# Apollo 13

## April 13, 1970, 330,000km from the earth

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A small explosion occurred at the No.2 oxygen tank of the support ship during the flight of Apollo 13. Apollo 13 was launched in 1970 for the purpose of making the third lunar landing. A portion of the outer shell was blown away, and several instruments that were stored in the support ship were also damaged by the explosion. In order to convert the oxygen tank of Apollo 10 for use in Apollo 13, the design was changed. The starting point of the cause was that the one of the technicians forgot to unfasten one screw when the tank was reinstalled.
The plan for the landing on the moon was aborted, the Apollo 13 made a U-turn at the moon, and she barely made it back to the earth using the little oxygen, water and electric power that remained.

### 1. Event

At 13:13 on April 13th, 1970, at 330,000km from the earth, a small explosion occurred at the No.2 oxygen tank of the support ship during the flight of Apollo 13 to the moon. A portion of the outer shell was blown away, and the instruments that were stored in the support ship were also damaged by the explosion. However, in spite of the heavy damage that occurred, it took another one hour to realize that the space ship was damaged beyond repair.

### 2. Course

At 13:13 on April 11th, 1970, Apollo 13 with three astronauts on board was launched to the moon. The astronauts, the pilot of the command ship and two captains of the landing ship, were all civilians.
On April 12th, the rocket was boosted lightly in order to direct Apollo 13 for the Hula Marrow Heights, the planned landing destination on the moon. Because of that action, the course of Apollo 13 was diverted from the free-return orbit. The free-return orbit is the safe orbit for the space ship because, whatever happens, if the space ship stays along that free-return orbit, it can be safely returned to the earth.
At around 21:00 on April 13th, the ground controllers were looking at the big screen that showed the motion picture for the television broadcast that was being sent by the astronauts of Apollo 13. The screen showed the captain of the landing ship and the captain of the commanding ship. One of the captains, who was also a member of the Apollo 8 expedition, started the introduction. Since the launch, the captain of the commanding ship had experienced a number of small problems. For example, one of the meters showing the remaining amount of the oxygen in the oxygen tank was

pointing beyond of the metered area.

There were two red lamps on the crew console that indicated “emergency warnings”. They would be lit if the onboard computer of Apollo 13 picked up some critical problems. Furthermore, there were a line of yellow lamps for indicating various minor problems.

At about five minutes past 21:00, the warning lamp at the console of the commanding center and one of the yellow lamps were lit. The yellow lamp indicated that a pressure drop had occurred in one of the hydrogen tanks of the support ship. In addition to the main propulsion system, a number of important devices were also installed in the support ship. One of them was the fuel cell system. Using the fuel cell system, oxygen and hydrogen were reacted to obtain electricity, and the water that is a by-product of the reaction was used in the space ship. There were two hydrogen tanks, two oxygen tanks, and three fuel cells. Therefore, if a problem happens with one of the tanks, the gas in that tank can be transferred to one of the other tanks.

The technician at the command center knew that the warning lamp for the hydrogen tanks occasionally becomes lit because he had been operating the purging of the remaining gas of the hydrogen tank. However, there was a defect in the system: when the warning lamp for the hydrogen system is lit and the warning system becomes occupied by this warning before any problem happens in the oxygen system, then if some problem occurs later in the oxygen system the warning lamp for the oxygen system would not be lit. He thought the condition of the oxygen tank must be confirmed, and so the message for executing the “ultra low temperature mixing (in order to obtain a correct reading from the meter showing the remaining amount, the gas is mixed by rotating the fan in the tank)” was sent to the pilot of Apollo 13 through the general controller.

About eight minutes after 21:00, the pilot of the commanding ship received the message and pushed the button for executing the “ultra low temperature mixing”. For a short time he experienced a light vibration but no other major changes. However, the yellow lamp indicating a problem in the electricity system was lit. In reality, it was speculated that 16 seconds after the switch for the “ultra low temperature mixing” was turned on, an electric discharge arc appeared between two bare wires in the No.2 oxygen tank. The oxygen in the tank was heated by the arc, the pressure rose, and in 24 seconds the dome shaped cap was blown away. Finally, the heat insulating materials between outer and inner shells were ignited, and the fire, fanned by the emitted oxygen, spread through the entire No.4 compartment of the support ship.

However, even at this point of the first major accident in space, nobody on the space ship realized the critical nature of the conditions. Furthermore, the ground controllers also did not realize what was happening. It took 15 minutes to gain an understanding of the rough details of the accident. It then took an additional hour to recognize that the space ship was damaged beyond repair: both of the oxygen tanks and all three of the fuel cells were damaged, and one of the two power supply lines was dead, which meant that there would be neither energy nor water supplies.

After the condition was confirmed, the plan for the lunar landing of Apollo 13 was aborted, the ship made a U-turn around the moon, and using the remaining oxygen, water and electricity, Apollo 13 returned to the earth. The entire crew was safely returned home.

### 3. Cause

The No.2 oxygen tank that was installed in Apollo 13 was originally designed for Apollo 10. However, because of a change in the design of Apollo 10, the tank was diverted for use in Apollo 13. When the tank was reinstalled in Apollo 13, the technician forgot to unfasten one screw, and because of that screw the tank fell about five cm. As a consequence of this shift, the fastener of the oxygen supply line in the tank was loosened, and a gap was created.

In the operation for purging the oxygen remaining in the tank before charging the tank with liquid oxygen, the purging was not completed because of the afore-mentioned gap. As a countermeasure, the temperature was raised using the inner heater in order to purge the remaining oxygen. The Teflon coating of the power line for the mixing fan was melted during the purging operation, and the copper wire was exposed.

At this time, the temperature that is supposed to be maintained at 85°F rose to 1000°F because of a malfunction of the thermostat. The thermostat was originally designed for 25VDC, but, because 65VDC was applied instead, an electric arc occurred and the contacts were melted together and could not open. Nobody realized the change in the voltage rating of the thermostat. Everybody concentrated on the gap as the cause of the problem.

After the launch, when the power for the “ultra low temperature mixing” was turned on, an arc was discharged at the exposed copper wires and the materials were ignited.

It is speculated that in the oxygen rich environment, Teflon burned fiercely, the flame reached to the upper portion of the tank, and finally a small explosion and an oxygen blowout occurred.

### 4. Immediate Response

The plan for landing on the moon was aborted, and Apollo 13 made a U-turn around the moon, returning to the earth on the remaining oxygen, water and electricity.

### 5. Countermeasures

NASA investigated the case thoroughly, conducted simulations, and reached the conclusions that are described above. Because complete logs existed for the maintenance of the parts, it was possible to clarify the details. This incident was a major lesson for NASA. It was decided that all parts must be reexamined when a specification is changed, and that deviations in the procedure must be avoided. Furthermore, NASA adopted the policy that safety should take precedence over the completion of a planned project. As a consequence, the launching of the Space Shuttle has been delayed

occasionally for safety reasons.

## 6. Knowledge

There would be inevitable consequences when one decides to start a project prematurely under pressure from higher up. Only one screw can cause a big accident. It is preferable to have a system that can automatically indicate what areas are affected by a change in design specifications. A small problem that is hidden in the shadow of a big problem sometimes causes an even bigger problem. Engineers must always make efforts to see the overall situation, and they need to have supporting systems to help them do so.

## 7. Reference

[1] “Thirteen: the flight that failed” written by Henry Cooper Jr. and translated by Takashi Tachibana