National Aeronautics and Space Administration

NASA Case Study

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The Pursuit of Images of Columbia

Launch: Impact—"No Apparent Effect…"

Space Shuttle *Columbia* launched at 10:39 A.M. on January 16, 2003, bound for a 16-day science research mission. The oldest orbiter in NASA's shuttle fleet, *Columbia* had first launched nearly 22 years earlier in 1981. The current mission, STS-107[1], was *Columbia*'s 28th flight and the 113th flight of the space shuttle program.

Nearly a minute and a half (81.9 seconds) after *Columbia* roared into the sky on the power of its three main engines and two flanking solid rocket boosters, and with the craft traveling at 1,650 mph, a briefcase-size slab of insulating foam ripped off from the external fuel tank and struck the leading edge of the orbiter's left wing. The effects, during Columbia's reentry into the atmosphere on February 1, were catastrophic, with the loss the spacecraft and all seven members of its crew.

Figure 1 - Following an uneventful countdown, liftoff occurred on-time at 10:39 A.M. EST on January 16, 2003. NASA Image

[1] Space Shuttle missions are designated with the prefix STS (Space Transportation System) followed by a number indicating the order that the missions were planned and approved. The numbers do not correlate to the order in which missions are launched.

During the launch, the break-off of foam went unnoticed by the shuttle crew and unseen and undetected by ground support teams. The following day, in video reviews of the launch, the foam strike and debris shower from the impact were seen for the first time—but the location of the strike was hidden from the camera angle.

Flight Day Two: "Single Mission Safe Re-Entry in Case of Impact"

The day following launch, a debris assessment team (DAT)[2] of engineers from NASA and the contractor United Space Alliance (USA) assembled to analyze the debris strike as captured in images of *Columbia*'s ascent. The team would have its first formal meeting the following Tuesday, January 21, with a final report due by Friday the 24th. Rodney Rocha, as NASA engineer in charge of the thermal protection system (TPS) of the orbiter's wings, would co-chair the team.[3]

By that afternoon, before the DAT met, the TPS safety assurance manager at United Space Alliance sent an email to a USA senior manager stating that the debris strike didn't look serious and that the orbiter could land safely. About the reinforced carbon-carbon (RCC) panels (see box below) that protected the edge of the wing, the manager wrote, "…analysis…says they have a single mission safe re-entry in case of impact that penetrates the system."

Concerning the tiles: "They have impact data that says the structure would get slightly hotter, but still be OK."

Thermal Protection System

The Thermal Protection System consists of over 24,000 tiles, applied by hand, and designed to protect the shuttle from the heat of reentry into the Earth's atmosphere. The nose and wing leading edge are further protected by reinforced carbon carbon (RCC), a hard structural material with reasonable strength across its operational temperature range (minus 250 degrees Fahrenheit to 3,000 degrees). "The development of the Reinforced Carbon Carbon (RCC) as part of the Thermal Protection System was key to meeting the wing leading edge design requirements. Its low thermal expansion coefficient minimizes thermal shock and thermoelastic stress." (CAIB, v.1, p.55). The minimization of thermoelastic stress explains its use on curved and non-flat surfaces of the orbiter, such as the wing leading edge. (i.e. the RCC can flex, move, and adapt with changing temperatures to protect the inside of the wing).

[2] The Debris Assessment Team was an ad-hoc group of NASA and Boeing individuals tasked with evaluating debris strikes. In the terms of CAIB member Widnall the "charter was very vague." The DAT did not report to the Mission Management Team.

[3] Rodney Rocha was not an expert on the Thermal Protection System or Reinforced Carbon Carbon, but rather an engineer from the JSC engineering directorate charged with asking the experts how bad damage could be.

Flight Days Three and Four: Crater: Not a "Safety of Flight" Issue

Over the weekend, Boeing engineers used a mathematical modeling tool called Crater to analyze potential damage to the orbiter. An Apollo-era program, Crater was not designed to measure damage from chunks of foam of the size that flew off the *Columbia*. Extrapolating beyond its data range, Crater predicted penetration of the TPS—an alarming result. The engineering team knew the model was somewhat risk-averse by calibration and beyond its range of certainty, so the results were downplayed as less than definitive.

Crater
Crater is a Boeing developed modeling tool "that uses a specially developed algorithm to predict the depth of a Thermal Protection System tile to which debris will penetrate. This algorithm, suitable for estimating small (on the order of three cubic inches) debris impacts, had been calibrated by the results of foam, ice, and metal debris impact testing. A similar Crater-like algorithm was also developed and validated with test results to assess damage caused by ice projectiles impacting the RCC leading edge panels. These tests showed that within certain limits, the Crater algorithm predicted more severe damage than was observed. This led engineers to classify Crater as a 'conservative' tool – one that predicts more damage than will actually occur." CAIB, v.1, p. 143.

Flight Day Four: "Mission Action Request to Visually Inspect"

At 11:24 P.M. Sunday night, Rodney Rocha sent an email to a JSC engineering directorate manager. The email asked if a visual inspection request was being made for Columbia's crew to examine the left wing for damage.

Flight Day Five: The DAT Informally Agrees on the Need for Images

By Monday, January 21, Rocha had not received a reply to his message.

That morning, DAT held an informal meeting. The team expanded to include NASA, Boeing, and USA experts in the movement of debris in airflows and in tiles and RCC. The team added aerothermal and thermal engineers as well as a safety representative from another NASA contractor, Science Applications International Corporation. The team agreed that on-orbit images of Columbia were needed.

Flight Day Six: "Can We Petition (Beg) for Outside Agency Assistance?"

On Tuesday, January 22, at the first formal DAT meeting, the team again expressed the need to obtain images of *Columbia* to ascertain what impact the debris strike might have had on the sensitive TPS. After the meeting, he wrote an email to his boss:

> *The meeting participants (Boeing, USA, NASA ES2 and ES3, KSC [Kennedy Space Center]) all agreed that we will always have big uncertainties in any transport/trajectory analyses and applicability/extrapolation of the old Arc-Jet test data until we get definitive, better, clearer photos of the wing and body underside. Without better images, it will be very difficult to even bound the problem and initialize thermal, trajectory, and structural analyses. Their answers may have a wide spread ranging from acceptable to not-acceptable to horrible, and no way to reduce uncertainty. Thus, giving MOD [Mission Operations Directorate] options for entry will be very difficult.*
>
> ***Can we petition (beg) for outside agency assistance****? [boldface in original] We are asking Frank Benz with Ralph Roe or Ron Dittemore to ask for such. Some of the old timers here remember we got such help in the early 1980's when we had missing tile concerns.*

Flight Day Seven: "'If it's not safe, say so.' It's that serious"

On Wednesday morning, the DAT held its second formal meeting. Not all of the engineers attending the meeting had learned that the Shuttle program was not pursuing images of Columbia. Mission Management for STS-107 (the formal name of the Columbia mission) had inquired who was requesting outside help getting imagery. Getting no specific answer, they cancelled the request for help from the Air Force that had been made informally.

The members of the DAT, however, "believed the need for imagery was obvious: without better pictures, engineers would be unable to make reliable predictions of the depth and area of damage caused by a foam strike that was outside of the experience base. However, team members concluded that although their need was important, they could not cite a "'mandatory' requirement" [necessary for Department of Defense assistance] for the request."

After the DAT meeting adjourned, "Rocha read the 11:45 a.m. e-mail from [Johnson Space Science manager] Paul Shack, which said that the Orbiter project was not requesting any outside imaging help. Rocha called Shack to ask if Shack's boss, engineering director Frank Benz, knew about the request. Rocha then sent several e-mails consisting of questions about the ongoing analyses and details on the Shuttle Program's cancellation of the imaging request."

More certain than ever of the need for imaging, and feeling a rising sense of urgency, Rocha next composed a draft email, to management addressed to 14 NASA employees:

> *In my humble technical opinion, this is the wrong (and bordering on irresponsible) answer from the SSP [Space Shuttle Program] and Orbiter not to request additional imaging help from any outside source. I must emphasize (again) that severe enough damage (3 or 4 multiple tiles knocked out down to the densification layer) combined with the heating and resulting damage to the underlying structure at the most critical location (viz., MLG [main landing gear] door/wheels/tires/hydraulics or the X1191 spar cap) could present potentially grave hazards. The engineering team will admit it might not achieve definitive high confidence answers without additional images, but, without action to request help to clarify the damage visually, we will guarantee it will not. Can we talk to Frank Benz before Friday's MMT [Mission Management Team[4]]? Remember the NASA safety posters everywhere around stating, "If it's not safe, say so"? Yes, it's that serious.*

Rocha never sent the email, explaining later that he did not want to "jump the chain of command." Instead, he printed the email and showed it only to an engineering colleague. The Columbia Accident Investigation Board report would later state that "NASA's culture of bureaucratic accountability emphasized chain of command, procedure, following the rules and procedures were essential for coordination, they had an unintended but negative effect. Allegiance to hierarchy and procedure had replaced deference to NASA engineers' technical expertise."[5]

Flight Day Eight: "A Dead Issue"

The morning of Thursday, January 23, Rocha received a return call from Mission Operations Directorate Representative Barbara Conte, to discuss imaging capabilities that might be available. This included Air Force imaging of the shuttle as it flew over Hawaii. According to the Columbia Accident Investigation Board (CAIB):

> *Conte asked Rocha if he wanted her to pursue such a request through Missions Operations Directorate channels. Rocha said no, because he believed program*

[4] The Mission Management Team (MMT) consists of "managers from Engineering, System Integration, the Space Flight Operations Contract Office, the Shuttle Safety Office, and the Johnson Space Center directors of flight crew operations, mission operations, and space and life sciences – convenes two days before launch and is maintained until the Orbiter safely lands. The Mission Management Team Chair reports directly to the Shuttle Program Manager. The Mission Management Team resolves outstanding problems outside the responsibility or authority of the Launch and Flight Directors." CAIB, v.1, p.32. For STS-107 the MMT Chair was Linda Ham.
[5] CAIB, v.1, p.200.

managers would still have to support such a request. Since they had already decided that imaging of potentially damaged areas was not necessary, Rocha thought it unlikely that the Debris Assessment Team could convince them otherwise without definitive data.

Conte conveyed Rocha's concern to Flight Director LeRoy Cain, and offered to help obtain imaging. In an email shortly after noon, Cain wrote, "The SSP was asked directly if they had any interest/desire in requesting resources outside of NASA to view the Obiter (ref. the wing leading edge debris concern). They said, "No." Cain's conclusion: "I consider it to be a dead issue."

Post-Accident Testing of Foam Damage to the Wing

Figure 2 - Results from the foam-impact test of the Columbia debris strike. NASA Image

In the aftermath of the accident, heroic efforts were made to recover all possible pieces of debris and to fully understand the cause of the accident. The Columbia Accident Investigation Board (CAIB) tested the impact of foam on various areas of the wing and proved what had been thought unthinkable: foam could indeed compromise the Thermal Protective System. Tests revealed a gaping hole in the RCC panel of the orbiter wing when hit by foam at the relevant speed. The Board concluded that "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, caused by a piece of insulating foam which separated from the left bipod ramp section of the External Tank at 81.7 seconds after launch, and struck the wing in the vicinity of the lower half of Reinforced Carbon-Carbon panel number 8."[6]

Primary Sources

- Columbia Accident Investigation Board (CAIB) Report
  URL: http://caib.nasa.gov/ or http://www.nasa.gov/columbia/caib/html/start.html
- Multiple interviews with Rodney Rocha.

[6] CAIB, v1, p. 9.