Apollo 13: A Successful Failure Essay, Research Paper

During a modification of Oxygen Tank No. 2 by NASA contractor, North American Rockwell, it was inadvertently dropped about 2 inches, which caused undetected damage to the interior assemblies. This damage eventually led the failure of the $400-million Apollo 13 mission.

The crew of Apollo 13 was responsible for several scientific experiments that were to be carried out during the mission. Atmospheric electrical phenomena experiments were designed to “study certain aspects of launch-phase electrical

phenomena.” An opportunity to study large mass impact phenomena on the Moon was available with this mission. Instead of sending the third stage of the launch vehicle into solar orbit, as had been done on previous missions, the trajectory of the Apollo 13 S-IVB was designed to cause it to hit the lunar surface. Equipment set up during the Apollo 12 mission would have been used to record the seismic signals. The crew was also assigned to install a heat flow experiment designed to measure the amount of heat coming from the inside of the Moon. This data would be used to determine whether the Moon actually had a molten core. This would provide new insight on the internal structure of the Moon.

The Apollo spacecraft (CM) was named Odyssey and the lunar module (LM), Aquarius. The CM was a conical pressure vessel with a maximum diameter of 3.9 m at its base and a height of 3.65 m. The CM was divided into three compartments, forward, aft, and the crew compartment. The forward compartment, in the nose of the cone, contained “the three 25.4 m diameter main parachutes, two 5 m drogue parachutes, and pilot mortar chutes for Earth landing.” The aft compartment, at around the base of the CM, “contained propellant tanks, reaction control engines, wiring, and plumbing.” Most of the volume of the CM, approximately 6.17m, is in the crew compartment. The lunar module was a two-stage vehicle designed for space operations near and on the Moon. The LM was originally designed to support two astronauts for 45 hours.

The crew Commander was 42-year-old Navy Captain James A. Lovell, Jr. Lovell’s partner on the moon, the lunar module pilot, was Fred Haise, Jr. Assigned to remain in lunar orbit aboard Odyssey, the command module pilot, Navy Lieutenant Commander Thomas K. Mattingly.

“Five days before the launch date of April 11th, it was discovered that a member of the backup crew, Air Force Major Charles M. Duke, Jr., had come down with rubella (German measles).” The prime crew was given blood tests to determine if they had immunity. Lovell and Haise were cleared, but Mattingly was not. Having recently been exposed to rubella and because it was likely that he could get sick in flight, he was replaced with 34-year-old John L Swigert, Jr., who did have immunity. A test pilot, Swigert had a mechanical engineering degree from the University of Colorado and a Master of Science degree in aerospace science from Rensselaer Polytechnic Institute.

The crew of Apollo 13 was boosted off Pad 39A of the Kennedy Space Center, right on time, at 2:13p.m., Easter Standard Time, Saturday, April 11, 1970. From the sounds, sights, and vibrations given off by the Saturn 5, the most powerful rocket in the world, everything seemed to be going smoothly to the casual observer. However, this was not the case. A series of minor flaws appeared during powered flight up through the atmosphere. Although not directly related, but precursors of the disaster to come two days later as the crew approached the Moon.

During the firing of the Saturn 5’s second stage, the center engine in a cluster of five cut off 132 seconds early as a result of unusually large oscillations in thrust chamber pressure. “This caused the remaining four engines to burn 34 seconds longer than planned.” This would, hopefully, take the vehicle to the planned acceleration at second stage cutoff. Even with this compensation, the velocity was 223 feet per second lower than planned. Again, the guidance computer attempted to correct this by causing the third stage, the S4B, to burn it’s single engine 9 seconds longer than programmed.

“Two hours and 35 minutes after launch, the crew fired the S4B a second time for a translunar injection.” Once out of Earth orbit, Lovell performed a transposition maneuver. He moved the command module away from the S4B, turned it around, and docked nose first with the lunar module, still encapsulated in the forward section of the S4B. Once the maneuver was complete and the Lunar Module was secured to the Apollo command module, the crew activated springs that pushed the LM-Apollo stack away from the S4B. As the stack moved away from the S4B, controllers at Houston directed it to its predetermined lunar crash site. At this point, all was well and the crew went on as planned.

At 9 p.m. on April 13th, Mission Control asked the crew to roll the spacecraft to the right about 60 degrees and try to photograph a comet named Benntt was supposed to be visible. They were also asked to stir the liquid oxygen and liquid hydrogen in the service module tanks in order to ensure proper feed to the fuel cell batteries, in which oxygen and hydrogen were mixed to produce electricity and as a by-product, water.

Then suddenly, Haise asked Houston to stand by a moment and then he said: “Hey, we’ve got a problem here.” There had been a main bus B interval, meaning, the amperage on the bus that distributed power to the ship had suddenly surged up and dropped back down.

The crew then reported that the main bus A was showing abnormally low voltage. A moment later, it was discovered that liquid oxygen Tank No. 2 supplying the fuel cells power system was reading zero. “We are venting something out into space,” Lovell said. “It’s a gas of some sort.” It was oxygen. The number 2 tank had ruptured. Two of the ships three fuel cell batteries were dead, leaving only one on line, and this one was showing signs of failing.

Houston instructed the crew to power down the ship as soon as possible until the trouble could be analyzed. In the meantime, the ship had began to pitch and roll from the venting gas.

When it was fully recognized, about 10:20 p.m. CST, on the 13th, Apollo 13 was 180,521 nautical miles from Earth, more then halfway to the Moon. The ship had suffered a terrible accident, the blowout of a liquid oxygen tank in the service module behind the command module. Because of this, it had lost most of its electric power. It was hopelessly crippled.

This meant that the crew would have to use the electric power and life support system in the lunar module, now their lifeboat, to return to Earth. “It was an unpleasant trip home; the lunar module temperature was on t a few degrees above freezing and water was rationed to just six ounces per person, per day.” Originally designed to sustain 2 people for 45 hours, but by carefully conserving both power and air, three astronauts survived for over 95 hours.

There was still some power from oxygen tank No. 1 supplying one fuel cell, but that tank was leaking, apparently damaged by the blowout of tank No. 2, and the power was fading. Only the command module storage batteries were left in Apollo, and these would have to be used for reentry into Earth atmosphere. The lunar module was now the crew’s only salvation.

As the crew began moving into the Aquarius and shutting down the command module, navigators at Mission Control computed a new course that would swing the ship around the Moon and bring it back to Earth. At 2:43 a.m. CST, April 14th the crew made the first course correction. They had to fire the Lunar Modules engines for 30.7 seconds. This would increase the velocity 38 feet per second, which put the ship in a free return trajectory that would intersect the Indian Ocean, off the coast of Africa in 90 hours and 30 minutes. That meant that splash down would be at 9:13p.m., Houston time, April 17th.

As they neared the Moon, Mission Control came up with a second course correction. They would burn the engines for an additional 263.4 seconds. This would increase the velocity by 861 feet per second. This would cut 9 hours and 6 minutes off of the return time and put splashdown in the mid-Pacific Ocean at 12:07 p.m., Houston time, April 17th. This made recovery easier since ships were already deployed in the Pacific.

This final course correction was scheduled for 8:41 p.m., April 14th. Apollo 13 rounded the Moon in its 77th hour of flight and headed back toward Earth at 7,064 feet per second.

At 12:07.41 p.m. CST, April 17th, in sight of the U.S.S. Iwo Jima, the Odyssey came through that atmosphere and landed into the ocean below. It took less then an hour for the crew to be removed and flown back to the carrier by helicopter.

The main power system for the Apollo spacecraft was contained in Bay No. 4 of the service module. Power at 28 volts, direct current, was supplied by three fuel cells. Oxygen was stored in a semiliquid state in two tanks mounted next to each other on a shelf in Bay 4. Hydrogen, kept in the same state, was stored in two tanks below the self.

In zero gravity, fluids don’t flow very well unless pushed by something. The method used was to boil it to build up the pressure in the tank. Each tank contained a heater coil, a thermostatic switch, and electric fans to stir up the mixture and promote even flow. “The thermostatic switch was designed to open and shut off the heating elements when the temperature reached 80?F.”

Each tank held 326 pounds of oxygen under pressure of 865 to 935 pounds per square inch. Although every tank had a bust pressure of 2200 pounds per square inch, and a relief valve that would dump oxygen when the pressure reached 1000 pounds, these safety measures could not prevent an explosion from a rapid build-up of pressure if a fire was started in a tank.

The root of this accident can be traced back to 1966, when the Beech Aircraft Corp. manufactured Tank No. 2. According to NASA, acceptance testing showed that heat was leaking into the tank at a higher rate than specifications permitted. After some reworking, the leakage was reduced, but was still considered to be unacceptable by the agency. “The tank was finally accepted after a formal waiver of this discrepancy.” Several other discrepancies that were regarded as minor by space agency inspectors were also accepted, according to NASA. These included oversized holes in the tank dome and electrical plug support and an oversized rivet hole in the heater assembly just above the lower fan. None of these items was regarded as serious in 1966 and none had anything to do with the explosion 4 years later. But they were symptomatic of a tendency toward oversight in which a more serious discrepancy could occur, undetected.

After it was shipped to North America, Tank No. 2, serial number 10024X-TA0009 , was first installed in service module 106 for the flight of Apollo 10. However, Tank No. 2 was removed from this flight because of a decision by NASA to modify vacuum pump on the tank dome. The modification required the removal of the oxygen tanks and the shelf on which they were mounted in the Service Module. As Tank No. 2 was being removed, it was accidentally dropped about 2 inches. Testing showed this accident caused no apparent damage to the tank. After the vacuum pump modifications, the tank was installed in service module 109 for the flight of Apollo 13.

Several weeks before each Apollo launch at the Kennedy Space Center, a countdown demonstration test series is carried out to detect any problems before the final countdown starts. During the demonstration test for Apollo 13, ground crews reported a problem in Tank No. 2. It could be filled normally, but could not be emptied in the normal way, by pumping gaseous oxygen into the vent line to push the liquid oxygen out through the fill line. This worked perfectly for Tank No.1, but not for Tank No. 2.

Ground crews thought there was a loose fitting that allowed the gaseous oxygen being pumped in the vent line to escape through the fill line with out pushing out much liquid oxygen in the tank. Later, the possibility that the fitting had been loosened when the tank was dropped at North American months before was considered to be a possible cause of the problem.

To empty the tanks, the ground crew turned on the heaters and fans to try to boil the oxygen from the tank. On March 27 and 28 the heaters and fans were turned on by applying 65 volts of direct current from the ground power supply for extended periods of 6 to 8 hours at a time.

Unknown to the ground crew, this had set stage for the accident. The 65 volts was far too much for the thermostatic switches that controlled the heaters. They were designed to operate on 28 volts from the spacecraft fuel cell generators. Although the switches would carry 65 volts when closed, they would fail in the closed position if they started to open to interrupt the load. At one point, the switches did start to open and were then welded shut during the long period when the heaters were operating with 65 volts to boil the oxygen out of the tank. The failure of the thermostatically controlled switches allowed temperatures in the heater assembly to reach 1000?F instead of shutting the heaters off at 80?F.

The fact that the safety switches had been welded shut and hence were not operating could have been detected at the Kennedy Space Center if someone had been watching heater current readings on Tank No. 2. Sensors would have shown that the heaters had exceeded that safety switch temperature limit.

“The blueprint for the accident was finally drawn by the Review Board. Because of a bump one day in the fall of 1969, a fitting might have been loosened. Because of that, a tank could not be emptied properly. Because of that, a ground crew applied the wrong voltage to the tank heaters. Because of an inadequate switch, overheating occurred, burning insulation off electrical wiring. Because of that, the wires eventually short circuited and a $400-million mission was aborted.”

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