

***Accident Case Study of
Organizational Silence & Communication Breakdown:
Shuttle Columbia, Mission STS-107***

**Space Shuttle Lessons-Learned & Knowledge-Capture Forum
at NASA KSC**

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The STS-107 crewmembers pose for their traditional in-flight crew portrait aboard the Space Shuttle Columbia. From the left (bottom row) are astronauts Kalpana Chawla, mission specialist; Rick D. Husband, mission commander; Laurel B. Clark, mission specialist; and Ilan Ramon, payload specialist. From the left (top row) are astronauts David M. Brown, mission specialist; William C. McCool, pilot; and Michael P. Anderson, payload commander. Credit: NASA

Relevant Quotes

Henry Pohl, former Director of JSC Engineering Directorate: *“Safety is everyone’s job.”*

National Safety Reporting System (NSRS) poster: *“If it’s not safe, say so!”*

Columbia Debris Traveling Display-Exhibit at JSC: *“Everyone that touches a mission, on every level, is responsible for what it represents and the lives that are involved.”*

JSC Mission Operations Directorate, JSC Building 4 Lobby: *“To always be aware that suddenly and unexpectedly we may find ourselves in a role where our performance has ultimate consequences. Vigilance.”*

Background: Mission STS-107

“On February 1 [2003], Space Shuttle *Columbia* was destroyed in a disaster that claimed the lives of all seven of its crew.” [*Ref. CAIB report]

On launch day (Jan. 16, 2003) a large chunk of foam, weighing about 1.7 LB, broke loose from the External Tank bi-pod area during ascent and struck the left wing at a relative speed of over 500 mph. This was observed during Columbia’s powered ascent by ground camera video and reported to Space Shuttle Program managers the day after launch.

As a result, the vehicle suffered severe overheating and disintegrated during planned atmospheric entry. This was caused by catastrophic damage on the Columbia’s left wing leading edge and its breached thermal protection system of reinforced carbon-carbon (RCC) panels.

Despite the wing impact damage, Columbia and its crew operated on-orbit throughout the mission with only a few minor problems and performed successful science objectives.

[*Details are documented in the official Columbia Accident Investigation Board (CAIB), Report Vol. 1, August 2003.]

This is the sort of simple calculation that the DAT should have been performed, but unfortunately did not. The numerical result indicates a very high impact load that the wing leading edge RCC panel cannot tolerate.

Newton's Second Law of Motion rewritten in terms of the foam debris projectile's momentum change:

$$- F = ma = m \frac{dv}{dt}$$

$$- F(dt) = m(dv)$$

$$- F(\Delta t) = m \int_{v_0}^{v_f} dv = m(v_f - v_0) = -mv_0$$

$$F_{peak} = \frac{\pi \rho (\text{Volume}) v_0^2}{4l}$$

Assuming that the projectile decelerated linearly over its characteristic length, assuming the impact force time history is a half-sine shape, and plugging all known parameter values (provided in CAIB report), the peak force → Thousands of pounds.

Of course, an RCC panel cannot tolerate such a concentrated force and maintain any structural integrity → It would break.

Debris Assessment Team (DAT)

- Formed on Flight Day 6 by United Space Alliance/Boeing. Had 30+ members, including multiple NASA Center & contractor engineers, and Safety. Rocha was representing JSC Structural Engineering Division (ES) as its Shuttle Chief Engineer, and was also Chairman of the Space Shuttle Loads & Dynamics Panel.
- DAT quandaries:
 - Was debris impact In-Family or Out-of-Family? [See definitions in Backup charts.]
 - So what, what did this really mean here?
 - And who owns us? [No clarification on these questions received.]
 - DAT had only three days to get “The Answer” to the Mission Evaluation Room (MER) and to the Mission Management Team (MMT).
- Engineers’ concerns were heightened by their interpretation of the Flight Day-2 video (albeit blurry and projectile strike location and damage were unknown).
 - Rocha queried JSC’s Thermal Design Branch (ES3) engineers. They possessed the expertise for the Orbiter thermal protection system for tile and reinforced carbon-carbon material. They were very concerned that the wing strike could be potentially catastrophic. They too became members of the DAT.
 - CAIB documents concerns expressed by the Inter-center Photo Working Group (Robert Page, Chair), Mr. Wayne Hale (Shuttle Program Manager for Launch Integration at KSC), Mr. Lambert Austin (Shuttle SE&I Office), and engineers from USA and Boeing.
 - All wanted an extra photo.

DAT, continued

- Drove the DAT's and these other individuals to submit urgent requests for definitive, extra imagery. Requests all shut down by SSP (Space Shuttle Program) managers. The denial of such requests confounded and confused the DAT members; crazy rumors started.
- DAT thus became hobbled. → No way to even initialize a meaningful and applicable damage-tolerance model & assessment without a clear view of actual damage.
- Situation of photo-denial and no clear management direction posed a dilemma to the DAT and others: *If Program management says, "No," or states, "not interested," to a gravely urgent request, then what to do next? Stand down our concerns? Do your best but "reasonable" assumptions, but don't guarantee a bad answer? My job is finished?*

DAT, continued

- Despite lack of critical info, DAT proceeded to produce a highly uncertain and flawed analysis. Met the 3-day deadline and presented to MER and SSP on Jan. 24, 2003.
 - Empirical tools were extremely sensitive to inputs. Usage was far outside the bounds of the test data. No actual damage configuration available, thus, not anchored to reality.
 - The DAT assessment, though citing high uncertainty and cautions on the assumptions and tools used, indicated “no safety of flight issue.” It was wrong.
- The week following the DAT presentation, Rocha and the JSC ES expert for Orbiter wheels/tires continued to harbor concerns centered around the possibility of an overheated tire exploding and catastrophically damaging the wing during Columbia’s descent and approach to the runway.
 - Equivocal emails, which were sent to NASA Langley Research Center’s Impact Dynamics Laboratory rep, JSC MOD mission controller, and NASA Headquarters/Brian O’Connor, caused more confusion among the recipients.
 - Rocha made a second attempt at extra imagery through MOD process. At Rocha’s request, a Shuttle Loads Panel representative approached the STS-107 Ascent/Entry Flight Director and MOD reps. They in turn asked Shuttle management again. Again the request was denied and was considered “a dead issue.”

Communication Breakdown, Contributing Factors

It will probably never be known if the loss of the Columbia vehicle and its crew could have been prevented, but in hindsight some important contributing factors to the improper and misleading flight safety assessment emerged:

- Ineffective and failed communication paths.
 - Confusing ownership of the issue and its assessment . Under the MER or MMT or neither?
 - Emails without management reply; emails with equivocal or unclear requests; face-to-face heated arguments with no follow-up action; etc
 - Lack of clear processes and reporting paths to employ—and to whom? Should DAT have submitted a so-called *Chit* to the MER, thus forcing an official and transparent response to a formal photo request?
 - Over-emphasis on communication protocol (“Don’t email managers in high positions.”)
 - DAT’s final assessment did not clearly focus and emphasize the large uncertainties of the modeled damage when presented.
- Curious lack of management (from low-to-high levels) to support and escort DAT requests to higher level. DAT seemed to be an odd ownerless entity left alone without clout to make any “requirement” for extra imagery. All this was contrary to NASA engineering experience, training, modeling & mentoring, and to the pre-flight readiness process.
- Mixed messages from management and JSC EA engineering integration organization:
 - “This foam strike is urgent, keep me informed, let me pose you questions, hurry and produce an analysis, but I’ll neglect your requests for more data.”
 - “I integrate information down, not upward.”

Communication Breakdown, Contributing Factors - continued

- JSC Engineering's pre-flight readiness process had evaporated by STS-107 even though there were significant pre-flight issues (Cracked Stoody BSTRA Balls, Flow Liner cracks, SRB ETA Ring material property discrepancy and flying with negative margins, STS-112 ET big foam loss and strike, etc.) → Launch pressure
- Weak evidence for managers to weigh. Good, with only minor damage on landing return? Or, so bad to be catastrophic? No data to resolve the issue.
- Active and energetic opposition by some individuals to a photo requests; strong resistance to taking extraordinary action; shouting and angry talk. Why?
- Pervasive *"Prove it's unsafe first!"* and *"If it's that bad, there's nothing we can do about it."*
- *"Normalization of Deviance"* belief at work: *"We've had foam strikes before and we always landed okay."* [Refer to Diane Vaughan's book, The Challenger Launch Decision]
- Absolved accountability: *"If they (upper management) have accepted the risk, my job is over, right?"*
- Emotional & attitude factors (anger, upset, distress, arrogance, denial,...)
 - Personalities clashing; the "Rocha filter" → Urgent concern is so weak in evidence, it then "drops through the crack" with no further action to investigate or resolve.
 - "I can't work with an angry person."

Lessons-Learned & Improvements Implemented in Return-to-Flight

- Mission Management Team (MMT) meets daily during a Space Shuttle mission.
- JSC Engineering Director (or designate) is a member of the MMT. Fully briefed of issues and concerns before the MMT commences its meeting. Also JSC EA-Director reps at the PRCB, Daily PRCB, SICB, etc.
- Establishment of the Independent Technical Authority (ITA) and the NASA Engineering Safety Council (NESC).
- Wealth of image assets & radar available to Shuttle SE&I and detailed high resolution images fed to the Debris Assessment Team (DAT). Special “focused inspections” are options available every mission.
- DAT reports results and conclusions directly and clearly to Orbiter Project Office, then to MMT, without undue “hurry up” pressure.
- Engineers are encouraged to speak up with concerns. Possible paths:
 - Supervisor(s)
 - Emails directly to upper management
 - Dissenting Opinions and Alternate Technical Views are welcome at meetings. Some program documents describe a process to do so, including an appeal to the NASA Administrator.
 - MMT anonymous forms at meetings
 - ITA and the NESC
 - Ombuds Office; National Safety Reporting System (NSRS)

Lessons-Learned & Improvements Implemented in Return-to-Flight, continued

- Repair kits (uncertified as-yet) for TPS tiles and the wing carbon panels are available every flight.
- Physics-based, test-validated analytic tools developed expressly for damage-tolerance assessments
- Provision for Contingency Shuttle Crew Support or ISS “safe haven” for astronauts if the orbiter is disabled or any damages are irreparable. [Note: It was impossible for Columbia to get to ISS.]
- Stand-by “Launch-on-Need” Orbiter can attempt rescue of another Orbiter or retrieval of crew from the ISS.

Cautions for the Future

- Uncertainty remains on repair methods and whether they can really work in combined & complex thermal, aerodynamic, and vibration environments. They may never get fully “certified.” The work site may be very difficult to access via EVA or the coupled RMS/Crewperson may be dynamically unstable.
- Level of briefing and detail presented to managers depends on their individual management style. Not standardized. Great sensitivity right after an accident to listen to everything. Wanes as time passes.
- Not as much direct soliciting of Dissenting Opinions or offers to abet them. They are not as strongly invited as in the accident’s immediate aftermath. Today one has to be quite assertive.
- Subtle and unconscious return of the “Prove it’s unsafe” paradigm.
- Emotional interaction factors are real and still can color what should be technical, rationale discussions.

Cautions for the Future

-continued-

- Beware of “Kill the (lone) messenger” mind set. Take your urgent message forward and upward with your informed and knowledgeable group of experts. [This worked beautifully for assessing the hazards posed by the hypothetical STS-400 Orbiter rescue mission of the STS-125 Orbiter/HST crew.]
- “Don’t overwork. Don’t over-stress. Take good care of yourself, physically and mentally.” However, these caring messages are seldom voiced by managers nowadays and seem to have expired.
- Aerospace vehicle operation always presents high risk and hazards. It is managers’ prerogative to accept risk. → NASA Headquarters-Safety, Brian O’Connor’s said: “I do accept risk, but I need engineers to tell me precisely what the risk is.” →
- *Engineers need to remain ever the vanguards of risk identification, its elucidation to management, and methods to reduce risk.*

Backup Material

Definitions, from the CAIB Report, page 122

- **In Family:** A reportable problem that was previously experienced, analyzed, and understood. Out of limits performance or discrepancies that have been previously experienced may be considered as in-family when specifically approved by the Space Shuttle Program or design project.
- **Out of Family:** Operation or performance outside the expected performance range for a given parameter or which has not previously been experienced.
- **Accepted Risk:** The threat associated with a specific circumstance is known and understood, cannot be completely eliminated, and the circumstance(s) producing that threat is considered unlikely to reoccur. Hence, the circumstance is fully known and is considered a tolerable threat to the conduct of a Shuttle mission.
- **No Safety-of-Flight-Issue:** The threat associated with a specific circumstance is known and understood and does not pose a threat to the crew and/or vehicle.

Excerpt from Rocha's email requesting extra imagery. Sent to JSC Engineering Directorate managers during STS-107 mission in progress, Jan. 23, 2003, 4:41 PM.
[Refer to CAIB report, pages 151 - 152]

"The meeting participants (Boeing, USA, NASA ES2 and ES3, KSC) all agreed 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 options for entry will be very difficult.

Can we petition (beg) for outside agency assistance? We are asking for Frank Benz with Ralph Roe or Ron Dittmore 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.

Despite some nay-sayers, there are some options for the team to talk about: On-orbit thermal conditioning for the major structure (but is in contradiction with tire pressure temp. cold limits), limiting high cross-range de-orbit entries, constraining right or left had turns during the Heading Alignment Circle (only if there is struc. damage to the RCC panels to the extent it affects flight control. "

Rodney Rocha

Structural Engineering Division (ES-SED)

- **ES Div. Chief Engineer (Space Shuttle DCE)**
- **Chair, Space Shuttle Loads & Dynamics Panel**

Mail Code ES2

JSC Organizations as of February 2003

Space Shuttle Program Office

- Director (R. Dittmore)
- Deputy Director (L. Ham)
- Shuttle SE&I (systems engineering & integration; L. Austin)
- Orbiter Vehicle Engineering (R. Roe)
- Mission Evaluation Room (MER; D. McCormack)

JSC Mission Operations Directorate

- Mission Control Room
- Flight Directors (L. Cain, others)

JSC Engineering Directorate

- Director (F. Benz)
- Deputy (L. Hansen)
- EA4 – Engineering Integration Office (P. Shack, others)
- MER support to Orbiter
- ES – Struc. Engr. Div. (I. Verinder, D. Drewry, R. Rocha, others; ES3- Thermal Branch)

Interactive Discussion with Audience:

What would you do?

In the Columbia post-accident Return-to-Flight period, there were significant improvements to the pre-flight and in-flight communication processes, and to empower engineers who have flight safety concerns and their need to express them.

Despite these positive changes, what more can be done?

- What other improvements should be implemented?
- How are flight safety responsibilities and accountabilities different between an organization and you as an individual? If a manager states, “I accept the risk,” but you are still harboring concerns, then what? How and when do you know to quit or stand-down your efforts?
- Assuming a grave issue or hazard is presenting a concern to some, how can you handle or manage a highly emotionally-charged person—whether in yourself or your colleagues or from an authority figure?
- Assuming you are assigned to a special assessment team, how would you manage an issue based on “weak” evidence, but for which the consequences of failure are catastrophic?
- Are emails an effective means to convey grave concerns?
- How would you encourage and seek out dissenting opinions in your team or project? What if you or someone else is all alone in holding a contrary view?
- How to detect and then prevent backsliding to old mindsets? How much push back can an individual do?