The Space Shuttle Challenger Disaster

Adapted from material by the Department of Philosophy and Department of Mechanical Engineering Texas A&M University
NSF Grant Number DIR-9012252

Introduction to the Case

On January 28, 1986, seven astronauts were killed when the space shuttle they were piloting, the Challenger, exploded at just over a minute into the flight. The failure of the solid rocket booster O-rings to seal properly allowed hot combustion gases to leak from the side of the booster and burn through the external fuel tank. The failure of the O-ring was attributed to several factors, including faulty design of the solid rocket boosters, insufficient low-temperature testing of the O-ring material and of the joints that the O-ring sealed, and lack of proper communication between different levels of NASA management.

Organizations/People Involved

Marshall Space Flight Center - in charge of booster rocket development
Larry Mulloy - challenged the engineers' decision not to launch
Morton Thiokol - Contracted by NASA to build the solid rocket booster
Alan McDonald - Director of the Solid Rocket Motors project
Bob Lund - Engineering Vice President
Robert Ebeling - Engineer who worked under McDonald
Roger Boisjoly - Engineer who worked under McDonald
Joe Kilminster - Engineer in a management position
Jerald Mason - Senior executive who encouraged Lund to reassess his decision not to launch.

Key Dates

1974 - Morton-Thiokol awarded contract to build solid rocket boosters.
November 1981 - O-ring erosion discovered after second shuttle flight.
January 24, 1985 - shuttle flight that exhibited the worst O-ring blowby.
July 1985 - Thiokol orders new steel billets for new field joint design.
August 19, 1985 - NASA Level I management briefed on booster problem.
January 27, 1986 - night teleconference to discuss effects of cold temperature on booster performance.
January 28, 1986 - Challenger explodes 72 seconds after liftoff.

Key Issues

How does the implied social contract of professionals apply to this case?
What professional responsibilities were neglected, if any?
Should NASA have done anything differently in their launch decision procedure?

Background

Pressure to launch

NASA managers were anxious to launch the Challenger for several reasons, including economic
considerations, political pressures, and scheduling backlogs. Unforeseen competition from the European Space Agency put NASA in a position in which it would have to fly the shuttle dependably on a very ambitious schedule to prove the Space Transportation System's cost effectiveness and potential for commercialization. This prompted NASA to schedule a record number of missions in 1986 to make a case for its budget requests.

The shuttle mission just prior to the Challenger had been delayed a record number of times due to inclement weather and mechanical factors. NASA wanted to launch the Challenger without any delays so the launch pad could be refurbished in time for the next mission, which would be carrying a probe that would examine Halley's Comet. If launched on time, this probe would have collected data a few days before a similar Russian probe would be launched.

There was probably also pressure to launch Challenger so that it could be in space when President Reagan gave his State of the Union address. Reagan's main topic was to be education, and he was expected to mention the shuttle and the first teacher in space, Christa McAuliffe.

**Solid rocket booster**

The shuttle solid rocket boosters (or SRBs), are key elements in the operation of the shuttle. Without the boosters, the shuttle cannot produce enough thrust to overcome the earth's gravitational pull and achieve orbit.

An SRB is attached to each side of the external fuel tank. Each booster is 149 feet long and 12 feet in diameter. Before ignition, each booster weighs 2 million pounds.

Solid rockets, in general, produce much more thrust per pound than their liquid fuel counterparts. The drawback is that, once the solid rocket fuel has been ignited, it cannot be turned off or even controlled. So it was extremely important that the shuttle SRBs be properly designed.

Morton Thiokol was awarded the contract to design and build the SRBs in 1974. Thiokol's design is a scaled-up version of a Titan missile, which had been used successfully for years. NASA accepted the design in 1976.

**O-rings**

Each SRB joint is sealed by two O-rings: the bottom ring known as the primary O-ring, and the top known as the secondary O-ring. (The Titan booster had only one O-ring. The second ring was added as a measure of redundancy since the boosters would be lifting humans into orbit. Except for the increased scale of the rocket's diameter, this was the only major difference between the shuttle booster and the Titan booster.)

The purpose of the O-rings is to prevent hot combustion gasses from escaping from the inside of the motor. To provide a barrier between the rubber O-rings and the combustion gasses, a heat-resistant putty is applied to the inner section of the joint prior to assembly. The gap between the tang and the clevis determines the amount of compression on the O-ring. To minimize the gap and increase the squeeze on the O-ring, shims are inserted between the tang and the outside leg of the clevis.

**Launch Delays**
The first delay of the *Challenger* mission was due to a weather front expected to move into the area, bringing rain and cold temperatures. Usually a mission wasn't postponed until inclement weather actually entered the area, but the Vice President was expected to be present for the launch and NASA officials wanted to avoid the necessity of the Vice President's having to make an unnecessary trip to Florida, so they postponed the launch early. The Vice President was a key spokesperson for the President on the space program, and NASA coveted his good will. The weather front stalled, and the launch window had perfect weather conditions; but the launch had already been postponed.

The second launch delay was caused by a defective microswitch in the hatch locking mechanism and by problems in removing the hatch handle. By the time these problems had been sorted out, winds had become too high. The weather front had started moving again, and appeared to be bringing record-setting low temperatures to the Florida area.

NASA wanted to check with all of its contractors to determine if there would be any problems with launching in the cold temperatures. Alan McDonald, director of the Solid Rocket Motor Project at Morton-Thiokol, was convinced that there were cold-weather problems with the solid rocket motors and contacted two of the engineers working on the project, Robert Ebeling and Roger Boisjoly. Thiokol knew there was a problem with the boosters as early as 1977, and had initiated a redesign effort in 1985. NASA Level I management had been briefed on the problem on August 19, 1985. Almost half of the shuttle flights had experienced O-ring erosion in the booster field joints. Ebeling and Boisjoly had complained to Thiokol that management was not supporting the redesign task force.

The Night Before the Launch

Temperatures for the next launch date were predicted to be in the low 20°s. This prompted Alan McDonald to ask his engineers at Thiokol to prepare a presentation on the effects of cold temperature on booster performance.

A teleconference was held between engineers and management from Kennedy Space Center, Marshall Space Flight Center in Alabama, and Morton-Thiokol in Utah. Boisjoly and another engineer, Arnie Thompson, knew this would be another opportunity to express their concerns about the boosters, but they had only a short time to prepare their data for the presentation. Thiokol's engineers gave an hour-long presentation, presenting a convincing argument that the cold weather would exaggerate the problems of joint rotation and delayed O-ring seating. The lowest temperature experienced by the O-rings in any previous mission was 53°F, on the January 24, 1985 flight. With a predicted ambient temperature of 26°F at launch, the O-rings were estimated to be at 29°F.

After the technical presentation, Thiokol's Engineering Vice President Bob Lund presented the conclusions and recommendations. His main conclusion was that 53°F was the only low-temperature data Thiokol had for the effects of cold on the operational boosters. The boosters had experienced O-ring erosion at this temperature. Since his engineers had no low-temperature data below 53°F, they could not prove that it was unsafe to launch at lower temperatures. He read his recommendations and commented that the predicted temperatures for the morning's launch was outside the database and NASA should delay the launch, so the ambient temperature could rise until the O-ring temperature was at least 53°F. This confused NASA managers because the booster design specifications called for booster operation as low as 31°F. (It later came out in the investigation that Thiokol understood that the 31°F limit temperature was for storage of the booster, and that the launch temperature limit was 40°F. Because of
this, dynamic tests of the boosters had never been performed below 40°F.)

Marshall's Solid Rocket Booster Project Manager, Larry Mulloy, commented that the data was inconclusive and challenged the engineers' logic. A heated debate went on for several minutes before Mulloy bypassed Lund and asked Joe Kilminster for his opinion. Kilminster was in management, although he had an extensive engineering background. By bypassing the engineers, Mulloy was calling for a middle-management decision, but Kilminster stood by his engineers. Several other managers at Marshall expressed their doubts about the recommendations, and finally Kilminster asked for a meeting off of the net, so Thiokol could review its data. Boisjoly and Thompson tried to convince their senior managers to stay with their original decision not to launch.

A senior executive at Thiokol, Jerald Mason, commented that a management decision was required. The managers seemed to believe the O-rings could be eroded up to one-third of their diameter and still seal properly, regardless of the temperature. The data presented to them showed no correlation between temperature and the blowby gasses which eroded the O-rings in previous missions. According to testimony by Kilminster and Boisjoly, Mason finally turned to Bob Lund and said, "Take off your engineering hat and put on your management hat."

Joe Kilminster wrote out the new recommendation and went back online with the teleconference. The new recommendation stated that the cold was still a safety concern, but their people had found that the original data was indeed inconclusive and their "engineering assessment" was that launch was recommended, even though the engineers had no part in writing the new recommendation and refused to sign it.

Alan McDonald, who was present with NASA management in Florida, was surprised to see the recommendation to launch and appealed to NASA management not to launch. NASA managers decided to approve the boosters for launch despite the fact that the predicted launch temperature was outside of their operational specifications.

The Launch

During the night, temperatures dropped to as low as 8°F, much lower than had been anticipated. To keep the water pipes in the launch platform from freezing, safety showers and fire hoses had been turned on. Some of this water had accumulated, and ice had formed all over the platform. There was some concern that the ice would fall off of the platform during launch and might damage the heat-resistant tiles on the shuttle. The ice inspection team thought the situation was of great concern, but the launch director decided to go ahead with the countdown. (Note that safety limitations on low temperature launching had to be waived and authorized by key personnel several times during the final countdown. These key personnel were not aware of the teleconference about the solid rocket boosters that had taken place the night before.)

At launch, the impact of ignition broke loose a shower of ice from the launch platform. Some of the ice struck the left-hand booster, and some ice was actually sucked into the booster nozzle itself by an aspiration effect. Although there was no evidence of any ice damage to the Orbiter itself, NASA analysis of the ice problem was wrong. The booster ignition transient started six hundredths of a second after the igniter fired. The aft field joint on the right-hand booster was the coldest spot on the booster: about 28°F. The booster's segmented steel casing ballooned and the joint rotated, expanding inward as it had on all other shuttle flights. The primary O-ring was too cold to seal properly, the cold-stiffened heat resistant putty that protected the rubber O-rings from the fuel collapsed, and gases at over 5000°F burned past
both O-rings across 70 degrees of arc.

Eight hundredths of a second after ignition, the shuttle lifted off. Engineering cameras focused on the right-hand booster showed about nine smoke puffs coming from the booster aft field joint. Before the shuttle cleared the tower, oxides from the burnt propellant temporarily sealed the field joint before flames could escape.

Fifty-nine seconds into the flight, Challenger experienced the most violent wind shear ever encountered on a shuttle mission. The glassy oxides that sealed the field joint were shattered by the stresses of the wind shear, and within seconds flames from the field joint burned through the external fuel tank. Hundreds of tons of propellant ignited, tearing apart the shuttle.

One hundred seconds into the flight, the last bit of telemetry data was transmitted from the Challenger.

Issues for Discussion

1. What could NASA management have done differently?
2. What, if anything, could their subordinates have done differently?
3. What should Roger Boisjoly have done differently (if anything)? In answering this question, keep in mind that, at his age, the prospect of finding a new job if he was fired was slim. He also had a family to support.
4. What do you (the students) see as your future engineering professional responsibilities in relation to both being loyal to management and protecting the public welfare?

The Challenger disaster presents several issues that are relevant to engineers. These issues raise many questions that may not have any definite answers, but can serve to heighten the awareness of engineers when faced with a similar situation.

One of the most important is engineers who are placed in management positions. It is important that these managers not ignore their own engineering experience, or the expertise of their subordinate engineers. Often a manager, even if she has engineering experience, is not as up-to-date on current engineering practices as are the actual practicing engineers. She should keep this in mind when making any sort of decision that involves an understanding of technical matters.

Another issue is the fact that managers encouraged launching due to the fact that there was insufficient low-temperature data. Since there was not enough data available to make an informed decision, this was not, in their opinion, grounds for stopping a launch. This was a reversal in the thinking that went on in the early years of the space program, which discouraged launching until all the facts were known about a particular problem. This same reasoning can be traced back to an earlier phase in the shuttle program, when upper-level NASA management was alerted to problems in the booster design, yet did not halt the program until the problem was solved.

As engineers test designs for ever-increasing speeds, loads, capacities and the like, they must always be aware of their obligation to society to protect the public welfare. After all, the public has provided engineers, through the tax base, with the means for obtaining an education and, through legislation, the means to license and regulate themselves. In return, engineers have a responsibility to protect the safety and well-being of the public in all of their professional efforts. This is part of the implicit social contract all engineers have agreed to when they accepted admission to an engineering college. The first canon in the ASME Code of Ethics urges engineers to "hold paramount the safety, health, and welfare of the public in the performance of their professional duties." Every major engineering code of ethics reminds
engineers of the importance of their responsibility to keep the safety and well being of the public at the
top of their list of priorities. Although company loyalty is important, it must not be allowed to override
the engineer's obligation to the public. Marcia Baron, in an excellent monograph on loyalty, states: "It is
a sad fact about loyalty that it invites...single-mindedness. Single-minded pursuit of a goal is sometimes
delightfully romantic, even a real inspiration. But it is hardly something to advocate to engineers, whose
impact on the safety of the public is so very significant. Irresponsibility, whether caused by selfishness or
by magnificently unselfish loyalty, can have most unfortunate consequences."²

Annotated Bibliography and Suggested References

Feynman, Richard Phillips. *What Do You Care What Other People Think: Further Adventures of a
request of Sharath Bulusu, as being pertinent and excellent reading - 8-25-00.


United States Congress House Committee on Science and Technology. *Investigation of the Challenger
Accident: Hearings before the Committee on Science and Technology, US House of Representatives,

United States Congress House Committee on Science and Technology. *Investigation of the Challenger
Accident: Report of the Committee on Science and Technology, House of Representatives, Ninety-Ninth

United States Congress House Committee on Science, Space, and Technology. *NASA's Response to the
Committee's Investigation of the "Challenger" Accident: Hearing before the Committee on Science,
Space, and Technology, U.S. House of Representatives, One Hundredth Congress, First session,

United States Congress Senate Committee on Commerce, Science, and Transportation, Subcommittee on
Science, Technology, and Space. *Space Shuttle Accident: Hearings before the Subcommittee on Science,
Technology, and Space of the Committee on Commerce, Science, and Transportation, United States
Senate, Ninety-Ninth Congress, Second session, on space shuttle accident and the Rogers Commission

Notes


2. Baron, Marcia. *The Moral Status of Loyalty*. Illinois Institute of Technology: Center for the Study of
Ethics in the Professions, 1984, p. 9. One of a series of monographs on applied ethics that deal
specifically with the engineering profession. Provides arguments both for and against loyalty. 28 pages
with notes and an annotated bibliography.