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The Space Shuttle Challenger Case:

Ethics and Engineering Dissent

by

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The first fundamental canon of the National Society of Professional Engineers (NSPE) states that engineers, in the fulfillment of their professional duties, shall “hold paramount the health, safety, and welfare of the public.” Under rules of practice considerations, the NSPE more specifically states that “if an engineer’s judgment is overruled under circumstances that endanger life or property, that the engineer shall notify their employer or client and such other authority as may be appropriate.” Thus, while the NSPE code supports engineers who, in those circumstances, notify entities outside of their employer, the code is also fulfilled through notification of one’s own employer. Most federal and state laws designed to protect employees dissenting from their employer, however, apply mostly to illegal or fraudulent financial activity, workplace safety regulations, and environmental laws, not an engineer’s judgment that life or property are in danger from decision making within a company. Thus, an engineer dissenting from an employer in this regard, whether inside or outside the company, in will find legal recourse against potential retaliation difficult to secure. Also, it can sometimes be difficult to determine when an honest difference of opinion crosses over into unsafe engineering. This case study of one of the most iconic episodes in engineering history is designed to bring out some of the difficulties in facing such a decision and give the engineer an understanding of their rights and responsibilities according to the NSPE codes of ethics.

A Known Problem

After the Apollo program for the National Aeronautical and Space Administration (NASA) ended, NASA found itself in the position of scaling down its ambitions. For its next ventures into space, NASA proposed, and Congress agreed to, a fleet of safe, reliable, re-usable ‘Space Shuttles’ that would carry satellites and other equipment into earth orbit, including to the developing international space station, and conduct scientific experiments in orbit. In this new venture, some of the satellites placed into orbit would also be commercial ones, thus defraying some of the costs of the shuttle program. These space shuttles would return to earth not with a splashdown this time, but by gliding through the atmosphere after re-entry and landing like an airplane. NASA conducted the first space shuttle test flights in the early 1980s, and began full service by 1982. Entering the new year in 1986, the shuttle program had launched and returned 25 missions. For the 26th mission, a special promotional program and outreach program was planned. A competition to select a ‘Teacher in Space’ to ride along with the astronauts was conducted, and after a national search, a winner was selected to be the centerpiece of a broad outreach program to interest the public, especially children, in science and space. Such opportunities were afforded to NASA since they now had a safe and reliable means of transport into near earth orbit and back.

On the day before the twenty-seventh launch, however, NASA made an unusual phone call. The NASA management team, all former engineers, had a question for Morton Thiokol (Thiokol), the company that designed the two Solid Rocket Boosters (SRBs) that help lift the Space Shuttle into orbit. It was known among the engineers and managers both at Thiokol and NASA that on six of the previous twenty-six launches, a tiny fraction of the fiery hot rocket propellent that the SRBs used to help lift the Space Shuttle into space had briefly escaped out of the side of one of the SRBs at a junction in the SRB casing where segments of the casing were connected together by rubber type seals called o-rings. Even though there were two redundant o-rings per seal, some of the rocket fuel had still escaped. These small leaks, or 'blow-by', were evidenced by charred marks of the booster rocket sections recovered after launches as well as on the o-rings themselves. Since only a tiny fraction of the propellent escaped out of the side of the rocket, however, these leaks did not affect the launches or the flights up through the atmosphere into orbit and were not seen as a reason to stop launching the shuttles. A redesign of the joint was in process, and the plan was to phase it. The unusual phone call was placed on this night because the NASA managers had a question about these SRB o-ring 'joints'. For the launch the next day, the predicted temperature at launch time, about 12:30 PM, was around 33 Deg F, about 20 Deg F colder than the previous coldest launch. The question NASA had for Thiokol was direct: would this 20 Deg F or so difference in temperature compared to the previous coldest launch exacerbate the known blow-by problem such that the shuttle system would enter a new realm of risk that was worse than the previous twenty-six launches, thus meriting a postponement of the Challenger launch.

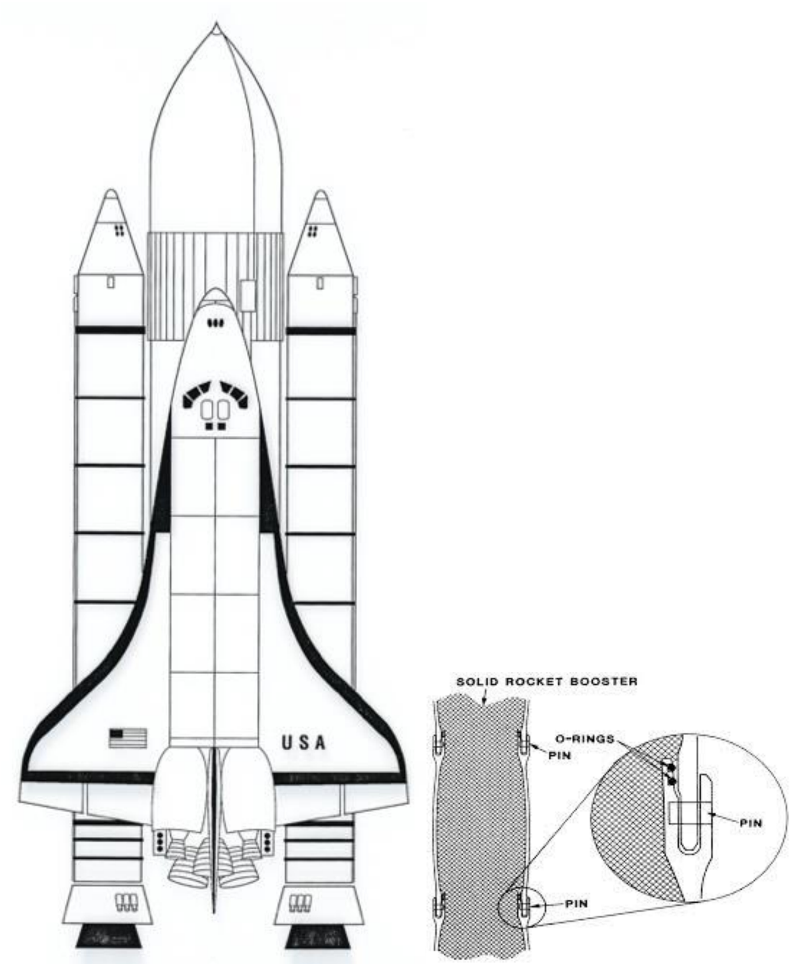
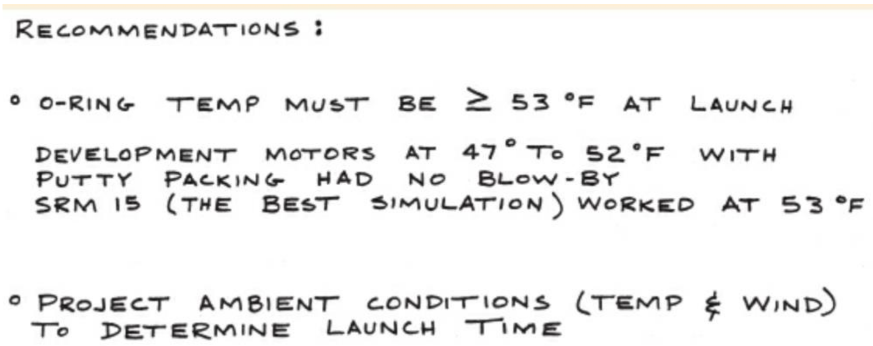


Figure 1 – Design of the Solid Rocket Booster (SRB) segmented casing joint connection. Two (account for this in text) rubber type o-rings form a seal between the inside of the tang inserted into the clevis. Two SRBs held solid rocket fuel used to help lift the shuttle into orbit.

Thiokol was on the spot to provide the information required to answer this question, given that the launch was scheduled in less than 24 hours. Did they have it? There were some indications from the previous launches that indicated that temperature might be a factor that might need to be taken into account in considering the risk of SRB o-ring joint failure. Of course, it is common sense that rubber type materials are stiffer at colder temperatures. But at launch, the firing of the rocket fuel heats the casing and o-rings up almost instantaneously. Could a of 20 Deg F reduced outside air temperature from the previous coldest launch be enough to slow the response of the o-rings to this sudden onrush of heat such that they might not seal the joint? At Thiokol, some tests had been run that checked the response times of the o-rings as a function of temperature. These measurements showed a change in the response time of a few milliseconds for the amount of temperature change predicted for launch. Could a delayed response on the order of milliseconds be enough to increase the risk of the system such that the launch should be postponed? Also, even though the second highest amount of 'blow-by' occurred on a launch at 75 Deg F, the launches with blow-by were clustered in the lower range of temperatures at launch. Further, photographs of recovered solid rocket booster casings showed that the blow-by from the 53 Deg launch was visibly darker than the blow-by from the other launches. Was all of that enough to signal a new regime of risk for the shuttle launch the next day? From the phone call initiated by NASA in the afternoon, it was agreed that at 8 pm that evening, a conference call meeting between Thiokol and NASA to attempt to address these questions would take place.

The Pre-launch Meeting

NASA was an important supplier of contracts for the Thiokol, and a good working relationship was thus crucial. Thiokol knew that NASA, as per standard policy, would not overrule a 'no-launch' recommendation that came from a contractor such as themselves, but such a delay would have its operational consequences. Indeed, at each launch the company had an employee stationed at the launch site on the day of the launch whose job it was to sign a document recommending launch. What would the repercussions be of not signing that document? At the 8 PM meeting, Thiokol presented the information that the o-ring response time might be slower by a few milliseconds, that 5 of the 6 previous launches with blow-by had occurred in the lower range of launch temperatures, including the previous coldest launch of 53 Deg F, and that at the color of the blow-by was visibly blacker at the 53 Deg launch. Given all of this, they then recommended that the shuttle not be launched the next day, and further asserted that going forward shuttles not be launched with an o-ring temperature below 53 Deg F, the temperature of the o-rings at the previous coldest flight.



RECOMMENDATIONS:

- O-RING TEMP MUST BE ≥ 53 °F AT LAUNCH

  DEVELOPMENT MOTORS AT 47° TO 52°F WITH PUTTY PACKING HAD NO BLOW-BY
  SRM 15 (THE BEST SIMULATION) WORKED AT 53 °F

- PROJECT AMBIENT CONDITIONS (TEMP & WIND) TO DETERMINE LAUNCH TIME

Figure 2 – The initial recommendation by the Solid Rocket Booster (SRB) contractor Morton Thiokol to not launch the Challenger recommended an o-ring temperature of at least 53 Deg F for future launches.

At this recommendation and its justification, the NASA managers were incredulous. One NASA manager noted that he was 'appalled' by their analysis. What if 52 Deg F was predicted instead of the currently predicted 33 Deg F? Would a 1 Deg change from what had come before be grounds for scrubbing the launch? Furthermore, there had already been launches scrubbed for other reasons when the temperature was below 53 Deg, including one at 40 Deg, and no mention of a 53 deg floor was raised by Thiokol on those occasions. Even more, the NASA group could not understand how Thiokol could ignore the fact that the second highest amount of blow-by had occurred at one of the highest launch temperatures of 75 Deg? Didn't that show that temperature was not the primary factor with regard to blow-by? If it was, then there must be an of explanation or analysis of the 75 Deg F blow-by launch. No such analysis was provided by the Thiokol team. Also considering that a temperature range was never in the launch specifications of the shuttle fleet, NASA felt that this recommendation for a 53 Deg F temperature floor was ad hoc and not justified through engineering analysis. The scheduling implication of such a temperature floor were also not lost on the NASA team, who noted that they would probably then have to wait till April to launch the next shuttle.

If the discussion had stopped at that point, the Challenger would not have been launched. As a matter of standard policy, NASA would not overrule the recommendation of a contractor. But it was here that Thiokol took an extra, pro-active step and requested from the NASA managers an off-line 'caucus' to discuss the matter further among themselves.

Take off your Engineer's Hat and Put on your Manager's Hat

In the caucus, the Thiokol engineers pressed their points again to their own managers. Pointing to the bench tests that showed a millisecond delay in o-ring response time, emphasizing that, in general, the worst cases of blow-by were at lower temperature launches, and noting that the blow by was 'darker' in the previous coldest temperature launch than in other launches with blow-by. The managers felt that those arguments had already been made and that they as a company were not addressing NASAs questions, in particular about the high temperature, high blow-by launch. A Thiokol manager noted that, "we are just spinning our wheels." It was at this point that one of the most famous quotes in engineering ethics was delivered. Stuck, and trying to figure out what to do, a Thiokol Vice President, who like everyone else in the room was a former engineer, directed an engineering manager to "take off your engineering hat and put on your management hat" in order to make a decision. Widely seen in post launch analyses of the Challenger case as a directive to capitulate to NASA, the Vice President asserted in congressional testimony after the fact that he only meant that the engineer's job was to produce, investigate, and scrutinize data and that at some point that process had to stop, and that the managers job was to then look at the data laid out as it was and to make a decision. Given that they were at a point that a decision needed to be made, the manager who was told to switch hats then noted to the assembled Thiokol team, "I think it's all right."

Thiokol then reconvened with NASA and told them that they had a new recommendation. Although temperature was a consideration, their new recommendation was to actually go ahead with the launch. Upon receiving this new recommendation, the NASA managers had a question for all those present on the conference call, including the Morton Thiokol engineers who had dissented to their own managers in the off-line caucus. "We understand your recommendation Thiokol, now does anyone here object to this recommendation?" The line was silent. One of the NASA engineers would say later that NASA took this as full assent on the part of Thiokol.

Despite the new recommendation on the part of Thiokol, there was still one obstacle to the launch. Another Vice President for Thiokol, Allan MacDonald who was on the conference call with NASA but not in the offline caucus and who was stationed at

Marshal Flight center and with the job of signing the document assenting to launch, refused to sign the document. This caused some consternation but was 'worked around' by faxing the document to Thiokol's home office in Utah where it was signed and sent back to NASA. The launch was on.

MTI ASSESSMENT OF TEMPERATURE CONCERN ON SRM-25 (51L) LAUNCH

- O CALCULATIONS SHOW THAT SRM-25 O-RINGS WILL BE 20° COLDER THAN SRM-15 O-RINGS
- O TEMPERATURE DATA NOT CONCLUSIVE ON PREDICTING PRIMARY O-RING BLOW-BY
- O ENGINEERING ASSESSMENT IS THAT:
  - O COLDER O-RINGS WILL HAVE INCREASED EFFECTIVE DUROMETER ("HARDER")
  - O "HARDER" O-RINGS WILL TAKE LONGER TO "SEAT"
    - O MORE GAS MAY PASS PRIMARY O-RING BEFORE THE PRIMARY SEAL SEATS (RELATIVE TO SRM-15)
      - O DEMONSTRATED SEALING THRESHOLD IS 3 TIMES GREATER THAN 0.038" EROSION EXPERIENCED ON SRM-15
  - O IF THE PRIMARY SEAL DOES NOT SEAT, THE SECONDARY SEAL WILL SEAT
    - O PRESSURE WILL GET TO SECONDARY SEAL BEFORE THE METAL PARTS ROTATE
      - O O-RING PRESSURE LEAK CHECK PLACES SECONDARY SEAL IN OUTBOARD POSITION WHICH MINIMIZES SEALING TIME
- O MTI RECOMMENDS STS-51L LAUNCH PROCEED ON 28 JANUARY 1986
  - O SRM-25 WILL NOT BE SIGNIFICANTLY DIFFERENT FROM SRM-15

JOE C. KILMINSTER, VICE PRESIDENT
SPACE BOOSTER PROGRAMS

MORTON THIOKOL INC
Wasatch Division

[Ref. 2/26-6]

Figure 3 – The second recommendation by Morton Thiokol notes that temperature data is "not conclusive" and that the colder launch planned for the Challenger (designated as SRM-25) will "not be significantly different" than the previous coldest launch (designated as SRM-15) and that they now recommend that the launch proceed.

Catastrophe after Liftoff

At the launch the next day, it seemed that trouble had been averted when the Challenger lifted safely off its pad with seemingly no issue. A standard procedure during the first part of a shuttle flight is to 'throttle down' the shuttle as it passes through the most turbulent part of the atmosphere. To reduce the stress and strain, the most dangerous of which comes from possible wind shears, the thrusters are reduced to around 60 percent of full capacity shortly after liftoff. Contrails left in the sky by the rocket engines were analyzed after the fact and it was determined that the wind shears that day were comparable with previous launches. After about a minute, as per normal procedure, the shuttle is then throttled back up as it heads into thinner atmosphere. It was upon this throttle up that the catastrophic effect of blow by that had actually occurred during this liftoff manifested. At the 72 second mark of the flight, ignited rocket fuel burst through a section of the SRB joint, which was just above a strut that held the SRB itself to the orbiter. Like an arc welder, this emanating torch severed the strut from the orbiter assembly. Having lost this structural connection and still under full thrust, the SRB twisted away from the orbiter assembly while still connected at the top, thus violently wresting apart the assembly of orbiter, main engine, and SRBs and leading to the release of a variety of gasses and emissions around the orbiter assembly. The crew cabin was a separate, self-contained, component of the orbiter assembly and it actually emerged from the flying debris and spraying gasses intact. Recovery operations showed that the cause of death for the seven astronauts on board was most likely be the impact of the depressurized crew cabin as it crashed back to the ocean.

Figure 4 – After the shuttle broke apart, the intact crew cabin was recorded on video passing in front of a plume of gasses.

An engineering disaster could hardly be more public. School children across the USA were watching live, a result of the multiyear promotion and competition to select the 'Teacher in Space' to ride along with the Challenger crew. The premise of the teacher in space promotion, of course, was that the Space Shuttle was a safe and reliable means of transport into orbit, like an airplane, which was also an important basis for congressional funding and the scheduling of frequent shuttle flights. This framing also obviated the inclusion of a parachute with the crew cabin, by the same logic that commercial airplanes are not fitted with plane level safety parachutes. The shock of a nation witnessing live such a failure of what was promoted as a safe operating system can hardly be overstated.

Engineers Demoted, Contract Retained

Two Morton Thiokol engineers involved in the pre-launch meetings took very different approaches after the catastrophe, and faced different consequences. One, Arne Lang, explained after the fact that he felt that the engineer's role was to raise possible issues with management and that that was where his job stopped. That is why he did not speak up in the teleconference over the silence of his mangers when NASA had asked if anyone disagreed with the recommendation to launch. Another, Roger Boisjoly, was adamant that both Morton Thiokol and NASA had made a grave decision that had ignored sound engineering recommendations. While Boisjoly also did not speak up in the teleconference when NASA had asked for objections, he spoke and wrote very publicly after the fact, framing the decision to launch as a case of management interests overruling engineering analysis. In congressional testimony as part of the Rogers commission inquiry into the disaster, however, Boisjoly did admit that prior to the launch he did not provide a quantitative analysis of possible o-ring joint failure temperature dependence, but rather a qualitative assessment that the colder launch temperature could put the system into a new risk regime. "I was asked to quantify my concerns," he told the commission, referring to NASAs request of him, "and I could not do it, I could not quantify my results." These different approaches after the failure led to different treatment by the company. Boisjoly was gradually moved to lesser assignments and eventually put on paid leave before quitting while Lang continued in his same position with the company. Further, Alan MacDonald, the vice president who refused to sign the document recommending launch, was moved to lesser assignments before retiring.

The U.S. Congress commissioned a report on the Challenger launch decision that held both NASA and Thiokol accountable. The Rogers report stated that "the fact that NASA did not take stronger action to solve this problem indicates that its top technical staff did not fully accept or understand the seriousness of the joint problem." Also, that in general "there (was) no clear understanding or agreement among the various levels of NASA management as to what constitutes a launch constraint or the process for imposing and waiving constraints." However, the report noted that Thiokol's advice and recommendations to NASA were "inconsistent." Further, the report recognized that the discussions the evening before the launch were initiated by NASA, not Thiokol, and that, "in as much as they had not come forth with the recommendation for a higher minimum temperature criterion on earlier occasions when it was planned to launch at temperatures below 53 degrees, it is unlikely that this recommendation would have been made on this occasion without the specific inquiry by NASA." Overall, the report noted that, "launch commit criteria and launch constraints should be established well in advance of a scheduled mission and should be based on rational, scientific and engineering arguments, including previous flight experience" and that the comparison to an airline was not apt, stating that, "it is the Committee's view that until such time as all elements of the (shuttle system) can be fully evaluated through extensive flight testing and trend analyses, it is premature to impose an operational flight schedule on the system in a manner comparable to that imposed upon, for example, an air transportation system."

For its part in the catastrophe, Morton Thiokol was fined $10M. They were also, however, given the contract to redesign the o-ring seal, also for $10M. After the redesign, which included a second slot for joining the SRB casing segments, there were no further problems with the joint for the subsequent 108 launches.

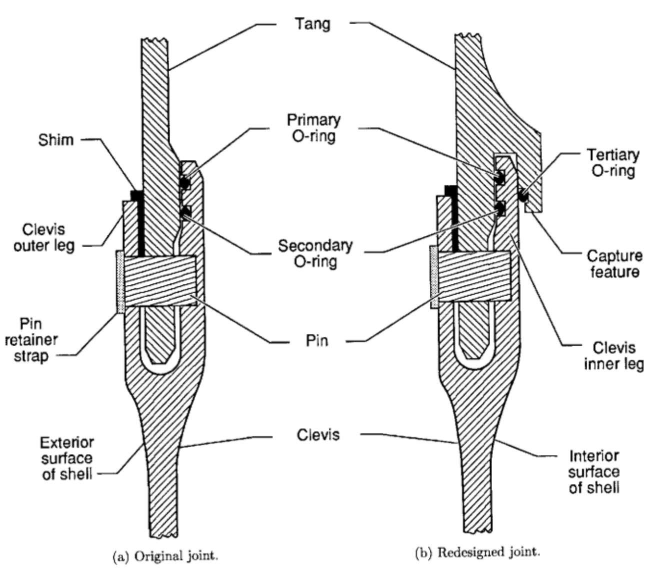


Figure 5 – O-ring joint redesign. In the new design a third o-ring was added between the clevis and the newly designed tang on the other side of the two original o-rings.

Conclusion

In the Challenger case, Thiokol engineers recommended to their company that the launch be postponed. While, by their own account, the engineers were “not able to quantify their concerns,” that was their engineering judgment. Thiokol then initially recommended to NASA that the launch be postponed. NASA resisted the engineers’ arguments and Thiokol then reconsidered, eventually over-ruling their own engineer’s judgments. When NASA asked if anyone disagreed with Thiokol’s final recommendation to launch the shuttle, no Thiokol engineers dissented. A Thiokol executive who was designated to sign the written launch recommendation refused to sign it, but another executive signed it in his place. According to the NSPE codes of ethics, the Thiokol engineers and the executive who refused to sign the launch recommendation fulfilled their duties by making it known to their employer that they disagreed with the decision. However, the NSPE code would have also supported them if they had formally disagreed to NASA or to another “appropriate authority”. The executive who refused to sign the written launch recommendation and an engineer who publicly criticized the launch decision were reassigned and demoted within the company. No legal action was taken against the company in this regard, as the legal landscape for such redress was not available at the time. While it exists in some jurisdictions now, retaliation laws for engineers who judge that their company is making decisions that endanger life or property remains in general insubstantial.

