The Challenger Disaster: Making it Personal

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Abstract – Few of our current engineering students were born when, 25 years ago, the Space Shuttle Challenger exploded. Since then, the disaster has been the subject of countless case studies in courses on engineering ethics, technical communication, and management systems. With the passage of time, the relevance of these studies to today's students may be open to question. The author, as a 15-year employee at Thiokol Corporation, worked alongside several individuals closely involved in the Challenger launch decision. As such, he was second-hand witness to a uniquely human side of engineering that applies today as it did a quarter century ago.

Keywords: Space Shuttle Challenger, engineering ethics, professional practices, technical communication

INTRODUCTION

The Space Shuttle Challenger disaster fundamentally changed the way the public views NASA, the way the public perceives the engineering profession, and the way engineers view themselves. The decision to launch, the technical reasons for the failure, and the management culture at the time of the accident have all been the subject of intense scrutiny, a Presidential Commission, congressional investigations, and numerous reports, papers and books. From an educational perspective, the incident has provided the opportunity to explore questions of engineering ethics, the relation between engineering and management, and the effective use of technical communication in conveying risk. It is a rare engineering curriculum that does not expose its students to at least one case study on the subject of Challenger.

The year 2011 marks the 25th anniversary of the Challenger tragedy. Few of our current engineering undergraduates were born when Challenger went down. Given the passage of a quarter century, the issue of convincing today's students of its relevance to their careers should be confronted even as the example of Challenger is used to convey timeless insights into engineering ethics. The loss of immediacy can be compensated for by the perspective gained by the intervening years and by reflecting on the personal experiences of the individuals involved. Who was involved in the decision to launch? How was the decision made? How did these people react to the events that unfolded as a result of the decision? And how were their careers affected over the long term?

For fifteen years, beginning five years after Challenger, the author was employed as an engineer at Thiokol, the manufacturer of the solid rocket boosters whose failure led to the disaster. During those years, he became acquainted with several of the engineers and managers involved in the events leading up to the launch and its aftermath. The perspective gained from their experiences and insights can add a personal dimension to accounts of the Challenger tragedy that will resonate with today's engineering students.

BACKGROUND

Most of us who were living on the morning of January 28, 1986 remember exactly where we were and what we were doing when we first learned of the explosion of the Space Shuttle Challenger 74.6 seconds into its flight. The public at large were shocked and saddened by the unexpected disaster. NASA at the time was widely considered to be infallible. Coming off the successful Apollo program of the late '60s and early '70s that sent men to the moon, the Space Shuttle program was touted as capable of providing routine, inexpensive access to space. The Challenger tragedy led to a very public re-examination of all aspects of Shuttle technology and the management culture at NASA and its contractors. The blue-ribbon Rogers Commission, appointed by President Reagan, held televised

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hearings aimed at identifying the root causes of the accident. Congressional hearings likewise investigated the accident. In the meantime, the Shuttle program was suspended for two-and-a-half years as all major systems and subsystems were re-evaluated, tested, and re-designed.

The investigations, coupled with engineering analysis and test, led to a reasonably clear consensus as to the basic technical cause of the failure [1]: rubber O-rings between segments at the aft field joint of the right solid rocket booster failed to properly seal due to extremely cold temperatures at the time of the launch. As a result, hot gas leaking from the booster impinged on, and burned through, the aft end of the external tank (encompassing a liquid oxygen tank at the forward end and a liquid hydrogen tank at the aft end) and attach strut. The strut failed, allowing the forward end of the booster to rotate into, and rupture, the liquid oxygen tank. The released oxygen mixed with leaking hydrogen causing the explosion that destroyed the Shuttle and its crew of seven astronauts.

Although the technical cause of the failure is fairly clear-cut, the reasoning behind the decision to launch in the face of known or unknown technical risks has been the subject of innumerable books, papers, and reports [2-4]. Did the engineers at NASA and at Morton-Thiokol, Inc. (the contractor responsible for the design and manufacture of the solid rocket boosters) fail to identify a clear temperature limitation on the operation of the motors? Was there a failure on the part of engineers to adequately communicate to management the risks inherent in a cold-temperature launch, or a failure of management to properly disseminate the available technical information? Were the program management systems in place inadequate to deal with a system as technologically complex as Shuttle? Had NASA begun to believe its own public relations department: that human space travel could be made routine, inexpensive, and free of risk? Had a culture of arrogance crept into the management at NASA and its contractors, and with it the belief that they could do no wrong? Did political and economic factors override good engineering judgment? Was everyone involved simply the victims of bad luck? In point of fact, all of the above likely played a role in the tragedy:

- The January 28 launch date was the third attempt to launch this flight of Challenger. The liftoff originally scheduled for January 26 was scrubbed due to a forecast of severe rain during the launch window; the weather that day turned out sunny and beautiful. The launch was rescheduled for the next day, but delayed when technicians were unable to remove the external handle of the door to the crew compartment. By the time the sticking handle was removed with a hacksaw, the launch window was closing and the weather had deteriorated as a cold front was coming through [3].
- The evening of January 27, as temperatures dropped and the forecast called for below-freezing air temperatures at launch, a teleconference was held between Morton-Thiokol and NASA personnel to review data on the effect of cold temperatures on the O-rings in the solid rocket boosters. Thiokol's engineers recommended no launch if the temperature of the O-rings was below 53°F. Their recommendation was overturned [3].
- Just prior to launch, an Ice Team typically measures the thickness of ice on the external tank with an infrared camera. This is a routine inspection; due to cryogenic liquids in the external tank, ice forms on its surface even in summer. By chance, the Team recorded a temperature of 8°F at the aft field joint of the right booster. Post-flight analysis indicated that unusual sustained WNW winds caused the air to be supercooled as it flowed over the external tank and to impinge on the aft field joint directly facing the external tank. The unusually low temperature recorded at the joint was not passed up through the management chain because it was the Ice Team's responsibility only to estimate the thickness of the ice [4].
- During the ignition transient, the right aft field joint leaked facing the external tank, but then resealed after a few seconds as motor pressure built up. At 58 seconds into launch, the Shuttle passed through the most severe wind shear recorded on any flight to date, causing the booster to flex and reopening the leak. By chance, the leak impinged directly on the attach strut and the external tank itself, leading to catastrophic failure [4].

If any one of the above scenarios had played out even slightly differently, it is likely that the Challenger launch would have proceeded without incident, and the crew would have returned home safely. As it was, a very public tragedy occurred, and the effects on NASA, the aerospace engineering industry, and the public trust were profound. Since then, studies and analyses of the events surrounding the Challenger accident have become a mainstay of college curricula. Corresponding issues of engineering ethics and the breakdown of technical communication have routinely been discussed on college campuses nationwide for many years.

With the passage of a quarter of a century, some may question the relevance of the Challenger accident to today's engineers. Certainly more recent engineering failures have occurred within the lifespan of today's students: the Space Shuttle Columbia and most recently the Deepwater Horizon to name two. As time passes, there may be a tendency to allow the discussions to evolve into dry considerations of management and communication systems and processes; there is certainly much to be learned from such considerations. But ultimately, the systems are implemented by people, and there is real value to our students in understanding the human element of engineering decision-making.

The morning of the Challenger accident, I was working in a cubicle in the structures department of a major aircraft manufacturer when the announcement came over the PA system. Five years later, I began working at Thiokol Corporation, the corporate successor to Morton-Thiokol, in northern Utah. Over the course of the next 15 years, I worked alongside, and in some cases worked for, several of the participants in the Challenger saga. The experience gave me at least a second-hand glimpse into what went on behind the scenes and an appreciation for the human side of this watershed event.

THE TELECONFERENCE

The teleconference held the evening preceding the launch came to play a prominent role in the testimony before the Rogers Commission, and has been thoroughly documented in the final report issued by the Commission [1], as well as in several books published since [2,3]. With the forecast of overnight temperatures in the teens, the teleconference was arranged at the request of Allan McDonald. McDonald had come up through the ranks of the engineering organization at Thiokol, and had recently moved into Program Management. A resident of Utah, he was at Kennedy Space Center for the Challenger Launch to serve as Thiokol's senior management representative in the Launch Control Center. Some months before, an engineering task force had been formed at Thiokol to investigate data that indicated problems of O-ring charring and blow-by from previous flights. McDonald requested that task force representatives present their preliminary findings.

The three-way conference call included engineers and managers from NASA and Thiokol in three different time zones. Among the participants were:

- At Kennedy Space Center in Florida, McDonald from Thiokol, along with Larry Mulloy, NASA Marshall Space Flight Center (MSFC) Solid Rocket Booster Project Manager, and Stan Reinartz, MSFC Shuttle Project Manager.
- At MSFC in Huntsville, Alabama, George Hardy, Deputy Director of Science and Engineering, along with a team of NASA engineers.
- At the Thiokol plant in northern Utah, engineering members of the O-ring task force, including Arnie Thompson, Brian Russell, and Roger Boisjoly; Robert Lund, Thiokol's Vice-President of Engineering; and Thiokol senior executives Joe Kilminster, VP of Space Booster Programs; Cal Wiggins, VP and General Manager of the Space Division; and Jerry Mason, Senior VP of Wasatch Operations.

Task force members had less than four hours to summarize their work in progress and prepare a presentation to NASA. In those days before widespread use of PCs and PowerPoint, Thiokol's handwritten presentation charts were faxed to Kennedy and Marshall. The Thiokol engineers, citing incomplete preliminary data, presented trends that indicated possible deleterious effects of cold temperatures on O-ring sealing effectiveness. Discussion of the data among the participants lasted over an hour until 10:00 pm ET. The conclusions and recommendations, presented by Lund, specified a minimum O-ring temperature of 53°F at launch.

The NASA managers on the line were clearly not pleased with the recommendation. Hardy said that he was appalled by Thiokol's conclusion, but he would not fly without Thiokol's concurrence. Mulloy, noting that the data presented was inconclusive, blurted, "My God, Thiokol, when do you want me to launch, next April?" It should be noted that it was not unusual for NASA officials to question, sometimes very bluntly, the interpretation of data presented at formal Flight Readiness Reviews held before every launch, as well as at informal, ad hoc conferences such as this. But always in the past, it was up to Thiokol to prove to NASA's satisfaction that it was safe to fly. This was the first time in any of the Thiokol participants' experience that NASA had challenged a recommendation that it was unsafe to fly. In the past, data that was inconclusive was automatically rejected to support a launch recommendation.

Clearly rattled by the unexpected reaction by Thiokol's biggest customer, Kilminster requested a five-minute off-line caucus by Thiokol personnel on the line in Utah. During the caucus, two of the engineers present, Boisjoly and Thompson, reiterated their objections to launch while acknowledging that the data were insufficient to prove that the O-rings would fail at low temperature. Mason, the Big Dog in the room favored a launch recommendation, and upon pointed questioning received support from two of the other three senior managers present: Wiggins and Kilminster. Lund, VP of Engineering, remained non-committal. Knowing that a launch recommendation required concurrence from Engineering, Mason finally said to Lund, "Bob, it's time for you to take off your engineering hat and put on your management hat." Lund, under pressure from his superiors, finally agreed that the launch should proceed with none of the constraints originally recommended by Engineering.

At the conclusion of the five-minute off-line caucus (which had turned into a 30-minute caucus) Thiokol came back on the line and communicated its new recommendations to NASA in Florida and Huntsville. Hardy requested that Thiokol provide its launch recommendation in writing and signed by a responsible Thiokol official. This was also a first: NASA had never before requested a signed recommendation to launch after a Flight Readiness Review. McDonald, Thiokol's senior manager present in Florida, was not a party to the discussions in Utah during the caucus. Baffled by the turn-around, he refused to sign the launch recommendation. Kilminster in Utah agreed to provide the signature and fax it to Kennedy and Marshall. And the launch proceeded as scheduled.

THE AFTERMATH

The next morning, the tragic explosion of Challenger was met with horror and disbelief worldwide. Employees of NASA and the scores of Shuttle contractors across the country shared these emotions, along with a nagging burden of uncertainty: was it a system for which I am responsible that led to the failure? Certainly nowhere was this sense of unease and foreboding more pronounced than among the Thiokol participants in the teleconference. It was a matter of weeks before it became evident that the O-rings were the leading candidates for the root cause of the failure. Painstaking analysis of telemetry and photographic data along with on-board instrumentation and a detailed fault-tree analysis eventually led to the final conclusion. Many of the teleconference participants from both Thiokol and NASA were called upon to testify before the Rogers Commission and the Congressional panel. It is safe to say their lives, both professional and personal, were changed forever.

Whether reading detailed accounts or abbreviated case studies of the events leading up to the accident, it is tempting to assign labels of "villain" or "hero" to the participants. In point of fact, all involved were just human beings, many of them engineers or managers with engineering backgrounds, who were suddenly and unexpectedly put in a position none had ever been put in before. Some reacted differently than others, but it is safe to say that every one of them came out of it with life-long regrets that they did not do something differently that could have led to a different outcome. As engineers, it may be a valuable exercise to put ourselves in the position of one of the members of the O-ring task force.

NO ORDINARY DAY

You get up on the morning of Monday, January 27, 1986 for the long drive to the Thiokol plant and a normal workday. The plant is located on 19,000 acres in a remote area of Northern Utah, so like most other Thiokol employees you face a 30-60 minute drive. To save wear and tear on your car and your body, you are in a carpool with three of your neighbors who also work at the plant. The carpool swings by your house and picks you up at 6:15. There is conversation about Super Bowl XX played the previous day: the Chicago Bears crushed the New England Patriots 46-10 at the Super Dome in New Orleans. The Challenger launch, having been scrubbed the day before, is scheduled before 8:00 local time, so you all plan to head straight for the cafeteria to watch the launch on television. Eventually the conversation ebbs, and all but the driver doze off.

When you arrive at the plant, you learn that the countdown is on hold, so you go to your desk and fill out your time card. As always, you are juggling a number of assignments; top priority at the moment is the Filament Wound Case program, slated to be the next generation case for the shuttle boosters, replacing steel with carbon fiber composite. Around 10:00 the word comes down that the launch has been scrubbed again, and rescheduled for tomorrow morning.

Early in the afternoon, you get a call from Arnie Thompson the lead engineer on the O-ring task force. This ad hoc task force is one of a half dozen groups of 4-5 engineers investigating various discrepancies on previous shuttle flights. After each flight, the solid rocket boosters are recovered from the Atlantic Ocean and shipped by rail back to Utah, where they are inspected, refurbished, and re-loaded with propellant for a future shuttle flight. Any deviations from nominal behavior on previous shuttle flights revealed by the inspection are formally catalogued. An engineering evaluation of the deviation is performed and dispositioned, and the results presented at the formal Flight Readiness Review before the next flight. Recurring anomalies, such as nozzle pocketing and ply lift, or O-ring char, erosion or blow-by may lead to formation of an engineering task force to perform tests, analysis, and possible recommendations for long-term corrective action.

The O-ring task force was formed about six months previously to investigate indications of impingement and intermittent blow-by of hot exhaust gases on the O-rings sealing the motor joint segments. Each of the two solid rocket boosters consists of four segments, joined at the forward, center, and aft field joints. A primary and a secondary O-ring provide sealing at each joint. Hot exhaust gases come into contact with the primary O-ring, but it is designed to prevent the gases from escaping through the joint. The secondary O-ring provides redundancy to the design. Inspections from previous flights have indicated that gases have passed the primary and impinged on the secondary O-ring on a number of occasions. The charge to the task force is to quantify the factors causing this undesirable blow-by and to determine the effects on flight safety.

Since its formation, the task force has been conducting evaluation of launch data, engineering thermal-structural analyses of the joints, and design, execution, and evaluation of subscale tests. Launch data has indicated some correlation between cold-weather launches and incidences of blow-by, but the correlation is far from perfect. Local temperature data in the vicinity of the joints at launch is largely unavailable, so rough estimates are required. Nevertheless, recent attention of the task force has been largely focused on the effect of joint temperature on O-ring sealing capabilities. Progress in quantifying the effects has been slow however. You, along with other members of the task force are juggling this assignment along with two to three others, and pushing the testing through the lab has been frustrated by other priorities.

It is against this background that Arnie Thompson calls you shortly after lunch. He got a call a few minutes ago from Al McDonald at the Cape. Forecast for the air temperature at the time of tomorrow's launch is 28°F, far colder than any previous shuttle launch, and Al is concerned about the integrity of the field joints at that temperature. He is setting up a telecon for 6:15 pm between Marshall, Kennedy, and Thiokol, and wants the task force to report on its findings and make an engineering recommendation. This will mean the task force has only a few hours to pull together all the data collected to date, summarize the results, come up with a recommendation, and put it all into a presentation for the customer.

You call the carpool driver and tell him not to wait the carpool for you; you call your wife and tell her you'll be late tonight and you'll get a bite at the company cafeteria; and you change your time card to reflect that you're now working on the O-ring charge number. You gather up your files and go down the hall to the conference room where the rest of the task force is gathering. The rest of the afternoon is spent with your co-workers going over the data and trying to make sense of it. At the end of the day you all agree that the data you have gathered so far is inconclusive; you are all convinced that low temperatures will hamper the ability of the O-rings to seal, but you are a long way away from establishing a supportable cut-off temperature. The consensus is that the prudent course is to recommend not launching if the temperature is below that of the coldest previous launch.

Arnie calls Bob Lund, VP of Engineering, to ask that he come to the conference room so the team can brief him on the presentation. The presentation charts are being prepared during that discussion, and Bob is supportive of the conclusions and recommendations of the task force. The charts are finalized, Bob runs through them one last time with the group. It is now 5:30; Bob leaves with the charts so copies can be made and they can be faxed to Huntsville and the Cape; and you head to the cafeteria to grab a quick bite before the teleconference.

Shortly after 6:00, everyone starts gathering in the big conference room on Mahogany Row. The engineering task force files in, followed eventually by the various inhabitants of the executive office suites. It is a bit of a surprise to you and the other task force members that the meeting will include four vice-presidents; normally a technical discussion with NASA will include only Lund and Kilminster. But this is the night before a launch, NASA is Thiokol's biggest customer, and the next buy of shuttle boosters by NASA is going out for bids in a couple of months.

The telephone hook-up is initiated, and by the time everyone is introduced and it is confirmed that each has a copy of the charts it is 6:45. Al at the Cape kicks off the meeting by summarizing the concern about the effect of low temperatures on O-ring performance and emphasizing that Thiokol's launch recommendation be based on an engineering, not a program, assessment. At that point, the engineers of the Task Force take over, and the charts are covered one by one. It is a painstaking process, since there is no video hookup and it is a little cumbersome keeping everyone on the same page. There is a lot of discussion involved; the NASA folks typically take a very active role in questioning the source and interpretation of any data presented, sometimes very contentiously. Of course, in the conference room in Utah you can't see either facial expressions or body language of your intended audience. After about an hour, Bob as Thiokol's VP of Engineering presents the conclusions and recommendations of the engineering team. Everyone in the room expects that, given the ongoing investigation by the task force and the inconclusive data, the Thiokol recommendation will be accepted by NASA as the most conservative course.

To everyone's surprise, NASA's Mulloy and Hardy take exactly the opposite position, challenging Thiokol's conclusions that low temperatures lead to unsafe conditions as being based on inconclusive data. After a few moments of stunned silence, Kilminster asks for a five-minute offline recess, and the phone in the conference room is put on mute. For the first time since the meeting began, Executive VPs Wiggins and Mason take the floor. The executives dominate the discussion, and in little more than 30 minutes Thiokol's engineering recommendation is reversed. As you leave the conference room you look at the other task force members in silent bewilderment.

It is now 8:30, and during the long drive home, you reflect on the events of the day. You spent six hours with your engineering colleagues building a case for conservatism based on incomplete, inconclusive data from an investigation in progress. Then, in barely 30 minutes, the best engineering judgment of the task force was overruled. You replay those 30 minutes in your mind, wondering if you should have spoken up to the executives in the caucus, wondering if it would have changed anything if you had. In the end, you just hope and pray that everything turns out all right tomorrow morning.

CONCLUSION

Of course, everything did not turn out all right the next morning, and everyone in that conference room in Utah ended up replaying the 30 minutes of the offline caucus not just during the drive home, but over and over again. It is safe to say that each one of them has spent untold hours second-guessing himself and playing what-if games. But in fact, on the morning of January 27, 1986, not one of those individuals knew what was waiting for him that evening.

Manned space flight is inherently risky. Established margins of safety are lower than any other endeavor in which human lives are at stake. While it could be argued that if any one of a dozen scenarios had turned out slightly differently Challenger would not have exploded, it could equally be argued that the other Shuttle flights were one wrong decision away from disaster.

Space transportation and other complex man-made systems are governed by immutable physical laws that determine the possible and the impossible. The engineering implementation of these systems combines these laws with complex human interactions. As engineering educators, we traditionally focus on aspects of engineering governed by physical principles and processes, even as it is the human side of engineering that often determines success or failure. How do we prepare our students and ourselves for those 30 minutes?

REFERENCES

There have been innumerable books and reports written about the Challenger accident. A complete list is beyond the scope of this paper. The following references represent, in the opinion of the author, the most compelling and authoritative accounts.

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