Organization at the Limit: Lessons from the Columbia Disaster

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Abstract

We review William Starbuck and Moshe Farjoun’s Organization at the Limit: Lessons from the Columbia Disaster, a book that provides a unique look at a rare empirical phenomenon: the total failure of a high−risk, high−reward organization. The National Aeronautics Space Administration (NASA) is a large, elaborate, and mature organization, which operates risky and complex technologies in an environment that emits ambiguous signals. In particular, NASA’s space shuttle, Columbia, disintegrated during re−entry, after completing its 16−day scientific research mission. All seven astronauts on board the Space Shuttle were killed. The Columbia Accident Investigation Board (CAIB, 2003) stated that this disaster was a product of NASA’s history, cultural traits, and long−term organizational practices. The multiple contributing factors give rise to eighteen chapters of various observers, interpretations, and evaluation criteria.

This paper reviews William Starbuck and Moshe Farjoun (2005) book and is intended to be a supplement for the senior−level Business Policy/ Strategic Management capstone course (BADM 449), which assigns the Harvard Multimedia Business Case: The Columbia’s Last Flight (Edmondson, Roberto and Bohmer, 2005). An abbreviated version of this paper can be found in Banerjee and Mahoney (2007). We thank Jeanne Connell, William Connell, Glenn Hoetker, James Mahoney and Judy Mahoney for helpful comments. The usual disclaimer applies.

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Abstract:

We review William Starbuck and Moshe Farjoun's *Organization at the Limit: Lessons from the Columbia Disaster,* a book that provides a unique look at a rare empirical phenomenon: the total failure of a high-risk, high-reward organization. The National Aeronautics Space Administration (NASA) is a large, elaborate, and mature organization, which operates risky and complex technologies in an environment that emits ambiguous signals. In particular, NASA's space shuttle, *Columbia,* disintegrated during re-entry, after completing its 16-day scientific research mission. All seven astronauts on board the Space Shuttle were killed. The *Columbia* Accident Investigation Board (CAIB, 2003) stated that this disaster was a product of NASA's history, cultural traits, and long-term organizational practices. The multiple contributing factors give rise to eighteen chapters of various observers, interpretations, and evaluation criteria.

The Space Traveling System (STS)-107 --- Space Shuttle *Columbia* --- whose 28th mission spanning 22 years was originally scheduled for launch in May 2000, had 18 separate delays, and finally launched on January 16, 2003. As the Space Shuttle *Columbia* descended to Earth on February 1, 2003, after completing its 16-day scientific research mission, it disintegrated 37 miles over northeastern Texas. All seven astronauts on board the Space Shuttle were killed: Commander Rick Husband, Pilot William McCool, Payload Commander Michael Anderson, Payload Specialist Ilan Ramon, and Mission Specialists David Brown, Kalpana Chawla and Laurel Clark, (Chien, 2006).

The physical cause of the loss of the *Columbia* and its crew was a breach (a 16-inch diameter hole) in the thermal protection system on the leading edge of the left wing, caused by a suitcase size piece of insulating foam weighing about 1.7 pounds that had separated from the external tank at 81.7 seconds after launch, and had collided at a speed of about 500 miles per hour at the time of impact with the Reinforced Carbon-Carbon (RCC) panel of the left wing. During re-entry this breach in the thermal protection system allowed super-heated gas (exceeding 3,000 degrees Fahrenheit) to burn through the leading edge insulation and to melt the aluminum structure of the left wing from the inside out until increasing aerodynamic forces caused loss of control, failure of the wing, and breakup of the Space Shuttle (CAIB, 2003: volume 1: 9-12).

However, the *Columbia* Accident Investigation Board (CAIB, 2003) also stated that this disaster was a product of NASA's history, cultural traits, and long-term organizational practices. Themes of the CAIB (2003) report include contributing factors to the *Columbia* disaster such as: technological uncertainty; a "can do" culture that minimized safety threats; severe time schedule pressures; budgetary constraints;

personnel downsizing; financial uncertainty; political uncertainty; lack of an agreed national vision for human space flight; fluctuating priorities; partially inconsistent efficiency and safety goals; mischaracterization of the shuttle as operational rather than developmental; lack of integrated management across program elements; political infighting; communication problems within the hierarchy; dependent and understaffed safety agents; organizational barriers that stifled concerns about safety; and a rule-following culture that took precedence over deference to the expertise of engineers. As Louisiana State University and A&M College Chancellor and former administrator of the National Aeronautics Space Administration (NASA), Sean O'Keefe, comments in the preface to Organization at the Limit: Lessons from the Columbia Disaster, those looking at NASA from the outside have the great opportunity "to learn from the hard lessons of others without experiencing the pain as deeply for themselves" (Starbuck and Farjoun, 2005: xix).

The introductory essay by the book's editors, William H. Starbuck (NYU) and Moshe Farjoun (York University) also emphasizes opportunities for learning. To be sure, the Columbia disaster damaged lives, reputations, legitimacy and trust. But, Farjoun and Starbuck (2005a) choose to take a different direction and emphasize instead the afforded opportunities to learn and improve the functioning of large and complex social systems. Furthermore, because disasters are unusual, the focus is on utilizing multiple observers, interpretations, and evaluation criteria to experience history more fully (March, Sproull, and Tamuz, 1991). In that regard, this book is unusual in the fields of Organization

Studies and Strategic Management because it is a collaborative effort to explain a decision-making situation from multiple perspectives.[2]

The 17 remaining chapters of this path-breaking book are briefly discussed here in turn. In chapter 2, Moshe Farjoun (2005a) provides an historical analysis of the space shuttle program at NASA, which highlights that early policy and technological decisions (e.g., the complexity of the shuttle designed to be all things for all people) became permanent features of the program's working environment. This working environment increasingly emphasized, for purpose of the organization's survival, efficiency goals (e.g., maintaining flight schedules) over safety goals (e.g., the crew safety panel was dissolved) (McCurdy, 2001). Standards were modified to keep flights on time and risk was increasingly accepted as normal in space flights (Vaughan, 1996). Further, the program's working environment coupled system stress due to objective resource scarcity with ambitious plans and claims made by both NASA's administrators and politicians (Klerkx, 2004). Patterns repeat and lessons are not learned not only because learning processes are ineffective but also for motivational and political reasons.

In chapter 3, Diane Vaughan (Columbia University) also considers whether NASA learned from their mistakes by comparing NASA's two space shuttle disasters, the C*hallenger*'s and *Columbia's* (CAIB, 2003; Vaughn 1990). Vaughan's (2005) analysis emphasizes slippery slopes leading to harmful outcomes that were created by years of technical reports defining risks away by repeatedly normalizing technical anomalies that deviated from expected performance for the O-ring and foam insulation shedding

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[2] The nearest forerunners are Allison and Zelikow's (1999) book on the Cuban Missile Crisis, and Moss and Sill's edited book (1981) concerning Three Mile Island, which also utilizes multiple theoretical lenses to interpret single chronologies of events.

respectively. Indeed, as early as 1981, the program encountered many insulation foam-shedding incidents that would later cause the *Columbia* disaster.

Early in the Space Shuttle Program, foam insulation loss from the external tank was considered a dangerous problem. Design engineers were extremely concerned about potential damage to the Space Shuttle and its fragile thermal protection systems, parts of which are so vulnerable to impacts that lightly pressing a thumbnail into them leaves a mark (CAIB, 2003: 126). However, as time passed and a large number of seemingly innocuous abnormalities were seen, the more dulled the senses became, and the frequency of foam insulation strikes to the Space Shuttle was sufficiently high to be dismissed as unremarkable and of limited consequence or simply an acceptable risk. Further, NASA's original technical culture had been converted over time to a culture of production that combined bureaucratic, cost efficiency, schedule efficiency, and technical mandates. This culture of production reinforced the decisions to continue with launches rather than delay while a thorough hazard analysis was conducted. The analysis considers the problem of the slippery slope (Miller, 1990, Turner, 1978), and suggests that it is important to research the effects of planned changes in order to forestall unintended consequences (Clarke, 1999, Tucker and Edmondson, 2003).

In Chapter 4, Moshe Farjoun (2005b) revisits the period from 1995 to 2003 that preceded the *Columbia* disaster, and based on a dialectical safety failure cycle model (Reason, 1997) identifies this time period as one in which the shuttle program encountered a *safety drift,* incrementally sliding into increasing levels of risk in order to stay on schedule. Impediments to learning and corrective actions during this safety drift are identified including the interaction of complex technology with organizational problems, faulty knowledge transfer mechanisms between programs, inadequate communications, flawed managerial processes, and problematic leadership transition. Moreover, many disasters develop as a result of latent errors that have incubated over long time periods (Turner, 1976). “Failure-free” periods enhance belief in future success, leading to fine-tuning adjustments that in fact lead to an increased likelihood of safety failure (Starbuck and Milliken, 1988). Miller’s (1994) study of 36 firms concludes that long time periods of repeated success foster structural and strategic inertia, inattention, insularity, and the loss of sensitivity to nuance. The fundamental managerial challenge is to learn and stay alert in the midst of a safety drift and prolonged safety success.

In chapter 5, Karlene Roberts, Peter Madsen and Vinit Desai (University of California at Berkeley) examine the failure of the *Columbia* mission in the larger context of space transportation. Drawing on research concerning high-reliability organizations that conduct relatively error-free operations over a long period of time, it is observed that organizations eventually encounter problems because people concerned with them fail to comprehend the complex interactions among different organizational subunits that contribute to the disaster.

Organizations frequently have problems due to neglecting coordination and failing to ensure independence of activities (Roberts and Bea, 2001). Organizations such as NASA commonly use redundancy of structures, personnel or technology to increase the reliability of outcomes (Heiman, 1997). The focus here is that such redundancy without independence may increase the perception of safety without increasing objective safety (Jervis, 1999). In particular, systems that are characterized by interactive complexity -- systems that have the potential to interact in unexpected ways -- are especially prone to disasters (Sagan, 1993). Indeed, there is a growing appreciation that large scale disasters such as the Mann-Gulch fire disaster in Montana (Weick, 1993); the Bhopal chemical plant explosion (Shrivastava, 1987), the Three Mile Island nuclear accident (Moss and Sills, 1981) and the Tenerife air crash of a KLM 747 and a Pan-Am 747 jumbo jet (Weick, 1990) are the result of separate small events that become linked and amplified in unpredictable ways, and are especially likely when systems become more tightly coupled and less linear. Further, another contributing factor in the *Columbia* disaster concerns NASA's size, geographical distribution, and cultural variation, which make effective communication and coordination difficult (McCurdy, 1994).

It has long been recognized in organization theory that vocabularies influence the process of cognition, primarily through categorization processes and their effects on organizations (March and Simon, 1958), and, in Chapter 6, William Ocasio (Northwestern University) utilizes historical and archival analysis to examine the interplay between language and culture in the *Columbia* disaster. In particular, Ocasio (2005) focuses on the meaning of the vocabulary of "safety of flight," which became viewed as a minimal constraint to satisfy rather than a goal to be improved.

In chapter 7, Sally Blount (NYU), Mary Waller (Tulane University), and Sophie Leroy (NYU) focus on time pressure as a key contributing factor in the *Columbia* disaster. The cognitive focus became time and consequently information-processing and decision-making capabilities deteriorated. When ambiguous information was encountered, the NASA staff systematically underestimated safety risks, while the costs of delays were consistently overestimated. Furthermore, many of these employees perceive being marginalized in the organization as the worst outcome to befall a NASA participant. This characteristic of a “can do culture run amok” aggravated the effects of time urgency and time stress on individual and group information-processing and decision-making during the time period leading up to the *Columbia* disaster. Those few employees who did suggest safety-related delays during the time leading up to the *Columbia* launch found themselves left off distribution lists and out of important meetings. Other employees who witnessed this process quickly learned to keep their concerns to themselves. In fact, a recent post-*Columbia* survey suggests that many NASA employees are still afraid to speak up about safety concerns. An important takeaway is that stakeholders should be suspicious, rather than reassured, when senior executives announce bold plans to increase efficiency and speed of decisions in complex systems that require “mindful” deliberations.

Continuing this theme, Angela Buljan (University of Zagreb) and Zur Shapira (NYU) in chapter 8 examine how intense attention to production scheduling served as a detriment to safety in NASA’s decision to launch *Columbia*. Indeed, some managerial layers in the hierarchy were under the impression that schedule delays were going to be detrimental to their personal careers. Pressures to meet time deadlines for launch became the focus of attention at the expense of more attention to safety, both before the *Columbia* flight and during the flight itself. Managers were so habitually focused on reaching their deadlines that the expressed concerns of engineers about potential problems associated with the damage of the foam insulation did not seem important enough to managers to switch their attention from the deadline to the safety issue. At NASA it appears that the tendencies of managers to overrule engineers, when the organization is under budget and time pressures are severe, are an endemic problem (Cabbage and Harwood, 2004).

In Chapter 9, Karl Weick (University of Michigan) considers the equivocal perception of a blurred puff by the left wing of the shuttle 81.7 seconds after takeoff, and maintains that people within NASA made sense of this perception in ways that were more and less "mindful." Interpretations are shaped by both abstractions and labels, which are part of the ongoing negotiations among participants concerning the meaning of a flow of events. A management style that routinely did not ask or listen to what the engineers were telling senior managers hampered effectiveness of interpretation. Bureaucracy and standard processes trumped thoroughness and reason (CAIB, 2003: 181). Weick and Sutcliffe (2001) consider the following five processes:

- *Preoccupation with Failure.* The organization was more preoccupied with success ("prove that it is unsafe") rather than being preoccupied with failure ("prove that is safe'). At NASA there was an "arrogance of optimism" (Landau and Chisholm, 1995) combined with overconfidence that made it difficult to look at failure or even acknowledge that it was a possibility (failure is not an option). Management tended to wait for dissent rather than seek it, which is likely to shut off reports of failure and other tendencies to speak up. In a culture that is less mindful and more preoccupied with success, abstracting rarely registers and preserves small deviations that signify the possibility of larger system problems. If the "can-do" bureaucracy is preoccupied with success, it is even more difficult for people to appreciate that success is a complex accomplishment in need of continuous re-accomplishment. A preoccupation with failure implements that message.

- *Reluctance to Simplify.* The organization did not see simplification tendencies as a potential threat to effectiveness. In a culture that is less mindful and more willing to simplify, abstracting is done superficially in a more coarse-grained manner that confirms expectations, suppresses details, and postpones the recognition of persistent anomalies. The *Columbia* disaster is an unfortunate illustration of how NASA's strong cultural bias and optimistic organizational thinking undermined effective decision-making. Over the course of 22 years, foam insulation strikes were normalized to the point that they were simply a "maintenance" issue --- a concern that did not threaten a mission's success.

- *Sensitivity to Operations.* The organization also tended not to give as much attention to the operational issues in the moment as it did to the strategic big picture. One example being that parts of the *Columbia*, which were designed for use of a 10-year time period were still in use without replacement in its 22nd year of operations. A second important example is the fact that if a foam insulation strike was classified as an in-flight anomaly it would mean the problem would have to be solved before the next launch, which would require an unknown amount of analytic time. This strategic consideration took attention from the operational requirements of the current mission. In a culture that is less mindful and more insensitive to operations, abstraction is loosely tied to details of the present situation, which impairs the situational awareness that can often detect and correct issues that soon turn into problems and finally into crises that can lead to catastrophic failure.

- *Resilience/Anticipation.* Wildavsky notes that: "Improvement in overall capability, i.e., a generalized capacity to investigate, to learn, and to act, without knowing in advance what one will be called to act upon, is vital protection against unexpected hazards" (1991:70). Most systems try to anticipate trouble spots, but the higher-reliability systems also give close attention to their capability to improvise, to act without knowing in advance what will happen, to contain unfolding trouble, and to bounce back after dangers materialize. To bounce back from the ambiguity of blurred images, NASA could, for example, have expanded data collection to include asking astronauts to download all of their film of the launch and to see if they could improvise some means to get an in-flight view of the damaged area. Although both actions were suggested, neither was done. In a culture that is less mindful and less resilient, abstracting is shallow due to limited action repertoires. A weak commitment to resilience reinforces reliance on past strategies, past successes, and simplifications, all of which make it easier to lose anomalous details and make it less likely that one will be cautious about their grasp of the situation.

- *Channeling Decision to Experts.* Finally, in a culture that is less mindful and more deferential to hierarchy, abstracting is less informed by frontline experience and expertise. Decisions are not channeled to those with expertise. In high reliability organizations, decisions migrate to those who have specific knowledge to respond appropriately to an event (Roberts, Stout and Halpern, 1994).

In chapter 10, Scott Snook and Jeffrey Connor (Harvard University) examine the imaging episode from a structural perspective and note the similarities among three seemingly different tragedies --- Children's Hospital in Boston, friendly fire in northern Iraq, and the *Columbia* decision. In particular, Snook and Connor (2005) draw attention to the concept of "structurally induced inaction": despite the large number of experts present, nobody acts at a crucial moment due to audience inhibition (e.g., embarrassment and fear of ridicule), social influence (e.g., if others are not acting, this must not be an emergency), and diffusion of responsibility (Latane and Darley, 1970). Snook (2000) acknowledges the merits of two apparently competing schools of thought by labeling these failures "normal accidents in highly reliable organizations." The accidents are "normal" because it is an inherent property of high-risk, complex systems to eventually fail (Perrow, 1984). The organizations are "highly reliable" because of their significant track record of success (LaPorte, Roberts and Rochlin, 1989). However, these highly reliable organizations, which are populated with specialists, are susceptible to processes leading to inaction (Roberts, 1990).

The more unanticipated, ambiguous, and ill defined the precipitating event (the weaker the signal), the more strongly will complex organizational structures suppress an appropriate organizational response (Weick and Roberts, 1993). Ultimately what makes a signal weak is that organizational actors perceive them to be that way. At its origins, each tragedy is fundamentally a problem of categorization, a lack of fit between an unanticipated, ill-defined event and our increasingly sophisticated but narrow cognitive schemas. As organizations become increasingly differentiated and as roles become increasingly specialized, the likelihood that an unforeseen and troublesome event will fit neatly into an existing organizational silo or an individual's specialist cognitive frame is decreased. Thus, high levels of differentiation can combine with unanticipated events to create a condition where no one sees the big picture, let alone feels ownership for it. This type of structurally induced blindness generates its own frustrating form of inaction.

In the case of *Columbia*, everyone owned the debris problem, and yet no one did. According to the *Columbia* Accident Investigation Board (CAIB, 2003), a NASA engineer or manager made three discrete requests for imagery, and at least eight "opportunities" were missed where actions may have resulted in the discovery of debris damage. In the end, this lack of clear ownership contributed to organizationally weak responses to foam insulation strikes. In the *Columbia* case people did *try* to act, but the sheer weight and complexity of the organization ultimately defeated attempts to investigate the anomaly.

Audience Inhibition. Perhaps the most dramatic example of audience inhibition came from Debris Assessment Team (DAT) Co-Chair, Rodney Rocha. After learning of management's decision to cancel his imagery request, Rocha wrote the following e-mail, printed out his e-mail, shared this e-mail with colleagues, but did *not* send the e-mail:

> 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 an outside source. I must emphasize (again) that severe enough damage … combined with the heating and resulting damage to the underlying structure at the most critical location … 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 … Remember the NASA safety posters everywhere around stating, "If it's not safe, say so"? Yes, it's that serious.

It is telling that Rocha quotes a safety poster that warns: "If it's not safe, say so" in an e-mail where he clearly believed that the Space Shuttle may not be safe, and yet he did not say so. He writes an e-mail that conveys strong convictions, but he does not send the message. When asked why not, Rocha replied that he: "did not want to jump the chain of command … he would defer to management's judgment on obtaining imagery" (CAIB, 2003: 157).

Social Influence. In this case, the behaviors of high-status managers defined the situation as one that did not require extraordinary action (e.g., obtaining additional imagery). From the start, program managers framed the event as one not to be overly concerned about and they did not place a high priority on a foam insulation strike. The message was not lost on Boeing analysts, who eventually wondered: "why they were working so hard analyzing potential damage areas if Shuttle Program management believed that damage was minor and that no safety-of-flight issues existed" (CAIB, 2003: 160).

Diffuse Responsibility. Ownership of the foam insulation problem within NASA was confused and diffused. Despite having created a specialized office (Space Shuttle Systems Integration Office), whose sole responsibility was to integrate such cross-functional boundary issues (such as foam insulation strikes), in the end, no single office believed that it owned this issue. This lack of ownership contributed to organizationally weak responses to foam insulation strikes. High levels of organizational differentiation can increase the psychological impact of bystander inaction mechanisms in ways that induce troubling organizational activities.

In chapter 11, Roger Dunbar (NYU) and Raghu Garud (Pennsylvania State University) focus on the concept of data indeterminacy and consequent inaction. Dunbar and Garud (2005) note that despite the fact that parts of the distributed knowledge system wanted to find out more about the damage the foam insulation strike had caused, the overall system was prematurely stopping exploration efforts and tipping toward an organizing mode focused on achieving predictable task performance. Management techniques imposed barriers that kept at bay both engineering concerns and dissenting views, and ultimately helped create blind spots that prevented them from seeing the danger the foam insulation strike posed (CAIB, 2003: 170). In high-risk situations, the emergence of such data indeterminacy can have disastrous consequences.

In chapter 12, Amy Edmondson, Michael Roberto, Richard Bohmer, Erika Ferlins, and Laura Feldman (Harvard University) introduce the concept of the *recovery window* -- a time period between a threat and a major disaster (or prevented disaster) in which constructive collection action is feasible -- to examine how high-risk organizations deal with ambiguous threats. In this case, the recovery window was the time period between the launch of the shuttle when shedding debris presented an ambiguous threat to the disastrous outcome 16 days later in which collective actions were systematically under-responsive. This under-responsiveness was due to NASA's emphasis on precise deadlines, which was a poor fit with the inherently uncertain activities associated with space travel. Social pressures to conform exacerbate the tendency to not raise safety issues that might cause delays. Such social pressure can be especially strong when large status and power differences exist among leaders and subordinates (Janis, 1982).

After NASA's Intercenter Photo Working Group notified individuals throughout the organization of photographic evidence of a foam insulation strike during launch, their warning went largely unheeded. Factors that may have caused the organization to discount this threat include: (1) active discounting of risk; (2) fragmented, largely discipline-based analyses; and (3) a "wait and see" orientation in action.

Research on human cognition shows that people are predisposed to downplay the possibility of ambiguous threats (Goleman, 1985) and to exhibit a "stubborn attachment to existing beliefs" (Wohlstetter, 1962: 393), making sense of situations automatically and then favoring information that confirms rather than disconfirms initial views. In addition to these individual-level cognitive factors, at the group-level a poor team design, combined with a lack of coordination and support, dampened the engineers' concerns about the foam insulation strike. For example, the Debris Assessment Team (DAT) that was assembled on the second day of the *Columbia* flight to analyze the foam insulation strike suffered in terms of both structure and positioning The DAT was an *ad hoc* group of NASA and Boeing engineers with poorly defined lines of authority and limited access to resources. Finally, at the organizational level, NASA is a complex organization that maintains strict reporting relationships. The structure constrains information flow to defined channels of communication. NASA's organizational structures and rules did not facilitate fast informal information flow concerning unexpected events. The rigidity of communication protocols inhibited exchange of ideas, questions and concerns, and encouraged the reporting of summarized results up the hierarchy. This filtering process diminished the quality (detail of comprehensiveness) of information flowing to key decision-makers. Program leaders spent at least as much time making sure hierarchical rules and processes were followed as they did trying to establish why anyone would want a picture of the Space Shuttle (CAIB, 2003: 181).

A preferred alternative would be an exploratory response characterized by over-responsiveness and a learning orientation. In highly uncertain situations --- such as the *Columbia* recovery window --- entertaining hunches, reasoning by analogy, imagining potential scenarios, and experimenting with novel, ill-defined alternatives become essential (Klein, 1998). Managers in high-risk systems should deliberately exaggerate (rather than discount) ambiguous threats --- even those that at first seem innocuous. Managers should actively direct and coordinate team analysis and problem solving. Managers ought to encourage an overall orientation toward action. Finally, to combat social pressures to conformity, managers must take active steps to generate psychological safety and to foster constructive conflict and dissent in order to achieve a learning orientation within the organization.

Chapter 13 by Frances Milliken, Theresa Lant and Ebony Bridwell-Mitchell (NYU) considers an organizational learning lens to highlight barriers to effective learning during the imaging episode. All of the requests of the Debris Assessment Team for additional images of the foam insulation strike were ignored, denied, or downplayed by higher-up NASA managers, including shuttle program managers. For engineers, the signal was the repeated refusal of their request for imagery; for managers it was the persistent resurfacing of requests for imagery coming from multiple channels. In the end, the engineers heeded the signal they received from managers, resulting in their silence and the cessation of signals sent to managers. In this case, as in many organizations, the interpretation favored by the more powerful constituency won, and because the managers did not perceive the foam insulation strike as a problem, the request for additional data went unfulfilled. This episode illustrates a general problem of organizational defenses. For example, Argyris (1990) demonstrates how withholding information can lead to organizational "pathologies," defensive routines and a lack of learning. Organizational mechanisms such as constructive conflict are suggested to improve learning and interpretation.

Chapter 14 by Nancy Leveson, Joel Crutcher-Gershenfeld, John Carroll, Betty Barrett, Alexander Brown, Nicolas Dulac, and Karen Marais (MIT) examine systems approaches to safety. The manned space flight program had confused lines of authority, responsibility, and accountability in a "manner that almost defies explanation" (CAIB, 2003: 186). This defective organizational structure was a strong contributor to a broken safety culture. The mantra of "faster, better, cheaper" created stresses in the formal matrix structure, relegating the safety organization to the role of providing "safety services" to engineering and operations. Over time, this combination had lead to inadequate focus on safety in many areas of the organization. System safety that was not affecting "a successful mission" became an after-the-fact or auditing activity only.

NASA employees also experienced a lack of psychological safety or trust about speaking up. Further, when engineers did speak up, managers did not listen and did not ask follow up questions. Managers created barriers against dissenting opinions by stating preconceived conclusions based on subjective knowledge and experience rather than on solid data. In the extreme, managers listened only to those who told them what they wanted to hear. The chapter offers a framework drawn from engineering systems and organization theory to understand disasters and safety in a more comprehensive way.

In chapter 15, David Woods (The Ohio State University) examines patterns present in the *Columbia* disaster in order to consider how organizations in general can learn and change *before* dramatic failures occur. NASA failed to balance safety risks with intense production pressures. As a result, this disaster matches a classic pattern --- a safety drift. When this pattern is combined with a fragmented distributed problem-solving process that is missing cross checks and is unable to see the big picture, the result is an organization that cannot even recognize the possibility that blind spots exist. Evidence of risk becomes invisible, and safety margins erode.

Based on materials in the CAIB report, there are five classic patterns (Hollnagel, 1993) also seen in other disasters: (1) Drift toward failure as defenses erode in the face of production pressure; (2) An organization that takes past success as a reason for confidence instead of investing in anticipating the changing potential of failure; (3) A fragmented distributed problem-solving process that clouds the big picture; (4) Failure to revise assessments as new evidence accumulates; and (5) Breakdowns at the boundaries of organizational units that impede communication and coordination. *Resilience engineering* is offered to combat these classic patterns.

Resilience engineering can enable organizations to better balance safety and efficiency goals, and can establish independent, involved, informed, and informative safety organizations. A system's resilience includes properties such as: (a) *Buffering capacity*: the size or kinds of disruptions the system can absorb or adapt to without a fundamental breakdown in performance or in the system's structure; (b) *Flexibility*: the system's capability to restructure itself in response to external changes or pressures; (c) *Margin*: how closely the system is currently operating relative to one or another kind of performance boundary; and (d) *Tolerance*: whether the system gracefully degrades as stress/pressure increase, or collapses quickly when pressure exceeds adaptive capacity.

Resilience engineering seeks to develop engineering and management practices to measure sources of resilience, provide decision support for balancing production/safety tradeoffs, and create feedback loops that enhance the organization's capability to monitor/revise risk models and to target safety investments (Cook, Woods and Miller, 1998). While NASA failed to make the production/safety tradeoff reasonably in the context of foam insulation strikes, the question for the future is how to help organizations make these tradeoffs better.

From the point of managing resilience, a safety organization needs the resources and authority to achieve the "I's" of an effective safety organization --- Independent, Involved, Informative, and Informed about how the organization is actually operating. Together these characteristics will *create foresight* about the changing patterns of risk before failure and harm occur.

In chapter 16, William Starbuck (NYU) and Johnny Stephenson (NASA) note that NASA is both one agency and several. Its ten centers are highly autonomous. Moreover, NASA centers have independent political support and some employ their own Congressional liaison personnel. Indeed, Johnson Space Center and Marshall Space Flight Center, which jointly control almost half of NASA's budget, have sufficient autonomy that they have been known to proceed contrary to direct instructions from NASA's headquarters (Klerkx, 2004). NASA's centers have distinctive personnel, cultures, and procedures. For example, the Jet Propulsion Laboratory operates as a Federally Funded Research and Development Center that works under contract with NASA and has greater personnel flexibility than other NASA centers.

The autonomy of its ten centers gives NASA as a whole resilience, fosters innovation and strengthens survivability. Decentralized contacts with numerous members of Congress facilitate greater contact and influence. Further, the centers' distinctive cultures foster different ways of thinking and the development of distinct ideas, debates and conflicts within NASA can help to reduce groupthink and to improve decision quality (Mason and Mitroff, 1981). However, NASA insiders have sometimes been disciplined for speaking too critically (Blount, Waller and Leroy, 2005).

NASA's structure reflects history and politics more than logical analysis of tasks it is currently pursuing. NASA's political environment has second-guessed NASA's decisions about what to do and how to do it and has generally restricted NASA's discretion. NASA’s high-profile goals in space travel and exploration require persistent efforts over long time horizons, whereas politicians who must face re-election campaigns in 2, 4, or 6 years tend to show little interest in goals that will require two or three decades to achieve. One central goals conflict involves the tradeoffs in technological innovation, cost, and safety.

Most organizations experience logical relationships between their task outcomes and their financial resources. If these organizations achieve substantive successes, their resources increase, and if they produce failures, their resources decrease. However, history reveals that NASA’s funding has not depended on its accomplishments. Indeed, after landing on the Moon, budget cuts immediately followed. In contrast, NASA received budget increases immediately after both the *Challenger* and the *Columbia* disaster. Similar effects of punishing achievement and rewarding manifest failures occurred more subtly. The negative correlation between accomplishments and resources has even extended to NASA’s contractors. When contractors have made mistakes and incurred cost overruns, NASA has given them more money (Klerkx, 1994).

NASA coordinates an inter-organizational network. In 2004, NASA employed about 19,600 people directly and about 38,900 people through contracts. That is, in 2004, only a third of the people working on NASA projects were NASA employees. Further, there are fuzzy boundaries between NASA’s activities and those of the Department of Defense (DOD). Some of NASA’s most senior leaders are of DOD heritage, boundaries between the two organizations are not always clear, and the mission objectives of DOD occasionally influence mission objectives within NASA. Within this inter-organizational network, the large aerospace companies have been active politically. In the defense sector, the four companies making the largest political contributions during the 2004 election cycle were Lockheed Martin, General Dynamics, Northrop Grumman, and Ratheon; and Boeing ranked tenth. As NASA's coalition partners have merged and consolidated, they have grown more powerful relative to NASA and more interested in operating independently of NASA. In summary, partnering relationships while essential are intrinsically complex within NASA's network. The shifting priorities and mandates of NASA's political environment as well as the different interests within NASA itself have added complexity to NASA's organization.

Chapter 17 by Henry McDonald (former Center Director at NASA and Professor at University of Tennessee) offers observations on NASA and on the lessons to be drawn from the *Columbia* disaster. In particular, potential lessons that NASA should draw from Organization Theory and Strategic Management are discussed. McDonald's concluding remarks are noteworthy: "As an engineer turned manager for a time, I shared many in the science community's skepticism of organizational theory ... Observing NASA management struggle with the shuttle and space station, I have gained a better appreciation of how these theories can help structure a more effective high reliability learning organization in a complicated high-technology environment replete with ambiguous safety signals" (2005: 346).

Chapter 18 by the books editors, William Starbuck and Moshe Farjoun, provides a summary of the book and lessons learned from studying NASA's evolution, including the *Columbia* disaster. Farjoun and Starbuck (2005b) emphasize that NASA is a large, elaborate, and mature organization, which operates risky and complex technologies in an environment that emits ambiguous signals. Moreover, NASA pursues challenging and often inconsistent long-run goals to satisfy multiple constituents in a politically charged organizational environment (McDonald, 2005). In addition, at the time of the disaster, NASA was facing tight budgetary constraints, personnel downsizing, severe scheduling pressures, leadership turnover, and technical, political, and financial uncertainty (Farjoun, and Starbuck, 2005a).

Many historical, social, political, and technological factors interacted across different organizational levels and in different subsystems to create unsafe conditions, unrealistic expectations, and faulty decision-making (Leveson *et al.* 2005). Imbalanced goals and ineffective learning combined with production pressures and fragmented problem solving that missed cross checks and the big picture (Woods, 2005).

The *Columbia* disaster occurred in a working environment that featured time pressure, risky shuttle technology, and a misleading characterization of the shuttle as "operational" rather than developmental. These features had roots in early policy and technological decisions, which were largely motivated to secure NASA's and the shuttle program's continued survival (Farjoun, 2005a). Over time, organizational stress was escalating, efficiency was receiving ever-increasing emphasis, communication was systemically problematic (Vaughan, 2005) and coordination problems cascaded though the organization (Blount, Waller and Leroy, 2005), which were exacerbated by ineffective knowledge transfer and leadership succession problems (Farjoun, 2005b).

History shaped events in critical ways. First, early technological choices continued to cause problems despite multiple upgrades in shuttle technology. Second, early successes imprinted a "can do" culture at NASA (Starbuck and Stephenson, 2005). These successes engendered optimism at NASA and made it confident in its capability to learn and to operate safely. Repeated successes bred inertia and insularity, solidified frames and vocabulary (Ocasio, 2005), and contributed to the shuttle program's safety drift (Farjoun 2005b).

Safety did not have the highest priority in the years preceding the *Columbia* disaster. Competing with safety were the often-conflicting goals of cost, time, and innovation (Buljan and Shapira, 2005). NASA's goal conflicts have been reinforced by its political environment (Starbuck and Stephenson, 2005), and by differences among professional groups such as scientists, engineers, and management (Milliken *et al.* 2005). Goal conflicts affected both the compromises made in shuttle technology and the information processing and decision-making concerning *Columbia's* mission (Farjoun, 2005a). NASA's unrelenting focus on efficiency and schedule targets had the unintended consequence of filtering external advice, blocking warning signals, and pushing the organization beyond its limits (Blount, Waller and Leroy, 2005). Managers were so focused on reaching their schedule targets that the foam insulation problems did not induce them to shift their attention to safety (Bulajan and Shapira, 2005).

NASA requires long and stable horizons to pursue its major goals but is vulnerable to short-run disturbances, shifting priorities, changing personnel, and political and technological uncertainty (Starbuck and Stephenson, 2005). NASA has viewed and publicized its technology as routine while also acknowledging its exploratory and risky nature (Dunbar and Garud, 2005). NASA has set ambitious goals in the face of survival threats and shrinking resources, and by doing so, has increasingly overstretched its resources (Vaughan, 2005).

NASA has found it especially difficult to balance the contradictory demands of differentiation and integration (Lawrence and Lorsch, 1967), resulting in "structurally-induced" inaction (Snook and Connor, 2005). Embedded in a large inter-organizational network, NASA's complex matrix organization failed to integrate effectively the varied and distributed tasks undertaken by different members of the organization and by different programs (Roberts, Madsen and Desai, 2005). A major problem in a fragmented and distributed system is "situation awareness," or the ability of individuals to see the big picture as it unfolds (Weick, Sutcliffe and Obstfeld, 1999). Under the dual conditions of incomplete knowledge and complexity, individuals do not see the nature and significance of events (Ocasio, 2005). Under these conditions, data appear indeterminate and people have difficulty discerning appropriate actions (Dunbar and Garud, 2005). Individual and social tendencies, manifested at individual and group levels, may impair analysis and problem solving (Edmondson*, et al.* 2005).

Coordination failures played out in various ways. The safety function failed to maintain an independent and credible voice in operational decisions (Woods, 2005). Rigid deadlines influenced decision-making and safety-efficiency tradeoffs (Blount, Waller and Leroy, 2005). Different units developed idiosyncratic vocabularies that obscured risks (Ocasio, 2005). Perception of ambiguous raw data and its interpretation in collectively shared categories were impaired (Weick, 2005). Managers and engineers struggled with their professional differences (Milliken *et al.* 2005).

Compelled by managers' focus on meeting target schedules and responding to stress, a need for closure, confusing priorities, and heightened uncertainties, employees cut corners, distrusted their superiors, and became confused about what they should be doing. Leaders tended to overreact in their ongoing reallocations of resources between the dual goals of safety and efficiency (Farjoun, 2005a). Individuals were unsure to what extent they needed to follow rules and procedures, and what incentives and penalties they needed to consider (Buljan and Shapira, 2005). Facing time and production pressures resulted in decision-makers being less likely to act mindfully (Weick, 2005).

The CAIB (2003) report places much emphasis on the organizational culture to explain why NASA continued to repeat ineffective behaviors. The different cultures of organizational units and occupations influenced problem solving and sense making (Vaughan, 2005), reinforced the agency's identity as invincible (Weick, 2005), impaired conflict resolution (Milliken, *et al.* 2005), and discouraged the voicing of concerns (Leveson*, et al.* 2005). Other important factors include individual and organizational incentives (Bulajan and Shapira, 2005), conflicting interests (Dunar and Garud, 2005), and policy and environmental constraints (Leveson, *et al.* 2005).

While evidence about learning is mixed, cognitive learning by individuals often seemed to have no effect on behaviors at the organizational level (Milliken *et al.* 2005). NASA rushed to restore organization routines before it absorbed appropriate lessons (Farjoun, 2005b). Learning processes have been disrupted by executive and employee turnover and by instabilities outside NASA's control (Starbuck and Stephenson, 2005). Knowledge transfer and information systems have been ineffective or have generated incorrect or incomplete information (Ocasio, 2005). NASA and its constituents have sometimes lacked the capabilities to learn, whereas at other times, they lacked motivations to make changes (Farjoun, 2005a; Vaughan, 2005).

One lesson to draw from the *Columbia* disaster is the importance of navigating mindfully in real time amid uncertainty and ambiguity (Farjoun and Starbuck, 2005b). Retrospective observers who know how actions turned out see past events as much more rationally ordered than current and future events (Starbuck and Milliken, 1988). Retrospective observers are unlikely to appreciate the complexity and disorder seen by real-time decision-makers. Real-time decision makers struggle to balance conflicting goals, to sort signal from noise in complex and ambiguous events, and to make judgment calls under resource, time, and informational constraints.

The CAIB (2003) report made several recommendations about ways that NASA could ensure leaders are in touch with lower-level concerns and could improve communication flows up and down the hierarchy and across units. Furthermore, decision-makers should not have too much confidence in edited and abstracted information (Weick, 2005) and should maintain skepticism about safety indicators (Farjoun, 2005b). Decision-makers should also staff leadership positions with people experienced in safety, and should empower middle managers to build information bridges both horizontally and vertically within the hierarchy (Farjoun and Starbuck, 2005b).

Decision-makers need to overcome their tendencies for self-confirming biases when searching for and interpreting information. Decision-makers also need to deal assertively with safety drift by engaging in periodic reassessments (Farjoun 2005b). Furthermore, decision-makers must be aware that faulty cognitions undermine learning, and a majority of managers have erroneous perceptions of both their organization's capabilities and the opportunities and threats in their organizations' environments (Mezias and Starbuck, 2003). Therefore, it is useful to create programs that seek to give managers more realistic perceptions. Organizations tend to focus their information gathering in areas that relate to past successes with the result that too little information is gathered in areas that are assumed to be irrelevant. Over long time periods, lack of learning due to continued success makes failure likely as behaviors become increasingly inappropriate to their evolving contexts and decision-makers have increasingly less information about new developments. Also, large organizations have great difficulty learning from failures. One pattern is that managers interpret large failures as having idiosyncratic and largely exogenous causes, and the larger the failure, the more idiosyncratic or exogenous causes they perceive. Furthermore, some managers turn failures --- both large and small --- into opportunities for personal advancement, which fosters cynicism in those around them (Farjoun and Starbuck, 2005b).

A distinctive aspect of the failures of NASA has been their *reproducibility:* failures have a high likelihood of recurring. Some of the risky conditions and patterns that produced the *Columbia* disaster had appeared in prior NASA failures. Two years after the *Columbia* disaster, NASA has regenerated a strong focus on setting and meeting schedules. Although agreement is widespread that the shuttle technology is unreliable, NASA is not developing alternative launch technologies. Such persistent patterns may foster another failure despite other changes NASA makes post-disaster (Farjoun, 2005b).

Another often-observed property of organizations is their need for unlearning (Hedberg, 1981). People need to discover the deficiencies of current routines and policies before they will consider adopting different routines or policies. The reasons for utilizing current shuttle technology are mostly political and social. Existing technologies and programs become institutionalized, drawing support from personnel with specialized jobs and personal identification with specific activities and decisions. Every organization finds it difficult to terminate a poor course of action, and impossible if there is ambiguity about how bad the course actually is, because doing so labels some prior decisions as erroneous (Staw, 1976).

Organizational tendencies for over-specialization, communication failure, imperfect learning, and biased or limited action become more likely to produce dysfunctional outcomes when coupled with complex technology, schedule pressures, and conflicting goals. Allocations of resources between the often-conflicting goals of safety and efficiency become all the more challenging when uncertainty is high, measures are less valid, and resources are scarce.

What factors push organizations to and beyond their limits? Among the possible factors are large size, fragmentation, turbulent and demanding environments, complex technology, slow learning, a weak prioritization of goals, a lack of respect by personnel across functional areas, managerial facades, and constraints that render problems unsolvable. When an organization reaches its limits, problems and errors keep emerging, solutions become ineffective or they lag, and risks escalate. Individuals are more likely to err and their errors are more likely to go undetected and uncorrected. Organizations can increase their resilience, reliability, and effectiveness by navigating mindfully, improving learning, unlearning bad habits, managing complexity systematically, and keeping organizations from exceeding their limits.

Faster, Better, Cheaper: Choose Two. Perhaps the most important lesson from NASA's Space Shuttle *Columbia* disaster, which we believe to be generalizable, is that it can be a grave mistake to try to be all things to all people. Strategy is about tradeoffs.

The function of management is to choose intra- and inter-project priorities. Moreover, as we move forward, NASA can achieve much in developing the Space Shuttle, returning to the Moon, or going to Mars. It would be wise, however, if NASA would focus attention on one mission at a time.

References

Allison, G. T. and P. Zelikow (1999). *Essence of Decision: Explaining the Cuban Missile Crisis*. New York, NY: Longman.

Argyris, C. (1990). *Overcoming Organizational Defenses: Facilitating Organizational Learning.* Boston, MA: Allyn Bacon.

Banerjee, P. M. and J. T. Mahoney (2007). "*Organization at the Limit: Lessons from the Columbia Disaster.* Edited by William Starbuck and Moshe Farjoun." *Academy of Learning Perspectives,* forthcoming.

Blount, S., M. J. Waller and S. Leroy (2005). Coping with temporal uncertainty: When rigid, ambitious deadlines don't make sense. In W. H. Starbuck and M. Farjoun (Eds.), *Organization at the Limit: Lessons from the Columbia Disaster* (pp. 122-139). Malden, MA: Blackwell Publishing.

Buljan, A. and Z. Shapira (2005). Attention to production schedule and safety as determinants of risk-taking in NASA's decision to launch the *Columbia* shuttle, In W. H. Starbuck and M. Farjoun (Eds.), *Organization at the Limit: Lessons from the Columbia Disaster* (pp. 140-156). Malden, MA: Blackwell Publishing.

Cabbage, M. and H. Harwood (2004). *COMM Check: The Final Flight of Shuttle Columbia*. New York, NY: Free Press.

CAIB (Columbia Accident Investigation Board) (2003). Report, 6 volumes. Government Printing Office, Washington, D.C. http://caib.nasa.gov/

Chien, P. (2006). *Columbia -- Final Voyage*: *The Last Flight of NASA's First Space Shuttle.* New York, NY: Springer.

Clarke, L. (1999). *Mission Improbable: Using Fantasy Documents to Tame Disaster*. Chicago, IL: University of Chicago Press.

Cook, R. I., D. D. Woods and C. Miller (1998). *A Tale of Two Stories*: *Contrasting Views on Patient Safety*. Chicago, IL: National Patient Safety Foundation.

Dunbar, R. and R. Garud (2005). Data indeterminacy: One NASA, two modes. In W. H. Starbuck and M. Farjoun (Eds.), *Organization at the Limit: Lessons from the Columbia Disaster* (pp. 202-219). Malden, MA: Blackwell Publishing.

Edmondson, A. C., M. A. Roberto, and M. J. Bohmer (2005). *The Columbia's Last Flight*. Harvard Multi-Media Business Case. Harvard Business School.

Edmondson, A. C., M. A. Roberto, R. M. J. Bohmer, E. M. Ferlins, and L. Feldman (2005). The recovery window: Organizational learning following ambiguous threats. In W. H. Starbuck and M. Farjoun (Eds.), *Organization at the Limit: Lessons from the Columbia Disaster* (pp. 220-245). Malden, MA: Blackwell Publishing.

Farjoun, M. (2005a). History and policy at the Space Shuttle Program. In W. H. Starbuck and M. Farjoun (Eds.), *Organization at the Limit: Lessons from the Columbia Disaster* (pp. 21-40). Malden, MA: Blackwell Publishing.

Farjoun, M (2005b). Organizational learning and action in the midst of safety drift: Revisiting the Space Shuttle Program's recent history. In W. H. Starbuck and M. Farjoun (Eds.), *Organization at the Limit: Lessons from the Columbia Disaster* (pp. 60-80). Malden, MA: Blackwell Publishing.

Farjoun, M., and W. H. Starbuck (2005a). Introduction: Organizational aspects of the *Columbia* disaster. In W. H. Starbuck and M. Farjoun (Eds.), *Organization at the Limit: Lessons from the Columbia Disaster* (pp. 3-18). Malden, MA: Blackwell Publishing.

Farjoun, M. and W. H. Starbuck (2005b). Lessons from the *Columbia* disaster. In W. H. Starbuck and M. Farjoun (Eds.), *Organization at the Limit: Lessons from the Columbia Disaster* (pp. 349-363). Malden, MA: Blackwell Publishing.

Goleman, D. (1985). *Vital Lies, Simple Truths: The Psychology of Self-Deception*. New York, NY: Simon & Schuster.

Hedberg, B. L. T. (1981). How organizations learn and unlearn. In P.C. Nystrom and W.H. Starbuck (Eds.), *Handbook of Organizational Design* (pp. 3-27). New York, NY: Oxford University Press.

Heimann, C. F. I. (1997). *Acceptable Risks: Politics, Policy, and Risky Technologies.* Ann Arbor, MI: University of Michigan Press.

Hollnagel, E. (1993). *Human Reliability: Analysis, Context and Control.* London, UK: Academic Press.

Janis, I. L. (1982). *Groupthink: Psychological Studies of Policy Decisions and Fiascos*. Boston, MA: Houghton-Mifflin.

Jervis, R. (1997). *System Effects: Complexity in Political and Social Life*. Princeton, NJ: Princeton University Press.

Klein, G. A. (1998). *Sources of Power: How People Make Decisions*. Cambridge, MA: MIT Press.

Klerkx, G. (2004). *Lost in Space*: *The Fall of NASA and the Dream of a New Space Age*. New York, NY: Pantheon.

Landau, M. and D. Chisolm (1995). The arrogance of optimism: Notes on failure avoidance management. *Journal of Contingencies and Crisis Management*, 3: 67-80.

LaPorte, T. R., K. H. Roberts and G. I. Rochlin (1989). *High Reliability Organizations: The Research Challenge*. Berkeley, CA: Institute of Governmental Studies, University of California at Berkeley.
Latane, B. and J. M. Darley (1970). *The Unresponsive Bystander: Why Doesn't He Help?* New York, NY: Appleton-CenturyCrofts.

Lawrence, P. R. and J. W. Lorsch (1967). *Organization and Environment*. Boston, MA: Harvard Business School Press.

Leveson, N. J. Cutcher-Gershenfeld, J. S. Carroll, B. Barrett, A. Brown, N. Dulac, and K. Marais (2005). Systems approaches to safety: NASA and the Space Shuttle disasters. In W. H. Starbuck and M. Farjoun (Eds.), *Organization at the Limit: Lessons from the Columbia Disaster* (pp. 269-288). Malden, MA: Blackwell Publishing.

March, J. G. and H. A. Simon (1958). *Organizations*. New York, NY: John Wiley.

March, J. G., L. S. Sproull and M. Tamuz (1991). Learning from samples of one or fewer. *Organization Science,* 2 (1): 1-13.

Mason, R. and I. Mitroff (1981). *Challenging Strategic Planning Assumptions*. New York, NY: John Wiley.

McCurdy, H. E. (1994). *Inside NASA: High Technology and Organizational Change in the U.S. Space Program*. Baltimore, MD: John Hopkins Press.

McCurdy, H. E. (2001). *Faster, Better, Cheaper: Low-Cost Innovation in the U.S. Space Program.* Baltimore, MD: John Hopkins Press.

McDonald, H. (2005). Observations on the *Columbia* accident. In W. H. Starbuck and M. Farjoun (Eds.), *Organization at the Limit: Lessons from the Columbia Disaster* (pp. 336-346). Malden, MA: Blackwell Publishing.

Mezias, J. M. and W. H. Starbuck (2003). Studying the accuracy of managers' perceptions: A research odyssey. *British Journal of Management*, 14: 3-17.

Milliken, F. J., T. K. Lant and E. N. Bridwell-Michell (2005). Barriers to the interpretation and diffusion of information about potential problems in organizations: Lessons from the Space Shuttle *Columbia*. In W. H. Starbuck and M. Farjoun (Eds.), *Organization at the Limit: Lessons from the Columbia Disaster* (pp. 246-266). Malden, MA: Blackwell Publishing.

Miller, D. (1990). *The Icarus Paradox: How Exceptional Companies Bring About Their Own Downfall*. New York, NY: Harper.

Miller, D. (1994). What happens after success: The perils of excellence. *Journal of Management Studies*, 31: 325-358.

Moss, T. H. and D. L. Sills (Eds.) (1981). *The Three Mile Island Accident: Lessons and Implications.* New York, NY: Academy of Sciences.

Ocasio, W. (2005). The opacity of risk: Language and the culture of safety in NASA's space shuttle program. In W. H. Starbuck and M. Farjoun (Eds.), *Organization at the Limit: Lessons from the Columbia Disaster* (pp. 101-121). Malden, MA: Blackwell Publishing.

Perrow, C. (1984). *Normal Accidents: Living with High Risk Technologies*. New York, NY: Basic Books.

Reason, J. (1997). *Managing the Risks of Organizational Accidents.* Brookfield, VT: Ashgate.

Roberts, K. H. (1990). Managing high reliability organizations. *California Management Review*, 32 (4): 101-114.

Roberts, K. H. and R. G. Bea (2001). Must accidents happen? Lessons from high reliability organizations. *Academy of Management Executive*, 15: 70-79.

Roberts, K. H., P. M. Madsen and V. M. Desai (2005). The space between in space transportation: A relational analysis of the failure of STS-107. In W. H. Starbuck and M. Farjoun (Eds.), *Organization at the Limit: Lessons from the Columbia Disaster* (pp. 81-97). Malden, MA: Blackwell Publishing.

Roberts, K. H., S. K. Stout and J. J. Halpern (1994). Decision dynamics in two high reliability military organizations. *Management Science*, 40: 614-624.

Sagan, S. D. (1993). *The Limits of Safety: Organizations, Accidents and Nuclear Weapons.* Princeton, N.J.: Princeton University Press.

Shrivastava, P. (1987). *Bhopal: Anatomy of a Crisis.* Cambridge, MA: Ballinger.

Snook, S. A. (2000). *Friendly Fire*: *The Accidental Shootdown of U.S. Black Hawks over Northern Iraq.* Princeton, N.J.: Princeton University Press.

Snook, S. A. and J. C. Connor (2005). The price of progress: Structurally induced inaction. In W. H. Starbuck and M. Farjoun (Eds.), *Organization at the Limit: Lessons from the Columbia Disaster* (pp.178-201). Malden, MA: Blackwell Publishing.

Starbuck,W. H. and M. Farjoun (Eds.) (2005), *Organization at the Limit: Lessons from the Columbia Disaster*. Malden, MA: Blackwell Publishing.

Starbuck, W. H. and F. J. Milliken (1988). Challenger: Fine-tuning the odds until something breaks. *Journal of Management Studies*, 25: 319-340.

Starbuck, W. H. and J. Stephenson (2005). Making NASA more effective. In W. H. Starbuck and M. Farjoun (Eds.), *Organization at the Limit: Lessons from the Columbia Disaster* (pp. 309-335). Malden, MA: Blackwell Publishing.

Staw, B. M. (1976). Knee-deep in the big muddy: A study of escalating commitment to a chosen course of action. *Organization Behavior and Human Performance,* 16: 27-44.

Tucker, A. L. and A. C. Edmondson (2003). Why hospitals don't learn from failures: Organizational and psychological dynamics that inhibit system change. *California Management Review*, 45 (Winter): 55-72.

Turner, B. A. (1976). The organizational and interorganizational development of disasters. *Administrative Science Quarterly*, 21: 378-397.

Turner, B. A. (1978). *Man-Made Disasters*. London, UK: Wykeham.

Vaughan, D. (1990). Autonomy, interdependence, and social control: NASA and the space shuttle *Challenger*. *Administrative Science Quarterly*, 35 (2): 225-257.

Vaughan, D. (1996). *The Challenger Launch Decision: Risky Technology, Culture, and Deviance at NASA.* Chicago, IL: University of Chicago Press.

Vaughan, D. (2005). System effects: On slippery slopes, repeating negative patterns, and learning from mistakes? In W. H. Starbuck and M. Farjoun (Eds.), *Organization at the Limit: Lessons from the Columbia Disaster* (pp. 41-59). Malden, MA: Blackwell Publishing.

Weick, K. E. (1990). The vulnerable system – An analysis of the Tenerife air disaster. *Journal of Management*, 16 (3): 571-593.

Weick, K. E. (1993). The collapse of sensemaking in organizations: The Mann-Gulch disaster. *Administrative Science Quarterly*, 38 (4): 628-652.

Weick, K. E. (2005). Making sense of blurred images: Mindful organizing in mission STS-107. In W. H. Starbuck and M. Farjoun (Eds.), *Organization at the Limit: Lessons from the Columbia Disaster* (pp. 159-177). Malden, MA: Blackwell Publishing.

Weick, K. E. and K. H. Roberts (1993). Collective mind in organizations. Heedful interrelating on flight decks. *Administrative Science Quarterly*, 38 (3): 357-381.

Weick, K. E. and K. M. Sutcliffe (2001). *Managing the Unexpected: Assuring High Performance in the Face of Complexity.* San Francisco, CA: Jossey-Bass.

Weick, K. E., K. M. Sutcliffe and D. Obstfeld (1999). Organizing for high reliability: Processes of collective mindfulness. *Research in Organizational Behavior*, 21: 81-123.

Wildavsky, A. (1991). *Searching for Safety*. New Brunswick, NJ: Transaction.

Wohlstetter, R. (1962). *Pearl Harbor: Warning and Decision*. Stanford, CA: Stanford University Press.

Woods, D. D. (2005). Creating foresight: Lessons for enhancing resilience from *Columbia*. In W. H. Starbuck and M. Farjoun (Eds.), *Organization at the Limit: Lessons from the Columbia Disaster* (pp. 289-308). Malden, MA: Blackwell Publishing.