Case Study 1

The Challenger Space Shuttle disaster and the Solid-Fuel Rocket Booster (SRB) project

Overview

On 28 January,1986 the Challenger space shuttle blew up 73 seconds after launch. Seven lives and three billion dollars worth of equipment was lost. The Challenger accident was the result of a faulty sealing system which allowed exhaust flames from the Solid-Fuel Rocket Boosters (SRB) to vent directly on the external tank, rupturing the tank and causing the explosion.

NASA identified the failure due to the improper sealing of the O-rings, the giant black rubber loops that help seal the segments of the SRBs. The O-ring is made of a fluoroelastomer, which seals the joint between two solid rocket booster sections. An elastomer is a material that can be deformed dramatically and recover its shape completely. A rubber band is an example of an elastomer.

In almost half of the shuttle flights there was O-ring erosion in the booster field joints. The launch took place in untested temperature conditions and in spite of serious warnings on the part of the engineers of Thiokol, the company that manufactured the SRBs. The sequence of events that led to the unfortunate events is examined in order to draw the necessary conclusions.

NASA was very anxious to proceed with the launch for a variety of reasons including, economic considerations and political pressure. To justify its budget NASA had scheduled a large number of missions in 1986. It was vital for the Challenger to be launched so that there would be enough time to refurbish the launch pad to prepare it for the next launch. The European Space Agency was providing added competition and there was political pressure for the Challenger to be in space when the president of the US gave the State of the Union address.

There were plenty of advanced warnings regarding the SRBs, from previous missions. Concerns had been voiced by Thiokol, the SRB manufacturing company, as to whether the fatal launch should have taken place. The cold weather, some of the coldest in Florida history, provided uncharted waters for the operation of the SRBs.

What went wrong? Why did NASA launch in spite of the evidence and warnings from Thiokol engineers? Should the launch have been cancelled?

Challenger space shuttle: A project success or a program failure?

At first sight, the Challenger incident can only be regarded as a failure. Loss of life and loss of equipment worth billions of dollars can only be associated with bad news. The television pictures of the Challenger's explosion made their way round the world and were broadcast over and over as the leading news story and will indelibly remain in people's minds for many years to come.

Before arriving at a verdict about the Challenger explosion, it is necessary to examine the various events that led to NASA's twenty-fifth shuttle mission, which proved to be fatal for the Challenger. Is it possible that the SRB project was a success, while the overall program was a failure?

Background information

To better understand the conditions that existed at the time of the launch some background information is presented below that includes:

- Technical information relating to the SRB project.
- Description of the program environment.
- Management restrictions associated to funding issues.
- Invisible political pressure.

The reusable space shuttle

In the post-Apollo era of the lunar landing the idea of a reusable space shuttle was born. The goal was to make access to space a routine matter, similar to flying an airplane. The space shuttle had to be reusable and economical to develop and operate. The design of the space shuttle was shaped by engineering considerations but also by pressure from the White House and Congress to reduce the cost.

There are three main components of a space shuttle:

1. The orbiter.
2. The external fuel tank.
3. The solid-fuel rocket boosters.

The orbiter is the vehicle which transports the astronauts into space. The orbiter is propelled by thrusters at the back of the orbiter and the purpose of the external fuel tank is to pump a combination of hydrogen and oxygen fuel to the orbiter's thrusters. The SRBs provide the majority of the thrust in order to place the orbiter in orbit. When the orbiter is close to orbit, the SRBs detach and the orbiter is propelled only by the thruster. The SRBs fall to earth, where they are collected to be reused in future missions. When the orbiter is in orbit the external fuel tank is also detached. The external fuel tank is not reused.

SRB history

The SRB is at the center of the Challenger disaster and its history needs to be examined. The SRB is a scaled up version of a Titan missile which had been used successfully for years. In general, solid-fuel rockets produce much more thrust than liquid-fuel rockets. One of their drawbacks is that once the solid-fuel rocket has been ignited they cannot be turned off or even controlled. It is therefore extremely important that the SRBs are properly designed, because if something goes wrong there is no second chance.

Each of the two SRBs was 149ft (45.42m) long and 12ft (3.7m) in diameter. Before ignition each booster rocket weighs 2 million pounds (0.9 million kilograms.) The shuttle's two solid-fuel booster rockets provide the main power to lift the orbiter and its external liquid-fuel tank to a height of around 28 miles (45 km.)

The life of each booster is around two minutes. When the SRBs are nearly empty of fuel they disengage from the space shuttle and will eventually fall into the Atlantic Ocean where they will be collected for use in a future mission.

A chronological history of the SRB used in the Challenger space shuttle is indicated below:

- 1974: The contract for building the SRBs was awarded to Thiokol.
- 1976: NASA accepted the SRB design.
- 1977: Joint rotation problems were discovered.
- 1981: O-ring erosion detected after the second shuttle flight.
- 1985: The worst problem relating to the O-rings was exhibited after the January 24, 1985 shuttle flight.
- 1985: On August 19, 1985, four months prior to the Challenger disaster, the NASA management was briefed on the booster problems.
- 1986: On January 27, 1986, a few hours prior to the launch, a teleconference took place between NASA and Thiokol to discuss the effects of cold temperature on the SRB performance.

Events leading to the launch

The decision by NASA to launch the Challenger space shuttle on 28 January, 1986 was controversial at best. There were plenty of warning signs during the launches that preceded the launch. In November 1981, after the shuttle's second mission, the O-rings seemed to have been eroded by hot gasses. The January 24, 1985 launch took place in similar cold-weather conditions as the fatal launch of January 28, 1986. After the mission the booster joints were examined by engineers at Thiokol who found traces of soot and grease caused by passage of hot combustion gases past the O-ring before it has completely sealed the joint. As a result Thiokol started studying the resiliency of O-rings at low temperatures. In July 1985 Thiokol ordered steel billets which would be used for a redesigned case field joint. The steel billets were not ready at the time of the Challenger launch.

The events a few days prior to the fatal launch are worth looking into. The Challenger was first scheduled to be launched on 22 January at 15:43. This was rescheduled for 23 January and then again rescheduled for 24 January. The launch was reset for 25 January because of bad weather at abort landing site in Dakar, Senegal. Launch was rescheduled for 27 January at 09:37 due to the prediction of unacceptable weather at Kennedy Space Center. Launch was delayed for 24 hours when ground servicing equipment hatch closing fixture could not be removed from orbiter hatch.

In a conference call the night of the 27 January, 1986, engineers at Thiokol recommended against launching below 53^{o}F, which was the coldest temperature at which a previous flight had launched. On the night before the launch, the temperature was expected to be as low as 18^{o}F, more than 30 degrees colder than any other launch. Thiokol engineering was overruled by its management and the go-ahead was given to proceed with the launch.

Second by second account of the Challenger launch

At 11:38 EST on January 28, 1986, the Challenger took off from the launch pad at Kennedy Space Center in Florida. The key events until its explosion are indicated below:

- 0.68 sec after ignition: Black smoke coming from bottom field joint of the right SRB, indicating that the rubber O-rings were being burned.
- 2.70 sec: Last puff of smoke seen.
- 45.00 sec: Three bright flashes shot across the Challenger's wings. Each of the flashes lasted 1/13 of a second and were unrelated to the events leading to the explosion.
- 58.80 sec: With enhanced film a flame was seen coming from the right SRB.
- 59.30 sec: Without enhanced film the flame could be seen increasing in size and beginning to push against the external tank.
- 64.70 sec: The first sight that the flame was hitting the external tank. There is also a change in the color of the flame indicating that the flame was being produced by the mixing with another substance. In this case the other substance was liquid Hydrogen stored in the external tank.
- 72.00 sec: Within the next 2 seconds there is sudden chain of events that destroyed the Challenger and killed its crew onboard. The Challenger was traveling at a speed of Mach 1.92 and a height of 46,000 feet.
- 73.62 sec: The last transmission from the Challenger.

Causes of the Challenger accident

A commission was appointed by the president of the US to investigate the accident. The Rogers Commission as it was called addressed the problems in the following two areas:

1. Mechanical problems.
2. Administrative problems.

The mechanical fault that led to the explosion of the Challenger was identified in the right solid rocket booster. A field joint between the sections of the SRB allowed exhaust flames to leak through the field joint. A field joint is a joint between the sections of the SRB that was assembled in the field at the Kennedy Space Center during the final construction of the booster. The leaked flames impinged upon the external fuel tank. The flames managed to penetrate and ignite the fuel in the external fuel tank, causing the explosion.

The failure of the sealing system on the field joint that led to the explosion of the Challenger was a result of the combination of four problems:

1. The tendency for holes to form in the putty which protected the seals from the high temperature exhaust gases.
2. The decomposition of the seals due to contact with the hot exhaust gases.
3. An instantaneous increase in the size of the gap between mating sections of the booster caused by the high internal pressures of the SRB.
4. The inability of the seal to quickly respond to the changing gap size during low temperature operating conditions.

The Administrative problems were more profound due to the simple fact that all mechanical problems associated with the field joint had been identified by the Thiokol engineers. All problems were identified as a potential risk, but there was difficulty in communicating these problems to the managers who were responsible for the launch. The decision to launch the Challenger despite the identified risks was a combination of poor communication and a difference in the evaluation of the risk.

Risk issues

Risk is largely subjective. If it wasn't subjective, it would be possible to accurately identify the risk and account for its effect, or even take the appropriate measures for eliminating the risk.

In the case of the SRB project, risk was assessed mainly by two categories of people, the engineers and the managers. Engineers based their risk assessment largely on their technical experience and facts. Managers were more inclined to take a risk due mainly to the fact that they were a bit removed from the technical issues and due to the fact that their job was to ensure that business proceeded without delays.

It was clear that engineers and managers were not of the same view regarding the risk associated with the use of the O-rings at untested low temperatures. Managers were happy to accept low temperature tests that were performed in laboratory conditions, while on the other hand engineers dismissed these tests as unrealistic.

There was no way to get rid of the subjective nature in evaluating risk since at both NASA and Thiokol there was no method for quantifying risk. On the one hand you had the engineers saying "I believe there is a big danger" and on the other hand the managers were saying "I believe that there is a smaller danger."

It may be amazing to note that NASA did not employ a quantitative method of risk assessment for such a high-profile project. The main reason is the expense associated with the data collection and statistical model generation. NASA employed no engineers trained in statistical sciences.

Thiokol managers held misconceptions regarding the safety issues related to the O-rings. They believed that the SRBs could be operated at temperatures ranging between 31^{o}F and 99^{o}F, although Thiokol engineering noted that there was no real-condition testing at these temperatures. The debate centered mainly on the lowest temperatures at which the SRBs could operate, since neither Thiokol nor NASA had official launch data that matched the conditions of the fatal launch.

There were other reasons who contributed to the optimistic approach by management compared to that by engineering. There was clear evidence that there was O-ring erosion on previous shuttle flights. Since this did not give rise to any catastrophic results, a false sense of security was developed. O-ring erosion was therefore something to be expected. The fact that there were relatively few accidents at NASA re-enforced the subjective approach to risk assessment. Since the risk assessors were right on so many occasions, what were the chances of being wrong on this occasion?

The difference in the manner that risk is assessed by managers and engineers lies primarily in their objectives. Managers are in the business of management or administration, while engineers have more interaction with the day-to-day activities. Managers needed to keep the shuttle program going in order to be able to justify their budget and were willing to take bigger risks.

Communication issues

The Roger Commission identified a breakdown in the communication as a contributing factor in the Challenger accident. Important information was not from Thiokol engineering regarding the SRBs did not find its way to the appropriate people at NASA in charge of the launch.

The management structure that was followed at both NASA and Thiokol was that followed by the traditional organization, with a single chain of command. Every employee could report to his manager and his manager to his manager and so on. This reporting structure is inefficient and is not suited for communicating important issues quickly to the appropriate management level for consideration.

As indicated in figure Case Study 1-1, the only way that a Thiokol engineer could voice his concerns to the NASA officials who were directly responsible for the launch, was first through the Thiokol hierarchy and then through the NASA hierarchy. The management procedures that were in place did not allow a Thiokol engineer who knew the ins and outs of the SRB to communicate with the launch manager at NASA.

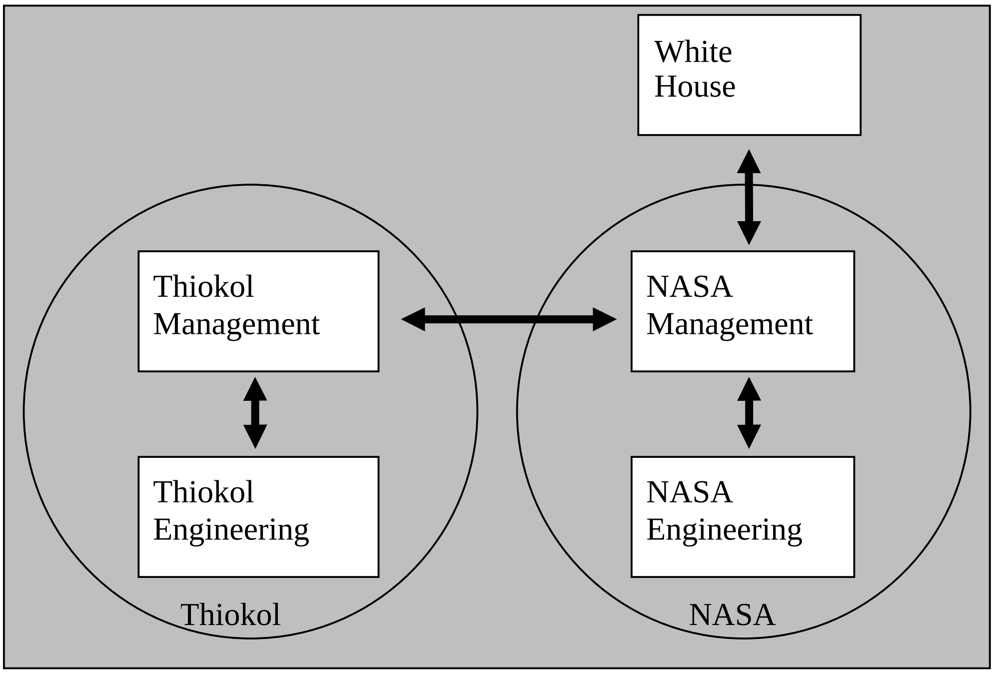

Figure Case Study 1-1

In the months preceding the launch, the Thiokol engineers warned about the impending danger. An excerpt from one of the communications summarizes their position.

"*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. … 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*."

Even on the eve of the launch, the Thiokol engineers warned against launching the Challenger below 53^{o}F, which was the lowest temperature that a launch had taken place. Their recommendation was not followed.

It is apparent that Thiokol engineering was aware of the problem associated with sealing the field joint. To make matters worse Thiokol engineering felt that Thiokol management had an inaccurate understanding of the importance of the O-ring problem.

In a conference call the night of the 27 January, 1986, engineers at Thiokol recommended against launching below 53^oF, which was the temperature at which a previous flight had launched. On the night before the launch temperatures were expected to be as low as 18^oF, more than 30 degrees colder than any other launch. Thiokol engineering was overruled by its management and the go-ahead was given to proceed with the launch. Yet no Thiokol engineer risked his job by picking up the telephone to inform the NASA manager responsible for the launch that the launch should be cancelled.

The communication inside NASA and Thiokol regarding the SRB project resembled in many cases the "telephone game" played by children. In the telephone game a child whispers to his neighbor child a message, who in turn whispers the message to the next child and so on until the message reaches the last child. By this time the original message has undergone a significant change, due mainly to inefficiency.

Information that was passed up the hierarchy at Thiokol to NASA officials regarding the SRB was distorted to fit the interests of management. In many cases the information was silenced and lost in the chain of command. Basic information regarding the SRBs and the fact that Thiokol engineers opposed the launch of the Challenger never reached the NASA officials responsible for the launch.

Discussion points

1. Identify the project.
2. Identify the players.
3. Chronological account of events.
4. Description of environment on the day of the launch.
5. Pressure to launch: There was a push to have 15 shuttle launches in 1986 and 24 launches by 1990.
6. Communication issues: Communication within Thiokol and between Thiokol and NASA. Management issues where reporting could only be done one level up.
7. Pressure to launch so that the launch schedule would proceed uninterrupted.
8. Political pressure to launch so that Challenger was to be in orbit while President Reagan gave the State of the Union address.

9. Risk: There was no process in place to quantify risk. Managers and Engineers had differing views based largely on their objectives.
10. Identify the interdependencies between the project and the project environment.
11. Was NASA taking an acceptable risk?
12. Why did NASA managers together with Thiokol managers overrule Thiokol engineers?
13. Was there miscommunication between NASA and Thiokol?
14. What were the causes of the accident?
15. Should NASA have proceeded with the launch?
16. Was there ample information to warrant the cancellation of the launch?
17. Was the SRB project a success or a failure?