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The Space Between in Space Transportation: A Relational Analysis of the Failure of STS 107[1]

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The loss of the space shuttle Columbia was the first time an American spaceship was destroyed as it returned to Earth. But there were previous close calls. In addition, Russia had two fatal accidents and a handful of near disasters returning its spacecraft to Earth (http://dsc.discovery.com/anthology/spotlight/shuttle/closecalls). The Columbia accident raises a number of vexing issues that are inherently technological, political, organizational, and social, and could probably have been raised with regard to other space exploration accidents and near misses. These issues are embedded in a situation of scarce resources, high political stakes, and complex relationships among NASA, the White House and Congress, and among the different NASA centers themselves.

If we can find a way to examine NASA in a politically and emotionally uncharged atmosphere we might better understand those things that need to be addressed in any organization operating in a highly uncertain and volatile environment. We suggest beginning with the overall notion of relationality in organizations and organizational systems and moving from there to a focus on how interactions at organizational interstices impact reliability. This approach offers a new lens to examining organizational processes that seem particularly applicable to NASA's situation, and

[1] STS stands for Space Transportation System

probably applicable to any organization seeking to become highly reliable or to maintain that status.

In this paper we discuss organizational problems and errors that occur when organizations fail to take cognizance of interfaces or "the space between." We then note the problem high reliability organizations (HROs) encounter because people concerned with them fail to heed the long incubation periods (with their interfaces) that contribute to disaster. We note that interface problems include both coordination neglect and the failure to insure independence of activities. We then focus on independence failure and its contribution to the Columbia accident. Finally, we recommend ameliorative steps NASA and other organizations can take.

Theory

The Space Between

Traditional research approaches in both the physical and social sciences focus on individual objects and entities, treating them as though they were largely independent of their surroundings. This perspective, especially important in western scholarship, allows for closely controlled experimentation and precise measurement. But over the past few decades scholars from many disciplines have noted that such scientific reductionism assumes away, ignores, or alters important features of the phenomena being studied (Miller, 1972; von Bertalanffy, 1968; Wolf, 1980). Alternatively ~~Alternative~~, relational and systems approaches to science emphasize that whatever is being studied must be treated as a nexus of relationships and influences rather than as an objective entity. From this perspective, understanding the relationships and interactions that exist among entities is as important to the study of a system as understanding the entities themselves.

Organizational theories incorporating this perspective include the networks perspective (), systems models (), social constructionism (), and action research (Schon, 1983). I used Rachel's version and she hadn't made these changes.

(Rachel's suggestion – below paragraph- Bradbury and Lichtenstein (2000) label the interdependence in relational research the "space between". This definition indicates the importance of relationships among the different entities under study as well as the relationship between the researcher and the subject of study.)

Bradbury and Lichtenstein (2000) label the phenomenon of interest in relational research the "space between," indicating the important of the relationships among the different entities under study as well as the relationship between the researcher and the subject of study. Bradbury and Lichtenstein (2000) note that the "space between" is a term borrowed from the theological philosopher, Martin Buber (1970). "Buber saw dialogue as a dialectical movement between human and nonhuman phenomena" (Bradbury and Lichtenstein, 2000, p. 551). "A relational orientation is based on the premise that whatever is being studied must be thought about as a configuration of relationships (Capra, 1996), not an independent 'objective' entity" (Bradbury and Lichtenstein, 2000, p. 552). This view is consistent with the structuration approach that describes organizations as produced through the interactions among people and existing social structures in which they work (e.g. Barley, 1986; Bourdieu, 1991; Giddens, 1984).

An examination of the Columbia Accident Investigation Board's final report (CAIB Report, 2003) discloses a number of relational issues. We suggest that taking a relational approach might help us identify both **(the)** points at which errors are likely to occur and **(the)** errors that occur at such points. We use the term "relational" broadly and note that organizations are relational to one another and their external constituencies, **(and that)** groups are relational to each other and to organizations and the people in them. Shift changes are relational, hand-offs are relational, people and groups are relational to organizational infrastructures, and so on. The issues ~~that~~ we discuss are quite general in that they may occur at several different levels in organizations—the interpersonal level, the subunit level, the inter-organizational level, or the population level.

Relationality and High Reliability

Roberts (1990) defines ~~high reliability organizations~~ HROs as those organizations that conduct relatively error-free operations over a long period of time, making consistently good decisions that result in high quality and reliable performance. Research on high reliability organizations began by taking the view that individual and group processes are at the heart of maintaining reliable operations (e.g. Roberts and Bea, 2001; Rochlin, LaPorte, and Roberts, 1987; Weick and Roberts, 1993). More recent research (e.g. Grabowski and Roberts, 1996 & 1999) suggests that understanding interactions across organizations and organizational components is also a key to developing a more complete picture of reliability enhancement.

This stream of HRO literature draws heavily on the disaster incubation model (DIM) put forward by the late Barry Turner (Turner, 1976a,b & 1978). DIM identifies six stages of disaster development: 1) starting point, 2) incubation period, 3) ~~precipitation~~ precipitating event, 4) onset, 5) rescue and salvage, and 6) full cultural readjustment. In an organizational context, the starting point represents the culturally accepted view of the hazards associated with the organization's functions and the related body of rules, laws, codes, and procedures designed to assure safe organizational navigation of these hazards. The starting point may occur at the founding of an organization or following a cultural readjustment in response to a significant event. Turner does not suggest that the culturally accepted beliefs associated with stage 1 are accurate in an objective sense but that they are functional enough to allow the organization to operate "normally" for some period of time.

An organizational disaster occurs because the accepted norms and beliefs of organizational members differ from the way the world really works. However, organizational participants continue to act as thought their original models are true. Inaccuracies in the organizational worldview may be present from the beginning (stage 1) or they may accumulate over time, or both. Inaccuracies in an organization's model of the world may build up over time if the organizational environment evolves over time but the organization does not update its models or because organizational members alter organizational models or routines.

Turner's second stage, the incubation period, represents a period of time during which minor failures persist or accumulate. The incubation period is characterized by a series of events that are at odds with existing organizational norms and beliefs but that go unnoticed or unheeded. These discrepant events represent opportunities for organizational members to recognize the inadequacy of their models and representation of the world. Vigilant organizations could take advantage of such discrepant events to bring their worldviews into closer alignment with reality. However, Turner observes that in organizations headed for disaster these events go completely unnoticed, are noticed ~~by~~

(but) misunderstood, or are noticed and understood but not adequately responded to (Turner, 1976b).

Turner's discrepant events are indicators of latent failures in an organizational system. Latent failures are decisions or actions that weaken an organization's defense system but **that?** happen some time before any recognizable accident sequence begins (Reason, 1997). Such latent failures lie dormant and unnoticed until they interact with a triggering event. Reason (1990) likens such latent failures 'resident pathogens' in the human body—diseases that are present but only manifest themselves when the body is weakened by external factors. One salient feature of the DIM is that latent failures made at high hierarchical levels in an organization are especially hazardous**(. This is)** because they are especially likely to increase the gap between the organization's representation of the world and reality.

Turner argues that the latent failures accumulated during the incubation period remain unnoticed until they interact with some ~~precipitation~~ precipitating event (stage 3). A precipitating event may be a minor error by a member of the organization, a set of unusual environmental conditions, or a technical problem. Precipitating events are conditions that normally would pose little danger to an organization, but when they interact in unexpected ways with latent failures, they can quickly disable organizational defenses. **(new Paragraph)** DIM's forth stage, onset, represents the initiation of the disaster and its immediate consequences, including the collapse of shared cultural understandings. The fifth stage, rescue and salvage, entails ad hoc alterations to organizational beliefs and models to allow organizational members to begin to respond to the disaster. The sixth and final stage, full cultural readjustment, includes detailed investigations of the disaster and its causes and subsequent alterations in organizational beliefs, rules, and procedures that take into account the organization's "new" reality.

The DIM holds many insights regarding disaster prevention and response. For our present purposes, DIM's most important observation is that **(causes of disasters develop)** disaster causes are develop over long periods of time and involve complex interactions among multiple latent failures. This point is similar to Perrow's (1984) argument that systems characterized by interactive complexity—systems composed of many components that have to **(the)** potential to interact in unexpected ways—are especially prone to system accidents. Disasters can only be understood from a relational perspective because they are fundamentally relational phenomena (Grabowski and Roberts, 1996). Latent failures in one part of an organization interact with latent failures in another area **(of the organization. Both failures)** ~~and both~~ interact with a precipitating event in ways that were never previously imagined. The relational perspective highlights two related but divergent organizational phenomena that weaken an organization's ability to stave off disaster: coordination neglect and dependence.

Coordination Neglect

Heath and Staudenmeyer (2000) **(define coordination neglect as the failure…)** ~~refer to the failure~~ to effectively integrate the varied and distributed tasks undertaken by different members of an organization ~~as coordination neglect~~. **(They argue that coordinating activates is important and that organizations …)** They talk about the importance of coordinating activities, and say that organizations put more time into partitioning activities and then focusing on activity components than they do to re-integrating activities. Partitioning is done to take advantage of specialization.

Specialization is also encouraged by reward systems that inappropriately emphasize individual performance.   After partitioning a task people focus on the components they've **(they have)** created. Component focus is often exacerbated because people focus on enhancing the quality of an individual component and fail to realize that even a high quality component will not function to keep an unintegrated system working. "In many examples of component focus, managers seem to focus on technology rather than on broader issues of organization" (Heath and Staudenmeyer, 200, p. 168).

According to Heath and Staudenmeyer, the most important means for integrating activities, particularly in complex and uncertain environments, is through communication. Two elements of communication are important in creating a failure to integrate. The first is inadequate communication **(which is)** ~~by which these authors mean~~ a failure for one or more partners to the communication to be able to take another's perspective. The other element is **(the)** failure to anticipate the need to translate across specialists. "Partitioning a task leads to Babelization, and if the Babbelings are not translated sufficiently integration fails" (Heath and Staudenmeyer, 200, p. 178).

Previous HRO research points to the danger of poor communication and coordination in organizations that deal with hazardous technologies (LaPorte and Consolini, 1991; Weick, 1990). Grabowski and Roberts (1997) argue, "In a large-scale system, communication can help make autonomy and interdependence among system members explicit and more understandable, providing opportunities for sense making in a geographically distributed system. More importantly, communication provides opportunities to discuss improvements in the system, including risk-mitigation strategies and approaches" (p. 156). Similarly, in their study of group to group collaboration in space mission design, Marks, Abrams, and Nassif (2003) note, "It is through the gaps where common meaning is lost or misconstrued, and conversely the connections where the potential exists for constructing and/or reconstructing meaning" (p.3). DO WE WANT ANY OF THIS? WE NEVER COME BACK TO THE COMMUNICATION ISSUE AGAIN.

NASA is certainly not free from concerns of coordination neglect (and its communication components – if we keep last two paragraphs). NASA's size, geographical distribution and cultural variation make effective communication and coordination difficult (McCurdy, 1993). One particularly glaring example of an accident caused in part by a failure of coordination is the September 23, 1999 loss of NASA's Mars Climate Orbiter spacecraft. NASA's investigation of the accident revealed that it ~~had come~~ came about at least in part because NASA engineers ~~had~~ used metric units in their calculations while Lockheed Martin engineers used English units (http://www.cnn.com/TECH/space/9909/30/mars.metric.02/).

Our reading of the CAIB Report disclosed a number of coordination neglect issues, some of which probably contributed to the demise of the Columbia. However, for the remainder of this chapter, we will focus on another relational issue—dependence—that has received considerably less attention ~~that~~ **(than)** coordination neglect in the literature, but probably played a much greater role in the Columbia disaster.

Dependence

In many instances organizations, groups, and individuals require a high level of independence to function effectively. For example, Bendor (1985) notes that inter-service rivalry following World War II led the U.S. Army, Navy, and Air Force to each independently develop strategic missiles. Although perhaps more expensive than a unified effort, the three independent missile programs each produced unique improvements in rocket technology that greatly improved American missile technology. It is unlikely that the technology would have improved so quickly had one, standard design been adopted from the outset.

Another common need for independence is found in organizations that use redundancy to improve safety and reliability. Engineers have long recognized that independent, redundant components can greatly increase the reliability of a mechanical system. For example, most satellites are equipped with at least two antennas to minimize the chance that an antenna malfunction will be incapacitating. Of course there are negative consequences of including redundant parts in a system, the principle one **(consequence)** being cost. However, reliability increases geometrically with the number of redundant parts while cost increases linearly (so for example, if satellite antennas were 80% reliable, a satellite with one antenna would have an 80% chance of communicating with earth, a two-antenna satellite would have a 96% chance, and a three-antenna satellite would have a 99% chance) . When reliability is important, redundant designs become cost-effective.

Redundancy can play a similar, reliability-enhancing effect on organizations and organizational systems. The HRO literature is filled with examples of how redundancy increases organizational reliability. La Porte and Consolini (1991) explain that the U.S. air traffic control system is enhanced by redundancy of personnel and communications technologies. Weick and Roberts (1993) argue that overlapping personnel responsibilities increase reliability on aircraft carriers because so many pairs of eyes are watching things that errors are unlikely to go unnoticed (also see Rochlin, La Porte, and Roberts, 1987). Finally, Roberts (1990) notes that redundancy in both technology and organization are necessary to maintain reliable power supplies in Pacific Gas and Electric's power distribution grid.

Similarly, political scientist and public policy scholars argue that inter-organizational redundancy improves reliability in administrational systems (Landau, 1969 & 1973; Bendor, 1985; Chisholm, 1989). This idea ~~has been~~ was further developed in the context of space shuttle Challenger disaster by Heimann (1993, 1997). Heimann argues that there are two main classes of administrative errors, type I errors and type II errors. An agency commits a type I error when it takes an action that should not have been taken (NASA's choice to launch Challenger). An agency commits a type II error when it fails to take an action that should have been taken (delaying a launch that had no real safety problems). Heimann goes on to argue that systems may incorporate redundancy in two ways: in series or in parallel. Figure 1 illustrates a system with serial redundancy.

[Figure 1 About Here]

In administrative systems with components in series the first component must approve a decision then pass it to the second component and so forth. If any one of the components fails to approve an action, the agency will not take the action. Thus, systems with serial redundancy are useful in the elimination of type I errors, but increase the occurrence of type II errors. A system with parallel redundancy, (see Figure 2), produces the opposite result.

[Figure 2 About Here]

In administrative systems with parallel components ~~in parallel,~~ only one of the components must successfully approve an action for the agency as a whole to take the action. This reduces the ~~changes~~ chances of the agency committing a type II error, but increases those of it committing a type I error. Heimann shows that an agency may decrease its chance of committing either type of error by adding additional components in series and in parallel. Finally, Heimann argues that due to increasing political pressure to reduce type II errors in the years preceding the Challenger disaster, NASA had shifted the structure of its reliability-and-quality-assurance (R&QA) functions such that R&QA units exhibited less serial and more parallel redundancy. This change increased the probability that NASA would experience a type I error which it did in the form of the Challenger accident.

The benefits of administrational redundancy, like those of any other form of redundancy, come with the caveat that redundant components must be independent. Engineering reliability theory explicitly assumes that redundant components in engineering systems are independent of one another. Systems engineers recognize that components are often not truly independent and refer to this situation as component dependence. But they typically assume independence **~~in any case (???)~~** to simplify calculations of system reliability and then make design decisions with the goal of decreasing component dependence.

~~There are~~ Two major classes of system failure ~~that~~ can occur when component dependence occurs: common cause failures and common mode failures. A common cause failure (CCF) is the failure of two or more components in a system due to the same event but where the failures are not consequences of each other. For example, if two components in a system that are both more likely to fail under humid conditions fail due ~~on~~ to a very humid day, this is a CCF. CCFs are especially likely in systems that use similar components redundantly to increase reliability because such components are affected similarly by environmental conditions. The second type of system failure that occurs due to component dependence is the common mode failure (CMF). A CMF is the failure of two or more components in a system where the failure of one component causes the other components to fail. It is this form of system failure that is of special concern in Perrow's work (1984). Perrow argues that when complex, unanticipated interactions among components may occur, redundant safety features can actually reduce the reliability of a system.

Organizational and administrational redundancy scholars adopt the assumption of component independence from the reliability engineering literature. Bendor (1985) suggests that the benefits of administrative redundancy hold even when some component dependence is present. This argument is true when only CCFs are considered, but does not apply to CMFs. For example, consider an administrational system with several identical components in series, each of which correctly rejects dangerous proposals 50% of the time (for simplicity, we will treat only the prevention of type I errors with serial redundancy here, but the principles are quite general and also apply to parallel redundancy). Assuming complete component independence, Figure 3 shows the probability that the system will act safely as a function of the number of components in it ~~the system~~.

[Figure 3 About Here]

Now **assume that the** in the same system there is a 10% chance of a CCF, a 10% chance that all of the system components will fail simultaneously from the same cause. Figure 4 illustrates this case.

[Figure 4 About Here]

Figure 4 shows that while the possibility of CCFs decreases the system reliability overall, it does not eliminate the advantages of redundancy. However, consider the same system under an assumption that 10% of component failures will lead to CMFs. In other words, one out of ten component failures will occur in such a way as to cause the other components in a system to fail as well. Figure 5 illustrates this situation.

[Figure 5 About Here]

Figure 5 shows that even with a small probability of CMF, increasing administrative redundancy can actually lead to more risky decisions. A system design that could appear to be reliability enhancing when a strict component view is taken, may actually be reliability reducing due to relationality. This insight is in concert with Turner's DIM model. Even in a system with multiple redundant safety units, a latent error (such as a poor decision) made by one unit can interact in unexpected ways with other latent errors and with a precipitating event to bring about catastrophe.

Dependence at NASA

The CAIB Report states that the direct physical cause of "the loss of Columbia and its crew was a breach in the Thermal Protection System on the Leading edge of the left wing. The breach was initiated by a piece of insulating foam that separated from the left bipod ramp of the External Tank and struck the wing" (p. 49). This was hardly the first instance of foam from the External Tank causing damage to the orbiter. Columbia was damaged by a foam strike on its first flight in 1981 and of the 79 shuttle flights for which photographic evidence is available the CAIB found evidence of foam shedding on 65. Furthermore, damage to the orbiters observed after shuttle flights suggest that foam shedding has occurred during every shuttle mission ever flown (CAIB Report, p. 122). The entire history of the shuttle program may thus be viewed as the "incubation period" for the Columbia disaster. Repeated discrepant events (foam strikes) occurred but did not garner enough attention to force NASA to change its worldview.

The CAIB Report shows that with the International Space Station assembly more than half complete, the Station and Shuttle programs had become irreversibly linked. Such dependence between the two programs served to reduce the value of STS-107's Flight Readiness Review because a delay in STS-107's launch would cause serious delays in the completion of the Space Station.[2] "Any problems with or perturbations to the planned schedule of one program reverberated through both programs" (CAIB Report, 2003, p.117). The Bush Administration's Fiscal Year 2002 budget declared that the U.S. part of the International Space Station (ISS) would be considered complete with the installation on the ISS of "Node 2", which would allow Europe and Japan to connect their laboratory modules to the station. Node 2 was to be launched on STS-120, scheduled to be launched on February 19, 2004, a date that appeared to be etched in stone (CAIB Report, 2003, p.131). Five shuttle launches to the Space Station were scheduled in the five months from October, 2003, through the launch of Node 2 in February, 2004. NASA clearly sent its employees the message that any technical problem that resulted in a slip to one launch would directly affect the Node 2 launch (CAIB Report, 2003, p. 136).

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[2] STS launches are not in numerical order.

In October, 2002, STS-112 flew and lost foam. The review board assigned an action to the loss but the due date for the action was left until after the next launch. The CAIB Report states “The pressing need to launch STS-113, to retrieve the International Space Station Expedition 5 crew… and to continue the countdown to Node 2 were surely in the back of the managers’ minds during these reviews” (2003, p. 138).

The STS-107 Mission Management Team Chair, Linda Ham, was present at the Program Requirements Control Board that discussed the foam loss from STS-112 and at the flight readiness review for STS-113. She was also Launch Integration Manager for the next mission, STS-14. After the foam loss from STS-107 most of Ham’s inquiries about the strike were not about what action to take for Columbia but to understand the implications for STS-114. The shuttle program concerns about the Columbia foam strike were not about the threat it might pose to STS-107, but about the threat it might pose to the schedule (CAIB Report, 2003, p.139).

Coordination in this case was too tightly linked and the dependence of the Space Station Program on the Shuttle Program had serious safety implication. People within the coordination stream (e.g., Ham) focused on components of their major interest, ignoring the effects that this focus could have on the other components.

As does every complex organization, NASA contracts out much of its work. In 1995 the Kraft Report noted that much inefficiency could be attributed to the diffuse and fragmented nature of the relationship between NASA and its contractors ~~our third example of the need for coordination.~~ WE LONG AGO ELIMINATED THE THREE EXAMPLE THING.The report recommended that NASA consolidate its activities in a single business unit. Historically NASA contracted redundancy into its systems as checks and balances by doing such things as employing two engineering teams at Kennedy Space Center. In November 1995, NASA awarded its operations contract to United Space Alliance on a sole source basis. Initially only a few contracts were transferred to United Space Alliance. Because other NASA centers successfully resisted transfer of their contracts the Space Flight Operations Contract's initial efficiencies were never realized.

The relationship between NASA and United Space Alliance is a prime example of component dependence. NASA handed over virtually all of the daily activities of shuttle maintenance and launch preparation to United Space Alliance, but maintained the role of oversight and verification. The United Space Alliance contract includes large performance-based bonuses based on on-time launches and work quality. This arrangement effectively eliminated much of the independence previously built into the shuttle launch preparation system. Because United Space Alliance pay is tied to NASA approval of work done, United Space Alliance employees have little incentive to bring up safety concerns not already raised by NASA. The value of the redundant safety and launch verification of space shuttles is significantly reduced by the incentives of the United Space Alliance contract. Furthermore, the independence of the Space Shuttle Program pre-launch safety assessment is itself brought into question because it is too closely tied to the Space Shuttle launch schedule. The CAIB Report states, "Because it lacks independent analytical rigor, the Pre-launch Assessment Review is only marginally effective…Therefore, the Board is concerned that the Pre-launch Assessment Review is not an effective check and balance in the Flight Readiness Review" (pg. 187). Such lack of independence reduces the effectiveness of redundant safety features while maintaining the illusion of safety.

Prior to the Columbia accident investigation, NASA's entire approach to safety was simultaneously filled with such tight coordination that independent and complementary safety approaches could not be realized. NASA's safety philosophy called for centralized policy formation at headquarters and oversight and decentralized execution at the enterprise, program, and project levels. For example:

> At Johnson, safety programs are centralized under a Director who oversees five divisions and an Independent Assessment Office… the Space Shuttle Division Chief is empowered to represent the Center, the Shuttle Program, and NASA Headquarters Safety and Mission Assurance at critical junctures in the safety process. This position therefore represents a critical node in NASA's Safety and Mission Assurance architecture that seems to the Board to be plagued with conflict of interest. It is a single point of failure without any checks and balances.
>
> Johnson also has a Shuttle Program Mission Assurance Manager who oversees United Space Alliance's safety organization…. Johnson's Space Shuttle Division Chief has the additional role of Shuttle Program Safety, Reliability and Quality Assurance Manager. Over the years this dual designation has resulted in a general acceptance of the fact that the Johnson Space Shuttle Division Chief performs duties on both the Center's and the Program's behalf. The detached nature of the support provided by the Space Shuttle Division Chief, and the wide band of the position's responsibilities throughout multiple layers of NASA's hierarchy, confuses lines of authority, responsibility, and accountability in a manner that almost defies explanation.
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> The fact that Headquarters, Center, and Program functions are rolled-up into one position is an example of how a carefully designed oversight process has been circumvented and made susceptible to conflict of interest (CAIB Report, 2003, p. 186).

It is clear when examined from a relational perspective, the necessary "spaces between" are non existent. A designed redundancy was effectively eliminated through lack of independence. **(The)** Coordination is too tight, it is the wrong kind of coordination, **(and the coordination is centered on one person.)**all in one person. In response to the Rogers Commission Report (Report of the Presidential Commission, 1986) of the space shuttle Challenger accident NASA established the Office of System Safety and Mission Assurance at Headquarters, but according to the CAIB that office is ill equipped to hold a strong and central role in integrating or coordinating safety functions.

> Given that the entire Safety and Mission Assurance organization depends on the Shuttle program for resources and simultaneously lacks the independent ability to conduct detailed analyses, cost and schedule pressures can easily and unintentionally influence safety deliberations. Structure and process places Shuttle safety programs in the unenviable position of having to choose between rubber-stamping engineering analyses, technical efforts, and Shuttle program decisions, or trying to carry the day during a committee meeting in which the other side almost always has more information and analytic capability (CAIB Report, 2003, p.187).

Although NASA and its contractors utilize several redundant safety and mission assurance organizations and groups, the Columbia disaster and CAIB investigation provide considerable evidence that dependence among these different safety components eliminates much of the benefit of redundancy.

The CAIB recommended that NASA "establish an independent Technical Engineering Authority responsible for technical requirements and all waivers to them, and build a disciplined systematic approach to identifying, analyzing and controlling hazards throughout the life cycle of the Shuttle System" (CAIB Report, 2003, p.226). The CAIB further recommended that this Authority be directly funded by NASA Headquarters. CAIB did not go further and recommend that the coordination and relationality issues between this Authority and the rest of NASA need to be carefully worked out and monitored. Given what we know about organizational cultural blinders that contribute to coordination problems we recommend that NASA or Congress ~~(i.e. one of the science committees)~~ JIM BAGIAN SAYS NEITHER COMMITTEE IS PREPARED TO DO THIS. establish a truly independent overseer for safety issues at NASA. How could true independence in such a safety organization be guaranteed? An examination of the Aerospace Corporation, a private, independent organization that provides launch verification and other services to the U.S. Air Force will shed light on this question.

The Aerospace Corporation

The Aerospace Corporation (Aerospace), a nonprofit corporation that operates as a federally funded research and development center (an FFRDC) for the U.S. Air Force. Aerospace was established in 1960 to ensure that the Air Force's Atlas missile was transformed into a reliable launch vehicle for use on NASA's first manned space program, the Mercury Program (Strom, 2001). The Air Force had previously adapted the Atlas missile for use as a launch vehicle, but prior to 1960 Atlas launch vehicles had failed on about a quarter of their attempted launches. NASA selected Atlas as the launch vehicle for Mercury nonetheless because it had enough thrust to get the Mercury capsule into orbit, but the 75% launch success rate was clearly too low for human space flight (Strom, 2001). Aerospace contributed to the design and testing of the Atlas vehicles and also developed a rigorous Flight Safety Review procedure (Tomei, 2003). The Mercury program was ultimately a great success and never experienced a significant accident during manned missions (Strom, 2001).

Aerospace has continued to provide many engineering, design, and safety services to the Air Force for more than 40 years. One of its chief functions is to perform launch verification and readiness assessments for all Air Force space launches. Aerospace's launch verification procedure is very broad, beginning with analysis of launch system design. Aerospace independently tests physical components and software, checks manufacturing process, and verifies correct assembly of the launch vehicle. Finally, Aerospace delivers a formal launch verification letter to the Air Force's Space and Missile Systems Center, monitors the launch, and analyses launch and post launch data (Tomei, 2003). All of the functions are redundant in the sense that Air Force and contractor personnel also perform most of the same functions. Aerospace's launch verification serves as an independent, objective assessment of launch safety that the Air Force uses in conjunction with its own analyses in ~~make~~ making launch decisions.

Aerospace's efforts have been very valuable to the Air Force and other U.S. government agencies. Aerospace CEO, E. C. Aldridge recently estimated that Aerospace saves the government $1-2 billion per year in cost savings from accident reduction (compared to Aerospace's annual budget of $365 million) (Aldridge, 1999). Due in part to Aerospace's efforts, the U.S. Air Force boasts a very low (2.9%) launch failure rate (Tomei, 2002 cited in the CAIB Report, p.184).

Aerospace enjoys a high degree of independence from the Air Force in performing its safety functions. It is an independent entity. While Aerospace depends on the Air Force for funding, it is organizationally distinct. ~~Furthermore, Aerospace's~~ Its budget is in no way tied to the Air Force's launch schedule. Furthermore, to the extent possible, Aerospace gathers its own data, makes its own measurements, and uses its own analysis techniques (Tomei, 2001). These activities make Aerospace informationally independent of the Air Force and its contractors. Finally, Aerospace's roughly 3000 employees are culturally independent of the Air Force. The vast majority of Aerospace employees were previously employed in the private sector aerospace industry where they had an average of 22 years of experience (Aldridge, 1999). This non-military background gives Aerospace employees a different perspective than that held by Air Force personnel, further enhancing the value of Aerospace as an independent component.

It is interesting to note that the Air Force experienced a string of three significant launch failures during the late 1990s. Aerospace CEO Aldridge testified before Congress that a partial explanation for these disasters was the reduced independence of Aerospace during that time period. He noted that Aerospace's budget had been reduced significantly since 1993 and that its workforce shrunk by roughly one third during the early 1990s (Aldridge, 1999). One of the principle results of this reduction in funding and staffing is that Aerospace now relies much more heavily on measurements and analyses provided by the Air Force and its contractors because Aerospace no longer has the capacity to gather data independently.

Here we have examples of the organizational juggling required to insure that appropriate attention is given coordination across "the space between" and independence within "the space between." Reliability here is represented by the subtle balance between the two. WE HAVEN'T PUT THESE TWO FEATURES TOGETHER WELL ENOUGH. NEED TO EXTEND ON THIS.

Recommendations for NASA

Before its funding cuts in the early 1990s, Aerospace displayed at least three different forms of independence from Air Force safety organizations. First, **(it displayed structural independence)** is structurally independent. Aerospace is a distinct entity, a non-profit organization operating a FFRDC rather than an arm of the Air Force. While it is true that Aerospace's funding is dependent on the Air Force (this dependence leading quite possibly to three recent accidents), it is structurally much more independent than any safety organization employed by NASA. Second, Aerospace is (or at least was) informationally independent. Aerospace tries not to rely on the same measurements, data, and analyses that are used by the Air Force. Independent information eliminates a serious cause of dependence among components and a serious potential for both CCFs and CMFs. Third, Aerospace is culturally independent. Aerospace employees have different backgrounds and experiences than most Air Force personnel (although similarity of experience between Aerospace and contractor employees could be a source of dependence). This means that Aerospace employees don't share all of the same norms, values, and models of those in the Air Force. Such independence of experience and culture allows Aerospace employees to question assumptions that Air Force personnel may take for granted.

The CAIB Report recommends NASA establish an independent technical authority (ITA) to consider issues of safety (p. 184).[3] The ITA will be responsible, at a minimum, for developing technical standards for all Space Shuttle Program projects, granting authority for all technical standards, conducting trend and risk analysis, conducting integrated hazard analysis, identifying anomalous events, and independently verifying launch readiness (p. 193). The ITA is to be funded directly from NASA Headquarters and should have no connection to or responsibility for schedule or program cost. The CAIB seems to suggest that the ~~TEA~~ ITA be organized as an independent body

[3] The name of the ITA suggests its close reliance on technical expertise even after the CAIB suggested many of NASA's problems were due to its lack of management expertise.

only under the authority of NASA headquarters. Such an arrangement could make the ITA relatively structurally independent, depending on how this plan is implemented. We would suggest that NASA make every effort to ensure that the ITA truly is independent of the other organizations involved in the Shuttle program. It may be politically impossible to establish the ITA completely outside of NASA's organizational structure (although we believe that Aerospace's status as an independent, non-profit organization has had significant benefits), but at the least the ITA should be given enough autonomy and power to withstand schedule pressures.

The ITA should be endowed with the authority and the responsibility to gather its own data, make its own analyses and run its own tests of hardware and software. Such informational independence will be costly as the ITA will be duplicating duplicates the efforts of others. But independent information will vastly reduce the dependence of ITA. Finally, the ITA should be staffed and administered by people with backgrounds that do not include NASA employment. Every organization develops its own norms, values and assumptions. This **(These)** norms and assumptions color the way organizational members view the world and make decisions. Employing people from private industry, the military, and possibly NASA centers not involved in the human spaceflight program will give ITA a degree of cultural independence. This recommendation is especially important at the highest levels of the ITA. Placing a career NASA administrator at the head of the ITA could effectively counteract the cultural independence that would be brought by lower-level employees coming from different backgrounds.

A relational perspective directs attention to the "spaces between" in NASA and across its relationships in the inter-organizational environment. This approach underscores the impact that connections and gaps across groups and entities can have in complex systems. A renewed focus on relational issues, and especially the issue of component dependence, will pay dividends to NASA and other organizations involved in space transportation and other high-risk areas.

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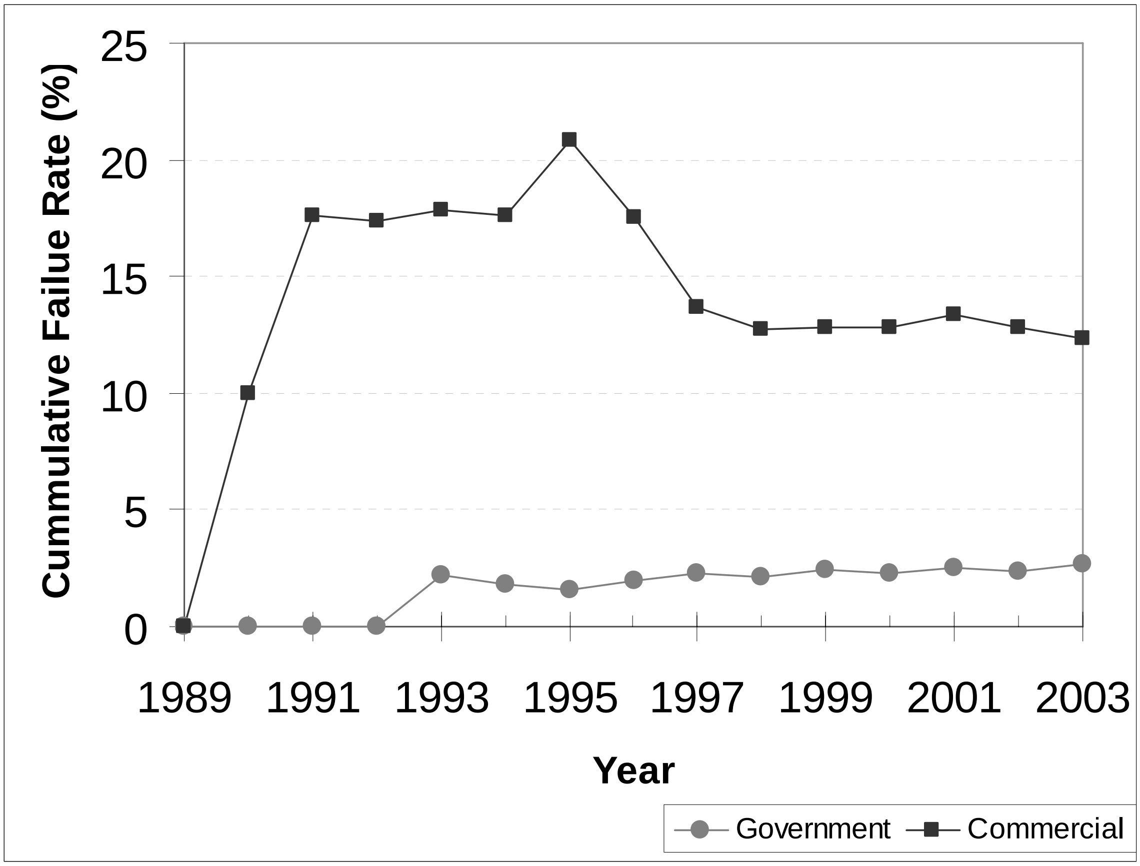

Figure 1. Cumulative failure rates of government and commercial launches from 1989 to 2003 inclusive.

Table 1. Launch Failure Likelihood for U.S. Orbital Launches, 1989-2003†

Variable	1	2
Government Launch		-2.064 **
		(0.693)
N LV Stages	0.526	0.722
	(0.349)	(0.390)
Launch Cost ($ million)	0.0024	0.004
	(0.004)	(0.004)
LEO Capacity (100 kg)	-0.005	-0.0005
	(0.010)	(0.011)
Cost per 100 kg	-0.126	-0.017
	(0.168)	(0.180)
Manned Flight	-1.711	-1.488
	(1.660)	(1.819)
Log-likelihood	-77.234	-71.422
Likelihood ratio		11.623 **
D.f. (vs. model no.)		1 (M1)

† Dependent Variable is whether an orbital launch attempt failed (1 = yes, 0 = no).
N = 404
*p < .05; **p < 0.01; two-tailed tests.
Note: Fixed-effects year coefficients included but not shown.

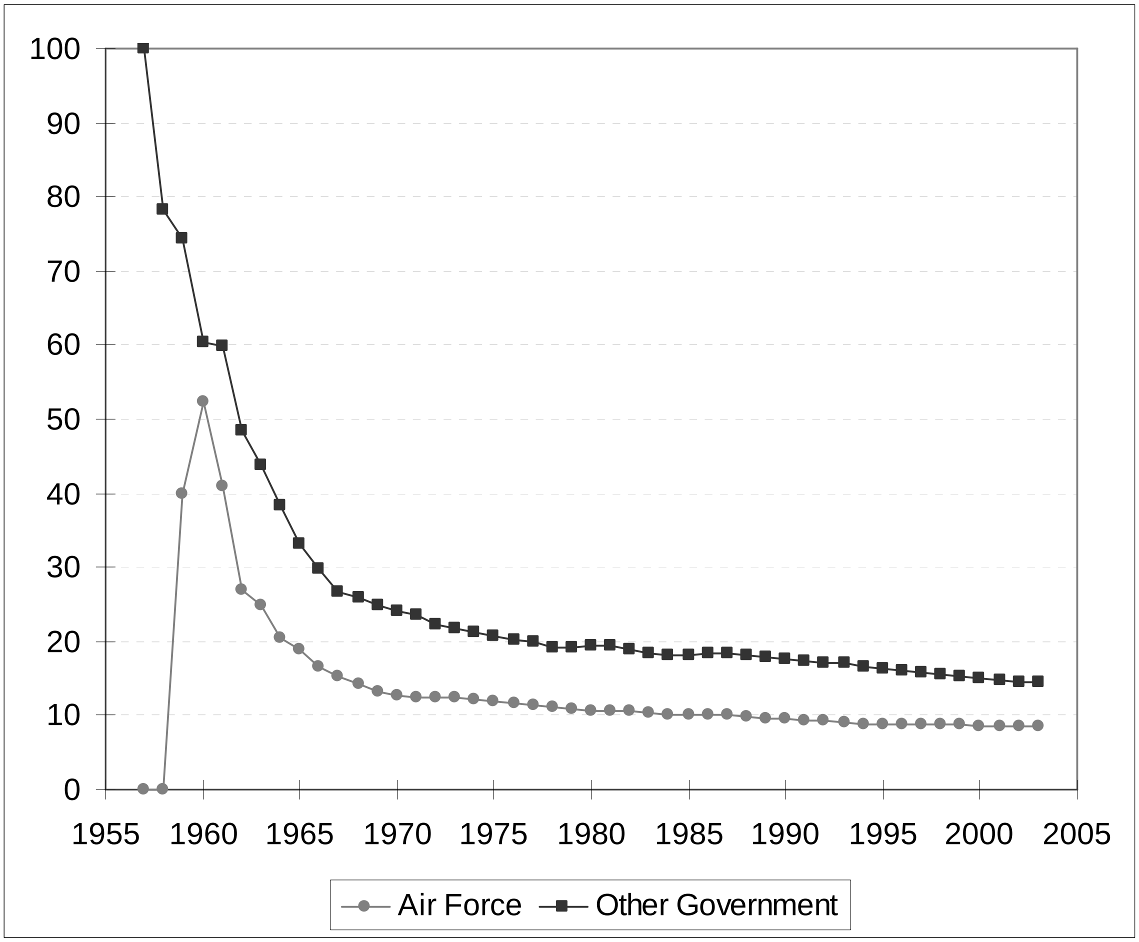

Figure 2. Cumulative failure rates of Air Force and other U.S. government launches from 1957 to 2003, inclusive.

Table 2. Launch Failure Likelihood for U.S. Government Orbital Launches, 1957-2003†

Variable	1		2	
Air Force Launch			-0.648	**
			(0.221)	
N LV Stages	0.071		-0.017	
	(0.137)		(0.142)	
Launch Cost ($ million)	-0.0003		0.003	
	(0.002)		(0.002)	
LEO Capacity (100 kg)	0.001		-0.0001	**
	(0.001)		(0.001)	
Cost per 100 kg	0.037		0.030	
	(0.021)		(0.018)	
Manned Flight	-2.133	**	-2.201	**
	(0.808)		(0.828)	
Log-likelihood	-407.564		-397.753	
Likelihood ratio			19.623	**
D.f. (vs. model no.)			1 (M1)	

† Dependent Variable is whether an orbital launch attempt failed (1 = yes, 0 = no).

N = 1285

*p < .05; **p < 0.01; two-tailed tests.

Note: Fixed-effects year coefficients included but not shown.