Houston, we've had a problem

On the 40th anniversary of the explosion on board the Apollo 13 spacecraft as it headed to the moon, Richard Corfield reports on the cause and how teamwork returned the three astronauts to Earth safely

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Three, two, one, lift off! On 11 April 1970, Apollo 13 blasted off from Nasa's base in Cape Kennedy, Florida, US, and headed to the moon. The mission: to learn more about the science of Earth's moon. But it never made it that far. Within three days of leaving Earth – and about 200 000 miles from home – the three men on board were fighting for their lives.

Fantastic teamwork brought the rocket's astronauts – Jim Lovell, Fred Haise and Jack Swigert – back down to Earth alive, and the flight of Apollo 13 has passed into the lore of space exploration as one of the greatest challenges that Nasa ever faced.

Scientific quest

The Apollo 11 and 12 missions had already shown that it was possible to land on the moon, and Apollo 13 had a different assignment. 'The first two flights to the moon were basically to prove that we could put a man on the moon and get him back safely,' explains Apollo 13 commander Lovell. 'But after that, the whole purpose of the lunar flights was for science – to learn more about the moon itself.'

Apollo 13 was heading for the Fra Mauro highlands, a hilly region near the Mare Imbrium – the second largest crater on the moon. 'The Fra Maura formation was believed to have been exposed by the large impact that created the Imbrium basin,' says Apollo geologist Farouk El-Baz. This basin, thought to have formed millions of years ago, with its hills and undulating valleys was a challenging place to land. But the chance of bringing back rocks that would date the Imbrium impact was too tempting to resist, according to El-Baz.

But it wasn't to be. On the morning of 13 April 1970, Swigert performed a routine stir of the tanks of liquid oxygen and hydrogen (contained in the spacecraft's service module) that supplied the command (re-entry) module's electricity-producing fuel cells. Immediately there was a bang, and a tremor ran through the spacecraft. For a second there was a stunned silence on board and then Swigert spoke the words that have gone down in history. 'Hey, Houston.

In short

- **40 years ago Apollo 13, carrying Jim Lovell, Fred Haise and Jack Swigert, headed to the moon to discover more about lunar science**
- **Three days into the mission there was an explosion on board, caused by an electrical problem**
- **Strong teamwork meant Nasa could overcome numerous hurdles, including power shortage, to get their three astronauts home unharmed**

We've had a problem here.'

Initially, Jack Lousma – the capsule communicator Swigert was talking to at Nasa's mission control in Houston, Texas – was at a loss. 'Say again please,' he requested. This time it was Lovell who replied, 'Houston, we've had a problem. We've had a main B bus undervolt.' One of the oxygen tanks had exploded.

John Aaron, a flight controller based at mission control at the time of the incident, explains the seriousness of the situation: 'the shock and damage of the explosion caused the fuel supply of oxygen and hydrogen to the fuel cells to be cut-off and thus no power could be generated, causing the voltage on main bus B [one of the spacecraft's two electricity supplies] to drop below proper operating range.'

'The spacecraft was designed to safely operate on one bus, however some system redundancy would be compromised in such a condition,' he adds.

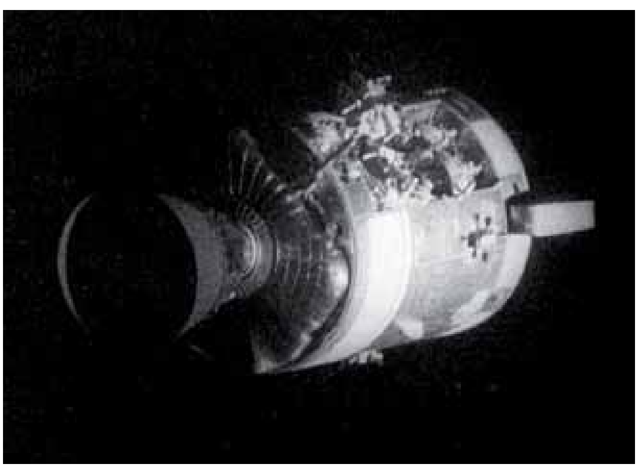
Then movement caught Lovell's eye. 'The severity of our situation dawned on us when I looked out the window and saw our oxygen escaping not only from the tank that had exploded but also from the second [and last] tank,' he says.

By this time mission control was registering what flight director Gene Kranz described as a cascading failure onboard Apollo 13. One failure was propagating into many failures, and such an event was considered so unlikely that the simulator specialists had never tried to simulate it, he explains.

With the oxygen tanks venting into space, Houston gave the order for the crew to leave the command module and move into the lunar module (the section of the spacecraft intended to make the trip to the moon's surface – while the command and service modules orbited the moon).

'The severity of our situation dawned on us when I saw oxygen was escaping from both the tanks'

Apollo 13's service module was badly damaged by the explosion



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Relocating in a hurry

The team needed to quickly move the orientation data from the navigation system of the command module into the lunar module. Lovell says, 'that was really the critical part, because we were not able to do any of our own [navigational] alignments in the lunar module due to the millions of pieces of mylar which were travelling with us due to the explosion.' The mylar insulating material was reflective, and was moving along in tandem with the spacecraft preventing the crew from identifying the stars that they routinely used as navigational aids.

So in the 15 minutes or so before the command module lost power, the three astronauts transferred the information, copying figures by hand and doing the mathematical corrections in their heads while staff at Houston checked them using slide rules. Lovell continues: 'we were able to transfer the guidance system and then to do the programming using the lunar module system.'

But there was another problem brewing. In Houston, Aaron realised that the power situation on the spacecraft would soon become critical. 'My first thoughts upon entering mission control that night was one of influencing the team to quickly terminate trouble shooting of the "failure" and instead power down the command module in order to save precious emergency battery power to support re-entry back at Earth,' he says. This module would have to be powered back up again, to be used by the astronauts to re-enter the Earth's atmosphere – as it was the only section of the spacecraft with parachutes and the heat shield needed to survive the extreme heat of re-entry.

As the astronauts settled into the lunar module, the mission controllers on the ground were busy identifying yet another imminent problem – the carbon dioxide concentration in the lunar module was rising. Carbon dioxide was removed from the atmosphere of both the command and lunar modules using lithium hydroxide filters. In theory it should have been a simple matter to use the extra filters from the command module but there was one major problem; those in the command module were square while the ones in the lunar module were round.

'Looking back on it now it was an

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mission control radioed up the welcome news that they were back in the re-entry corridor.

It was almost time for the crew to start the command module's power-up procedures for re-entry. On the ground Ken Mattingly – an astronaut who had pulled out of the Apollo 13 mission at the last minute due to health concerns – was streamlining the command module's power-up procedures to save vital amps. Jack Clemons, an Apollo 13 systems engineer based at mission control says, 'it was fortuitous that they had Mattingly. Here was a guy that had been intimately involved with all spacecraft's systems and mission planning until just a few days before launch. He knew what the astronauts would be doing at every point in the flight and was able to effectively beta test the new and innovative procedures that were being made up before they were transmitted to the spacecraft.'

All over the US, Nasa contractors were equally busy. 'The command module's navigation systems had never been designed to be put into cold storage for several days in space and then switched on again,' explains Chris Riley, author of the book *Haynes Apollo 11 owner's workshop manual* and co-producer of *In the shadow of the moon* (a film about the Apollo missions). 'So the guys at the Massachusetts Institute of Technology who had designed the inertial guidance system got a refrigerated meat wagon and they stuck the powered-down flight spare in there for several days and then restarted it. It came back on without any problems and in doing so gave an estimate for how long that procedure would take in space – just a couple of hours.'

Under normal circumstances the bottom section of the lunar module would be left on the moon, and the top section ditched around the moon's orbit once the astronauts were back in the command module. Only the command and service modules would head back to Earth. Then, just before re-entry into Earth's atmosphere, the service module would be ejected (also known as jettisoned).

In the case of Apollo 13, since the lunar module had come back from the moon, it too would have to be jettisoned just before re-entry. This caused yet another headache for mission control because the lunar module carried a plutonium power source. The decision was taken that it would be released at a precisely

engineering goof obviously,' says Lovell. 'We didn't have enough lunar module canisters, and the lunar module was only designed to support two people for two days not three people for four days,' – the time it would take to get back to Earth. But Kranz points out there was an engineering reason for the different shapes of the filters, 'the lunar module was weight and volume critical, so a round scrubber fitted better into the available space.'

Houston again provided the solution. Using the cover of the flight manual, a plastic bag, duct tape and a couple of spacesuit hoses, the astronauts were directed to jury-rig an adapter so that the square cartridges could be connected to the round filters.

So near, yet so far

Soon Apollo 13 had to contend with yet another issue. The spacecraft was moving out of the critical trajectory corridor that would bring it back to Earth at a safe angle to re-enter through the Earth's atmosphere. It would be necessary to fire the lunar module's engine to bring the spacecraft back into the re-entry corridor but there was no spare power to switch on the lunar module's computer which, under normal circumstances, controlled the duration and intensity of the engine firing. The burn would have to be done manually by the astronauts. Fortuitously Lovell had been a member of the Apollo 8 crew which had experimented with using the terminator – the line which divides night from day on the face of the Earth – as a fixed celestial reference point in the event of a computer failure and knew that it could be done successfully. Lovell ignited the engine while he and Haise controlled the spacecraft's orientation. Swigert's role was to time the 29s burn. Afterwards

The DIY adapter meant square cartridges fitted into the lunar module's round CO_2 filters

The command module, containing the three astronauts, was retrieved from the Pacific Ocean

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Fred Haise, Jim Lovell and Jack Swigert (left to right) returned home to a hero's welcome

calculated time that would dump it in the Tonga Trench – one of the deepest parts of the Pacific Ocean.

As they approached the moment when the command module's heat shield would touch the outer layers of the Earth's atmosphere, mission control found that the command module was still shallowing in its re-entry corridor. As Aaron explains, 'the largest contributor to shallowing was likely caused by venting from the lunar module water "boiler" used for cooling.' The consequences of too much shallowing were terrifying, according to Clemons: 'if they hit the atmosphere too shallow it would not provide enough braking for the spacecraft and it would bounce off into space.' But by now, having jettisoned the lunar module (with the only functioning engine), there was nothing that they could do to correct it.

On 17 April 1970, Apollo 13 plunged into the tenuous upper reaches of the Earth's atmosphere. For four minutes there was silence due to the radio communication blackout imposed by the ionisation of re-entry. Many feared the worst: that the heat shield had failed. Clemons says, 'we were sure that they were dead, that they had burned up during re-entry.' But eventually they heard Swigert's voice returning Houston's repeated hails. According to Clemons, the mood in mission control was exultant: 'it was like winning the World Cup on the final kick!'

Home sweet home

The three Apollo 13 astronauts were feted as heroes and the mission is described by Kranz as Nasa's finest hour. But what caused the explosion in the first place? A detailed inquest showed that Apollo 13 was carrying its own time bomb before lift off.

In 1965 the voltage to the heaters in the oxygen tanks was raised from 28 to 65 volts, but the heater's thermostatic switches weren't adapted to suit the change. During one final test on the launch pad, the heaters were on for a long period of time – and due to the unsuitable thermostat, the wire leading to the stirrer motor inside one of the oxygen tanks was subjected to very high temperatures. This caused the teflon insulation around the wire to degrade. 'The thermal switch did not cut-off the heater in the tank at the proper temperature of 80°F [27°C] and the tank temperatures as a result went to over 800°F resulting in damage to the internal wiring of the tank,' says Kranz. When a current was applied to the motor to stir the oxygen, the wire short circuited and ignition occurred, leading quickly to a large overpressure in the tank resulting in an explosion.

Mission control in Houston, Texas, played a large part in Nasa's finest hour

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Understandably Lovell never flew in space again, preferring to watch the remaining Apollo missions from mission control and his home near Houston. Swigert also left the astronaut corps, and was elected to Congress by his native state of Colorado but sadly died of cancer before he could take office. Haise, however, ventured into the great unknown again in 1977, flying five flights as commander of the space shuttle Enterprise for the shuttle approach and landing tests programme which preceded the operational deployment of the shuttle orbiters.

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