CHAPTER 8

History As Cause: *Columbia* and *Challenger*

The Board began its investigation with two central questions about NASA decisions. Why did NASA continue to fly with known foam debris problems in the years preceding the *Columbia* launch, and why did NASA managers conclude that the foam debris strike 81.9 seconds into *Columbia*'s flight was not a threat to the safety of the mission, despite the concerns of their engineers?

8.1 ECHOES OF *CHALLENGER*

As the investigation progressed, Board member Dr. Sally Ride, who also served on the Rogers Commission, observed that there were "echoes" of *Challenger* in *Columbia*. Ironically, the Rogers Commission investigation into *Challenger* started with two remarkably similar central questions: Why did NASA continue to fly with known O-ring erosion problems in the years before the *Challenger* launch, and why, on the eve of the *Challenger* launch, did NASA managers decide that launching the mission in such cold temperatures was an acceptable risk, despite the concerns of their engineers?

The echoes did not stop there. The foam debris hit was not the single cause of the *Columbia* accident, just as the failure of the joint seal that permitted O-ring erosion was not the single cause of *Challenger*. Both *Columbia* and *Challenger* were lost also because of the failure of NASA's organizational system. Part Two of this report cites failures of the three parts of NASA's organizational system. This chapter shows how previous political, budgetary, and policy decisions by leaders at the White House, Congress, and NASA (Chapter 5) impacted the Space Shuttle Program's structure, culture, and safety system (Chapter 7), and how these in turn resulted in flawed decision-making (Chapter 6) for both accidents. The explanation is about system effects: how actions taken in one layer of NASA's organizational system impact other layers. History is not just a backdrop or a scene-setter. History is cause. History set the *Columbia* and *Challenger* accidents in motion. Although Part Two is separated into chapters and sections to make clear what happened in the political environment, the organization, and managers' and engineers' decision-making, the three worked together. Each is a critical link in the causal chain.

This chapter shows that both accidents were "failures of foresight" in which history played a prominent role.[1] First, the history of engineering decisions on foam and O-ring incidents had identical trajectories that "normalized" these anomalies, so that flying with these flaws became routine and acceptable. Second, NASA history had an effect. In response to White House and Congressional mandates, NASA leaders took actions that created systemic organizational flaws at the time of *Challenger* that were also present for *Columbia*. The final section compares the two critical decision sequences immediately before the loss of both Orbiters – the pre-launch teleconference for *Challenger* and the post-launch foam strike discussions for *Columbia*. It shows history again at work: how past definitions of risk combined with systemic problems in the NASA organization caused both accidents.

Connecting the parts of NASA's organizational system and drawing the parallels with *Challenger* demonstrate three things. First, despite all the post-*Challenger* changes at NASA and the agency's notable achievements since, the causes of the institutional failure responsible for *Challenger* have not been fixed. Second, the Board strongly believes that if these persistent, systemic flaws are not resolved, the scene is set for another accident. Therefore, the recommendations for change are not only for fixing the Shuttle's technical system, but also for fixing each part of the organizational system that produced *Columbia*'s failure. Third, the Board's focus on the context in which decision making occurred does not mean that individuals are not responsible and accountable. To the contrary, individuals always must assume responsibility for their actions. What it does mean is that NASA's problems cannot be solved simply by retirements, resignations, or transferring personnel.[2]

The constraints under which the agency has operated throughout the Shuttle Program have contributed to both

Shuttle accidents. Although NASA leaders have played an important role, these constraints were not entirely of NASA's own making. The White House and Congress must recognize the role of their decisions in this accident and take responsibility for safety in the future.

8.2 Failures of Foresight: Two Decision Histories and the Normalization of Deviance

Foam loss may have occurred on all missions, and left bipod ramp foam loss occurred on 10 percent of the flights for which visible evidence exists. The Board had a hard time understanding how, after the bitter lessons of *Challenger*, NASA could have failed to identify a similar trend. Rather than view the foam decision only in hindsight, the Board tried to see the foam incidents as NASA engineers and managers saw them as they made their decisions. This section gives an insider perspective: how NASA defined risk and how those definitions changed over time for both foam debris hits and O-ring erosion. In both cases, engineers and managers conducting risk assessments continually normalized the technical deviations they found.[3] 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 initial Shuttle design predicted neither foam debris problems nor poor sealing action of the Solid Rocket Booster joints. To experience either on a mission was a violation of design specifications. These anomalies were signals of potential danger, not something to be tolerated, but in both cases after the first incident the engineering analysis concluded that the design could tolerate the damage. These engineers decided to implement a temporary fix and/or accept the risk, and fly. For both O-rings and foam, that first decision was a turning point. It established a precedent for accepting, rather than eliminating, these technical deviations. As a result of this new classification, subsequent incidents of O-ring erosion or foam debris strikes were not defined as signals of danger, but as evidence that the design was now acting as predicted. Engineers and managers incorporated worsening anomalies into the engineering experience base, which functioned as an elastic waistband, expanding to hold larger deviations from the original design. Anomalies that did not lead to catastrophic failure were treated as a source of valid engineering data that justified further flights. These anomalies were translated into a safety margin that was extremely influential, allowing engineers and managers to add incrementally to the amount and seriousness of damage that was acceptable. Both O-ring erosion and foam debris events were repeatedly "addressed" in NASA's Flight Readiness Reviews but never fully resolved. In both cases, the engineering analysis was incomplete and inadequate. Engineers understood what was happening, but they never understood why. NASA continued to implement a series of small corrective actions, living with the problems until it was too late.[4]

NASA documents show how official classifications of risk were downgraded over time.[5] Program managers designated both the foam problems and O-ring erosion as "acceptable risks" in Flight Readiness Reviews. NASA managers also assigned each bipod foam event In-Flight Anomaly status, and then removed the designation as corrective actions were implemented. But when major bipod foam-shedding occurred on STS-112 in October 2002, Program management did not assign an In-Flight Anomaly. Instead, it downgraded the problem to the lower status of an "action" item. Before *Challenger*, the problematic Solid Rocket Booster joint had been elevated to a Criticality 1 item on NASA's Critical Items List, which ranked Shuttle components by failure consequences and noted why each was an acceptable risk. The joint was later demoted to a Criticality 1-R (redundant), and then in the month before *Challenger*'s launch was "closed out" of the problem-reporting system. Prior to both accidents, this demotion from high-risk item to low-risk item was very similar, but with some important differences. Damaging the Orbiter's Thermal Protection System, especially its fragile tiles, was normalized even before Shuttle launches began: it was expected due to forces at launch, orbit, and re-entry.[6] So normal was replacement of Thermal Protection System materials that NASA managers budgeted for tile cost and turnaround maintenance time from the start.

It was a small and logical next step for the discovery of foam debris damage to the tiles to be viewed by NASA as part of an already existing maintenance problem, an assessment based on experience, not on a thorough hazard analysis. Foam debris anomalies came to be categorized by the reassuring term "in-family," a formal classification indicating that new occurrences of an anomaly were within the engineering experience base. "In-family" was a strange term indeed for a violation of system requirements. Although "in-family" was a designation introduced post-*Challenger* to separate problems by seriousness so that "out-of-family" problems got more attention, by definition the problems that were shifted into the lesser "in-family" category got less attention. The Board's investigation uncovered no paper trail showing escalating concern about the foam problem like the one that Solid Rocket Booster engineers left prior to *Challenger*.[7] So ingrained was the agency's belief that foam debris was not a threat to flight safety that in press briefings after the *Columbia* accident, the Space Shuttle Program Manager still discounted the foam as a probable cause, saying that Shuttle managers were "comfortable" with their previous risk assessments.

From the beginning, NASA's belief about both these problems was affected by the fact that engineers were evaluating them in a work environment where technical problems were normal. Although management treated the Shuttle as operational, it was in reality an experimental vehicle. Many anomalies were expected on each mission. Against this backdrop, an anomaly was not in itself a warning sign of impending catastrophe. Another contributing factor was that both foam debris strikes and O-ring erosion events were examined separately, one at a time. Individual incidents were not read by engineers as strong signals of danger. What NASA engineers and managers saw were pieces of ill-structured problems.[8] An incident of O-ring erosion or foam bipod debris would be followed by several launches where the machine behaved properly, so that signals of danger were followed by all-clear signals – in other words, NASA managers and engineers were receiving mixed signals.[9] Some signals defined as weak at the time were, in retrospect, warnings of danger. Foam debris damaged tile was assumed (erroneously) not to pose a danger to the wing. If a primary O-ring failed, the secondary was assumed (erroneously) to provide a backup. Finally, because foam debris strikes were occurring frequently, like O-ring erosion in the years before *Challenger*, foam anomalies became routine signals – a normal part of Shuttle operations, not signals of danger. Other anomalies gave signals that were strong, like wiring malfunctions or the cracked balls in Ball Strut Tie Rod Assemblies, which had a clear relationship to a "loss of mission." On those occasions, NASA stood down from launch, sometimes for months, while the problems were corrected. In contrast, foam debris and eroding O-rings were defined as nagging issues of seemingly little consequence. Their significance became clear only in retrospect, after lives had been lost.

History became cause as the repeating pattern of anomalies was ratified as safe in Flight Readiness Reviews. The official definitions of risk assigned to each anomaly in Flight Readiness Reviews limited the actions taken and the resources spent on these problems. Two examples of the road not taken and the devastating implications for the future occurred close in time to both accidents. On the October 2002 launch of STS-112, a large piece of bipod ramp foam hit and damaged the External Tank Attachment ring on the Solid Rocket Booster skirt, a strong signal of danger 10 years after the last known bipod ramp foam event. Prior to *Challenger,* there was a comparable surprise. After a January 1985 launch, for which the Shuttle sat on the launch pad for three consecutive nights of unprecedented cold temperatures, engineers discovered upon the Orbiter's return that hot gases had eroded the primary and reached the secondary O-ring, blackening the putty in between – an indication that the joint nearly failed.

But accidents are not always preceded by a wake-up call.[10] In 1985, engineers realized they needed data on the relationship between cold temperatures and O-ring erosion. However, the task of getting better temperature data stayed on the back burner because of the definition of risk: the primary erosion was within the experience base; the secondary O-ring (thought to be redundant) was not damaged and, significantly, there was a low probability that such cold Florida temperatures would recur.[11] The scorched putty, initially a strong signal, was redefined after analysis as weak. On the eve of the *Challenger* launch, when cold temperature became a concern, engineers had no test data on the effect of cold temperatures on O-ring erosion. Before *Columbia*, engineers concluded that the damage from the STS-112 foam hit in October 2002 was not a threat to flight safety. The logic was that, yes, the foam piece was large and there was damage, but no serious consequences followed. Further, a hit this size, like cold temperature, was a low-probability event. After analysis, the biggest foam hit to date was redefined as a weak signal. Similar self-defeating actions and inactions followed. Engineers were again dealing with the poor quality of tracking camera images of strikes during ascent. Yet NASA took no steps to improve imagery and took no immediate action to reduce the risk of bipod ramp foam shedding and potential damage to the Orbiter before *Columbia*. Furthermore, NASA performed no tests on what would happen if a wing leading edge were struck by bipod foam, even though foam had repeatedly separated from the External Tank.

During the *Challenger* investigation, Rogers Commission member Dr. Richard Feynman famously compared launching Shuttles with known problems to playing Russian roulette.[12] But that characterization is only possible in hindsight. It is not how NASA personnel perceived the risks as they were being assessed, one launch at a time. Playing Russian roulette implies that the pistol-holder realizes that death might be imminent and still takes the risk. For both foam debris and O-ring erosion, fixes were in the works at the time of the accidents, but there was no rush to complete them because neither problem was defined as a show-stopper. Each time an incident occurred, the Flight Readiness process declared it safe to continue flying. Taken one at a time, each decision seemed correct. The agency allocated attention and resources to these two problems accordingly. The consequences of living with both of these anomalies were, in its view, minor. Not all engineers agreed in the months immediately preceding *Challenger*, but the dominant view at NASA – the managerial view – was, as one manager put it, "we were just eroding rubber O-rings," which was a low-cost problem.[13] The financial consequences of foam debris also were relatively low: replacing tiles extended the turnaround time between launches. In both cases, NASA was comfortable with its analyses. Prior to each accident, the agency saw no greater consequences on the horizon.

8.3 System Effects: The Impact of History and Politics on Risky Work

The series of engineering decisions that normalized technical deviations shows one way that history became cause in both accidents. But NASA's own history encouraged this pattern of flying with known flaws. Seventeen years separated the two accidents. NASA Administrators, Congresses, and political administrations changed. However, NASA's political and budgetary situation remained the same in principle as it had been since the inception of the Shuttle Program. NASA remained a politicized and vulnerable agency, dependent on key political players who accepted NASA's ambitious proposals and then imposed strict budget limits. Post-*Challenger* policy decisions made by the White House, Congress, and NASA leadership resulted in the agency reproducing many of the failings identified by the Rogers Commission. Policy constraints affected the Shuttle Program's organization culture, its structure, and the structure of the safety system. The three combined to keep NASA on its slippery slope toward *Challenger* and *Columbi*a. NASA culture allowed flying with flaws when problems were defined as normal and routine; the structure of NASA's Shuttle Program blocked the flow of critical information up the hierarchy, so definitions of risk continued unaltered. Finally, a perennially weakened safety system, unable to critically analyze and intervene, had no choice but to ratify the existing risk assessments on these two problems. The following comparison shows that these system effects persisted through time, and affected engineering decisions in the years leading up to both accidents.

The Board found that dangerous aspects of NASA's 1986 culture, identified by the Rogers Commission, remained unchanged. The Space Shuttle Program had been built on compromises hammered out by the White House and NASA headquarters.[14] As a result, NASA was transformed from a research and development agency to more of a business, with schedules, production pressures, deadlines, and cost efficiency goals elevated to the level of technical innovation and safety goals.[15] The Rogers Commission dedicated an entire chapter of its report to production pressures.[16] Moreover, the Rogers Commission, as well as the 1990 Augustine Committee and the 1999 Shuttle Independent Assessment Team, criticized NASA for treating the Shuttle as if it were an operational vehicle. Launching on a tight schedule, which the agency had pursued as part of its initial bargain with the White House, was not the way to operate what was in fact an experimental vehicle. The Board found that prior to *Columbia*, a budget-limited Space Shuttle Program, forced again and again to refashion itself into an efficiency model because of repeated government cutbacks, was beset by these same ills. The harmful effects of schedule pressure identified in previous reports had returned.

Prior to both accidents, NASA was scrambling to keep up. Not only were schedule pressures impacting the people who worked most closely with the technology – technicians, mission operators, flight crews, and vehicle processors – engineering decisions also were affected.[17] For foam debris and O-ring erosion, the definition of risk established during the Flight Readiness process determined actions taken and not taken, but the schedule and shoestring budget were equally influential. NASA was cutting corners. Launches proceeded with incomplete engineering work on these flaws. *Challenger*-era engineers were working on a permanent fix for the booster joints while launches continued.[18] After the major foam bipod hit on STS-112, management made the deadline for corrective action on the foam problem *after* the next launch, STS-113, and then slipped it again until *after* the flight of STS-107. Delays for flowliner and Ball Strut Tie Rod Assembly problems left no margin in the schedule between February 2003 and the management-imposed February 2004 launch date for the International Space Station Node 2. Available resources – including time out of the schedule for research and hardware modifications – went to the problems that were designated as serious – those most likely to bring down a Shuttle. The NASA culture encouraged flying with flaws because the schedule could not be held up for routine problems that were not defined as a threat to mission safety.[19]

The question the Board had to answer was why, since the foam debris anomalies went on for so long, had no one recognized the trend and intervened? The O-ring history prior to *Challenger* had followed the same pattern. This question pointed the Board's attention toward the NASA organization structure and the structure of its safety system. Safety-oriented organizations often build in checks and balances to identify and monitor signals of potential danger. If these checks and balances were in place in the Shuttle Program, they weren't working. Again, past policy decisions produced system effects with implications for both *Challenger* and *Columbia*.

Prior to *Challenger*, Shuttle Program structure had hindered information flows, leading the Rogers Commission to conclude that critical information about technical problems was not conveyed effectively through the hierarchy.[20] The Space Shuttle Program had altered its structure by outsourcing to contractors, which added to communication problems. The Commission recommended many changes to remedy these problems, and NASA made many of them. However, the Board found that those post-*Challenger* changes were undone over time by management actions.[21] NASA administrators, reacting to government pressures, transferred more functions and responsibilities to the private sector. The change was cost-efficient, but personnel cuts reduced oversight of contractors at the same time that the agency's dependence upon contractor engineering judgment increased. When high-risk technology is the product and lives are at stake, safety, oversight, and communication flows are critical. The Board found that the Shuttle Program's normal chain of command and matrix system did not perform a check-and-balance function on either foam or O-rings.

The Flight Readiness Review process might have reversed the disastrous trend of normalizing O-ring erosion and foam debris hits, but it didn't. In fact, the Rogers Commission found that the Flight Readiness process only affirmed the pre-*Challenger* engineering risk assessments.[22] Equally troubling, the Board found that the Flight Readiness process, which is built on consensus verified by signatures of all responsible parties, in effect renders no one accountable. Although the process was altered after *Challenger*, these changes did not erase the basic problems that were built into the structure of the Flight Readiness Review.[23] Managers at the top were dependent on engineers at the bottom for their engineering analysis and risk assessments. Information was lost as engineering risk analyses moved through the process. At succeeding stages, management awareness of anomalies, and therefore risks, was reduced either because of the need to be increasingly brief and concise as all the parts of the system came together, or because of the need to produce consensus decisions at each level. The Flight Readiness process was designed to assess hardware and take corrective actions that would transform known problems into acceptable flight risks, and that is precisely what it did. The 1986 House Committee on Science and Technology concluded during its investigation into *Challenger* that Flight Readiness Reviews had performed exactly as they were designed, but that they could not be expected to replace engineering analysis, and therefore they "cannot be expected to prevent a flight because of a design flaw that Project management had already determined an acceptable risk."[24] Those words, true for the history of O-ring erosion, also hold true for the history of foam debris.

The last line of defense against errors is usually a safety system. But the previous policy decisions by leaders described in Chapter 5 also impacted the safety structure and contributed to both accidents. Neither in the O-ring erosion nor the foam debris problems did NASA's safety system attempt to reverse the course of events. In 1986, the Rogers Commission called it "The Silent Safety System."[25] Pre-*Challenger* budget shortages resulted in safety personnel cutbacks. Without clout or independence, the safety personnel who remained were ineffective. In the case of *Columbia*, the Board found the same problems were reproduced and for an identical reason: when pressed for cost reduction, NASA attacked its own safety system. The faulty assumption that supported this strategy prior to *Columbia* was that a reduction in safety staff would not result in a reduction of safety, because contractors would assume greater safety responsibility. The effectiveness of those remaining staff safety engineers was blocked by their dependence on the very Program they were charged to supervise. Also, the Board found many safety units with unclear roles and responsibilities that left crucial gaps. Post-*Challenger* NASA still had no systematic procedure for identifying and monitoring trends. The Board was surprised at how long it took NASA to put together trend data in response to Board requests for information. Problem reporting and tracking systems were still overloaded or underused, which undermined their very purpose. Multiple job titles disguised the true extent of safety personnel shortages. The Board found cases in which the same person was occupying more than one safety position – and in one instance at least three positions – which compromised any possibility of safety organization independence because the jobs were established with built-in conflicts of interest.

8.4 Organization, Culture, and Unintended Consequences

A number of changes to the Space Shuttle Program structure made in response to policy decisions had the unintended effect of perpetuating dangerous aspects of pre-*Challenger* culture and continued the pattern of normalizing things that were not supposed to happen. At the same time that NASA leaders were emphasizing the importance of safety, their personnel cutbacks sent other signals. Streamlining and downsizing, which scarcely go unnoticed by employees, convey a message that efficiency is an important goal. The Shuttle/Space Station partnership affected both programs. Working evenings and weekends just to meet the International Space Station Node 2 deadline sent a signal to employees that schedule is important. When paired with the "faster, better, cheaper" NASA motto of the 1990s and cuts that dramatically decreased safety personnel, efficiency becomes a strong signal and safety a weak one. This kind of doublespeak by top administrators affects people's decisions and actions without them even realizing it.[26]

Changes in Space Shuttle Program structure contributed to the accident in a second important way. Despite the constraints that the agency was under, prior to both accidents NASA appeared to be immersed in a culture of invincibility, in stark contradiction to post-accident reality. The Rogers Commission found a NASA blinded by its "Can-Do" attitude,[27] a cultural artifact of the Apollo era that was inappropriate in a Space Shuttle Program so strapped by schedule pressures and shortages that spare parts had to be cannibalized from one vehicle to launch another.[28] This can-do attitude bolstered administrators' belief in an achievable launch rate, the belief that they had an operational system, and an unwillingness to listen to outside experts. The Aerospace Safety and Advisory Panel in a 1985 report told NASA that the vehicle was not operational and NASA should stop treating it as if it were.[29] The Board found that even after the loss of *Challenger*, NASA was guilty of treating an experimental vehicle as if it were operational and of not listening to outside experts. In a repeat of the pre-*Challenger* warning, the 1999 Shuttle Independent Assessment Team report reiterated that "the Shuttle was not an 'operational' vehicle in the usual meaning of the term."[30] Engineers and program planners were also affected by "Can-Do," which, when taken too far, can create a reluctance to say that something cannot be done.

How could the lessons of *Challenger* have been forgotten so quickly? Again, history was a factor. First, if success is measured by launches and landings,[31] the machine appeared to be working successfully prior to both accidents. *Challenger* was the 25th launch. Seventeen years and 87 missions passed without major incident. Second, previous policy decisions again had an impact. NASA's Apollo-era research and development culture and its prized deference to the technical expertise of its working engineers was overridden in the Space Shuttle era by "bureaucratic accountability" – an allegiance to hierarchy, procedure, and following the chain of command.[32] Prior to *Challenger*, the can-do culture was a result not just of years of apparently successful launches, but of the cultural belief that the Shuttle Program's many structures, rigorous procedures, and detailed system of rules were responsible for those successes.[33] The Board noted that the pre-*Challenger* layers of processes, boards, and panels that had produced a false sense of confidence in the system and its level of safety returned in full force prior to *Columbia*. NASA made many changes to the Space Shuttle Program structure after *Challenger*. The fact that many changes had been made supported a belief in the safety of the system, the invincibility of organizational and technical systems, and ultimately, a sense that the foam problem was understood.

8.5 History as Cause: Two Accidents

Risk, uncertainty, and history came together when unprecedented circumstances arose prior to both accidents. For *Challenger*, the weather prediction for launch time the next day was for cold temperatures that were out of the engineering experience base. For *Columbia*, a large foam hit – also outside the experience base – was discovered after launch. For the first case, all the discussion was pre-launch; for the second, it was post-launch. This initial difference determined the shape these two decision sequences took, the number of people who had information about the problem, and the locations of the involved parties.

For *Challenger*, engineers at Morton-Thiokol,[34] the Solid Rocket Motor contractor in Utah, were concerned about the effect of the unprecedented cold temperatures on the rubber O-rings.[35] Because launch was scheduled for the next morning, the new condition required a reassessment of the engineering analysis presented at the Flight Readiness Review two weeks prior. A teleconference began at 8:45 p.m. Eastern Standard Time (EST) that included 34 people in three locations: Morton-Thiokol in Utah, Marshall, and Kennedy. Thiokol engineers were recommending a launch delay. A reconsideration of a Flight Readiness Review risk assessment the night before a launch was as unprecedented as the predicted cold temperatures. With no ground rules or procedures to guide their discussion, the participants automatically reverted to the centralized, hierarchical, tightly structured, and procedure-bound model used in Flight Readiness Reviews. The entire discussion and decision to launch began and ended with this group of 34 engineers. The phone conference linking them together concluded at 11:15 p.m. EST after a decision to accept the risk and fly.

For *Columbia*, information about the foam debris hit was widely distributed the day after launch. Time allowed for videos of the strike, initial assessments of the size and speed of the foam, and the approximate location of the impact to be dispersed throughout the agency. This was the first debris impact of this magnitude. Engineers at the Marshall, Johnson, Kennedy, and Langley centers showed initiative and jumped on the problem without direction from above. Working groups and e-mail groups formed spontaneously. The size of Johnson's Debris Assessment Team alone neared and in some instances exceeded the total number of participants in the 1986 *Challenger* teleconference. Rather than a tightly constructed exchange of information completed in a few hours, time allowed for the development of ideas and free-wheeling discussion among the engineering ranks. The early post-launch discussion among engineers and all later decision-making at management levels were decentralized, loosely organized, and with little form. While the spontaneous and decentralized exchanging of information was evidence that NASA's original technical culture was alive and well, the diffuse form and lack of structure in the rest of the proceedings would have several negative consequences.

In both situations, all new information was weighed and interpreted against past experience. Formal categories and cultural beliefs provide a consistent frame of reference in which people view and interpret information and experiences.[36] Pre-existing definitions of risk shaped the actions taken and not taken. Worried engineers in 1986 and again in 2003 found it impossible to reverse the Flight Readiness Review risk assessments that foam and O-rings did not pose safety-of-flight concerns. These engineers could not prove that foam strikes and cold temperatures were unsafe, even though the previous analyses that declared them safe had been incomplete and were based on insufficient data and testing. Engineers' failed attempts were not just a matter of psychological frames and interpretations. The obstacles these engineers faced were political and organizational. They were rooted in NASA history and the decisions of leaders that had altered NASA culture, structure, and the structure of the safety system and affected the social context of decision-making for both accidents. In the following comparison of these critical decision scenarios for *Columbia* and *Challenger*, the systemic problems in the NASA organization are in italics, with the system effects on decision-making following.

NASA had conflicting goals of cost, schedule, and safety. Safety lost out as the mandates of an "operational system" increased the schedule pressure. Scarce resources went to problems that were defined as more serious, rather than to foam strikes or O-ring erosion.

In both situations, upper-level managers and engineering teams working the O-ring and foam strike problems held opposing definitions of risk. This was demonstrated immediately, as engineers reacted with urgency to the immediate safety implications: Thiokol engineers scrambled to put together an engineering assessment for the teleconference, Langley Research Center engineers initiated simulations of landings that were run after hours at Ames Research Center, and Boeing analysts worked through the weekend on the debris impact analysis. But key managers were responding to additional demands of cost and schedule, which competed with their safety concerns. NASA's conflicting goals put engineers at a disadvantage before these new situations even arose. In neither case did they have good data as a basis for decision-making. Because both problems had been previously normalized, resources sufficient for testing or hardware were not dedicated. The Space Shuttle Program had not produced good data on the correlation between cold temperature and O-ring resilience or good data on the potential effect of bipod ramp foam debris hits.[37]

Cultural beliefs about the low risk O-rings and foam debris posed, backed by years of Flight Readiness Review decisions and successful missions, provided a frame of reference against which the engineering analyses were judged. When confronted with the engineering risk assessments, top Shuttle Program managers held to the previous Flight Readiness Review assessments. In the *Challenger* teleconference, where engineers were recommending that NASA delay the launch, the Marshall Solid Rocket Booster Project manager, Lawrence Mulloy, repeatedly challenged the contractor's risk assessment and restated Thiokol's engineering rationale for previous flights.[38] STS-107 Mission Management Team Chair Linda Ham made many statements in meetings reiterating her understanding that foam was a maintenance problem and a turnaround issue, not a safety-of-flight issue.

The effects of working as a manager in a culture with a cost/efficiency/safety conflict showed in managerial responses. In both cases, managers' techniques focused on the information that tended to support the expected or desired result at that time. In both cases, believing the safety of the mission was not at risk, managers drew conclusions that minimized the risk of delay.[39] At one point, Marshall's Mulloy, believing in the previous Flight Readiness Review assessments, unconvinced by the engineering analysis, and concerned about the schedule implications of the 53-degree temperature limit on launch the engineers proposed, said, "My God, Thiokol, when do you want me to launch, next April?"[40] Reflecting the overall goal of keeping to the Node 2 launch schedule, Ham's priority was to avoid the delay of STS–114, the next mission after STS-107. Ham was slated as Manager of Launch Integration for STS-114 – a dual role promoting a conflict of interest and a single-point failure, a situation that should be avoided in all organizational as well as technical systems.

NASA's culture of bureaucratic accountability emphasized chain of command, procedure, following the rules, and going by the book. While rules and procedures were essential for coordination, they had an unintended but negative effect. Allegiance to hierarchy and procedure had replaced deference to NASA engineers' technical expertise.

In both cases, engineers initially presented concerns as well as possible solutions – a request for images, a recommendation to place temperature constraints on launch. Management did not listen to what their engineers were telling them. Instead, rules and procedures took priority. For *Columbia*, program managers turned off the Kennedy engineers' initial request for Department of Defense imagery, with apologies to Defense Department representatives for not having followed "proper channels." In addition, NASA administrators asked for and promised corrective action to prevent such a violation of protocol from recurring. Debris Assessment Team analysts at Johnson were asked by managers to demonstrate a "mandatory need" for their imagery request, but were not told how to do that. Both *Challenger* and *Columbia* engineering teams were held to the usual quantitative standard of proof. But it was a reverse of the usual circumstance: instead of having to prove it was safe to fly, they were asked to prove that it was unsafe to fly.

In the *Challenger* teleconference, a key engineering chart presented a qualitative argument about the relationship between cold temperatures and O-ring erosion that engineers were asked to prove. Thiokol's Roger Boisjoly said, "I had no data to quantify it. But I did say I knew it was away from goodness in the current data base."[41] Similarly, the Debris Assessment Team was asked to prove that the foam hit was a threat to flight safety, a determination that only the imagery they were requesting could help them make. Ignored by management was the qualitative data that the engineering teams did have: both instances were outside the experience base. In stark contrast to the requirement that engineers adhere to protocol and hierarchy was management's failure to apply this criterion to their own activities. The Mission Management Team did not meet on a regular schedule during the mission, proceeded in a loose format that allowed informal influence and status differences to shape their decisions, and allowed unchallenged opinions and assumptions to prevail, all the while holding the engineers who were making risk assessments to higher standards. In highly uncertain circumstances, when lives were immediately at risk, management failed to defer to its engineers and failed to recognize that different data standards – qualitative, subjective, and intuitive – and different processes – democratic rather than protocol and chain of command – were more appropriate.

The organizational structure and hierarchy blocked effective communication of technical problems. Signals were overlooked, people were silenced, and useful information and dissenting views on technical issues did not surface at higher levels. What was *communicated to parts of the organization was that O-ring erosion and foam debris were not problems.*

Structure and hierarchy represent power and status. For both *Challenger* and *Columbia*, employees' positions in the organization determined the weight given to their information, by their own judgment and in the eyes of others. As a result, many signals of danger were missed. Relevant information that could have altered the course of events was available but was not presented.

Early in the *Challenger* teleconference, some engineers who had important information did not speak up. They did not define themselves as qualified because of their position: they were not in an appropriate specialization, had not recently worked the O-ring problem, or did not have access to the "good data" that they assumed others more involved in key discussions would have.[42] Geographic locations also resulted in missing signals. At one point, in light of Marshall's objections, Thiokol managers in Utah requested an "off-line caucus" to discuss their data. No consensus was reached, so a "management risk decision" was made. Managers voted and engineers did not. Thiokol managers came back on line, saying they had reversed their earlier NO-GO recommendation, decided to accept risk, and would send new engineering charts to back their reversal. When a Marshall administrator asked, "Does anyone have anything to add to this?," no one spoke. Engineers at Thiokol who still objected to the decision later testified that they were intimidated by management authority, were accustomed to turning their analysis over to managers and letting them decide, and did not have the quantitative data that would empower them to object further.[43]

In the more decentralized decision process prior to *Columbia*'s re-entry, structure and hierarchy again were responsible for an absence of signals. The initial request for imagery came from the "low status" Kennedy Space Center, bypassed the Mission Management Team, and went directly to the Department of Defense separate from the all-powerful Shuttle Program. By using the Engineering Directorate avenue to request imagery, the Debris Assessment Team was working at the margins of the hierarchy. But some signals were missing even when engineers traversed the appropriate channels. The Mission Management Team Chair's position in the hierarchy governed what information she would or would not receive. Information was lost as it traveled up the hierarchy. A demoralized Debris Assessment Team did not include a slide about the need for better imagery in their presentation to the Mission Evaluation Room. Their presentation included the Crater analysis, which they reported as incomplete and uncertain. However, the Mission Evaluation Room manager perceived the Boeing analysis as rigorous and quantitative. The choice of headings, arrangement of information, and size of bullets on the key chart served to highlight what management already believed. The uncertainties and assumptions that signaled danger dropped out of the information chain when the Mission Evaluation Room manager condensed the Debris Assessment Team's formal presentation to an informal verbal brief at the Mission Management Team meeting.

As what the Board calls an "informal chain of command" began to shape STS-107's outcome, location in the structure empowered some to speak and silenced others. For example, a Thermal Protection System tile expert, who was a member of the Debris Assessment Team but had an office in the more prestigious Shuttle Program, used his personal network to shape the Mission Management Team view and snuff out dissent. The informal hierarchy among and within Centers was also influential. Early identifications of problems by Marshall and Kennedy may have contributed to the Johnson-based Mission Management Team's indifference to concerns about the foam strike. The engineers and managers circulating e-mails at Langley were peripheral to the Shuttle Program, not structurally connected to the proceedings, and therefore of lower status. When asked in a post-accident press conference why they didn't voice their concerns to Shuttle Program management, the Langley engineers said that people "need to stick to their expertise."[44] Status mattered. In its absence, numbers were the great equalizer. One striking exception: the Debris Assessment Team tile expert was so influential that his word was taken as gospel, though he lacked the requisite expertise, data, or analysis to evaluate damage to RCC. For those with lesser standing, the requirement for data was stringent and inhibiting, which resulted in information that warned of danger not being passed up the chain. As in the teleconference, Debris Assessment Team engineers did not speak up when the Mission Management Team Chair asked if anyone else had anything to say. Not only did they not have the numbers, they also were intimidated by the Mission Management Team Chair's position in the hierarchy and the conclusions she had already made. Debris Assessment Team members signed off on the Crater analysis, even though they had trouble understanding it. They still wanted images of *Columbia*'s left wing.

In neither impending crisis did management recognize how structure and hierarchy can silence employees and follow through by polling participants, soliciting dissenting opinions, or bringing in outsiders who might have a different perspective or useful information. In perhaps the ultimate example of engineering concerns not making their way upstream, *Challenger* astronauts were told that the cold temperature was not a problem, and *Columbia* astronauts were told that the foam strike was not a problem.

NASA structure changed as roles and responsibilities were transferred to contractors, which increased the dependence on the private sector for safety functions and risk assessment while simultaneously reducing the in-house capability to spot safety issues.

A critical turning point in both decisions hung on the discussion of contractor risk assessments. Although both Thiokol and Boeing engineering assessments were replete with uncertainties, NASA ultimately accepted each. Thiokol's initial recommendation against the launch of *Challenger* was at first criticized by Marshall as flawed and unacceptable. Thiokol was recommending an unheard-of delay on the eve of a launch, with schedule ramifications and NASA-contractor relationship repercussions. In the Thiokol off-line caucus, a senior vice president who seldom participated in these engineering discussions championed the Marshall engineering rationale for flight. When he told the managers present to "Take off your engineering hat and put on your management hat," they reversed the position their own engineers had taken.[45] Marshall engineers then accepted this assessment, deferring to the expertise of the contractor. NASA was dependent on Thiokol for the risk assessment, but the decision process was affected by the contractor's dependence on NASA. Not willing to be responsible for a delay, and swayed by the strength of Marshall's argument, the contractor did not act in the best interests of safety. Boeing's Crater analysis was performed in the context of the Debris Assessment Team, which was a collaborative effort that included Johnson, United Space Alliance, and Boeing. In this case, the decision process was also affected by NASA's dependence on the contractor. Unfamiliar with Crater, NASA engineers and managers had to rely on Boeing for interpretation and analysis, and did not have the training necessary to evaluate the results. They accepted Boeing engineers' use of Crater to model a debris impact 400 times outside validated limits.

NASA's safety system lacked the resources, independence, personnel, and authority to successfully apply alternate perspectives to developing problems. Overlapping roles and responsibilities across multiple safety offices also undermined the possibility of a reliable system of checks and balances.

NASA's "Silent Safety System" did nothing to alter the decision-making that immediately preceded both accidents. No safety representatives were present during the *Challenger* teleconference – no one even thought to call them.[46] In the case of *Columbia*, safety representatives were present at Mission Evaluation Room, Mission Management Team, and Debris Assessment Team meetings. However, rather than critically question or actively participate in the analysis, the safety representatives simply listened and concurred.

8.6 CHANGING NASA'S ORGANIZATIONAL SYSTEM

The echoes of *Challenger* in *Columbia* identified in this chapter have serious implications. These repeating patterns mean that flawed practices embedded in NASA's organizational system continued for 20 years and made substantial contributions to both accidents. The Columbia Accident Investigation Board noted the same problems as the Rogers Commission. An organization system failure calls for corrective measures that address all relevant levels of the organization, but the Board's investigation shows that for all its cutting-edge technologies, "diving-catch" rescues, and imaginative plans for the technology and the future of space exploration, NASA has shown very little understanding of the inner workings of its own organization.

NASA managers believed that the agency had a strong safety culture, but the Board found that the agency had the same conflicting goals that it did before *Challenger*, when schedule concerns, production pressure, cost-cutting and a drive for ever-greater efficiency – all the signs of an "operational" enterprise – had eroded NASA's ability to assure mission safety. The belief in a safety culture has even less credibility in light of repeated cuts of safety personnel and budgets – also conditions that existed before *Challenger*. NASA managers stated confidently that everyone was encouraged to speak up about safety issues and that the agency was responsive to those concerns, but the Board found evidence to the contrary in the responses to the Debris Assessment Team's request for imagery, to the initiation of the imagery request from Kennedy Space Center, and to the "we were just 'what-iffing'" e-mail concerns that did not reach the Mission Management Team. NASA's bureaucratic structure kept important information from reaching engineers and managers alike. The same NASA whose engineers showed initiative and a solid working knowledge of how to get things done fast had a managerial culture with an allegiance to bureaucracy and cost-efficiency that squelched the engineers' efforts. When it came to managers' own actions, however, a different set of rules prevailed. The Board found that Mission Management Team decision-making operated outside the rules even as it held its engineers to a stifling protocol. Management was not able to recognize that in unprecedented conditions, when lives are on the line, flexibility and democratic process should take priority over bureaucratic response.[47]

During the *Columbia* investigation, the Board consistently searched for causal principles that would explain both the technical and organizational system failures. These principles were needed to explain *Columbia* and its echoes of *Challenger*. They were also necessary to provide guidance for NASA. The Board's analysis of organizational causes in Chapters 5, 6, and 7 supports the following principles that should govern the changes in the agency's organizational system. The Board's specific recommendations, based on these principles, are presented in Part Three.

Leaders create culture. It is their responsibility to change it. Top administrators must take responsibility for risk, failure, and safety by remaining alert to the effects their decisions have on the system. Leaders are responsible for establishing the conditions that lead to their subordinates' successes or failures. The past decisions of national leaders – the White House, Congress, and NASA Headquarters – set the *Columbia* accident in motion by creating resource and schedule strains that compromised the principles of a high-risk technology organization. The measure of NASA's success became how much costs were reduced and how efficiently the schedule was met. But the Space Shuttle is not now, nor has it ever been, an operational vehicle. We cannot explore space on a fixed-cost basis. Nevertheless, due to International Space Station needs and scientific experiments that require particular timing and orbits, the Space Shuttle Program seems likely to continue to be schedule-driven. National leadership needs to recognize that NASA must fly only when it is ready. As the White House, Congress, and NASA Headquarters plan the future of human space flight, the goals and the resources required to achieve them safely must be aligned.

Changes in organizational structure should be made only with careful consideration of their effect on the system and their possible unintended consequences. Changes that make the organization more complex may create new ways that it can fail.[48] When changes are put in place, the risk of error initially increases, as old ways of doing things compete with new. Institutional memory is lost as personnel and records are moved and replaced. Changing the structure of organizations is complicated by external political and budgetary constraints, the inability of leaders to conceive of the full ramifications of their actions, the vested interests of insiders, and the failure to learn from the past.[49]

Nonetheless, changes must be made. The Shuttle Program's structure is a source of problems, not just because of the way it impedes the flow of information, but because it has had effects on the culture that contradict safety goals. NASA's blind spot is it believes it has a strong safety culture. Program history shows that the loss of a truly independent, robust capability to protect the system's fundamental requirements and specifications inevitably compromised those requirements, and therefore increased risk. The Shuttle Program's structure created power distributions that need new structuring, rules, and management training to restore deference to technical experts, empower engineers to get resources they need, and allow safety concerns to be freely aired.

Strategies must increase the clarity, strength, and presence of signals that challenge assumptions about risk. Twice in NASA history, the agency embarked on a slippery slope that resulted in catastrophe. Each decision, taken by itself, seemed correct, routine, and indeed, insignificant and unremarkable. Yet in retrospect, the cumulative effect was stunning. In both pre-accident periods, events unfolded over a long time and in small increments rather than in sudden and dramatic occurrences. NASA's challenge is to design systems that maximize the clarity of signals, amplify weak signals so they can be tracked, and account for missing signals. For both accidents there were moments when management definitions of risk might have been reversed were it not for the many missing signals – an absence of trend analysis, imagery data not obtained, concerns not voiced, information overlooked or dropped from briefings. A safety team must have equal and independent representation so that managers are not again lulled into complacency by shifting definitions of risk. It is obvious but worth acknowledging that people who are marginal and powerless in organizations may have useful information or opinions that they don't express. Even when these people are encouraged to speak, they find it intimidating to contradict a leader's strategy or a group consensus. Extra effort must be made to contribute all relevant information to discussions of risk. These strategies are important for all safety aspects, but especially necessary for ill-structured problems like O-rings and foam debris. Because ill-structured problems are less visible and therefore invite the normalization of deviance, they may be the most risky of all.

Challenger launches on the ill-fated STS-33/51-L mission on January 28, 1986. The Orbiter would be destroyed 73 seconds later.

ENDNOTES FOR CHAPTER 8

The citations that contain a reference to "CAIB document" with CAB or CTF followed by seven to eleven digits, such as CAB001-0010, refer to a document in the Columbia Accident Investigation Board database maintained by the Department of Justice and archived at the National Archives.

1 Turner studied 85 different accidents and disasters, noting a common pattern: each had a long incubation period in which hazards and warning signs prior to the accident were either ignored or misinterpreted. He called these "failures of foresight." Barry Turner, *Man-made Disasters*, (London: Wykeham, 1978); Barry Turner and Nick Pidgeon, *Man-made Disasters*, 2nd ed. (Oxford: Butterworth Heinneman,1997).

2 Changing personnel is a typical response after an organization has some kind of harmful outcome. It has great symbolic value. A change in personnel points to individuals as the cause and removing them gives the false impression that the problems have been solved, leaving unresolved organizational system problems. See Scott Sagan, *The Limits of Safety*. Princeton: Princeton University Press, 1993.

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

4 William H. Starbuck and Frances J. Milliken, "Challenger: Fine-tuning the Odds until Something Breaks." Journal of Management Studies 23 (1988), pp. 319-40.

5 *Report of the Presidential Commission on the Space Shuttle Challenger Accident*, (Washington: Government Printing Office, 1986), Vol. II, Appendix H.

6 Alex Roland, "The Shuttle: Triumph or Turkey?" *Discover*, November 1985: pp. 29-49.

7 *Report of the Presidential Commission*, Vol. I, Ch. 6.

8 Turner, *Man-made Disasters*.

9 Vaughan, *The Challenger Launch Decision*, pp. 243-49, 253-57, 262-64, 350-52, 356-72.

10 Turner, *Man-made Disasters*.

11 U.S. Congress, House, *Investigation of the Challenger Accident*, (Washington: Government Printing Office, 1986), pp. 149.

12 *Report of the Presidential Commission*, Vol. I, p. 148; Vol. IV, p. 1446.

13 Vaughan, *The Challenger Launch Decision*, p. 235.

14 *Report of the Presidential Commission*, Vol. I, pp. 1-3.

15 Howard E. McCurdy, "The Decay of NASA's Technical Culture," *Space Policy* (November 1989), pp. 301-10.

16 *Report of the Presidential Commission*, Vol. I, pp. 164-177.

17 *Report of the Presidential Commission*, Vol. I, Ch. VII and VIII.

18 *Report of the Presidential Commission*, Vol. I, pp. 140.

19 For background on culture in general and engineering culture in particular, see Peter Whalley and Stephen R. Barley, "Technical Work in the Division of Labor: Stalking the Wily Anomaly," in Stephen R. Barley and Julian Orr (eds.) *Between Craft and Science*, (Ithaca: Cornell University Press, 1997) pp. 23-53; Gideon Kunda, *Engineering Culture: Control and Commitment in a High-Tech Corporation*, (Philadelphia: Temple University Press, 1992); Peter Meiksins and James M. Watson, "Professional Autonomy and Organizational Constraint: The Case of Engineers," *Sociological Quarterly* 30 (1989), pp. 561-85; Henry Petroski, *To Engineer is Human: The Role of Failure in Successful Design* (New York: St. Martin's, 1985); Edgar Schein. *Organization Culture and Leadership*, (San Francisco: Jossey-Bass, 1985); John Van Maanen and Stephen R. Barley, "Cultural Organization," in Peter J. Frost, Larry F. Moore, Meryl Ries Louise, Craig C. Lundberg, and Joanne Martin (eds.) *Organization Culture*, (Beverly Hills: Sage, 1985).

20 *Report of the Presidential Commission*, Vol. I, pp. 82-111.

21 Harry McDonald, Report of the Shuttle Independent Assessment Team.

22 *Report of the Presidential Commission*, Vol. I, pp. 145-148.

23 Vaughan, *The Challenger Launch Decision*, pp. 257-264.

24 U. S. Congress, House, *Investigation of the Challenger Accident*, (Washington: Government Printing Office, 1986), pp. 70-71.

25 *Report of the Presidential Commission*, Vol. I, Ch.VII.

26 Mary Douglas, *How Institutions Think* (London: Routledge and Kegan Paul, 1987); Michael Burawoy, *Manufacturing Consent* (Chicago: University of Chicago Press, 1979).

27 *Report of the Presidential Commission*, Vol. I, pp. 171-173.

28 *Report of the Presidential Commission*, Vol. I, pp. 173-174.

29 National Aeronautics and Space Administration, Aerospace Safety Advisory Panel, "National Aeronautics and Space Administration Annual Report: Covering Calendar Year 1984," (Washington: Government Printing Office, 1985).

30 Harry McDonald, Report of the Shuttle Independent Assessment Team.

31 Richard J. Feynman, "Personal Observations on Reliability of the Shuttle," *Report of the Presidential Commission,* Appendix F:1.

32 Howard E. McCurdy, "The Decay of NASA's Technical Culture," *Space Policy* (November 1989), pp. 301-10; See also Howard E. McCurdy, *Inside NASA* (Baltimore: Johns Hopkins University Press, 1993).

33 Diane Vaughan, "The Trickle-Down Effect: Policy Decisions, Risky Work, and the Challenger Tragedy," *California Management Review*, 39, 2, Winter 1997.

34 Morton subsequently sold its propulsion division of Alcoa, and the company is now known as ATK Thiokol Propulsion.

35 *Report of the Presidential Commission*, pp. 82-118.

36 For discussions of how frames and cultural beliefs shape perceptions, see, e.g., Lee Clarke, "The Disqualification Heuristic: When Do Organizations Misperceive Risk?" in *Social Problems and Public Policy*, vol. 5, ed. R. Ted Youn and William F. Freudenberg, (Greenwich, CT: JAI, 1993); William Starbuck and Frances Milliken, "Executive Perceptual Filters – What They Notice and How They Make Sense," in *The Executive Effect*, Donald C. Hambrick, ed. (Greenwich, CT: JAI Press, 1988); Daniel Kahneman, Paul Slovic, and Amos Tversky, eds. *Judgment Under Uncertainty: Heuristics and Biases* (Cambridge: Cambridge University Press, 1982); Carol A. Heimer, "Social Structure, Psychology, and the Estimation of Risk." *Annual Review of Sociology 14 (1988): 491-519; Stephen J. Pfohl, Predicting Dangerousness* (Lexington, MA: Lexington Books, 1978).

37 *Report of the Presidential Commission,* Vol. IV: 791; Vaughan, *The Challenger Launch Decision,* p. 178.

38 *Report of the Presidential Commission*, Vol. I, pp. 91-92; Vol. IV, p. 612.

39 *Report of the Presidential Commission*, Vol. I, pp. 164-177; Chapter 6, this Report.

40 *Report of the Presidential Commission*, Vol. I, p. 90.

41 *Report of the Presidential Commission*, Vol. IV, pp. 791. For details of teleconference and engineering analysis, see Roger M. Boisjoly, "Ethical Decisions: Morton Thiokol and the Space Shuttle Challenger Disaster," *American Society of Mechanical Engineers*, (Boston: 1987), pp. 1-13.

42 Vaughan, *The Challenger Launch Decision,* pp. 358-361.

43 *Report of the Presidential Commission*, Vol. I, pp. 88-89, 93.

44 Edward Wong, "E-Mail Writer Says He was Hypothesizing, Not Predicting Disaster," *New York Times*, 11 March 2003, Sec. A-20, Col. 1 (excerpts from press conference, Col. 3).

45 *Report of the Presidential Commission*, Vol. I, pp. 92-95.

46 *Report of the Presidential Commission*, Vol. I, p. 152.

47 Weick argues that in a risky situation, people need to learn how to "drop their tools:" learn to recognize when they are in unprecedented situations in which following the rules can be disastrous. See Karl E. Weick, "The Collapse of Sensemaking in Organizations: The Mann Gulch Disaster." *Administrative Science Quarterly* 38, 1993, pp. 628-652.

48 Lee Clarke, *Mission Improbable: Using Fantasy Documents to Tame Disaster*, (Chicago: University of Chicago Press, 1999); Charles Perrow, *Normal Accidents*, op. cit.; Scott Sagan, *The Limits of Safety*, op. cit.; Diane Vaughan, "The Dark Side of Organizations," *Annual Review of Sociology*, Vol. 25, 1999, pp. 271-305.

49 Typically, after a public failure, the responsible organization makes safety the priority. They sink resources into discovering what went wrong and lessons learned are on everyone's minds. A boost in resources goes to safety to build on those lessons in order to prevent another failure. But concentrating on rebuilding, repair, and safety takes energy and resources from other goals. As the crisis ebbs and normal functioning returns, institutional memory grows short. The tendency is then to backslide, as external pressures force a return to operating goals. William R. Freudenberg, "Nothing Recedes Like Success? Risk Analysis and the Organizational Amplification of Risks," *Risk: Issues in Health and Safety* 3, 1: 1992, pp. 1-35; Richard H. Hall, *Organizations: Structures, Processes, and Outcomes,* (Prentice-Hall. 1998), pp. 184-204; James G. March, Lee S. Sproull, and Michal Tamuz, "Learning from Samples of One or Fewer," *Organization Science*, 2, 1: February 1991, pp. 1-13.