

Communication Failures Contributing to the Challenger Accident: An Example for Technical Communicators

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Abstract—Examination of the public documents available on the Challenger explosion shows that a history of miscommunication contributed to the accident. This miscommunication was caused by several factors, including managers and engineers interpreting data from different perspectives and the difficulty of believing and then sending bad news, especially to superiors or outsiders. An understanding of the dynamics at work in the Challenger case can help engineers and engineering managers elsewhere reduce miscommunication in their own companies.

A TECHNOLOGICAL FAILURE such as the explosion of the space shuttle Challenger can be puzzling in retrospect. Investigation often reveals that various people in the organization involved knew that the failure was likely and knew how to prevent it, and yet that knowledge was not shared within the organization as a whole. How does it happen that such important knowledge is not communicated? In the case of the Challenger, why did those who knew of the problem with the shuttle's solid rocket boosters not convince those in power to stop the launch?

The answer to this question lies in a complex set of factors, the most important of which seem to be (1) managers and engineers viewing the same facts from different perspectives, and (2) the general difficulty of either sending or receiving bad news, particularly when it must be passed to superiors or outsiders. An analysis of the communication failures that contributed to the Challenger accident is potentially of great interest to engineers and their managers because a large part of an engineer's job is to communicate both good and bad news upward to management for decision-making. The Challenger explosion was a horrifying public event, but it resulted from factors that are probably at work more quietly in many other organizations.

The first of these factors—managers and engineers viewing the same facts from different perspectives—suggests that knowledge is not simply seeing facts but rather interpreting them, and that interpretation varies depending upon one's vantage point. Communication, then, is not just shared information; it is shared interpretation. Achieving shared interpretation within an organization is relatively easy if the sender and receiver of communication share the same cor-

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porate role and hence the same concerns and values. If sender and receiver are from different corporate subcultures, however (as they often are in technical communication), then achieving shared interpretation is more difficult [1, 2]. In an appendix to the *Report of the Presidential Commission on the Space Shuttle Accident*, for instance, Commission Member R. P. Feynman notes the difference between probability estimates of flight failure and loss of life by managers—1 in 100,000—and engineers—1 in 100 [3, V. 1, p. F-1]. This difference occurred despite the fact that the managers were almost all engineers by training. Presumably, managers and working engineers had much the same background and many of the same facts at their disposal, but they interpreted the facts quite differently because they approached them from different points of view.

By the same token, communication about the solid rocket booster joint that failed was made more difficult because it was bad news. Research has repeatedly shown that bad news is often not passed upward in organizations [4, 5]. Moreover, even when bad news is sent, people are less likely to believe it than good news [6, 7]. In the shuttle disaster, bad news moved up only slowly from engineers to management within NASA; Marshall Space Center, where the shuttle program was headquartered; and Morton Thiokol International (MTI), the contractor responsible for the solid rocket boosters. It also moved slowly among the organizations because they were in a hierarchical relationship, with MTI dependent on Marshall for the contract and Marshall dependent on NASA for funds and career opportunities.

Additionally, the three organizations seemed to view one another as outsiders despite the fact that they were working jointly on the same project and, in the case of NASA and Marshall, were nominally part of the same agency. So the taboo against airing organizational dirty linen in public was added to the general difficulties of bad news transmission [8]. Communication about O-ring problems, then, had to overcome the barriers to moving bad news between engineering and management subcultures, up through organizational hierarchies, and out to other organizations. Under these circumstances, it is hardly surprising that the communication failed.

The following paragraphs explain, first, what failed physi-

cally on the shuttle system, and then what failed in the organizations' attempts to understand those physical problems and communicate about them in the 2-year period before the January 28, 1986, launch. I hope that this presentation will give engineers and engineering managers some insight into how to minimize the occurrence of events like the Challenger accident.

PHYSICAL CAUSE OF THE ACCIDENT

The physical cause of the Challenger explosion was the failure of a rubber seal in the solid rocket booster. The shuttle system consisted of three parts: the orbiter, which contained crew and experimental equipment; a large tank of liquid fuel, which was used by the orbiter's engines during liftoff; and two solid rocket boosters, which assisted at liftoff and were jettisoned to be recovered and reused on later flights. These solid rocket boosters (SRBs) were made in segments, which were stacked together at the launch site. The joints between the segments were sealed with two O-rings, which were protected from the heat of combustion by putty. The joint was pressure sealed, meaning that during rocket firing, expanding gases from burning fuel pushed the putty into the air space in the joint; this compressed air, in turn, pushed the O-ring into place and held it there. The second O-ring in each joint, in theory, provided redundancy or backup for the primary ring. During the Challenger launch, the O-rings in one of the SRB joints failed to seal, allowing hot gases to escape from the side of the SRB and burn a hole into the nearby liquid fuel tank, which exploded approximately 73 seconds into the flight.

In hindsight, the failure of the O-rings should not have been unexpected. From early 1984 on, postflight evidence increasingly showed that the joint seals were failing to meet design expectations. After every shuttle flight, the SRBs were recovered, disassembled for inspection, and readied for reuse in future flights. The inspections looked for any anomaly indicating the O-rings had not functioned as they should, and specifically for anything such as charred or eroded surfaces, which would indicate that the rings had failed to seal or had come into close contact with the heat of combustion. Before February 1984, only one O-ring anomaly had been found on the first nine flights. Beginning with the tenth shuttle flight, however, launched two years before Challenger on February 3, 1984, anomalies occurred on more than 50 percent of the flights [3, V. 1, p. 155].

We now know that the increased number of O-ring anomalies after early 1984 was probably caused by the use of increased pressure in the leak check done on the SRB joints after assembly at the launch site. The leak check involved blowing air into the joint through a hole located between the two O-rings and testing to see if the joint pressurized or sealed. Flights one through seven were tested at a pressure of 50 psi, flights eight and nine at 100 psi. From flight ten on, tests were done at 200 psi. In May 1985,

MTI experiments showed that the increased pressure was likely to have blown holes through the putty that shielded the primary O-ring from the hot blast of ignition [3, V. 1, p. 156]. The holes were particularly damaging, because they not only allowed the hot gases to penetrate but actually focused them, so that they would cause maximum O-ring erosion, which is the eating away of the edge of the O-ring by the hot gases rushing past before the ring seals. Ironically, the pressure at which the leak check was conducted was increased to 200 psi because of concern that the joints were not sealing. Some officials believed that the blow holes were necessary—unless they existed, the putty rather than the O-ring could seal the joints during the test, and a defective O-ring could escape detection [3, V. 1, p. 134].

EARLY RESPONSES TO BAD NEWS: DISBELIEF AND FAILURE TO SEND UPWARD

When O-ring anomalies first began appearing in early 1984, neither engineers nor management at MTI treated them as serious problems in their communications to Marshall. They did not send a grave interpretation of the data upward and, judging by internal documents, did not believe one themselves. Marshall's reactions are more ambiguous, for they treated the O-ring situation as serious when they communicated downward to MTI but as relatively minor when they communicated up to NASA headquarters.

After MTI engineers saw erosion on the February 3, 1984, flight, they filed a problem report, and O-rings were entered into formal problem tracking systems at both Marshall and MTI. In an action that illustrates the difficulty of accepting bad news, MTI claimed (in a subsequent briefing to Marshall) that the problem was not serious because even if the primary O-ring were damaged, the second ring would provide redundancy and seal [3, V. 1, p. 128]. Tests done more than a year earlier had shown the secondary O-rings to be unreliable because of a phenomenon called joint rotation. Joint rotation means that under the pressure of launch, the two sides of the O-ring joint bent apart, widening the gap the O-ring had to seal. Joint rotation was apparently especially hard on the secondary ring, making it likely to pull completely out of its groove and never seal at all.

As a result of these tests, Marshall had changed the joint's classification from criticality 1R (a critical system with backup) to criticality 1 (a critical system without such backup) in December 1982. However, those involved in shuttle design apparently found this change hard to accept. Marshall personnel, for instance, apparently believed that they had redundancy in all but exceptional cases [3, V. 1, p. 128]. At MTI, the difficulty of belief was even more marked. Some MTI engineers and officials told the Presidential Commission that they were not notified of the criticality rating change, although their names appear on distri-

bution lists on MTI documents [3, V. 1, p. 128]. Did these people lie about being notified? It seems more likely that they literally could not keep the bad news in mind.

Marshall's response to MTI's briefing illustrates what would be a pattern in their reaction to the O-ring difficulties. Some people at Marshall were willing to say that there was a serious problem—as long as any failure was perceived as MTI's. On February 28, for instance, John Miller, chief of the solid rocket motor branch at Marshall, wrote to his superior, George Hardy, through project engineer Keith Coates, urging that tests be done to see if the leak checks were causing problems. In an unusual recognition of the seriousness of the matter, Miller said O-ring failure could be "catastrophic" [3, V. 1, p. 245]. The next day, Coates also wrote to Hardy saying that MTI's briefing had minimized the extent of joint rotation possible and thus was too optimistic [3, V. 1, p. 128].

When the O-ring problem had to be claimed as Marshall's, however, and NASA had to be informed, Marshall, too, became optimistic. On March 8, 1984, a Flight Readiness Review for the eleventh shuttle flight was held at Marshall. These reviews were held at four levels, with each level resolving what problems it could and passing unresolved issues on to the next higher one. The March 8 meeting was Level III, meaning that it was a meeting between Marshall and its contractors and that the highest officials present were the Marshall project managers. At the meeting, MTI reported that maximum erosion on the O-rings would be 0.09 inch and that tests had shown that the rings would function with 0.095 inch of erosion. The 0.005-inch difference appears to be an extremely small safety margin. Rather than report a serious problem to a Level II meeting at Johnson Space Center, however, Marshall apparently accepted the margin, because this same information was entered in the Marshall problem assessment report with a note that future flights need therefore not be delayed. The Marshall problem tracking record reads: "Remedial action—none required" [3, V. 1, p. 128].

The 0.005-inch safety margin was also used as a rationale to justify no flight interruptions at the Level I briefing of top NASA personnel on March 27. NASA accepted Marshall's recommendation but wrote to Lawrence Mulloy, SRB project manager at Marshall, asking for further study of the O-rings. Mulloy had Marshall engineer Lawrence Wear ask MTI to identify the cause of erosion, determine its seriousness, and define any necessary changes.

Internal MTI documents show that the contractor was examining the problem but with little sense of urgency, again evidencing the tendency to see the problem in the best light possible. MTI analyzed the erosion history and test data and, on May 4, presented Marshall with a plan for studying the O-rings to produce the information NASA had asked for. The information was not actually produced, however, until a briefing on August 19, 1985—16 months later.

Despite its optimism to NASA, Marshall was apparently uncomfortable with this pace and pressed for prompt action than MTI was giving. On July 2, L. H. Sayers, MTI's Director of Engineering Design, suggested by phone to Marshall's Ben Powers that tests done to date by MTI were sufficient [3, V. 1, p. 134]. This again implies that MTI did not perceive the matter to be crucial or dangerous.

Early signs of serious O-ring problems, then, were generally not believed at MTI, were accepted at Marshall only when it was possible to see the problem as MTI's, and were not sent upward to NASA headquarters.

CONTINUED BAD NEWS REJECTION DESPITE CONTRADICTIONARY EVIDENCE

The optimistic view of the O-rings persisted at both MTI and Marshall over the 1984–85 period despite mounting evidence that the rings were not functioning well. This evidence had to do with the effect of cold on the rings and the amount of erosion that could occur in an O-ring.

On January 24, 1985, the fifteenth shuttle flight was launched at a temperature of 53°F, the lowest up to that time. It showed much greater O-ring erosion than any previous flight. Tests have since shown that cold reduces O-ring resiliency and increases the time to seal, thereby exacerbating the problems the joint was already experiencing. The damage on the fifteenth flight was severe enough to bring concern about the rings to the fore again. On January 31, Mulloy wrote to Wear asking him to get MTI to prepare information on O-ring erosion for a Level III Flight Readiness Review scheduled for February 8. At that review, MTI personnel mentioned the cold as a factor in the damage but labeled the risk "acceptable," mostly because they assumed the secondary ring would seal if the first one failed.

An optimistic interpretation of the data on cold was held by both managers and engineers at MTI, and one of the primary advocates of continued launch was MTI engineer Roger Boisjoly, who would later be one of the primary opponents to the launch of Challenger. The split between managerial and engineering interpretation of the data did not develop for four or five more months. MTI's claim that the secondary O-rings would seal is a further example of retaining previous theories in the face of contradictory evidence because, as noted above, the redundancy of the secondary ring had been in question since late 1982.

As they had done earlier, Marshall management accepted MTI's rationale, at least in what it told NASA. A Level I Review was held on February 21. At this meeting, the influence of temperature was not mentioned, and only a single reference was made to O-ring erosion, saying redundancy made the risk acceptable [3, V. 1, p. 136]. Although each of the next four flights experienced joint seal

problems, neither MTI nor Marshall seemed unduly concerned. Perhaps the very frequency of the problem added to its acceptability because the damage kept occurring with no serious consequences.

On June 25, however, one of the joints from a flight that had been launched April 29 was examined and found to have severe erosion of not only the primary ring, but even the secondary ring, calling its redundancy into question once again. As mentioned above, MTI had predicted maximum erosion of 0.09 inch for the primary seal. The primary O-ring on this joint was eroded 0.171 inch, almost double the predicted maximum and far beyond the 0.095 inch MTI had claimed to know was safe. This was bad news indeed. It could not be ignored, since an engineer from NASA headquarters was present when the damage was discovered. The engineer wrote to Michael Weeks at NASA on June 28, reporting the damage. The joint affected was a nozzle joint—that is, the joint linking the SRB to the flared section at its base. The NASA engineer blamed the damage on the fact that, in contrast to the rest of the SRB joints, which were now pressure-tested at 200 psi, nozzle joints were still being tested at only 100 psi, which might have permitted a defective ring to escape notice [3, V. 1, pp. 137–38].

In July 1985, Mulloy placed a launch constraint on the nozzle joints. This, in theory, meant that no other flights would take place until O-ring erosion at the nozzle joint had been fixed or shown not to be a problem. By including only the nozzle joints in the constraint, Mulloy was taking the most optimistic view possible of the problem. He reasoned that the nozzle joint had failed, not because of defective design, but because of a defective ring that had escaped notice in the nozzle joint's less rigorous leak test. Thus he believed that the leak test, and not the joint, was problematic. As a consequence, although he had assigned the launch constraint, Mulloy waived it for every subsequent flight, including Challenger, believing he was justified because Marshall increased to 200 psi the leak check pressure on the nozzle joint.

The launch constraint was treated as bad news by both MTI and Marshall. MTI officials testifying before the Commission all said they did not know about it, although subsequent MTI documents refer by document number to the report imposing the constraint [3, V. 1, p. 137]. The officials apparently did not take the news in. NASA officials, on the other hand, seem genuinely not to have been informed of the constraint, although regulations required that Level II be told. Marshall seems to have kept the news to itself rather than pass it out and up to NASA [3, V. 1, p. 138].

INTERNAL VERSUS EXTERNAL COMMUNICATION OF CONCERN FROM MTI ENGINEERS

Despite MTI's ignorance of the launch constraint, the damage discovered in late June seems to have galvanized its

engineers into action. Among them, at least, there seems to have been increased recognition of the problem's existence and its seriousness. MTI engineer Roger Boisjoly, for instance, became increasingly insistent about the potential danger from the O-rings. On July 22, his activity report predicted loss of the contract or flight failure if no solution was found. On July 31, he sent the following memo to R. K. Lund, MTI's Vice President of Engineering [3, V. 1, pp. 249–50]:

SUBJECT: SRM O-ring Erosion/Potential Failure Criticality.

This letter is written to insure that management is fully aware of the seriousness of the current O-ring erosion problem in the SRM joints from an engineering standpoint. The mistakenly accepted position on the joint problem was to fly without fear of failure and to run a series of design evaluations which would ultimately lead to a solution or at least a significant reduction of the erosion problem. This position is now drastically changed as a result of the SRM 16A nozzle joint erosion which eroded a secondary O-ring with the primary O-ring never sealing.

If the same scenario should occur in a field joint (and it could), then it is a jump ball as to the success or failure of the joint because the secondary O-ring cannot respond to the clevis opening rate and may not be capable of pressurization. The result would be a catastrophe of the highest order—loss of human life.

An unofficial team [a memo defining the team and its purpose was never published] with leader was formed on 19 July 1985 and was tasked with solving the problem for both the short and long term. This unofficial team is essentially nonexistent at this time. In my opinion, the team must be officially given the responsibility and the authority to execute the work that needs to be done on a non-interference basis (full time assignment until completed).

It is my honest and very real fear that if we do not take immediate action to dedicate a team to solve the problem with the field joint having the number one priority, then we stand in jeopardy of losing a flight along with all the launch pad facilities.

It is evident from this memo that Boisjoly's interpretation of the data had changed and that he was trying to communicate his new interpretation to his management. This memo does not give much space to new or old factual information, but rather concentrates on what the facts mean. Boisjoly's concern is evidenced both by the way he faults his own company (particularly his own management) and by his use of emotional language unusual in engineering documents. The memo implies, for instance, that MTI management may have an inaccurate understanding of the situation. The company's previous position was "mistakenly accepted." The company had planned to solve the problem but had not actually gotten to work to do so. The situation had changed "drastically," and a "catastrophe" could result. Boisjoly's memo and subsequent similar ones

evidently had some effect on their receiver, because on the night before Challenger flew, Lund did at least begin by recommending against launch. Boisjoly's concern, however, was kept within MTI. He marked his memo *COMPANY PRIVATE* at both top and bottom. Although he was sufficiently alarmed to try to reach his superiors, he still attempted to keep bad news from the prying eyes of outsiders.

Bad news went to Marshall only in response to specific questions from them. On August 9, MTI engineer Brian Russell wrote to Marshall's Jim Thomas about results of tests investigating the effect of cold on the O-rings. The tests had been initiated after the January 24 flight showed such severe damage. The tone of Russell's letter makes an instructive contrast to Boisjoly's [3, V. 5, pp. 1568-69]:

SUBJECT: Actions Pertaining to SRM Field Joint Secondary Seal

Per your request, this letter contains the answers to the two questions you asked at the July Problem Review Board telecon.

1. *Question:* If the field joint secondary seal lifts off the metal mating surfaces during motor pressurization, how soon will it return to a position where contact is re-established?

Answer: Bench test data indicate that the o-ring resiliency (its capability to follow the metal) is a function of temperature and the rate of case expansion. MTI measured the force of the o-ring against Instron plattens, which simulated the nominal squeeze on the o-ring and approximated the case expansion distance and rate.

At 100°F the o-ring maintained contact. At 75°F the o-ring lost contact for 2.4 seconds. At 50°F the o-ring did not re-establish contact in ten minutes at which time the test was terminated.

The conclusion is that secondary sealing capability in the SRM field joint cannot be guaranteed.

2. *Question:* If the primary o-ring does not seal, will the secondary seal seat in sufficient time to prevent joint leakage?

Answer: MTI has no reason to suspect that the primary seal would ever fail after pressure equilibrium is reached, i.e., after the ignition transient. If the primary o-ring were to fail from 0 to 170 milliseconds, there is a very high probability that the secondary o-ring would hold pressure since the case has not expanded appreciably at this point. If the primary seal were to fail from 170 to 330 milliseconds, the probability of the secondary seal holding is reduced. From 330 to 660 milliseconds the chance of the secondary seal holding is small. This is a direct result of the o-ring's slow response compared to the metal case segments as the joint rotates.

Please call me or Mr. Roger Boisjoly if you have additional questions concerning this issue.

Russell and Boisjoly were actually of much the same opinion on the dangers of the joint, and Boisjoly helped Russell write the memo shown here, but Russell is speaking to outsiders and this affects the memo. The memo is not in any way untruthful, but it is not very communicative. In a sense, it is the opposite of Boisjoly's memo. It gives just the facts, providing little interpretation. Its tone is adamantly objective, in contrast to Boisjoly's more emotional one. In retrospect, some of the facts Russell gives should have been frightening. Note, for instance, that if there was joint rotation, the secondary O-ring never sealed when it was tested at 50°F. The conclusion reached from this information was "that secondary sealing ... cannot be guaranteed." This is a negative wording of the finding, which was that at 50°F or below, MTI could pretty well guarantee no secondary seal.

That this memo did not communicate its intent is shown by the fact that the people who read it were uncertain about what it meant. Thomas copied the memo to be sent to NASA headquarters, but when the memo went through Mulloy's office for his signature, Mulloy returned it to Thomas saying it sounded like old news. The NASA official to whom Thomas was sending it has since said that even had he received the memo, he might not have understood it. "I don't know if anybody at that time understood the joint well enough to realize that the data was crucial," he said. When Mulloy was asked why he had not treated the temperature data as more important, he said he had not realized its significance, adding, "There were a whole lot of people who weren't smart enough to look behind the veil and say, 'Gee, I wonder what this means.'" [9]. As can be seen, the urgency in Boisjoly's memo had not been conveyed to Marshall. Marshall officials had been given the facts about the effects of cold on the O-rings. They did not, however, interpret those facts in the same alarmed manner Boisjoly and Russell did, and Russell's memo did not attempt to communicate the more pessimistic interpretation.

Thus, MTI engineers concluded that the O-ring problems were serious before their management did. However, in their written communication, they varied the extent to which they voiced that seriousness, depending on whether their audience was internal or external.

THE SPLIT BETWEEN MANAGERS AND ENGINEERS

As is suggested by Boisjoly's memo above, MTI managers and engineers were beginning to disagree over the seriousness of the O-ring problem, and engineers had a difficult time communicating their view upward. Support from the mini-culture of the task force probably made it easier than it had been previously for engineers to recognize the problem and speak up about it. On October 1, MTI engineers

Roger Ebeling and S. R. Stein complained in separate internal MTI memos to management that the O-ring task force was being slowed by administrative delays and lack of cooperation [3, V. 1, pp. 252-53]. Both men complained that, although the task force members regarded their work as urgent, administrators required that all testing and design be done according to routines established for more leisurely long-term development.

On October 3, the team met with Joe Kilminster, MTI's Vice President of Space Programs, to discuss these administrative difficulties, but apparently the members were not successful in convincing him of the gravity of the situation. On October 4, Roger Boisjoly's activity report complained bitterly that "upper management apparently feels" MTI has the SRB contract "for sure and the customer be damned" [3, V. 1, p. 255]. In December, Ebeling actually told fellow task force members that MTI should not ship any more SRBs to Marshall until the problem was solved. However, consistent with patterns of bad news transmittal, he did not tell this to any of his superiors [3, V. 1, p. 142].

In January 1986, final preparation for Challenger's flight began. A launch scheduled for January 27 was cancelled and rescheduled for the next day. The temperature at launch time was 36°F, 17° colder than it had been for any previous launch. When MTI engineers, including Ebeling, Russell, and Boisjoly, heard of the predicted low temperatures, they became alarmed enough to convince Lund, their Vice President of Engineering, to recommend that the launch be delayed until the temperature of the joints reached 53°F, the previous lowest launch temperature. In their argument, they cited the information from Russell's memo and the severe erosion from the 53°F launch the previous January.

In a teleconference involving numerous MTI and Marshall managers and engineers, Lund, MTI's Vice President of Engineering, did recommend delaying launch. Marshall was apparently surprised by MTI's action and, refusing to accept the bad news, they resisted the recommendation. George Hardy, who headed engineering at Marshall, said he was "appalled" [3, V. 1, p. 94]. He later testified to the Presidential Commission that he meant he was appalled at MTI's data, but MTI personnel believed he said he was appalled at their recommendation. Mulloy apparently asked if they expected him to wait until April to launch.

In general, Marshall challenged, not MTI's facts, but the conclusions drawn from them. Mulloy and Hardy conceded that the primary ring might be slower to seal in the cold and that the increased time to seal would allow more erosion to take place. But they argued that the ring would seal eventually and that the joint could sustain three times the worst erosion they had seen to date and still have a good seal. In the time before the primary ring sealed, joint rotation would not yet have taken place; therefore, the second-

ary ring would still be good. Moreover, they believed that temperature could not be the deciding factor because, although they had had severe erosion at 53°F, they had also had it at 75°F. (It is true that erosion occurred at various temperatures. However, the Commission later pointed out that 15 percent of the flights launched above 65°F had O-ring anomalies, while 100 percent of those launched below that temperature had them.) In the face of Marshall's opposition, Joe Kilminster, MTI's Vice President of Space Programs, asked that MTI have a private caucus off the phone line.

During the caucus, it became obvious that MTI was split along role lines. The engineers continued to argue against launch. Boisjoly says that, in the caucus, "there was never one comment in favor ... of launching by any engineer or other nonmanagement person in the room" [3, V. 1, p. 93]. And in words that describe his listeners shutting out bad news, he says he himself argued until it became clear "that no one wanted to hear what I had to say" [3, V. 4, p. 697].

At this point, Jerald Mason, MTI's Senior Vice President, said it was obvious that all present would not reach agreement and that a management decision would have to be made. He polled the other three vice presidents in the room, first asking Lund, who had presented the recommendation not to launch, to take off his "engineering hat" and put on his "management hat" [3, V. 1, p. 94]. When Lund changed his role, he changed his position, and the four managers voted unanimously to launch. Engineer Brian Russell describes an atmosphere in which it was difficult to maintain opposition to the launch, wondering "whether I would have the courage, if asked, ... to stand up and say no" [3, V. 4, p. 822]. As it happened, no engineer was asked to vote, and MTI went back on the conference line and reversed its earlier warning.

During the time MTI was caucusing, Marshall engineer Ben Powers also told his immediate supervisors that he agreed with MTI's recommendation not to launch, but his supervisors did not pass his view upward to Hardy and Mulloy. Similarly, Hardy and Mulloy did not pass on to NASA officials the fact that MTI engineers were opposed to the launch. At 11:38 the next morning, Challenger took off.

CONCLUSION

Looking at prelaunch miscommunications, then, several factors are apparent. First, no one at MTI or Marshall wanted to believe the growing evidence of O-ring problems. Second, even when MTI engineers came to believe that a problem existed, they had a difficult time convincing their management, with its different perspective on operations, to interpret the facts in the same light. In turn, on the night before launch, MTI personnel were unable to convince Marshall of the situation's gravity, even though

they looked at the same facts, because Marshall, too, saw things differently. Finally, both engineers and managers at MTI were especially reluctant to communicate bad news to those outside the company.

All of this suggests a number of precautions engineers and their managers might take in the face of the same kind of pressure-induced miscommunication. From a manager's point of view, one of the most important precautions is to establish an atmosphere in which engineers feel free to communicate bad news as well as good. A number of writers have offered advice on how this can be done [8, 10, 11, 12, 13]. Establishing an open atmosphere takes time and a concerted effort from the whole organization. It cannot be done on short notice when emergencies arise.

In addition, pressures for holding back bad news should be anticipated to be especially strong when contractors are involved. Encouraging bad news transmittal is difficult when the bearer of bad tidings is afraid of losing a contract. Contracts can, perhaps, be designed to lessen this fear, but those issuing the contracts should be alert for any sign of problems, since full disclosure of bad news is unlikely in this situation.

Lastly, managers and engineers alike should anticipate that they are probably erring on the side of optimism in interpreting data bearing on already established designs and programs. Failure to believe bad news is probably caused by a number of factors, including reluctance to admit that one was wrong, fear of practical consequences such as expensive redesign, and a kind of intellectual inertia that

makes it easier to persist in an already established belief than to change it. Such optimism can, however, have disastrous consequences, especially when coupled with other forces, as the Challenger accident demonstrates.

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Be not the slave of words.

Thomas Carlyle, in Sartor Resartus