Explosion of the Space Shuttle Challenger

[January 28, 1986, USA]

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As people all over the world watched on TV, NASA's space shuttle Challenger (Fig. 1) exploded immediately after launch, and took lives of all 7 members of the crew. The causes were loss of elasticity in an o-ring due to low temperature and fuel leak due to faulty design.

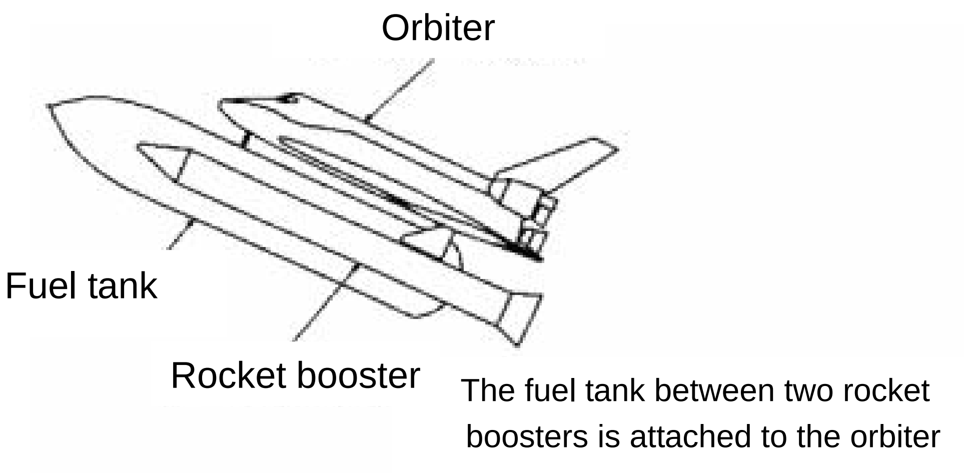

Fig. 1Overview of the space shuttle [2]

1. Event

As people all over the world watched on TV, the space shuttle Challenger of United States NASA (National Aeronautics and Space Administration) exploded shortly after the launch, and took lives of all 7 members of the crews.

2. Course

On January 28, 1986, the space shuttle Challenger developed flame on the side of the Solid Rocket Booster shown in Fig. 1 (Photo 1, arrowed) immediately after the launch, and exploded soon after.

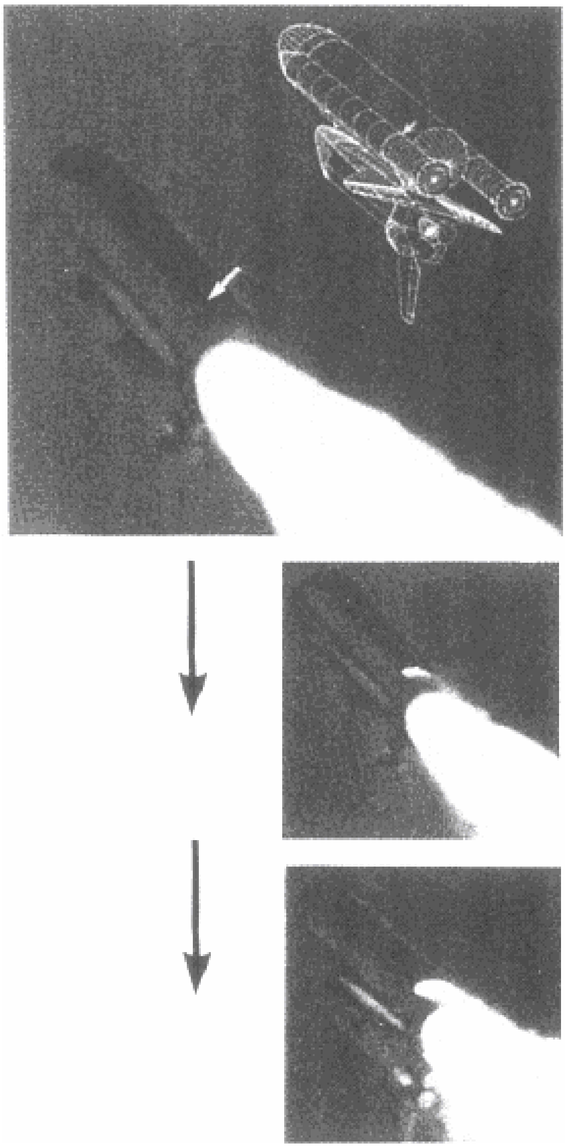

Photo 1. Explosion [2]

The above shows pictures of the Orbiter attached facing down. Here, the black smoke is spurting from the rocket booster in front due to the gas leak from the arrowed area, and the picture at the bottom shows white smoke coming out.

3. Cause

Feynman, a member of the Presidential Commission headed by William Rogers, discovered the main cause of the explosion as follows:

1) There were two solid Rocket Boosters on this shuttle for shooting the shuttle into orbit. Some assembly was necessary for these Solid Rocket Boosters at the launch site and O-rings (as shown in Fig. 2) were used in the joint area. (1/4 inch thickness and 12 feet in diameter). The ambient temperature at the day of the launch was –1 to 2 degree Celsius (36 °F), about 13 to 14 degrees colder than the

next coldest previous launch. Due to the cold weather, the o-rings stiffened and lost elasticity causing seal failure. It is presumed that fuel leaked from the gas leak inspection hole was ignited by flame from the aft field, and resulting in an explosion. Photo 2 shows black smoke puffing due to the gas leak from the booster before the launch (arrow at right-bottom corner of the photo). In order to prove this, Feynman did the experiment at a public meeting placing an o-ring in ice water to prove the loss of elasticity in the o-ring.

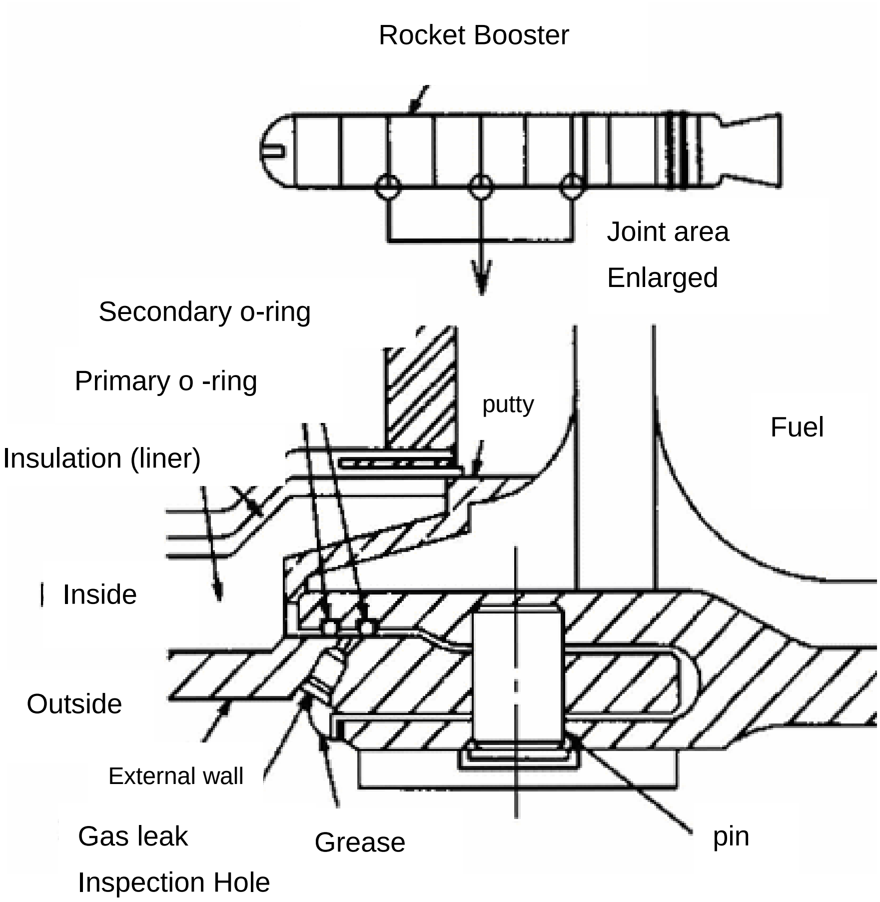

Fig. 2, Structure of the Joint area of the Rocket Booster [2]

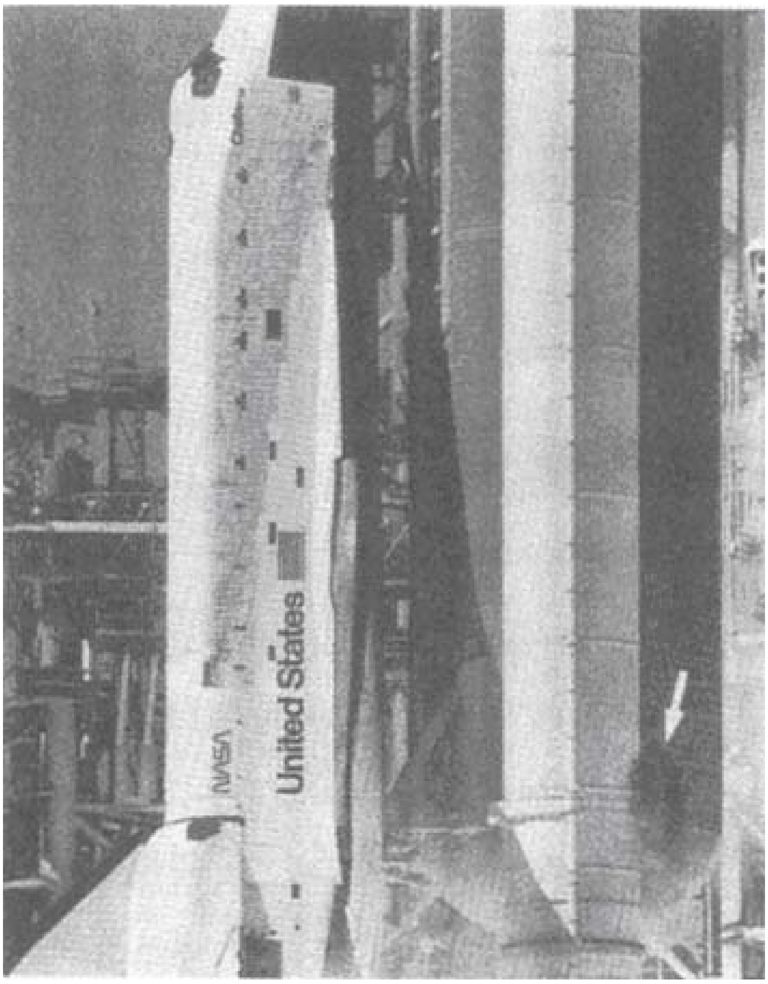

Photo 2, Black smoke photographed from the launch pad [2]

2) The investigation has shown that the o-ring manufacturer and NASA knew the problem with o-ring elasticity at low temperature, and the launch continued in spite of the manufacturer's suggestion of canceling the launch.
3) The direct cause of the o-ring seal failure was loss of elasticity due to low temperature, but faulty design was also a contributing factor. When chamber pressure in the rocket booster increased during use, the external walls between joints expanded, called "joint rotation" phenomenon, because the walls of the joint area was thicker than the external walls between the joint areas. In this situation, (shown in Fig. 3) moment of inertia occurs to break the joint where the o-ring seals. In addition, there were some distortions from the previous use on the rocket boosters. Those distortions were corrected before re-use but there were still some problems which were not completely corrected and caused gaps in the seal area. They knew these possibilities, but no effective solutions took place.

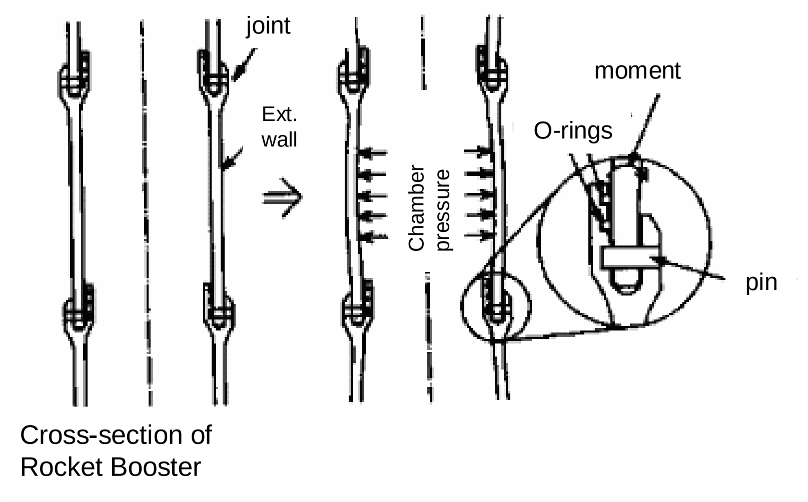

Fig. 3, Joint Rotation [2]

4) The analysis showed that in addition to these technical problems, there were other problems such as insufficient communication between the management and engineers at the site within NASA. Another problem was pressure on NASA to ignore some technical issues in order to meet the following year's budget.

4. Immediate Actions

After this accident, the Presidential Committee was formed to investigate the cause of the accident and former Secretary of State, Rogers, was appointed as the chairman. Dr. Feynman, who is the author of this report's references, was also appointed as one of the commissioners and provided significant contribution to the investigation. In order to find the cause of the accident and to take necessary measures, the launch of shuttles were put on hold for two years. This delay had quite an impact on the United States' Space Plan.

5. Countermeasure:

A. Countermeasures for fuel leaks (Fig. 4)

1) J-shape grooved adhesive seals replaced the previous putty seals. Even if the chamber pressure increased after launch, the pressure would go to the J-shape groove and improves the seal effect.
2) The seal area had an interference with the o-ring added in order to decrease gap against joint rotation phenomenon.
3) Heaters were installed to avoid loss of o-ring elasticity
4) Gas leak inspection holes were added to improve the confirmation of o-ring seal function.

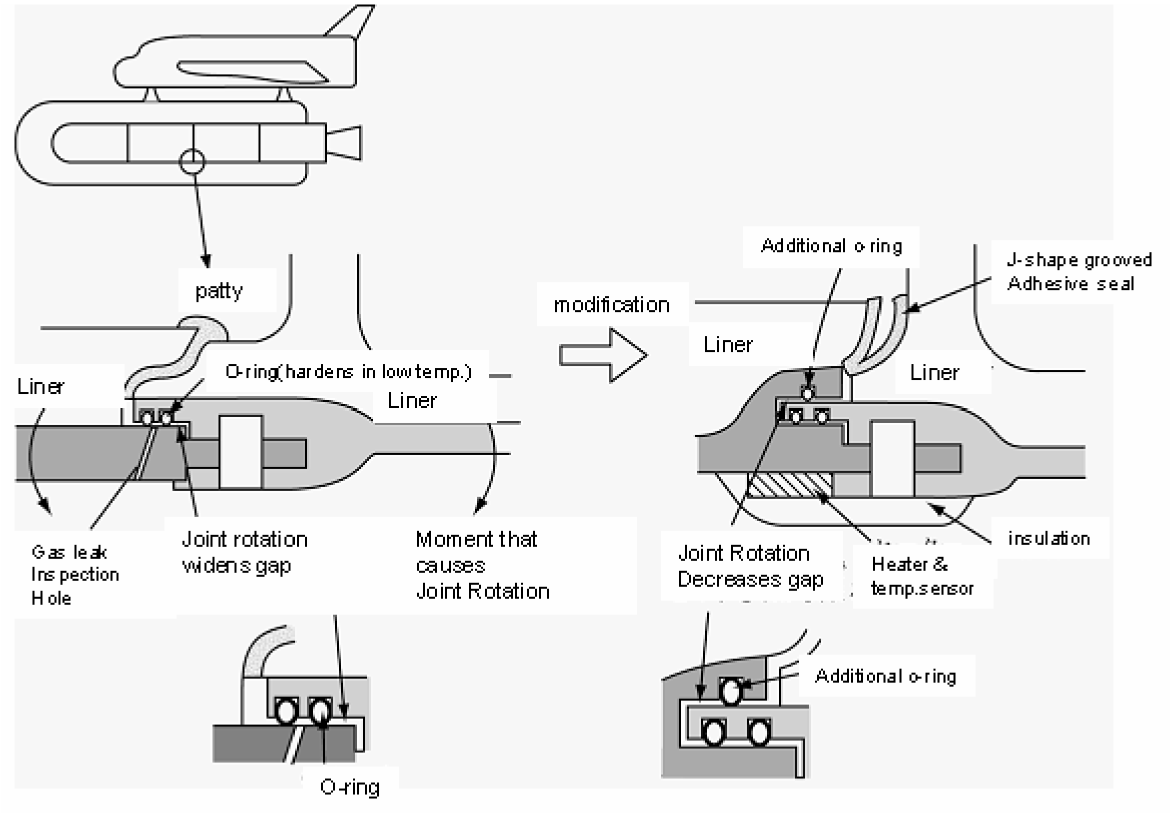

Fig. 4, Fuel Leak Prevention after the explosion of Space Shuttle Challenger [5]

B. Improvements in management aspects

1) Reconstruct shuttle project management system (Clarification of authorities and responsibilities)
2) Improve risk evaluation and risk analysis in order to secure safe flights
3) Improve communication between on-site engineers and management
4) Understanding and responding to the deterioration level associated with flight history.

6. Summary

In addition to the faulty design allowing gas leak from the joints, the o-ring lost its elasticity because of the cold temperature. These combined factors caused fuel gas to leak and the rocket booster exploded. In spite of the designers warning before the launch, the management continued the launch as scheduled.

7. Knowledge

1) Cause of a big disaster may be a small problem on a mechanical element, such as the o-ring.
2) In a large project, an organization may get divided and information may not spread to the whole organization. Once an organization is formed, inappropriate decisions may be made in order to protect the existence of the organization, and often lead to

an accident.

3) Even if there was success in the past, condition and environment variation may cause an accident (in this case low temperature).

8. Background

NASA developed space shuttles as space transportation systems. Space shuttles consist of an orbiter, rocket boosters, a fuel tank, and three main engines. In addition, a system to recover the orbiter for reuse was applied. At the time of the development, the goal was to save money by recycling the orbiter. This system leads NASA to reduce launching costs by using the same orbiter repeatedly. The first flight with this system was in 1982. Until this Challenger accident, they had completed 9 flights successfully. Up to the Colombia 3 disaster in 2003, they had 113 launches, and there were only two failures, Challenger and Columbia. In Columbia's disaster, insulation of the external fuel tank peeled off and hit the wing creating a hole. If they had reused the Apollo's disposed rocket, the crew would have been safe even when the insulation had fallen off since the crew was at the top part of the ship.

＜References＞

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