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SYSTEM EFFECTS: ON SLIPPERY SLOPES, REPEATING NEGATIVE PATTERNS, AND LEARNING FROM MISTAKE?

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> *Accident: nonessential quality or circumstance; 1. an event or circumstance occurring by chance or arising from unknown or remote causes; lack of intention or necessity; an unforeseen or unplanned event or condition; 2. sudden event or change occurring without intent or volition through carelessness, unawareness, ignorance, or a combination of causes and producing an unfortunate result; 3. an adventitious characteristic that is either inseparable from the individual and the species or separable from the individual but not the species;* broadly, *any fortuitous or nonessential property, fact or circumstance (~ of appearance) (~ of reputation) (~ of situation).*
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> ***Webster's Third New International Dictionary***

Accidents, we might conclude from this definition, do not arise from the innate, essential, intrinsic, or real nature of things. They occur from chance alone, having an unpredictable quality, proceeding from an unrecognized principle, from an uncommon operation of a known principle, or from a deviation from normal. The resulting picture is of an event for which there is no forewarning and which therefore is not preventable. However, a comparison of NASA's two space shuttle accidents contradicts these general understandings. Unforeseen, yes, unfortunately, but the origins of both were patterned and systemic, not random or chance occurrences, thus both might have been prevented.

In a press conference a few days after the *Columbia* tragedy, NASA's space shuttle program manager Ron Dittemore held up a large piece of foam approximately the size of the one that fatally struck *Columbia* and discounted it as a probable cause of the accident, saying "We were comfortable with it." Prior to the *Challenger* accident in 1986, that phrase might have been said about O-ring erosion by the person then occupying Dittemore's position. The O-ring erosion that caused the loss of *Challenger* and the foam debris problem that took *Columbia* out of the sky both had a long history.

Both accidents involved longitudinal processes in which NASA made a gradual slide into disaster. The history of decisions about the risk of O-ring erosion that led to *Challenger* and the foam debris that resulted in *Columbia* was littered with early warning signs that were either misinterpreted or ignored. For years preceding both accidents, technical experts defined risk away by repeatedly normalizing technical anomalies that deviated from expected performance. The significance of a long incubation period is that it provides greater opportunity to intervene and to turn things around, avoiding the harmful outcome. But that did not happen. How – and why – was this possible?

Within weeks after beginning the official investigation, the *Columbia* Accident Investigation Board began noting additional strong parallels between *Columbia* and *Challenger*. Comparing their investigative data on the organizational causes of *Columbia* with those of *Challenger* (Vaughan 1996, 1997), the CAIB systematically looked for similarities and differences, but found few differences.[1] The CAIB concluded that NASA's second accident resulted from an organizational system failure, pointing out that the systemic causes of *Challenger* had not been fixed. Both "accidents" arose from the innate, essential, intrinsic, and real nature of NASA's organizational system: a complex constellation of interacting factors that included NASA's political/economic environment, organization structure, and layered cultures that affected how people making technical decisions defined and redefined risk.

In *System Effects* (1997), Jervis analyzes the unintended consequences of purposive social action. Although Jervis, a political scientist, focuses on the system of international relations and interaction between nation-states, he builds a generalizable argument by identifying the principles of system dynamics that decouple intentions from outcomes. Because these principles apply to a variety of social actors, they have far-ranging and comprehensive implications for organizational analysis. Jervis seeks to explain how social systems work, and why so often they produce unintended consequences. He acknowledges the importance of emergent properties, but gives major attention to dense interconnections: units, and how relations with others are strongly influenced by interactions in other places and at earlier periods of time. Consequently, disturbing a system produces chains of consequences that extend over time and have multiple effects that cannot be anticipated. His analysis incorporates the extensive interdisciplinary literature on systems theory and the important work of Perrow (1984). However, Jervis's work is distinguished from its predecessors in several ways: (1) these are systems of human interaction, so how actors interpret the system and strategize is significant; (2) structure is strongly influential, but not fully determinant: agency and contingency also are important; and (3) time, history, and the trajectory of actions and interactions matter.

These principles characterized NASA's organizational system, explaining the origins of these two accidents. Specifically, the CAIB found the causes of both were located in the dynamic connection between the following three layers of NASA's organizational system (CAIB, 2003: ch. 8):

- *Interaction, decisions, and the normalization of deviance.* As managers and engineers made each decision, continuing to launch under the circumstances they had made sense to them. The immediate context of decision-making was an important factor. Although NASA treated the shuttle as if it were an operational vehicle, it was experimental: alterations of design and unpredictable flight conditions led to anomalies on many parts on every mission. Because having anomalies was normal, neither O-ring erosion nor foam debris were the signals of danger they seemed in retrospect, after the accidents. Also, the pattern of information had an impact on how they defined and redefined risk. Prospectively, as the anomalies were occurring, engineers saw signals of danger that were mixed: an anomalous incident would be followed by a mission with either less or no damage, convincing them that they had fixed the problem and understood the parameters of cause and effect; or signals were weak: incidents that were outside what had become defined as the acceptable parameters were not alarming because their circumstances were so unprecedented that they were viewed as unlikely to repeat; and finally, signals became routine, occurring so frequently that the repeating pattern became a sign that the machine was operating as predicted. The result was the production of a cultural belief that the problems were not a threat to flight safety – a belief repeatedly reinforced by the safe return of each mission. Flying with these flaws became normal and acceptable, not deviant, as it appeared to outsiders after the accidents.

- *NASA's institutional environment and the culture of production.* Historic political and budgetary decisions made in NASA's external environment had system effects, changing the organization culture. NASA's original pure technical culture was converted into a culture of production that merged bureaucratic, technical, and cost/schedule/efficiency mandates. This culture of production reinforced the decisions to proceed. Meeting deadlines and schedule was important to NASA's scientific launch imperatives and also for securing annual Congressional funding. Flight was always halted to permanently correct other problems that were a clear threat to take the space shuttle out of the sky (a cracked fuel duct to the main engine, for example), but the schedule and resources could not give way for a thorough hazard analysis of ambiguous, low-lying problems that the vehicle seemed to be tolerating. Indeed, the successes of the program led to a belief that NASA's shuttle was an operational, not an experimental, system, thus affirming that it was safe to fly. Further, the fact that managers and engineers obeyed the cultural insistence on allegiance to hierarchy, rules, and protocol reinforced that belief because NASA personnel were convinced that, having followed all the rules, they had done everything possible to assure mission safety.
- *Structural secrecy.* Both problems had gone on for years. Why had no one responsible for safety oversight acted to halt NASA's two transitions into disaster? Individual secrecy – the classic explanation of individuals trying to keep bad news from top management – does not work here. Everyone at the agency knew about the two problems and their histories; the question was, how did they define the risk? Structural secrecy, not individual secrecy, explained the failure of Administrators and safety regulators to intervene. By structural secrecy, I mean the way that organization structure and information dependence obscured problem seriousness from people responsible for oversight. NASA's four-tiered Flight Readiness

> Review, a formal, adversarial, open-to-all structure designed to vet all engineering risk assessments prior to launch, did not call a halt to flying with these anomalies because top Administrators and other participating technical specialists were dependent upon project groups for engineering information and analysis. Each time project managers and engineers assessed risk, finding anomalies safe to fly, their evidence and conclusions were passed up the hierarchy, forming the basis for further assessments. Instead of reversing the pattern of flying with erosion and foam debris, Flight Readiness Review ratified it.
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> Structural secrecy also interfered with the ability of safety regulators to halt NASA's gradual slide by obscuring problem seriousness. NASA's internal safety organization was dependent upon the parent organization for authority and funding, so (1) safety suffered personnel cuts and deskilling as more oversight responsibility was shifted to contractors in an economy move, and (2) it had no ability to independently run tests that might challenge existing assessments. NASA's external safety panel had the advantage of independence, but was handicapped by inspection at infrequent intervals. Unless NASA engineers defined something as a serious problem, it was not brought to the attention of safety personnel. As a result of structural secrecy, the cultural belief that it was safe to fly with O-ring erosion and foam debris prevailed throughout the agency in the years prior to each of NASA's tragedies.

These three factors combined in system effects that produced both *Challenger* and *Columbia*: a decision-making pattern normalizing technical anomalies, creating a cultural belief that it was safe to fly; a culture of production that encouraged continuing to launch rather than delay while a thorough hazard analysis was conducted; and structural secrecy, which prevented intervention to halt NASA's incremental descent into poor judgment. The amazing similarity between the organizational causes of these accidents, 17 years apart, raises two questions: Why do negative patterns persist? Why do organizations fail to learn from mistakes and accidents? In this chapter, I examine NASA's experience to gain some new insight into these questions. My data for this analysis are my experience as a researcher and writer on the staff of the *Columbia* Accident Investigation Board, conversations and meetings with NASA personnel at headquarters, a NASA "Forty Top Leaders Conference" soon after the CAIB report release, and a content analysis of the two official accident investigation reports (Presidential Commission, 1986; CAIB, 2003). Whatever NASA might have learned from these accidents, these reports identify the official lessons to be learned.

I first review the conclusions of the Presidential Commission investigating the *Challenger* accident (1986) and its recommendations for change, the changes NASA made, and why those changes failed to prevent the identical mistake from recurring in *Columbia*. Next, I contrast the Commission's findings with those of the CAIB report, discuss the CAIB's recommendations for changing NASA, the direction NASA is taking in making changes, and the challenges the space agency faces in preventing yet a third accident. The thesis of this chapter is that strategies to reduce the probability of mistakes and accidents need to address the relevant social conditions located in the organizational system. Thus, the lessons for managers and Administrators from NASA's two accidents are, first, that in order to reduce the potential for gradual slides and repeating negative patterns, organizations must go beyond the easy focus on individual failure to identify and correct the social causes located in organizational systems. Second, designing and implementing solutions that are matched to the social causes is a crucial but challenging enterprise that calls for social science input and expertise.

THE PRESIDENTIAL COMMISSION: CONNECTING CAUSES AND STRATEGIES FOR CONTROL

The Commission's report followed the traditional accident investigation format of prioritizing the technical causes of the accident and identifying human factors as "contributing causes," meaning that they were of lesser, not equal, importance. NASA's organizational system was not attributed causal significance. Nonetheless, the report went well beyond the usual human factors focus on individual incompetence, poor training, negligence, mistake, and physical or mental impairment to identify some relevant social causes. Below I consider the fit between the Commission's findings (causes) and its recommendations (strategies for control), NASA's changes, and their effectiveness.

Chapters 5 and 6 examined decisions about the O-ring problems, adhering to the traditional human factors/individual failure model. A "flawed decision-making process" was cited as the primary causal agent. Managerial failures dominated the findings: managers in charge had a tendency to solve problems internally, not forwarding them to all hierarchical levels; inadequate testing was done; neither the contractor nor NASA understood why the O-ring anomalies were happening; escalated risk-taking was endemic, apparently "because they got away with it the last time" (1986: 148); managers and engineers failed to carefully analyze flight history, so data were not available on the eve of *Challenger*'s launch to properly evaluate the risks; the anomaly tracking system permitted flight to continue despite erosion, with no record of waivers or launch constraints, and paid attention to only anomalies "outside the data base."

Chapter 7, "The Silent Safety Program," initially addressed safety problems in the traditional accident investigation frame: lack of problem reporting requirements; inadequate trend analysis; misrepresentation of criticality; lack of safety personnel involvement in critical discussions (1986: 152). Acknowledging that top administrators were unaware of the seriousness of the O-ring problems, the Commission labeled the problem a "communication failure," implicating individual managers and deflecting attention from organization structure as a cause. However, the Commission made a break with the human factors approach by addressing the organization of the safety structure. The Commission found that in-house safety programs were dependent upon the parent organization for funding, personnel, and authority. This dependence showed when NASA reduced the safety workforce, even as the flight rate increased. In another economy move, NASA had increased reliance upon contractors for safety, relegating many NASA technical experts to desk-job oversight of contractor activities. At the same time that this strategy increased NASA dependence on contractors, it undermined in-house technical expertise.

In chapter 8, "Pressures on the System," the Commission made another break with accident investigation tradition by examining schedule pressure at NASA. However, this pressure, according to the report, was NASA-initiated, with no reference to external demands or restrictions on the agency that might have contributed to it. The fault again rested with individuals, this time NASA's own leaders. "NASA began a planned acceleration of the space shuttle launch schedule . . . In establishing the schedule, NASA had not provided adequate resources for its attainment" (1986: 164). The report stated that NASA declared the shuttle "operational" after the fourth experimental flight even though the agency was not prepared to meet the demands of an operational schedule. NASA leaders' belief in operational capability, according to the Commission, was reinforced by the space shuttle history of 24 launches without a failure prior to *Challenger* and to NASA's legendary "can-do" attitude, in which the space agency always rose to the challenge, draining resources away from safety-essential functions to do it (1986: 171–7).

The Commission's recommendations for change were consistent with the causes identified in their findings (1986: 198–201). To correct NASA's "flawed decision making," the report called for changes in individual behavior and procedures. It mandated NASA to eliminate the tendency of managers not to report upward, "whether by changes of personnel, organization, indoctrination or all three" (1986: 200); develop rules regarding launch constraints; record Flight Readiness Reviews and Mission Management Team meetings. Astronauts were to be brought in to management to instill a keen awareness of risk and safety. The Commission mandated a review of shuttle management structure because project managers felt more accountable to their center administration than to the shuttle program director: thus vital information was not getting forwarded to headquarters.

Requiring structural change to improve a problematic safety structure, the Commission called for centralizing safety oversight. A new Shuttle Safety Panel would report to the shuttle program manager. Also, an independent Office of Safety, Reliability and Quality Assurance (SR&QA) would be established, headed by an associate NASA Administrator, with independent funding and direct authority over all safety bodies throughout the agency. It would report to the NASA Administrator, rather than program management, thus keeping safety separate structurally from the part of NASA responsible for budget and efficiency in operations. Finally, to deal with schedule pressures, the Commission recommended that NASA establish a flight rate that was consistent with its resources and recognize in its policies that the space shuttle would always be experimental, not operational.

How did the space agency respond? NASA strategies for change adhered to the targets pointed out by the Commission. Consistent with the individual emphasis of human factors analysis, NASA managers responsible for flawed decisions were either transferred or took early retirement. NASA also addressed the flawed decision-making by following traditional human factors paths of changing policies, procedures, and processes that would increase the probability that anomalies would be recognized early and problems corrected. But NASA went further, using the opportunity to make change to "scrub the system totally." The agency re-baselined the Failure Modes Effects Analysis. All problems tracked by the Critical Items List were reviewed, engineering fixes implemented when possible, and the list reduced. NASA established data systems and trend analysis, recording all anomalies so that problems could be tracked over time. Rules were changed for Flight Readiness Review so that engineers, formerly included only in the lower-level reviews, could participate in the entire process. Astronauts were extensively incorporated into management, including participation in the final pre-launch Flight Readiness Review and signing the authorization for the final mission "go."

At the organizational level, NASA made several structural changes, centralizing control of operations and safety (CAIB, 2003: 101). NASA shifted control for the space shuttle program from Johnson Space Center in Houston to NASA headquarters in an attempt to replicate the management structure at the time of *Apollo*, thus striving to restore communication to a former level of excellence. NASA also initiated the recommended Headquarters Office of Safety, Reliability and Quality Assurance (renamed Safety and Mission Assurance) but instead of the direct authority over all safety operations, as the Commission recommended, each of the centers had its own safety organization, reporting to the center director (CAIB, 2003: 101). Finally, NASA repeatedly acknowledged in press conferences that the space shuttle was and always would be treated as an experimental, not operational, vehicle and vowed that henceforth safety would take priority over schedule in launch decisions. NASA began a concerted effort to bring resources and goals into alignment.

Each of these changes targeted the causes identified in the report, so why did the negative pattern repeat, producing *Columbia*? First, from our post-*Columbia* position of hindsight we can see that the Commission did not identify all layers of NASA's organizational system as targets for change. The culture of production and the powerful actors in NASA's institutional environment whose actions precipitated "Pressures on the System" by their policy and budgetary decisions do not become part of the contributing cause scenario. NASA is obliged to bring resources and goals into alignment, although resources are determined externally. NASA took the blame for safety cuts (Presidential Commission report, 1986: 160), while the external budgetary actions that forced NASA leaders to impose such efficiencies were not mentioned. Further, the Commission did not name organization culture as a culprit, although production pressure is the subject of an entire chapter. Also, NASA's historic "can-do" attitude (a cultural attribute) is not made part of the recommendations. Thus, NASA was not sensitized to possible flaws in the culture or that action needed to be taken to correct them. In keeping with the human factors approach, the report ultimately places responsibility for "communication failures" not with organization structure, but with the individual middle managers responsible for key decisions and inadequate rules and procedures. The obstacles to communication caused by hierarchy and the consequent power that managers wielded over engineers, stifling their input in crucial decisions, are not mentioned.

Second, the CAIB found that many of NASA's initial changes were implemented as the Commission directed, but the changes to the safety structure were not. NASA's new SR&QA did not have direct authority, as the Commission mandated; further, the various center safety offices in its domain remained dependent because their funds came from the very activities that they were overseeing (CAIB, 2003: 101, 178–9). Thus, cost, schedule, and safety all remained the domain of a single office. Third, the CAIB found that other changes – positive changes – were undone over time. Most often, the explanation of deteriorated conditions after a mishap or negative outcome is institutionalized laxity and forgetting: the initial burst of attention to problems wanes as the routine and stress of daily work draw people's work efforts in new directions, and old habits, routines, and structures reassert themselves. It is not possible to know to what extent that was true of NASA. However, subsequent events stemming from political and budgetary decisions made by the White House and Congress also undermined changes made by NASA.

Although NASA's own leaders played a role in determining goals and how to achieve them, the institutional environment was not in their control. NASA remained essentially powerless as a government agency dependent upon political winds and budgetary decisions made elsewhere. Thus, NASA had little recourse but to try to achieve its ambitious goals – necessary politically to keep the agency a national budgetary priority – with limited resources. The new, externally imposed goal of the International Space Station (ISS) forced the agency to mind the schedule and perpetuated an operational mode. As a consequence, the culture of production was unchanged; the organization structure became more complex. This structural complexity created poor systems integration; communication paths again were not clear.

Also, the initial surge in post-*Challenger* funding was followed by budget cuts, such that the new NASA Administrator, Daniel Goldin, introduced new efficiencies and smaller programs with the slogan, "faster, better, cheaper," a statement later proved to have strong cultural effects. As a result of the budgetary squeeze, the initial increase in NASA safety personnel was followed by a repeat of pre-accident economy moves that again cut safety staff and placed even more responsibility for safety with contractors. The accumulation of successful missions (defined as flights returned without accident) also reinvigorated the cultural belief in an operational system, thus legitimating these cuts: fewer resources needed to be dedicated to safety. The subsequent loss of people and transfer of safety responsibilities to contractors resulted in a deterioration of post-*Challenger* improvements in trend analyses and other NASA safety oversight processes.

Fourth, NASA took the report's mandate to make changes as an opportunity to make other changes the agency deemed worthwhile, so the number of changes actually made is impossible to know and assess. The extent to which additional changes might have become part of the problem rather than contributing to the solution is also unknown. Be aware, however, that we are assessing these changes from the position of post-*Columbia* hindsight, which focuses attention on all the negatives associated with the harmful outcome (Starbuck, 1988). The positive effects, the mistakes avoided, by post-*Challenger* changes, tend to be lost in the wake of *Columbia*. However, we do know that increasing system complexity increases the probability of mistake, and some changes did produce unanticipated consequences. One example was NASA's inability to monitor reductions in personnel during a relocation of Boeing, a major contractor, which turned out to negatively affect the technical analysis Boeing prepared for NASA decision-making about the foam problem (CAIB, 2003: ch. 7).

Finally, NASA believed that the very fact that *many changes had been made* had so changed the agency that it was completely different than the NASA that produced the *Challenger* accident. Prior to the CAIB report release, despite the harsh revelations about organizational flaws echoing *Challenger* that the CAIB investigation frequently released to the press, many at NASA believed no parallels existed between *Columbia* and *Challenger* (NASA personnel, conversations with author; Cabbage and Harwood, 2004: 203).

THE CAIB: CONNECTING CAUSES WITH STRATEGIES FOR CONTROL

The CAIB report presented an “expanded causal model” that was a complete break with accident investigation tradition. The report fully embraced an organizational systems approach and was replete with social science concepts. In the “Executive Summary,” the report articulated both a “technical cause statement” and an “organizational cause statement.” On the latter the board stated that it “places as much weight on these causal factors as on the more easily understood and corrected physical cause of the accident” (CAIB, 2003: 9). With the exception of the “informal chain of command” operating “outside the organization’s rules,” this organizational cause statement applied equally to *Challenger*:

> The organizational causes of this accident are rooted in the space shuttle program’s history and culture, including the original compromises that were required to gain approval for the shuttle, subsequent years of resource constraints, fluctuating priorities, schedule pressures, mischaracterization of the shuttle as operational rather than developmental, and lack of an agreed national vision for human space flight. Cultural traits and organizational practices detrimental to safety were allowed to develop, including reliance on past success as a substitute for sound engineering practices (such as testing to understand why systems were not performing in accordance with requirements); organizational barriers that prevented effective communication of critical safety information and stifled professional differences of opinion; lack of integrated management across program elements; and the evolution of an informal chain of command and decision-making processes that operated outside the organization’s rules.
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> ***(CAIB, 2003: 9)***

In contrast to the Commission’s report, the CAIB report was a social analysis that explained how the layers of NASA’s organizational system combined to cause this second accident. Chapter 5, “From *Columbia* to *Challenger*,” analyzed NASA’s institutional environment. Tracking post-*Challenger* decisions by leaders in NASA’s political and budgetary environment, it showed their effect on NASA’s organization culture: the persistence of NASA’s legendary can-do attitude, excessive allegiance to bureaucratic proceduralism and hierarchy due to increased contracting out, and the squeeze produced by “an agency trying to do too much with too little” (CAIB, 2003: 101–20) as funding dropped so that downsizing and sticking to the schedule became the means to all ends. The political environment continued to produce pressures for the shuttle to operate like an operational system, and NASA accommodated. Chapter 6, "Decision Making at NASA," chronicled the history of decision-making on the foam problem. Instead of managerial failures, it showed how patterns of information – the weak, mixed, and routine signals behind the normalization of deviance prior to *Challenger* – obscured the seriousness of foam debris problems, thus precipitating NASA's second gradual slide into disaster. In contrast to the Commission, the CAIB presented evidence that schedule pressure directly impacted management decision-making about the *Columbia* foam debris hit. Also, it showed how NASA's bureaucratic culture, hierarchical structure, and power differences created missing signals, so that engineers' concerns were silenced in *Columbia* foam strike deliberations.

Chapter 7, "The Accident's Organizational Causes," examined how the organizational culture and structure impacted the engineering decisions traced in chapter 6. A focal point was the "broken safety culture," resulting from a weakened safety structure that created structural secrecy, causing decision-makers to "miss the signals the foam was sending" (2003: 164). Organization structure, not communication failure, was responsible for problems with conveying and interpreting information. Like the Presidential Commission, the CAIB found that systems integration and strong independent NASA safety systems were absent. This absence combined with the hierarchical, protocol-oriented management culture that failed to decentralize and to defer to engineering expertise after the *Columbia* foam hit. Chapter 8, "History as Cause: *Columbia* and *Challenger*," compared the two accidents, showing the system effects. By showing the identically patterned causes resulting in the two negative slides, it established the second accident as an organizational system failure, making obvious the causal links between the culture of production (chapter 5), the normalization of deviance (chapter 6), and structural secrecy (chapter 7). It demonstrated that the causes of *Challenger* had not been fixed. By bringing forward the thesis of "History as Cause," it showed how both the history of decision-making by political elites and the history of decision-making by NASA engineers and managers had twice combined to produce a gradual slide into disaster.

Now consider the fit between the board's causal findings and its recommendations for change. Empirically, the CAIB found many of the same problems as did the Commission, and in fact recognized that in the report (2003: 100): schedule pressure, dependent and understaffed safety agents, communication problems stemming from hierarchy, power differences, and structural arrangements, poor systems integration and a weakened safety system, overburdened problem-reporting mechanisms that muted signals of potential danger, a can-do attitude that translated into an unfounded belief in the safety system, a success-based belief in an operational system, and bureaucratic rule-following that took precedence over deference to the expertise of engineers. However, the CAIB data interpretation and causal analysis differed. Thus, the CAIB targeted for change each of the three layers of NASA's organizational system and the relationship between them. First, at the interaction level, decision-making patterns that normalize deviance would be altered by "strategies that increase the clarity, strength, and presence of signals that challenge assumptions about risk," which include empowering engineers, changing managerial practices, and strengthening the safety system (2003: 203).

Second, organization structure and culture were both pinpointed. The broken safety culture was to be fixed by changing the safety structure. The Commission dealt with structural secrecy by structural change that increased the possibility that signals of danger would be recognized and corrected, not normalized. The CAIB mandated an "Independent Technical Engineering Authority" with complete authority over technical issues, its independence guaranteed by funding directly from NASA headquarters, with no responsibility for schedule or program cost (2003: 193). Second, NASA's headquarters office of Safety and Mission Assurance (formerly SR&QA) would have direct authority and be independently resourced. To assure that problems on one part of the shuttle (e.g., the foam debris from the external tank) took into account ramifications for other parts (e.g., foam hitting the orbiter wing), the Space Shuttle Integration Office would be reorganized to include the orbiter, previously not included. Also, other recommended strategies were designed to deal with power differences between managers and engineers. For example, the CAIB advocated training the Mission Management Team, which did not operate in a decentralized mode or innovate, instead adhering to an ill-advised protocol in dealing with the foam strike. As Weick (1993) found with forest firefighters in a crisis, the failure "to drop their tools," which they were trained to always carry, resulted in death for most. The CAIB recommendation was to train NASA managers to respond innovatively rather than bureaucratically and to decentralize by interacting across levels of hierarchy and organizational boundaries (2003: 172).

Third, to deal with NASA's institutional environment and the culture of production, the CAIB distributed accountability at higher levels:

> The White House and Congress must recognize the role of their decisions in this accident and take responsibility for safety in the future . . . Leaders create culture. It is their responsibility to change it . . . 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.
> ***(2003: 196, 203)***

CHANGING NASA

The report made it imperative that NASA respond to many recommendations prior to the Return to Flight Evaluation in 2005.[2] Although at this writing change is still under way at NASA, it is appropriate to examine the direction NASA is taking and the obstacles the agency is encountering as it goes about implementing change at each level of the agency's organizational system.

Interaction, decision-making, and the normalization of deviance

Because the space shuttle is and always will be an experimental vehicle, technical problems will proliferate. In such a setting, categorizing risk will always be difficult, especially with low-lying, ambiguous problems like foam debris and O-ring erosion, where the threat to flight safety is not readily apparent and mission success constitutes definitive evidence. In order to make early warning signs about low-lying problems that, by definition, will be seen against a backdrop of numerous and more serious problems, more salient, NASA created a new NASA Engineering and Safety Center (NESC) as a safety resource for engineering decisions throughout the agency. NESC will review recurring anomalies that engineering had determined do not affect flight safety to see if those decisions were correct (Morring, 2004a). Going back to the start of the shuttle program, NESC will create a common database, looking for early-warning signs that have been misinterpreted or ignored, reviewing problem dispositions and taking further investigative and corrective action when deemed necessary. However, as we have seen from *Columbia* and *Challenger*, what happens at the level of everyday interaction, interpretation, and decision-making does not occur in a vacuum, but in an organizational system in which other factors affect problem definition, corrective actions, and problem dispositions. A second consideration is clout: how will NESC reverse long-standing institutionalized definitions of risk of specific problems, and how will it deal with the continuing pressures of the culture of production?

NASA's institutional environment and the culture of production

NASA remains a politically vulnerable agency, dependent on the White House and Congress for its share of the budget and approval of its goals. After *Columbia*, the Bush administration supported the continuation of the space shuttle program and supplied the mission vision that the CAIB report concluded was missing: the space program would return to exploration of Mars. However, the initial funds to make the changes required for the shuttle to return to flight and simultaneously accomplish this new goal were insufficient (Morring, 2004b). Thus, NASA, following the CAIB mandate, attempted to align goals and resources by phasing out the Hubble telescope program and, eventually, planning to phase out the shuttle itself. Further, during the stand-down from launch while changes are implemented, the ISS is still operating and remains dependent upon the shuttle to ferry astronaut crews, materials, and experiments back and forth in space. Thus, both economic strain and schedule pressure still persist at NASA. How the conflict between NASA's goals and the constraints upon achieving them will unfold is still unknown, but one lesson from *Challenger* is that system effects tend to reproduce. The board mandated independence and resources for the safety system, but when goals, schedule, efficiency, and safety conflicted post-*Challenger*, NASA goals were reigned in, but the safety system also was compromised.

Structural secrecy

In the months preceding the report release, the board kept the public and NASA informed of some of the recommended changes so that NASA could get a head start on changes required for Return to Flight. With the press announcement that the CAIB would recommend a new safety center, NASA rushed ahead to begin designing a center, despite having no details about what it should entail. When the report was published, NASA discovered that the planned NASA Engineering and Safety Center it had designed and begun to implement was not the independent technical authority that the board recommended. Converting to the CAIB-recommended structure was controversial internally at NASA, in large part because the proposed structure (1) did not fit with insiders' ideas about how things should work and where accountability should lie, and (2) was difficult to integrate into existing operations and structures (cf. Sietzen and Cowing, 2004). NESC is in operation, as described above, but NASA is now working on a separate organization, the independent technical authority, as outlined by the CAIB.

Whereas CAIB recommendations for changing structure were specific, CAIB directions for changing culture were vague. The report's one clear instruction for making internal change was for correcting the broken safety culture by changing the structure of the safety system. The CAIB was clear about implicating NASA leaders, making them responsible for changing culture. But what was the role of NASA leaders in cultural change, and how should that change be achieved? The CAIB report left no clear guidelines. During my participation in meetings at NASA after report release, it was clear that NASA leaders did not understand how to go about changing culture. Trained in engineering and accustomed to human factors analysis, changing culture seemed "fuzzy." Further, many NASA personnel believed that the report's conclusion about agency-wide cultural failures wrongly indicted parts of NASA that were working well. Finally and more fundamentally, they had a problem translating the contents of the report to identify what cultural changes were necessary and what actions they implied.

So how to do it? NASA's approach was this. On December 16, 2003, NASA headquarters posted a Request For Proposals on its website for a cultural analysis followed by the elimination of cultural problems detrimental to safety. Verifying the CAIB's conclusions about NASA's deadline-oriented culture, proposals first were due January 6, then the deadline was extended by a meager ten days. Ironically, the CAIB mandate to achieve cultural change itself produced the very production pressure about which the report had complained. Designated as a three-year study, NASA required data on cultural change in six months (just in time for the then-scheduled date of the Return to Flight Evaluation), and a transformed culture in 36 months.

The bidders were corporate contractors with whom NASA frequently worked. The awardee, Behavioral Science Technology, Inc., conducted a "cultural analysis" survey to gather data on the extent and location of cultural problems in the agency. The ability of any survey to tap into cultural problems is questionable, because it relies solely on insiders, who can be blinded to certain aspects of their culture. A better assessment results when insider information is complemented by outside observers who become temporary members, spending sufficient time there to be able to identify cultural patterns, examine documents, participate in meetings and casual conversations, and interview, asking open-ended questions. A further problem is implied in the survey response rate of 40 percent, indicating that insider viewpoints tapped will not capture agency-wide cultural patterns. This work is still in progress as I write. In a status report (Behavioral Science Technology, 2004) BST's "Problem Statement" indicates they translated the CAIB report into a human factors approach, focusing on communication and decision-making, failing to grasp the full dimensions of the CAIB's social analysis. The "Problem Statement" reads:

> The Columbia Accident Investigation Board's view of organizational causes of the accident:
> 1 Barriers prevent effective communication of critical safety information and stifled professional differences of opinion.
> 2 Failure to recognize that decision-making was inappropriately influenced by past success.
> 3 Acceptance of decision-making processes that operated outside of the organization's rules.
>
> ***(2004: 7)***

These statements are correct, but omit the environmental and organizational conditions that produced them. Logically, the BST strategy for change was individually oriented, training managers to listen and decentralize and encouraging engineers to speak up. Thus, NASA's response is, to date, at the interaction level only, leaving other aspects of culture identified in the report – such as cultural beliefs about risk, goals, schedule pressures, structure, and power distribution – unaddressed.

CONCLUSION: LESSONS LEARNED

The dilemmas of slippery slopes, repeating negative patterns, and learning from mistakes are not uniquely NASA's. We have evidence that slippery slopes are frequent patterns in man-made disasters (Turner, 1978; Snook, 2000; Vaughan, 1996). We also know that slippery slopes with harmful outcomes occur in other kinds of organizations where producing and using risky technology is not the goal. Think of the incursion of drug use into professional athletics, US military abuse of prisoners in Iraq, and Enron – to name some sensational cases in which incrementalism, commitment, feedback, cultural persistence, and structural secrecy seem to have created an organizational "blind spot" that allowed actors to see their actions as acceptable and conforming, perpetuating a collective incremental descent into poor judgment. Knowing the conditions that cause organizations to make a gradual downward slide, whether the man-made disasters that result are technical, political, financial, public relations, moral, or other, does give us some insight into how it happens that may be helpful to managers and Administrators hoping to avoid these problems.

In contradiction to the apparent suddenness of their surprising and sometimes devastating public outcomes, mistakes can have a long incubation period. How do early-warning signs of a wrong direction become normalized? A first decision, once taken and met by either success or no obvious failure (which also can be a success!), sets a precedent upon which future decisions are based. The first decision may be defined as entirely within the logic of daily operations because it conforms with ongoing activities, cultural norms, and goals. Or, if initially viewed as deviant, the positive outcome may neutralize perceptions of risk and harm; thus what was originally defined as deviant becomes normal and acceptable as decisions that build upon the precedent accumulate. Patterns of information bury early-warning signs amidst subsequent indicators that all is well. As decisions and their positive result become public to others in the organization, those making decisions became committed to their chosen line of action, so reversing direction – even in the face of contradictory information – becomes more difficult (Salancik, 1977).

The accumulating actions assume a taken-for-granted quality, becoming cultural understandings, such that newcomers may take over from others without questioning the status quo; or, if objecting because they have fresh eyes that view the course of actions as deviant, they may acquiesce and participate upon learning the decision logic and that "this is the way we do it here." Cultural beliefs persist because people tend to make the problematic nonproblematic by defining a situation in a way that makes sense of it in cultural terms. NASA's gradual slides continued because (1) the decisions made conformed to the mandates of the dominating culture of production and (2) organization structure impeded the ability of those with regulatory responsibilities – top Administrators, safety representatives – to critically question and intervene.

Why do negative patterns repeat? Was it true, as the press concluded after *Columbia*, that the lessons of *Challenger* weren't learned? When we examined the lessons of *Challenger* identified in the findings and recommendations of the Commission's 1986 report, cause was located primarily in individual mistakes, misjudgments, flawed analysis, flawed decision-making, and communication failures. The findings about schedule pressures and safety structure were attributed also to flawed decision-making, not by middle managers but by NASA leaders. In response, the Commission recommended adjusting decision-making processes, creating structural change in safety systems, and bringing goals and resources into alignment. NASA acted on each of those recommendations; thus, we could say that the lessons were learned. The *Columbia* accident and the CAIB report that followed taught different lessons, however. They showed that an organizational system failure, not individual failure, was behind both accidents, causing the negative pattern to repeat. So, in retrospect, we must conclude that from *Challenger* NASA learned incomplete lessons. Thus, they did not connect their strategies for control with the full social causes of the first accident.

Events since *Columbia* teach an additional lesson: we see just how hard it is to learn and implement the lessons of an organization system failure, even when they are pointed out, as the CAIB report did. Further, there are practical problems. NASA leaders had difficulty integrating new structures with existing parts of the operation; cultural change and how to go about it eluded them. Some of the CAIB recommendations for change were puzzling to NASA personnel because they had seen their system working well under most circumstances. Further, understanding how social circumstances affect individual actions is not easy to grasp, especially in an American ethos in which both success and failure are seen as the result of individual action.[3] Finally, negative patterns can repeat because making change has system effects that can produce unintended consequences. Changing structure can increase complexity and therefore the probability of mistake; it can change culture in unpredictable ways (Jervis, 1997; Perrow, 1984; Sagan, 1993; Vaughan, 1999).

Even when the lessons are learned, negative patterns can still repeat. The process and mechanisms behind the normalization of deviance make incremental change hard to detect until it's too late. Change occurs gradually, the signs of a new and possibly harmful direction occurring one at a time, injected into daily routines that obfuscate the developing pattern. Moreover, external forces are often beyond a single organization's ability to control. Cultures of production, whether production of police statistics, war, profits, or timely shuttle launches, are a product of larger historical, cultural, political, ideological, and economic institutions. Making organizational change that contradicts them is difficult to implement, but in the face of continuing and consistent institutional forces even more difficult to sustain as time passes. Attributing repeating negative patterns to declining attention and forgetting of lessons learned as a crisis recedes into history neglects the sustaining power of these institutionalized external forces. The extent to which an organization can resist these conditions is likely to vary as its status and power vary. Although, compared to some, NASA seems a powerful government agency, its share of the federal budget is small compared to other agencies. In the aftermath of both accidents, political and budgetary decisions of elites that altered goals and resources made it difficult to create and sustain a different NASA where negative patterns do not repeat. It may be argued that, under the circumstances, NASA's space shuttle program has had a remarkable safety record.

But even when everything possible is done, we cannot have mistake-free organizations because as Jervis (1997) argues and the NASA case verifies, system effects will produce unanticipated consequences. Further, all contingencies can never be predicted, most people don't understand how social context affects individual action, organizational changes that correct one problem may, in fact, have a dark side, creating unpredictable others, and external environments are difficult to control. Although all mishaps, mistakes, and accidents cannot be prevented, both of NASA's accidents had long incubation periods, thus they *were preventable*. By addressing the social causes of gradual slides and repeating negative patterns, organizations can *reduce the probability* that these kinds of harmful outcomes will occur. To do so, connecting strategies to correct organizational problems with their organization system causes is crucial. Social scientists can play a significant role.

First, we have research showing the problem of the slippery slope is perhaps more frequent than we now imagine (Miller, 1990; Turner, 1978), but less is known about cases where this pattern, once begun, is reversed (but see Kanter, 2004). Building a research base about organizations that make effective cultural change and reverse downward slides is an important step. Further, by their writing, analysis, and consulting, social scientists can:

1 Teach organizations about the social sources of their problems.
2 Advise on strategies that will address those social causes.
3 Prior to implementation of change, research the organizational system effects of planned changes, helping to forestall unintended consequences (see authors in this volume; see also, e.g., Clarke, 1999; Edmondson et al., 2005; Kanter, 1983, 2004; Roberts, 1990; Tucker and Edmondson, 2003; Weick et al., 1990).
4 Advise during the implementation of planned changes. As Pressman and Wildavsky (1984) observed, even the best plans can go awry without proper implementation.

Second, NASA's problem of the cultural blind spot shows that insiders are unable to identify the characteristics of their own workplace structure and culture that might be causing problems. This suggests that, rather than waiting until after a gradual slide into disaster or repeat of a negative pattern to expose the dark side of culture and structure, organizations would benefit from ongoing cultural analysis by ethnographically trained sociologists and anthropologists giving regular feedback, annually replaced by others to avoid seduction by the cultural ethos and assure fresh insights. Bear in mind this additional obstacle: the other facet of NASA's cultural blind spot was that the agency's success-based belief in its own goodness was so great that it developed a pattern of disregarding the advice of outside experts (CAIB, 2003: ch. 5). To the extent that the CAIB report's embrace of an organizational system approach becomes a model for other accident investigation reports, other organizations may become increasingly aware of the social origins of mistakes and of the need to stay in touch with how their own organizational system is working.

NOTES

1 Although the patterns were identical, two differences are noteworthy. First, for O-ring erosion, the first incident of erosion occurred on the second shuttle flight, which was the beginning of problem normalization; for foam debris, the normalization of the technical deviation began *even before the first shuttle was launched*. Damage to the thermal protection system – the thousands of tiles on the orbiter to guard against the heat of re-entry – was expected due to the forces at launch and during flight, such that replacement of damaged tiles was defined from the design stage as a maintenance problem that had to be budgeted. Thus, when foam debris damage was observed on the orbiter tiles after the first shuttle flight in 1981, it was defined as a maintenance problem, not a flight hazard. This early institutionalization of the foam problem as routine and normal perhaps explains a second difference. Before the *Challenger* disaster, engineering concerns about proceeding with more frequent and serious erosion were marked by a paper trail of memos. The foam debris problem history also had escalations in occurrence, but showed no such paper trail, no worried engineers. Other differences are discussed in Vaughan, 2003.

2 Prior to resuming shuttle launches, progress on these changes is being monitored and approved by a NASA-appointed board, the Covey–Stafford board, and also by the US Congress, House Committee on Science, which has official oversight responsibilities for the space agency.

3 After a presentation in which I translated the cultural change implications of the CAIB report to a group of Administrators at NASA headquarters, giving examples of how to go about it, two Administrators approached me. Drawing parallels between the personalities of a *Columbia* engineer and a *Challenger* engineer who both acted aggressively to avert an accident but, faced with management opposition, backed off, the Administrators wanted to know why replacing these individuals was not the solution.

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