the request for imagery placed on Flight Day 1 by calling a Department of Defense representative at KSC. The Defense Department representative was not the designated official for coordinating imagery requests; nevertheless, he began to investigate how to address Hale's inquiry. However, he did not put forth a formal request.

Around this time, Austin called Ham to inform her of the inquiries being made regarding assistance from the Department of Defense. Ninety minutes later, NASA cancelled the informal requests for imagery. According to the CAIB, Ham ordered the requests cancelled because she could not find out exactly who needed imagery. She called the members of the MMT, who each stated that they had not requested imagery, were not aware of an "official" request, and did not see a "requirement" for imagery. Notably, Ham did not contact the DAT directly to determine if its members wanted additional imagery.

After canceling the request, Ham e-mailed JSC engineers to confirm that foam did not pose a "safety-of-flight" issue. Their responses indicated that uncertainties still existed, particularly regarding the sensitivity of the RCC panels. However, no action was taken to obtain further imagery. Later, Shack informed Rocha that management had chosen not to pursue images. Rocha was astounded. He called Shack to discover management's reasoning, only to hear Shack's reply: "I'm not going to be a Chicken Little on this."

On that same day, the DAT conducted its second official meeting. All members learned that Shuttle Program managers had decided against seeking additional imagery. Though the DAT believed that better imagery was critical to its analysis, members could not cite a "mandatory" requirement for new photographs. As such, they adjourned the meeting without agreeing to further pursue imagery requests.

An angry Rocha later wrote a scathing e-mail, saying, "In my humble technical opinion, this is the wrong (and bordering on irresponsible) answer…not to request additional imaging help from any outside source. I must emphasize (again) that severe enough damage…could potentially present grave hazards." However, Rocha did not send the e-mail to his superiors or to Shuttle Program managers. Instead, he simply showed it to his colleagues. He later explained, "engineers were often told not to send messages much higher than their own rung in the ladder."

Flight Day 7

During that afternoon, Rocha encountered Schomburg in the hallway. The two began heatedly discussing the need for imagery. Schomburg insisted that foam strikes had occurred many times without catastrophic consequences. Rocha countered that there was still a possibility of damage severe enough to cause burn-through during reentry. He recalled that the disagreement closed with Schomburg's remark, "Well, if it's that bad, there's not a damn thing we can do about it!"

Flight Day 8

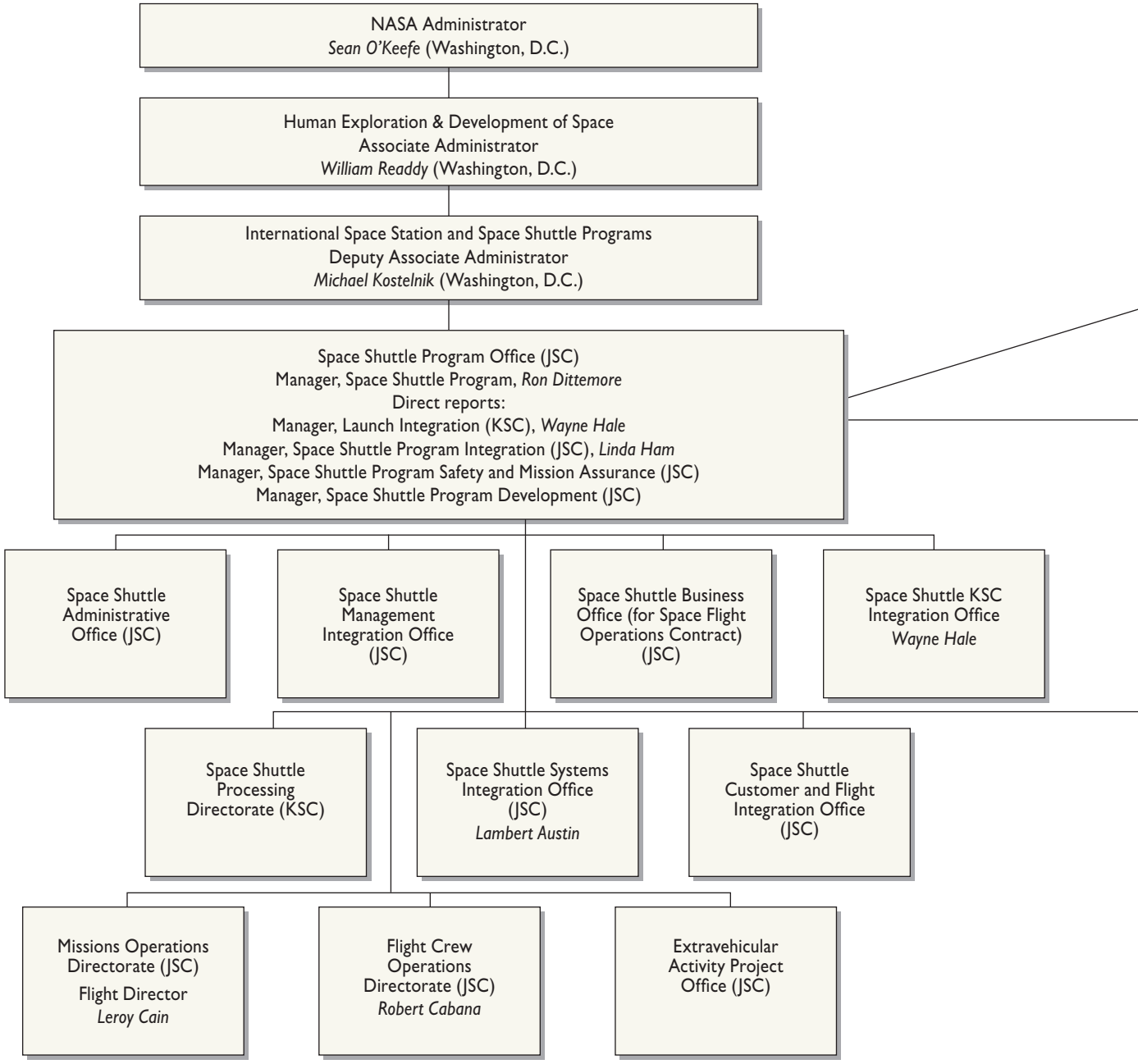
On January 24, Boeing and United Space Alliance managers presented the DAT's findings to MER manager McCormack. Engineers filled the briefing room and even spilled out into the hallway. The presentation detailed the team's methodology, five impact scenarios based on Crater, and predicted threat to the *Columbia* for reentry. The analysis focused on impact to the tiles but not to the RCC panels. The team had one scenario left to run, but it believed the results would not drastically differ from the first five. While the DAT felt convinced its analysis was thorough and complete—given the limited information at its disposal—it emphasized that questions and uncertainty remained. For example, they were not entirely sure where the debris hit the Orbiter or at what speed the impact took place. Still, the presentation concluded that no safety-of-flight issue existed.

Rocha, who was listening to the meeting, later told McCormack he did not think the level of uncertainty surrounding the DAT's conclusions had been communicated clearly. He also wished that McCormack had stressed that the analysis of one scenario remained incomplete. McCormack agreed to correct any misperceptions, which he did at the January 27 MMT meeting. On Flight Day 11, McCormack informed the MMT that the DAT's analysis had been ongoing but was now complete. He confirmed that the DAT concluded that the strike did not constitute a safety-of-flight issue.

Two days later, on Sunday, January 26, Rocha sent an e-mail to his managers and the DAT commending the team members for their work. He felt that they had briefed the MER thoroughly, and they had successfully communicated their concerns as much as possible. There were no more mentions of the foam strike until February 1, when the *Columbia* broke up during reentry on Flight Day 16.

Exhibit 1

The Space Shuttle



Acronyms

CAIB: *Columbia* Accident Investigation Board
DAT: Debris Assessment Team
FRR: Flight Readiness Review
JSC: Johnson Space Center, Houston, TX
KSC: Kennedy Space Center, Merritt Island, FL
MER: Mission Evaluation Room
MMT: Mission Management Team
MSFC: Marshall Space Flight Center, Huntsville, AL
RCC: Reinforced Carbon-Carbon
SRB: Solid Rocket Booster
TPS: Thermal Protection System

Program

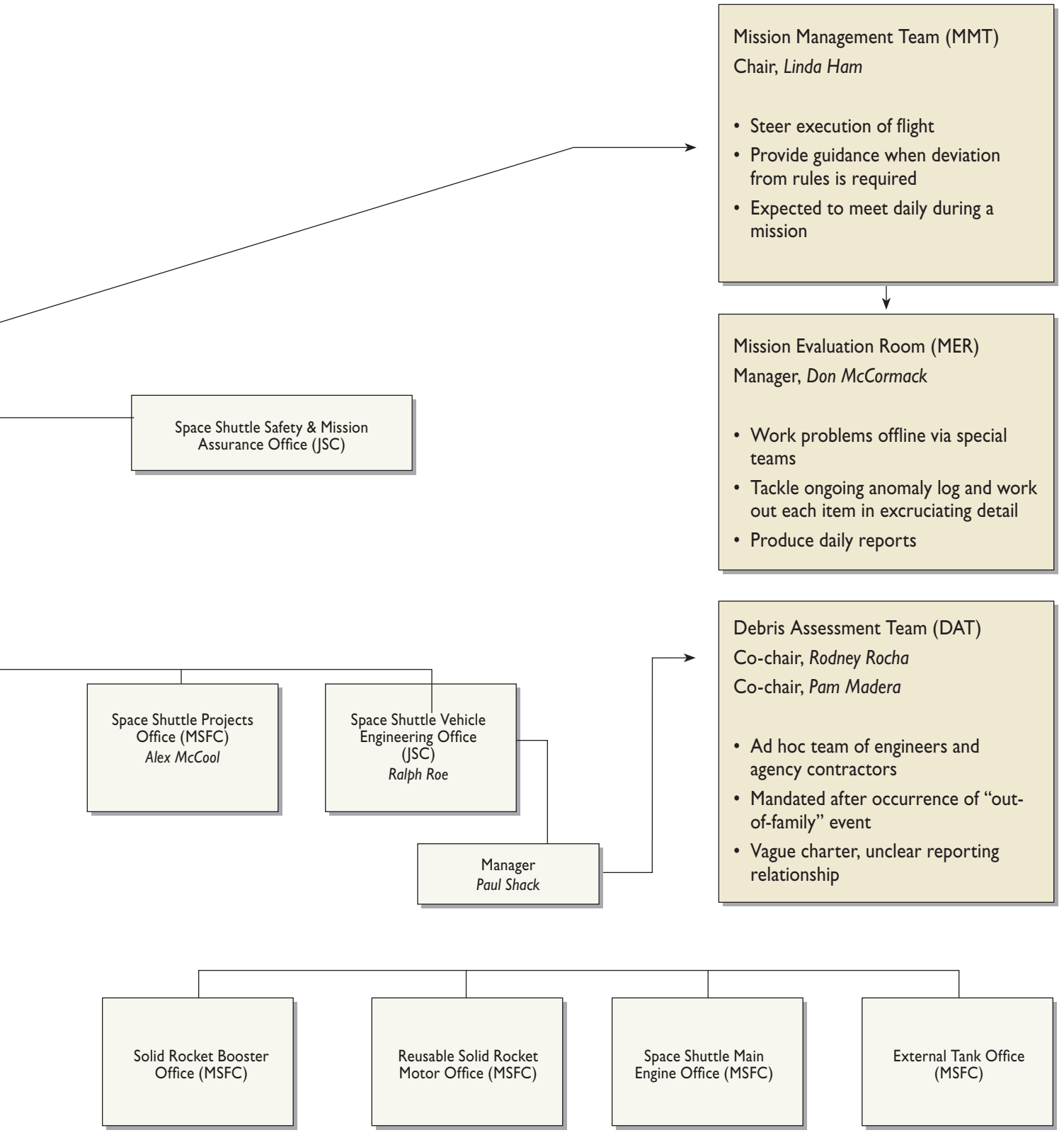
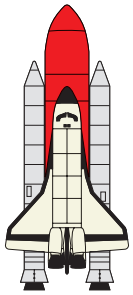


Exhibit 2

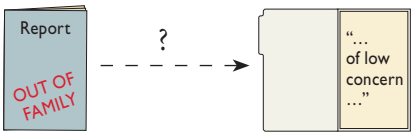
Columbia's

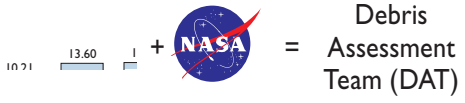
Launch Day



Foam debris strikes the left wing of the orbiter 81.7 seconds after take-off

Day 1





Incident classified as "out of family" event; triggered formation of ancillary team headed by Rocha

NASA officials informed of strike, not of high concern

Rocha

Case in Brief

- Space Shuttle *Columbia* launched 16-day mission January 16, 2003 (STS-107)
- Seven-member crew conducted scientific experiments described as "leading edge"
- Foam strike upon launch managed by:
  - Johnson Space Center (JSC), Houston, TX
  - Kennedy Space Center (KSC), Merritt Island, FL

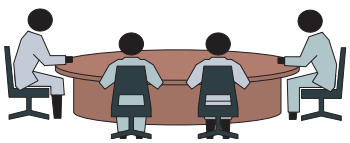
Day 16

PHOTO CREDIT: GETTY IMAGES.

Columbia broke apart upon reentry into Earth's atmosphere

Day 8

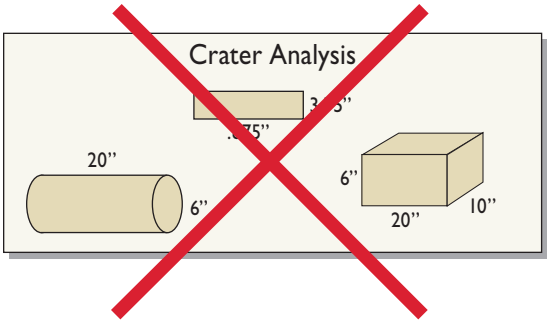
McCormack



All teams briefed; no safety-of-flight issue concluded

Final Mission

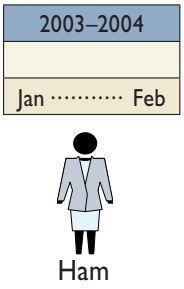
Days 2, 3, and 4



Conclusions produced using Crater technology discounted, despite threatening predictions

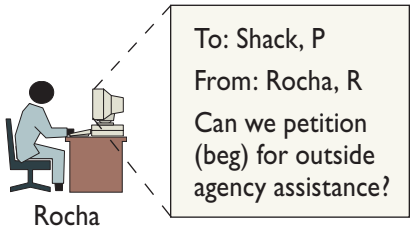
Considerable Foam-Shedding Events

Flight	Date	Event
STS-1	4/81	Replaced 300 tiles
STS-32R	1/90	2nd foam event
STS-35	12/90	Foam loss deemed safety of flight issue
STS-50	6/92	3rd foam event
STS-52	10/92	4th foam event, undetected
STS-62	10/94	5th foam event, undetected
STS-87	11/97	Foam loss deemed accepted risk
STS-107	1/03	7th foam event



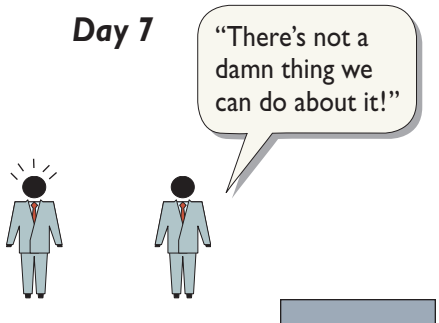
Ham concerned with impact on turnaround time

Day 5



Rocha sought additional imagery via informal chain of command, not MER or MMT

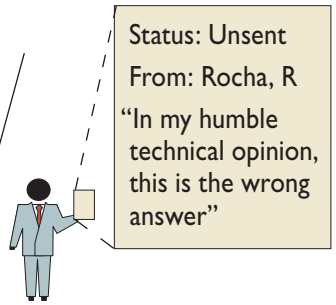
Day 7



Rocha and Schomburg argue over potential for burn-through during reentry

Ham unable to locate origin of imagery request; cancelled the request

Day 6



Rocha wrote, but did not send, a strongly worded e-mail chastising the decision to ignore the pursuit of additional imagery