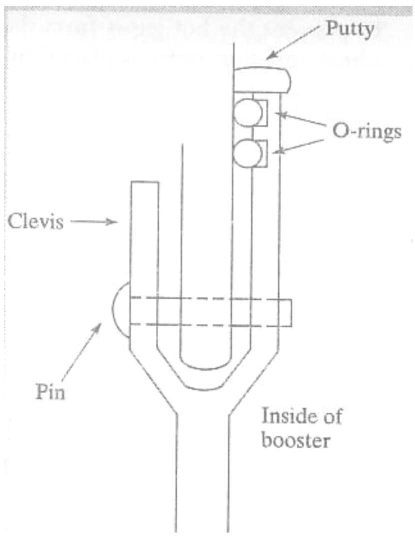
THE SPACE SHUTTLE CHALLENGER ACCIDENT

BACKGROUND

The space shuttle was designed to be a reusable launch vehicle. The vehicle consists of an orbiter, which looks much like a medium-sized airliner (minus the engines!), two solid-propellant boosters, and a single liquid-propellant booster. At takeoff, all of the boosters are ignited and lift the orbiter out of the earth’s atmosphere. The solid rocket boosters are only used early in the flight and are jettisoned soon after takeoff, parachute back to earth, and are recovered from the ocean. They are subsequently repacked with fuel and are reused. The liquid-propellant booster is used to finish lifting the shuttle into orbit, at which point the booster is jettisoned and burns up during reentry. The liquid booster is the only part of the shuttle vehicle that is not reusable. After completion of the mission, the orbiter uses its limited thrust capabilities to reenter the atmosphere and glides to a landing.

The accident on January 28, 1986 was blamed on a failure of one of the solid rocket boosters. Solid rocket boosters have the advantage that they deliver far more thrust per pound of fuel than do their liquid-fueled counterparts, but have the disadvantage that once the fuel is lit, there is no way to turn the booster off or even to control the amount of thrust produced. In contrast, a liquid-fuel rocket can be controlled by throttling the supply of fuel to the combustion chamber or can be shut off by stopping the flow of fuel entirely.

In 1974, the National Aeronautics and Space Administration (NASA) awarded the contract to design and build the solid rocket boosters for the shuttle to Morton Thiokol. The design that was submitted by Thiokol was a scaled-up version of the Titan missile, which had been used successfully for many years to launch satellites. This design was accepted by NASA in 1976. The solid rocket consists of several cylindrical pieces that are filled with solid propellant and stacked one on top of the other to form the completed booster. The assembly of the propellant-filled cylinders was performed at Thiokol’s plant in Utah. The cylinders were then shipped to the Kennedy Space Center in Florida for assembly into a completed booster.

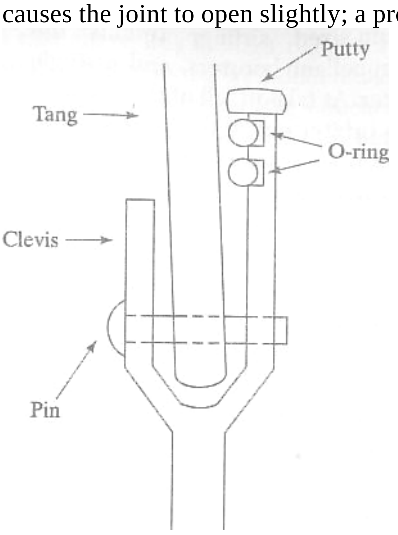


A key aspect of the booster design are the joints where the individual cylinders come together, known as the field joints, illustrated schematically in Figure 1.la. These are tang and clevis joints, fastened with 177 clevis pins. The joints are sealed by two O-rings, a primary and a secondary. The O-rings are designed to prevent hot gases from the combustion of the solid propellant from escaping. The O-rings are made from a type of synthetic rubber and so are not particularly heat resistant.

To prevent the hot gases from damaging the O-rings, a heat-resistant putty is placed in the joint. The Titan booster had only one O-ring in the field joint. The second O-ring was added to the booster for the shuttle to provide an extra margin of safety since, unlike the Titan, this booster would he used for a manned space craft.

EARLY PROBLEMS WITH THE SOLID ROCKET BOOSTERS

Problems with the field-joint design had been recognized long before the launch of the Challenger. When the rocket is ignited, the internal pressure causes the booster wall to expand outward, putting pressure on the field joint. This pressure causes the joint to open slightly; a process called “joint rotation,’ illustrated in Figure 1.lb. The joint was designed so that the internal pressure pushes on the putty, displacing the primary O-ring into this gap, helping to seal it. During testing of the boosters in 1977, Thiokol became aware that this joint-rotation problem was more severe than on the Titan and discussed it with NASA, Design changes were made, including an increase in the thickness of the O-ring, to try to control this problem.



Further testing revealed problems with the secondary seal, and more changes were initiated to correct that problem. In November of 1981, after the second shuttle flight, a post-launch examination of the booster field joints indicated that the O-rings were being eroded by hot gases during the launch. Although there was no failure of the joint, there was some concern about this situation, and Thiokol looked into the use of different types of putty and alternative methods for applying it to solve the problem. Despite these efforts, approximately half of the shuttle flights before the Challenger accident had experienced some degree of O-ring erosion. Of course, this type of testing and redesign is not unusual in engineering. Seldom do things work correctly the first time, and modifications to the original design are often required.

It should be pointed out that erosion of the O-rings is not necessarily a bad thing. Since the solid rocket boosters are only used for the first few minutes of the flight, it might be perfectly acceptable to design a joint in which O-rings erode in a controlled manner. As long as the O-rings don't completely burn through before the solid boosters run out of fuel and are jettisoned, this design should be fine. However, this was not the way the space shuttle was designed, and O-ring erosion was one of the problems that the Thiokol engineers were addressing.

The first documented joint failure came after the launch on January 24, 1985, which occurred during very cold weather. The post-flight examination of the boosters revealed black soot and grease on the outside of the booster, which indicated that hot gases from the booster had blown by the O-ring seals. This observation gave rise to concern about the resiliency of the O-ring materials at reduced temperatures Thiokol performed tests of the ability of the O-rings to compress to fill the joints and found that they were inadequate. In July of 1985, Thiokol engineers redesigned the field joints without O-rings. Instead, they used steel billets, which should have been better able to withstand the hot gases. Unfortunately, the new design was not ready in time for the Challenger flight in early 1986.

THE POLITICAL CLIMATE

To fully understand and analyze the decision making that took place leading to the fatal launch, it is important also to discuss the political environment under which NASA was operating at the time, NASA'S budget was determined by Congress, which was becoming increasingly unhappy with delays in the shuttle project and shuttle performance, which wasn't meeting initial promises. NASA had billed the shuttle as a reliable, inexpensive launch vehicle for a variety of scientific and commercial purposes, including the launching of commercial and military satellites. It had been promised that the shuttle would be capable of frequent flights (several per year) and quick turnarounds and would be competitively priced with more traditional non-reusable launch vehicles. NASA was feeling some urgency in the program because the European Space Agency was developing what seemed to be a cheaper alternative to the shuttle, which could potentially put the shuttle out of business.

These pressures led NASA to schedule a record number of missions for 1986 to prove to Congress that the program was on track. Launching a mission was especially important in January 1986, since the previous mission had been delayed numerous times by both weather and mechanical failures. NASA also felt pressure to get the Challenger launched on time so that the next shuttle launch, which was to carry a probe to examine Halley's Comet, would be launched before a Russian probe designed to do the same thing. There was additional political pressure to launch the Challenger before the upcoming state-of-the-union address, in which President Reagan hoped to mention the shuttle and a special astronaut—the first teacher in space, Christa McAuliffe - in the context of his comments on education.

THE DAYS BEFORE THE LAUNCH

Even before the accident, the Challenger Launch didn't go off without a hitch, as NASA had hoped. The first launch date had to be abandoned due to a cold front expected to move through the area. The front stalled and the launch could have taken place on schedule. But the launch had already been postponed in deference to Vice President George Bush, who was to attend. NASA did not want to antagonize Bush, a strong NASA supporter, by postponing the launch due to inclement weather after he had arrived. Launch of the shuttle was further delayed by a defective micro switch in the hatch-locking mechanism. When this problem was resolved, the front had changed course and was now moving through the area. The front was expected to bring extremely cold weather to the launch site, with temperatures predicted to be in the low 20's (ºF) by the new launch time

Given the expected cold temperatures, NASA checked with all of the shuttle contractors to determine if they foresee any problems with launching the shuttle in cold temperatures. Alan McDonald, the director of Thiokol's Solid Rocket Motor Project, was concerned about the cold weather problems that had been experienced with the solid rocket boosters. The evening before the scheduled launch, a teleconference was arranged between engineers and management from the Kennedy Space Center, NASA'S Marshall Space Flight Center in Huntsville, Alabama, and Thiokol in Utah to discuss the possible effects of cold temperatures on the performance of the solid rocket boosters. During this teleconference, Roger Boisjoly and Arnie Thompson, two Thiokol engineers, who had worked on the solid-propellant booster design, gave an hour-long presentation on how the cold weather would increase the problems of joint rotation and sealing of the joint by the O-rings.

Their point was that the lowest temperature at which the shuttle had previously been launched was 53°F, on January 24, 1985, when there was blow-by of the O-rings. The O-ring temperature at Challenger's expected launch time the following morning was predicted to be 29°F, far below the temperature at which NASA had previous experience. After the engineer's presentation, Bob Lund, the vice president for engineering at Morton Thiokol, presented his recommendations. He reasoned that since there had previously been severe O-ring erosion at 53°F and the launch would take place at significantly below this temperature where no data and no experience were available. NASA should delay the launch until the O-ring temperature could be at least 53°F. Interestingly, in the original design, it was specified that the booster should operate properly down to an outside temperature of 31°F.

Larry Mulloy, the Solid Rocket Booster project manager at Marshall and a NASA employee, correctly pointed out that the data were inconclusive and disagreed with the Thiokol engineers. After some discussion, Mulloy asked Joe Kilminster, an engineering manager working on the project, for his opinion. Kilminster backed up the recommendation of his fellow engineers. Others from Marshall expressed their disagreement with the Thiokol engineer's recommendation, which prompted Kilminster to ask to take the discussion off line for a few minutes. Boisjoly and other engineers reiterated to their management that the original decision not to launch was the correct one.

A key fact that ultimately swayed the decision was that in the available data, there seemed to be no correlation between temperature and the degree to which blow-by gasses had eroded the O-rings in previous launches. Thus, it could be concluded that there was really no trend in the data indicating that launch at the expected temperature would necessarily be unsafe. After much discussion, Jerald Mason, a senior manager with Thiokol, turned to Lund and said, "Take off your engineering hat and put on your management hat," a phrase that has become famous in engineering ethics discussions. Lund reversed his previous decision and recommended that the launch proceed. The new recommendation included an indication that there was a safety concern due to the cold weather, but that the data were inconclusive and the launch was recommended. McDonald, who was in Florida, was surprised by this recommendation and attempted to convince NASA to delay the launch, but to no avail.

THE LAUNCH

Contrary to the weather predictions, the overnight temperature was 8°F, colder than the shuttle had ever experienced before. In fact, there was a significant accumulation of ice on the launchpad from safety showers and fire hoses that had been left on to prevent the pipes from freezing. It has been estimated that the aft field joint of the right-hand booster was at 28°F.

NASA routinely documents as many aspects of launches as possible. One part of this monitoring is the extensive use of cameras focused on critical areas of the launch vehicle. One of these cameras, looking at the right booster, recorded puffs of smoke coming from the aft field joint immediately after the boosters were ignited. This smoke is thought to have been caused by the steel cylinder of this segment of the booster expanding outward and causing the field joint to rotate. But, due to the extremely cold temperature, the O-ring didn't seat properly. The heat-resistant putty was also so cold that it didn't protect the O-rings, and hot gases burned past both O-rings. It was later determined that this blow-by occurred over 70° of arc around the O-rings.

Very quickly, the field joint was sealed again by byproducts of the solid rocket-propellant combustion, which formed a glassy oxide on the joint. This oxide formation might have averted the disaster had it not been for a very strong wind shear that the shuttle encountered almost one minute into the flight. The oxides that were temporarily sealing the field joint were shattered by the stresses caused by the wind shear. The joint was now opened again, and hot gases escaped from the solid booster. Since the booster was attached to the large liquid-fuel booster, the flames from the solid-fuel booster blow-by quickly burned through the external tank. The liquid propellant was ignited and the shuttle exploded.

THE AFTERMATH

As a result of the explosion, the shuttle program was grounded as a thorough review of shuttle safety was conducted. Thiokol formed a failure-investigation team on January 31, 1986 which included Roger Boisjoly. There were also many investigations into the cause of the accident, both by the contractors involved (including Thiokol) and by various government bodies. As part of the governmental investigation, President Reagan appointed a blue-ribbon commission, known as the Rogers commission, after its chair. The commission consisted of distinguished scientists and engineers who were asked to look into the cause of the accident and to recommend changes in the shuttle program. One of the commission members was Richard Feynman, a Nobel Prize winner in physics, who ably demonstrated to the country what had gone wrong. in a demonstration that was repeatedly shown on national news programs, he demonstrated the problem with the O-rings by taking a sample of the O-ring material and bending it, The flexibility of the material at room temperature was evident, He then immersed it in ice water. When Feynman again bent the O-ring, it was very clear that the resiliency of the material was severely reduced, a very clear demonstration of what happened to the O-rings on the cold launch date in Florida.

As part of the commission hearings, Boisjoly and other Thiokol engineers were asked to testify. Boisjoly handed over to the commission copies of internal Thiokol memos and reports detailing the design process and the problems that had already been encountered. Naturally, Thiokol was trying to put the best possible spin on the situation, and Boisjoly's actions hurt this effort. According to Boisjoly, after this action he was isolated within the company, his responsibilities for the redesign of the joint were taken away, and he was subtly harassed by Thiokol management.

Eventually; the atmosphere became intolerable for Boisjoly and he took extended sick leave from his position at Thiokol. The joint was redesigned, and the shuttle has since flown numerous successful missions. However, the ambitious launch schedule originally intended by NASA has never been met. It was reported in 2001 that NASA has spent $5 million to study the possibility of installing some type of escape system to protect the shuttle crew in the event of an accident. No decision has yet been made. Possibilities include ejection seats or an escape capsule that would work during the first three minutes of flight. These features were incorporated into earlier manned space vehicles and in fact were in place on the shuttle until 1982. Whether such a system would have saved the astronauts aboard the Challenger is unknown.

SPACE SHUTTLE CHALLENGER ACCIDENT: WHO'S WHO

ORGANIZATIONS

NASA	The National Aeronautics and Space Administration, responsible for space exploration. The space shuttle is one of NASA's programs.
Marshall Space Flight Center	A NASA facility that was In charge of the solid rocket booster development for the shuttle.
Morton Thiokol	A private company that won the contract from NASA for building the solid rocket boosters for the shuttle.

PEOPLE

NASA	
Larry Mulloy	Solid Rocket Booster Project manager at Marshall
Morton Thiokol	
Roger Boisjoly and Anile Johnson	Engineers who worked on the Solid Rocket Booster Development Program.
Joe Kilminster	Engineering manager on the Solid Rocket Booster Development Program
Alan McDonald	Director of the Solid Rocket Booster Project.
Bob Lund	Vice president for engineering
Jerald Mason	General manager.

ISSUES

1. The astronauts on the Challenger mission were aware of the dangerous nature of riding a complex machine such as the space shuttle, so they can be thought of as having given informed consent to participating in a dangerous enterprise. What role did informed consent play in this case? Do you think that the astronauts had enough information to give informed consent to launch the shuttle that day?
2. Can an engineer who has become a manager truly ever take off her engineer's hat? Should she?
3. Some say that the shuttle was really designed by Congress rather than NASA. What does this statement mean! What are the ramifications if this is true?
4. Aboard the shuttle for this flight was the first teacher in space. Should civilians be allowed in what is basically an experimental launch vehicle? At the time, many felt that the placement of a teacher on the shuttle was for purely political purposes. President Reagan was widely seen as doing nothing while the American educational system decayed. Cynics felt that the teacher-in-space idea was cooked up as a method of diverting attention from this problem and was to be seen as Reagan's doing something for education while he really wasn't doing anything. What are the ethical implications if this scenario is true?
5. Should a launch have been allowed when there was no test data for the expected conditions? Keep in mind that it is probably impossible to test for all possible operating conditions. More generally, should a product be released for even when It hasn't been tested over all expected operational conditions? When the data is inconclusive, which way should the decision go?
6. During the aftermath of the accident. Thiokol and NASA investigated possible causes of the explosion. Boisjoly accused Thiokol and NASA of intentionally downplaying the problems with the O-rings while looking for other causes of the accident. If true, what are the ethical implications of this type of investigation?
7. It might be assumed that the management decision to launch was prompted in part by concerns for the health of the company and the space program as a whole. Given the political climate at the time of the launch, if problems and delays continued, ultimately Thiokol might have lost NASA contracts, or NASA budgets might have been severely reduced. Clearly, this scenario could have led to the loss of many jobs at Thiokol and NASA. How might these considerations ethically be factored into the decision?
8. Engineering codes of ethics require engineers to protect the safety and health of the public in the course of their duties. Do the astronauts count as the "public" in this context?
9. What should NASA management have done differently? What should Thiokol management have done differently?
10. What else could Boisjoly and the other engineers at Thiokol have done to prevent the launch from occurring?