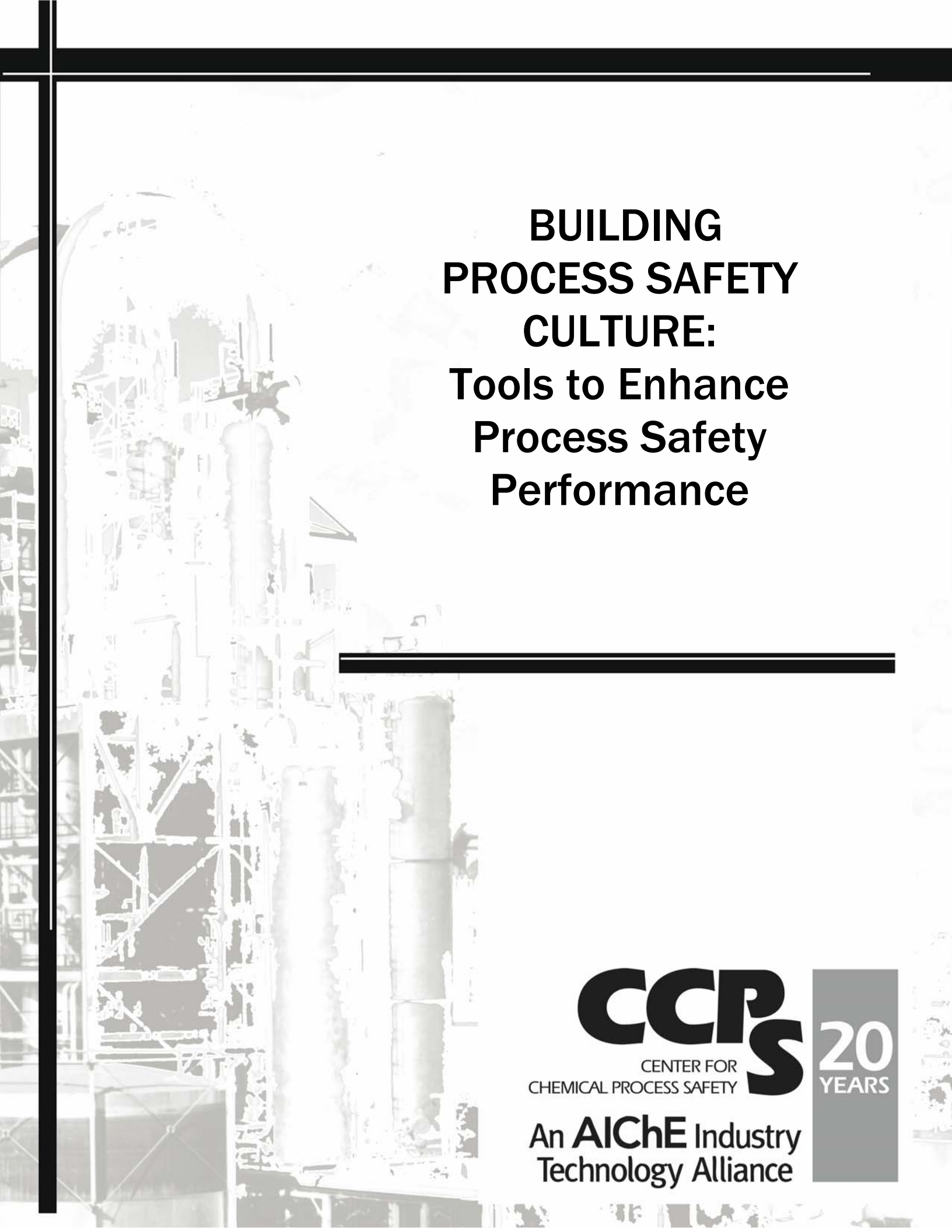

BUILDING PROCESS SAFETY CULTURE: Tools to Enhance Process Safety Performance

CCPS
CENTER FOR CHEMICAL PROCESS SAFETY
20 YEARS
An AIChE Industry Technology Alliance

Process Safety Culture Toolkit

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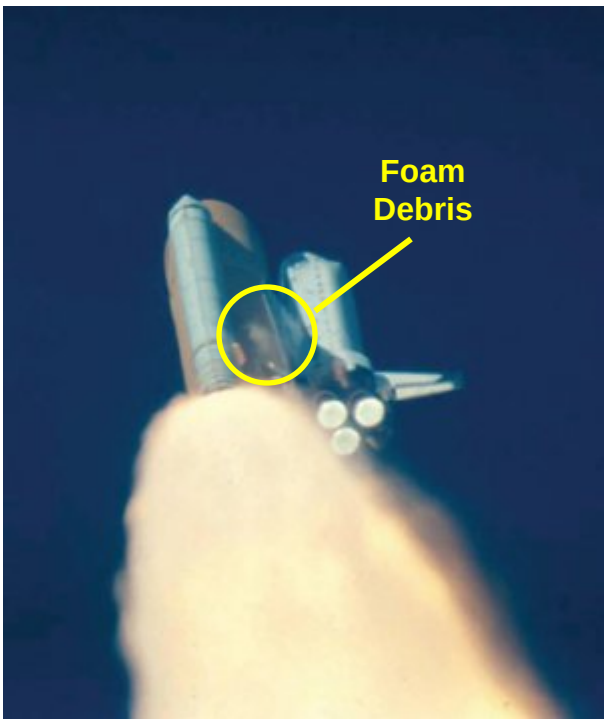
Columbia Case History

[The following information has been taken from the US government publication *Columbia Accident Investigation Board Report* (the CAIB report).]

On Saturday, February 1, 2003, the space shuttle Columbia disintegrated during re-entry into the Earth's atmosphere while attempting to land after a 17-day mission in space. All seven astronauts were killed when the crew module portion of the shuttle subsequently broke up. Debris from the shuttle was scattered over 2000 square miles of east Texas.

Columbia had been launched from Cape Kennedy on January 16, 2003. At approximately 82 seconds into the launch, a large piece of insulating foam (approximately 20 inches by 20 inches by 2 to 6 inches in size) broke off of the external fuel tank and impacted the underside of Columbia's left wing. At the time of impact, the foam was moving at a speed of about 500 mph relative to Columbia.



The foam impact was discovered on the second day of the mission during the review of launch videos. Considerable discussion and analysis occurred during the balance of the mission, focusing on whether or not any of the delicate tiles that make up the shuttle's thermal protection system (TPS) could have been damaged. NASA management ultimately discounted the significance of the impact and no inspection for damage was made, nor were any contingency plans for dealing with TPS damage formulated.

In reality, the impact had created a hole in the heat-resistant reinforced carbon-carbon (RCC) panels on the leading edge of the wing. During re-entry, superheated air entered through this breach into the cavity in the wing behind the RCC panels. The breach widened, destroying the insulation protecting the support structure for the leading edge of the wing. Subsequent melting of the thin aluminum spars within the wing resulted in its catastrophic failure. Columbia, tumbling out of control a speed in excess of 10,000 mph, was torn apart.

The subsequent investigation revealed the following:

- Shortly after the discovery of the insulation strike during the review of the video on

Flight Day 2, mission staff requested additional photographic imaging that could have been obtained using classified military assets. This was one of three separate imagery requests that were either overruled or denied by higher-level NASA management. In all, the Investigation Board identified 8 "missed opportunities" that might otherwise have provided information from video, photographs, or direct visual inspection which could have identified the damage to Columbia.

- A Debris Assessment Team (DAT) was formed to evaluate the significance of the debris strike. In advocating for their imagery requests, the DAT was put in the position of having to prove, absent the information from the imagery, that a safety-of-flight issue existed… in order to justify the imagery needed to confirm or refute a safety-of-flight issue. As with Challenger, 17 years before, the technical experts were forced to invert their normal safety role. Instead of having to substantiate the safety of a course of action, they had to prove the negative; i.e., the "un-safety" of the lack of action.
- While the shuttle systems specifications were explicit that shedding of debris (such as insulation foam) during launch was not to be tolerated, NASA was aware of at least six prior missions where insulation had come loose from the same location experienced with Columbia.
- Damage to the TPS tiles on the underside of the shuttle, from foam strikes and other causes, had become a routine aspect of shuttle missions that had been "normalized," even though it potentially jeopardized crew safety and mission integrity. Rather than being perceived as a safety-of-flight issue (as NASA standards would have defined it), TPS damage had come to be viewed as a routine maintenance item.

- As the Columbia mission continued, mission managers quickly demonstrated the attitude that they did not believe the foam strike was a problem based, in part, upon experience with past foam strikes. One manager, with regards to the imagery request, was quoted as commenting, "… it was no longer being pursued, since even if we saw something, we couldn't do anything about it." Management's lack of interest in understanding the problem and its potential implications made it more difficult for the technical experts to communicate and advocate their concerns.

The CAIB identified a number of disturbing similarities in NASA's performance and safety practices that contributed to both the Challenger and Columbia disasters. A number of internal and external audits were conducted during the period between Challenger and Columbia (General Accounting Office [GAO, 1990], Shuttle Independent Assessment Team [IAT, 1999], and Space Shuttle Competitive Task Force [RAND Corporation, 2002]). These audits revealed that the many of the Challenger learnings related to organizational and cultural issues had not been applied by NASA. As the

CAIB report described, "The Shuttle Program's safety culture is straining to hold together the vestiges of a once robust systems safety program."

The following observations and findings from the CAIB report are organized according to the six cultural learnings described in the PowerPoint presentation.

Maintain Sense Of Vulnerability

- The Columbia investigation, the Challenger investigation, and audits in the interim repeatedly pointed to the NASA culture as being typified by a "Can Do" attitude that was inspired by past successes and which discouraged individuals from stepping forward and suggesting "Can't Do." The IAT observed that the Shuttle Program was inappropriately using previous success as a justification for accepting increased risk.
- As with Challenger, NASA was viewing near-misses (in this case, foam strikes which did not impact mission safety) as successes rather than near-failures. The CAIB quoted one author who noted that "The Shuttle Program turned the experience of failure into the memory of success."
- The CAIB went on to note that "… management made erroneous assumptions about the robustness of a system based upon prior success rather than on dependable engineering data and rigorous testing" and suggested that NASA's "safety culture no longer asks hard enough questions about risk."
- The CAIB concluded that "Organizations that deal with high-risk operations must always have a healthy fear of failure – operations must be proved safe, rather than the other way around. NASA inverted this burden of proof."

Combat Normalization Of Deviance

- The CAIB described the decision-making process for both Challenger and Columbia as follows: "In all official engineering analyses and launch recommendations prior to the accidents, evidence that the design was not performing as expected was reinterpreted as acceptable and non-deviant, which diminished perceptions of risk throughout the agency."
- The CAIB concluded that the "…premium placed on maintaining an operational schedule, combined with ever-decreasing resources, gradually led Shuttle managers and engineers to miss signals of potential danger. Foam strikes on the Orbiter's Thermal Protection System, no matter what the size of the debris, were 'normalized' and accepted as not being a 'safety-of-flight risk.'"
- The burden placed on the DAT team to support its requests for imagery illustrated what NASA had come to regard as "normal." Foam strikes were now normal and not a cause for concern. Exceptional proof would be required to justify the cost (and, perhaps, the "loss of face" associated with asking another federal agency for help) of obtaining the requested imagery.

Establish an Imperative for Safety

- Budget reductions, schedule pressures, and additional programs (notably, NASA's support of the International Space Station [ISS] project, and the shuttle's role in transporting personnel and supplies to the station) had placed NASA in a paradoxical position exemplified by the slogan that had typified NASA's attitude through the 1990's - "Faster, better, cheaper", communicating the imperative of achieving all three goals simultaneously.
- NASA's commitment to a particular ISS milestone (i.e., "core complete") was driving the shuttle program schedule. To meet the February 2004 deadline for core complete, NASA had scheduled 10 shuttle flights in 16 months. While not as ambitious as the pre-Challenger launch schedule, this commitment (which NASA management was unwilling to consider modifying) was proving extremely difficult to meet in light of resource constraints and the aging shuttle fleet. The CAIB concluded that the focus that shuttle managers placed on this milestone colored analytical and decision-making processes, preventing recognition of the significance of the foam strike issue.
- The Rogers Commission, which had investigated the Challenger incident, determined in its 1986 report that the safety oversight role within NASA lacked potency. Staff cutbacks and reorganizations had deprived this function of the independence, technical resources, and clout necessary to combat trends such as the undue influence of schedule pressures on launch-related safety decisions. Many of the same concerns were revealed in audits by the GAO, the IAT, and the RAND Corporation.
- The IAT observed: "…the workforce has received a conflicting message due to the emphasis on achieving cost and staff reductions, and the pressures placed on increasing scheduled flights." The CAIB concluded: "Despite periodic attempts to emphasize safety, NASA's frequent reorganizations in the drive to become more efficient reduced the budget for safety, sending employees conflicting messages and creating conditions more conducive to the development of a conventional bureaucracy than to the maintenance of a safety-conscious research-and-development organization."
- The computer screen saver, which counted down the days, hours, minutes, and seconds to the deadline for ISS "core complete" is a graphic example of the potential for communicating mixed messages regarding the relative importance of "production vs. protection."

Perform Valid/Timely Hazard/Risk Assessments

- The CAIB noted that the conclusions in a large number of hazard reports were based upon subjective and qualitative judgments, rather than hard analysis. Statements such as "believed" and "based on experience from previous flights this hazard is an 'Accepted Risk'" were common.
- The CAIB concluded that "…overwhelming evidence indicates that Program leaders decided the foam strike was merely a maintenance problem long before any analysis had begun."
- Several audits, including the AIT audit, had identified deficiencies in the problem and waiver tracking systems. The CAIB determined that prior studies had identified 5396 hazards that could impact mission integrity. Of these, 4222 were ranked as "Criticality 1/1R," meaning that they posed the potential for loss of crew and orbiter. However, associated requirements had been waived for 3233 of these 1/1R hazards and, at the time of the Columbia investigation, more than 36% of those waivers had not been reviewed in the previous 10 year period.
- In 2001, NASA was only requiring hazard analyses on shuttle components at the subsystem level. Integrated analyses of Shuttle as a whole were no longer required to be conducted.
- NASA attempted to model the potential damage that the foam might have caused to the wing. However, the semi-empirical computer model used was not appropriate to the task. The estimated volume of the foam piece was 640 times larger than the samples against which the model had been calibrated and validated. Furthermore, the analysts conducting the modeling had only recently taken over responsibility for such work and were making their first unsupervised used of the tool. They did not have the perspective to recognize that the results of their work were not valid.
- The CAIB concluded that NASA's approach to hazard and risk assessments suffered from an oversimplification of thought and that it was "… an unfortunate illustration of how NASA's strong cultural bias and optimistic organizational thinking undermined effective decision-making."

Ensure Open and Frank Communications

- The IAT audit identified "…failures of communications to flow up from the "shop floor" and down from supervisors to workers" and the CAIB observed that the "…exchange of communication across the Shuttle program hierarchy is structurally limited, both upward and downward."
- The record of the activities during the mission shows that considerable analysis was being conducted, and that technical staff was sharing concerns and opinions within their own work groups, but that this information was not being effectively shared across organizational lines.
- The CAIB concluded that attitudes evidenced by Shuttle Program managers

discourage the free exchange of information and concerns and that "…at every junction [of the Columbia mission], the Shuttle Program's structure and processes, and therefore the managers in charge, resisted new information."

- When technical information was moved up through the organization, its content and clarity suffered as is was progressively condensed for higher levels of management. An initial damage assessment prepared by the DAT for a lower level briefing had to be cut down considerably to make it "fit" the 40 minutes allowed on the schedule. This same information was cut down further to a three-minute discussion topic for the Mission Management Team. After a review of a tape of the Mission Management Team meeting, the CAIB concluded that there was "… a noticeable 'rush' by the meeting's leader to the preconceived bottom line that there was 'no safety-of-flight' issue."

Learn and Advance the Culture

- The history of the events leading up to the Columbia disaster, both during the mission and in the years preceding the mission, show that NASA continued to make many of the same mistakes that had led to the Challenger disaster. For example:
  - The integrity and potency of the safety oversight function had been allowed to again erode.
  - An overly ambitious launch schedule (relative to the capabilities of the organization) was imposing an undue influence on safety-related decision-making.
  - NASA was once again relying on "past performance as a guarantee of future success."
  - Conditions and events totally inconsistent with NASA's technical basis for mission safety were being "normalized."
  - Rigid organizational and hierarchical policies were preventing the free and effective communication of safety concerns. Rank and stature were once again trumping expertise.
- The Rogers Commission had addressed each of these concerns in its 1986 report. Subsequent audits had pointed out the continued existing of some, if not all, of these concerns.
- NASA had not internalized the Challenger learnings, and had not effectively addressed the lingering cultural deficiencies that ultimately led to the Columbia disaster.
- The CAIB, in its report, took NASA to task with respect to its failure to address these cultural issues, noting "… NASA's view of its safety culture… did not reflect reality… NASA remained in denial… NASA's safety culture has become reactive, complacent, and dominated by unjustified optimism…"