



APOLLO 13

50TH ANNIVERSARY
11-17 APRIL 1970



an essay by
HAMISH LINDSAY



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extracted from content on the
Honeysuckle Creek Tracking Station
website, developed by Colin Mackellar.

www.honeysucklecreek.net

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THE APOLLO 13 CREW



Jim Lovell, Jack Swigert and Fred Haise
NASA image s70-36485

AS-508/CSM-109/LM-7 MISSION H-2 NCG 738

Commander : Jim Lovell

Command Module Pilot : Jack Swigert

Lunar Module Pilot : Fred Haise

Back-up Crew:

John Young, Charles Duke
(Swigert replaced Ken Mattingly)

Notes

This account of the Apollo 13 mission, uses references from "Tracking Apollo to the Moon," by Hamish Lindsay plus other books/individuals acknowledged at the end of the essay.

Its timeline is based on Australian Eastern Standard Time (AEST), not the usual US Central (Spacecraft) Time. Ground Elapsed Time (GET), i.e. the time from 00:00:00 at launch, is included for a quick sequential reference where events occurred in the mission, and to relate it to the Apollo Flight Journal on the Internet.

To identify Space/Ground dialog the text is shown in *italics*. A list of official acronyms used in the text is at the end of the essay.

To use links, an internet connection is required.

Mission Fact Box

Launch from Pad 39A, Cape Kennedy
1413:00 US EST, 1913:00 UT, 0513:00 AEST,
Sunday 12 April 1970 (Australian time)

Spacecraft Names

Command Module: Odyssey
Lunar Module: Aquarius

Intended Lunar Landing Site

Fra Mauro Highlands

Time of Accident

55:54:53 GET, 0306:18 UT, 1306:18 AEST,
Tuesday 14 April 1970 (Australian Time)

Distance from Earth at time of accident

~322,000 kilometres

Quotable Quotes

Jack Swigert:

"Okay Houston, we've had a problem here."

Jim Lovell:

"Houston, we've had a problem."

Splashdown

142:54:41 GET, 1807:41 UT, 0407:41 AEST
Saturday 18 April 1970 (Australian time)

Total mission elapsed time

5 days 22 hours 54 minutes 41 seconds

Total distance travelled in space

1,002,123 kilometres



“HOUSTON, WE’VE HAD A PROBLEM HERE.”

12–18 April 1970¹

by Hamish Lindsay

Introduction

The Mission Insignia for Apollo 13 showed the god Apollo, representing the Sun, riding his chariot across the surface of the Moon to symbolise the Apollo Project bringing back new knowledge from the Moon.

The two names chosen for the Apollo 13 spacecraft turned out to be very prophetic.

The Command Module was called *Odyssey* from Homer and Arthur C. Clarke’s fictitious works. Lovell liked the sound and felt it was going to follow the dictionary’s description of a long and eventful voyage.

The Lunar Module was called after the sign of the Zodiac and star constellation Aquarius, the water carrier, at times identified with Zeus pouring the waters of life down from the heavens. Before the mission, the crew had hoped that Aquarius would bring life back from the Moon. After the mission they were glad it did!

Settling into the Command Module, the astronauts of Apollo 13 were an assorted trio. Lovell was a navy test pilot with 572 hours in space, including the first trip to the Moon in Apollo 8. He had more time in space than any other human at the time. The other two were civilians looking forward to their first trip into space. Haise, a serious family man, had been a journalist turned naval aviator. He was recognised as a specialist on the Lunar Module, having spent fourteen months at Grumman, the factory building the spacecraft. He knew every switch, wire and connector in the spacecraft. Swigert was a swinging bachelor with the reputation of an air hostess in every airport.

Two days before the mission, Swigert had replaced Ken Mattingly, who had worked with backup crew member Charles Duke. Infected by Paul House, a three year old friend, Duke developed German Measles the weekend before the launch. As Mattingly was found to have no immunity to the disease, the doctors were afraid he might break out in a severe rash at the moment Lovell and Haise were on the Moon’s surface, when swollen fingers and sore muscles could have slowed him up, particularly in an emergency. Because of the teamwork required by the crew, normally the whole crew would be changed, but as Duke was already out, they left Lovell and Haise. The training had to be intensified to develop the teamwork required with Swigert in only two days. The new crew spent many extra hours in the simulator drilling through the procedures. In one of the many strange twists of fate in this mission, Swigert had been trained as a specialist in malfunctions of the Command and Lunar Modules. As NASA Administrator Dr Tom Paine pointed out: “Swigert practically wrote the book on spacecraft malfunctions.”

Ironically, Mattingly never did break out with Rubella.

Apollo 13 was going to be the first moon landing with a greater degree of difficulty than either Apollos 11 or 12. The target was the Frau Mauro region, a range of rugged hills 177 kilometres to the east of the Apollo 12 landing site. Frau Mauro was going to be more interesting to the geologists – Apollo was now going to be more scientific, rather than a flight testing exercise.

1. Australian time

Sunday 12 April 1970 – LAUNCH

Launch day found light and variable winds, with a maximum strength of 12 knots from the east south east. Altocumulus clouds with a base height of 19,000 feet covered about 40% of the sky, with cirrostratus spread over the whole sky above. The temperature was 24°C and relative humidity 57%. A perfect launch day.



[Hear the launch and first few minutes of flight](#) as received in Australia by shortwave from The Voice of America. Recorded by Colin Mackellar. 2.2MB mp3 Runtime: 4:44.

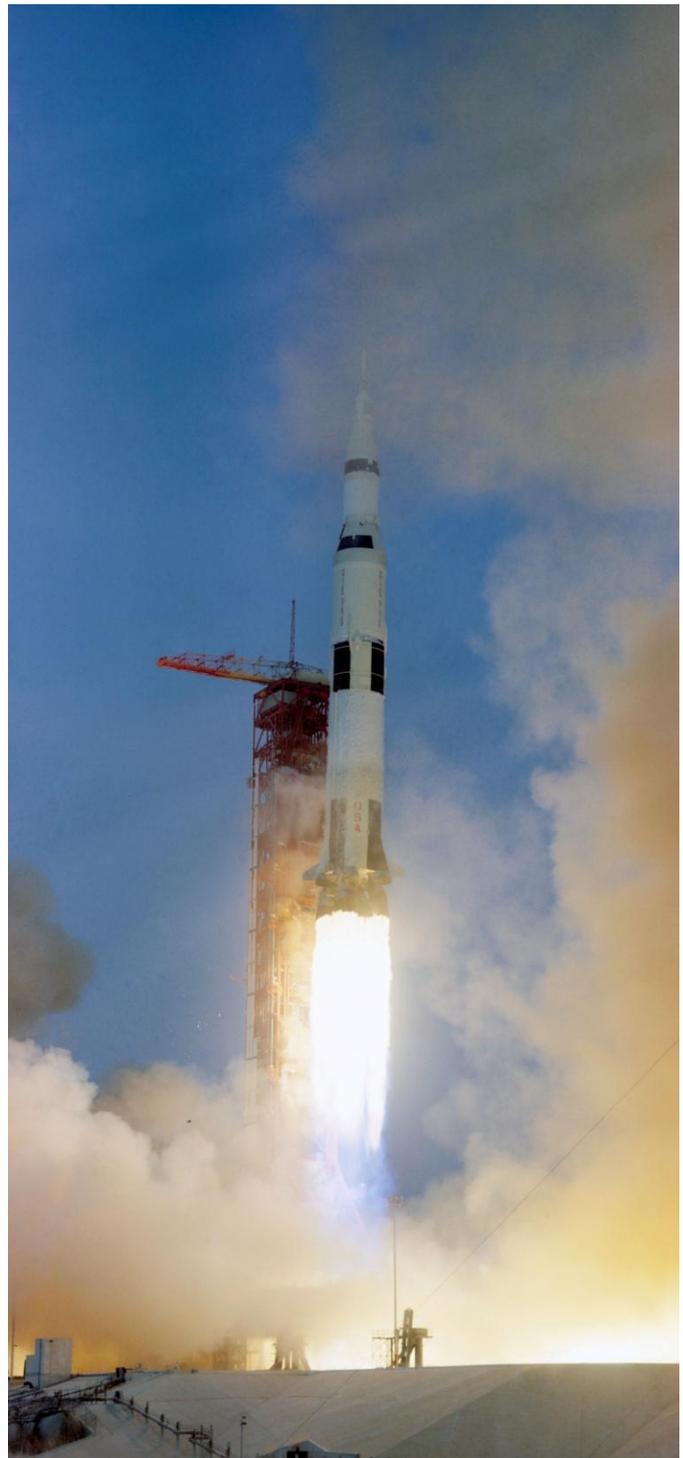
Originally scheduled for 12 March 1970, Apollo 13 left Pad 39A at 1413 USEST 11 April 1970 (0513 AEST on Sunday 12 April). There was trouble right away. Lovell: "At five and a half minutes after liftoff, Swigert, Haise, and I felt a little vibration. Then the centre engine of the S-II stage shut down two minutes early. This caused the remaining four engines to burn 34 seconds longer than planned, and the SIVB third stage had to burn 9 seconds longer to put us into orbit. No problem; the SIVB had plenty of fuel."

Apollo 13 entered Earth orbit at 0525:39 AEST and went into a 185.7 by 183.9 kilometre orbit with period of 88.2 minutes and a speed of 28,053.2 kilometres per hour. Translunar injection was at 0754:47 AEST with a 5 minute 50.8 second burn and Apollo 13 was heading for the Moon at 26,600.4 kilometres per hour.

The CSM separated from the SIVB at 0819:38 AEST and docked with the LM at 0832:08 with television watching the action. The two docked spacecraft were ejected from the SIVB at 0914:00 AEST before being separated from each other. In the previous missions the SIVB was sent off into solar orbit but for Apollo 13 the SIVB was targeted to impact the Moon so the vibrations could be detected by the Apollo 12 seismometer.

Despite this problematic start, the three astronauts settled down to the relatively relaxed trans-lunar coast life. The peace of Sunday was broken by an agitated Swigert calling Houston. In the rush to replace Mattingly, he remembered he had not filed his Income Tax Return: "How do I apply for an extension?" he asked, "Things kinda happened

real fast down there and I need an extension. I'm really serious...."



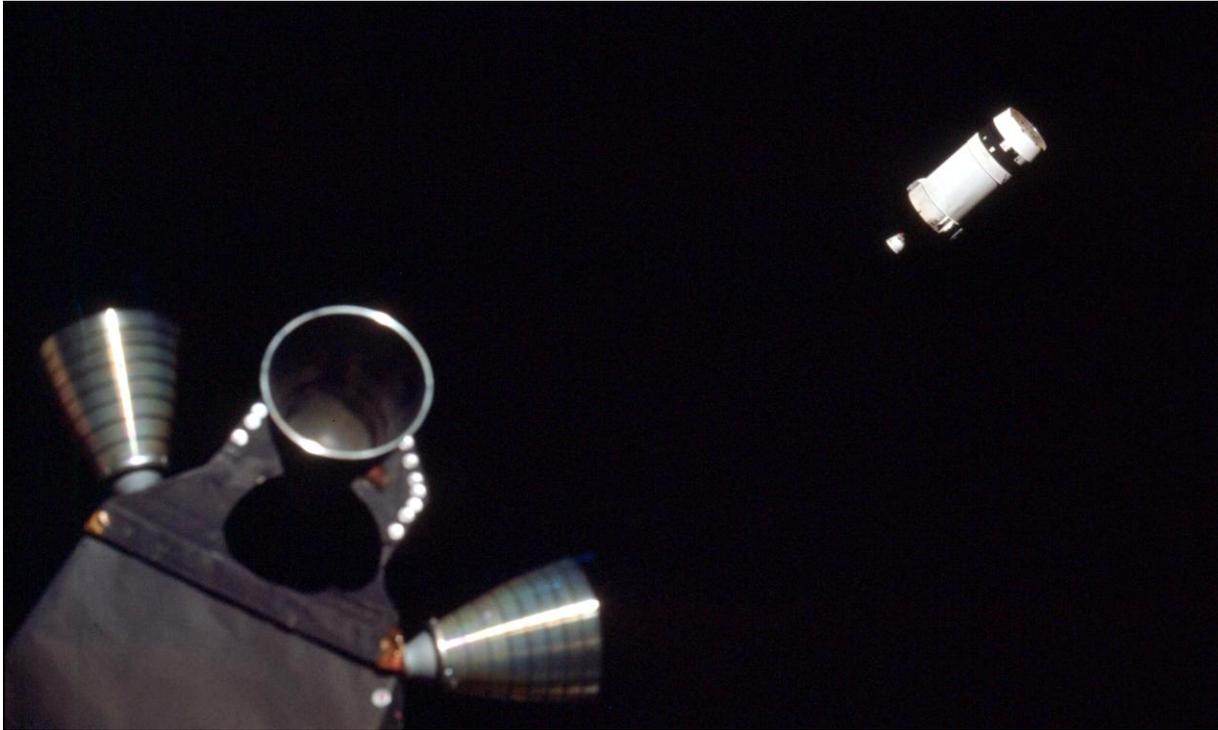
Apollo 13 launch. NASA image: s70-34854

"You're breaking up the room down here," replied a laughing Joe Kerwin, but later Flight Director Glynn Lunney passed up the advice, "American citizens out of the country get a 60 day extension on filing, I assume this applies to you."



The original crew of Apollo 13: from left – James A. Lovell, Jr, Thomas K. Mattingly II, and Fred W. Haise, Jr.
Photos courtesy of Ed Hengeveld via the Apollo Image Gallery.





Apollo 13 crew snapped this photo of the SIVB as they moved away. NASA image AS-13-60-8585.

Monday 13 April 1970

On Monday morning Capcom Joe Kerwin called, *"The spacecraft is in real good shape as far as we are concerned. We are bored to tears down here."* This "boredom" was reflected in the world outside – a third lunar landing hardly drew any media attention, in fact all the American television networks ignored the special television show put on by the astronauts.

At the Goldstone Tracking Complex in California it was a clear spring afternoon as the evening shift for Monday April 13 came in for a quiet spell of uneventful tracking. Bill Wood, C Shift leader at the DSS-12 Pioneer Wing Station:

"Pioneer, the half Coyote, half German Shepherd station mascot greeted us at the gate as usual, before we took over tracking the signal from the Saturn IVB. Ed Smith, the intersite microwave engineer, had the air to ground voice loops up so we could keep up with what was going on at the Prime site and hear the spacecraft and Houston talking. Things were very quiet, even boring."

It wasn't long before this mood was to change, to change dramatically.

Tuesday 14 April 1970

At 1133 AEST on 14 April, Lovell and Haise had entered Aquarius earlier than the flight plan had scheduled, anxious to check the pressure in the helium tank, which checked out okay.



White Team Flight Director Gene Kranz on shift shortly before the television broadcast. From 16mm NASA footage, screenshot by Colin Mackellar.

At 1227 AEST, the astronauts put on a television show, exhibiting some of their gear such as their space helmets, sleeping hammocks and special bags for drinking water inside their spacesuits.

Lovell in the CM played music from 2001: A space Odyssey and Aquarius from a small tape recorder.

Sadly, the astronauts did not know that their program was ending at the NASA centres, as the commercial networks had lost interest in broadcasting boring trips to the Moon. Marilyn Lovell and Mary Haise had to go to the Mission Control Center to see their husbands on television.



Fred Haise take the few viewers of the broadcast on a tour of the Lunar Module, Aquarius.



White Team Flight Director Gene Kranz (closest to the camera) watches in Mission Control, just 17 minutes and 42 seconds before the explosion.

GET: on screen [at top left](#), 55:37:11; GET of explosion: 55:54:53. NASA image.



Astronauts Vance Brand and Jack Lousma (Capcom) enjoy the TV show.
From 16mm NASA footage, screenshot by Colin Mackellar.

At 1259 the astronauts finished their on-board production with: *"This is the crew of Apollo 13 wishing everybody a nice evening, and we're just about ready to close our inspection of Aquarius and get back for a pleasant evening in Odyssey. Goodnight."*

Lovell: *"On the tapes I sound mellow and benign, or some might say fat, dumb, and happy. A pleasant evening indeed! Nine minutes later the roof fell in....."*

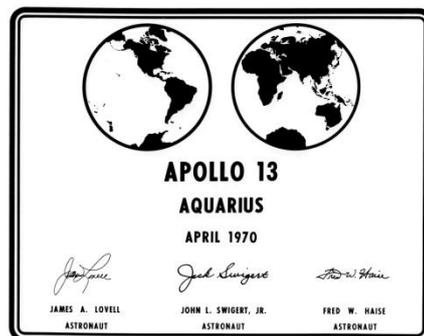
As the astronauts were copying down a message from Houston, on a control panel just above them a yellow caution light glowed to indicate a low pressure in hydrogen tank #1 in the Service Module.

Back at Houston the same warning glared at EECOM Sy Liebergot from the sloping panel of his console. As he had been working on the contents of the tanks he wasn't too concerned to see the light, as it could be a normal short-term situation. In the weightlessness of space the cryogenically stored gases could stratify into layers of different densities and give a false quantity reading, but to make sure, Liebergot told Capcom Jack Lousma to ask the astronauts to stir both the hydrogen tanks, using paddles

operated by electric motors. Normally this stirring was performed each day after the sleep period, but Liebergot wanted an extra stir before they went to sleep as he had been having trouble reading the quantity in the oxygen tank #2, so he suggested they stir the oxygen tanks too.

Lousma: *"Thirteen, we've got one more item for you when you get the chance. We'd like you to stir up your cryo tanks....."*

Swigert answered *"Okay, stand by"* and at 1306:18 AEST flicked the switches labelled H₂ and O₂ FANS on to stir the contents of the hydrogen and oxygen tanks.



Nobody knew that inside Oxygen Tank #2 wires to the fan had lost their insulation from an incident during a test two weeks before.

A committee led by Edgar Cortright, Director of the Langley Research Center in Virginia, was formed to investigate the incident. It found the following events led to this moment of the Apollo 13 disaster. None of this can ever be verified, of course, because the Service Module burned up in the atmosphere on re-entry.

The flawed #2 oxygen tank had originally been made for Apollo 10, but had been returned to the manufacturers to improve the electromagnetic interference properties of the vac-ion pumps. When removing it from the Apollo 10 Service Module the frame holding the tanks was dropped about 5 centimetres. Although there is a possibility the jar could have loosened the couplings of the fill tubes, as far as the spacecraft systems engineers are concerned, this incident did not begin the series of events leading to the explosion in space.

In the oxygen tank there were a set of tube assemblies in the neck of the tank to fill and empty the tank on the ground, and a different set for use in space to pipe the oxygen to either a fuel cell, or to the cabin atmosphere. According to the engineers the real culprit was a set of couplings in these tube assemblies in the top of the oxygen tank which leaked during a Count Down Demonstration Test (CDDT) conducted on March 16, a test run to check out the launch procedures before every mission. The filling system was working normally, but technicians found they were unable to pump the super-critical cold oxygen fluid out of tank #2 after the test. Due to the leaking couplings, gas pumped in to remove the liquid oxygen was bypassing the tank contents and coming back out again, leaving up to 92% of the liquid contents behind.

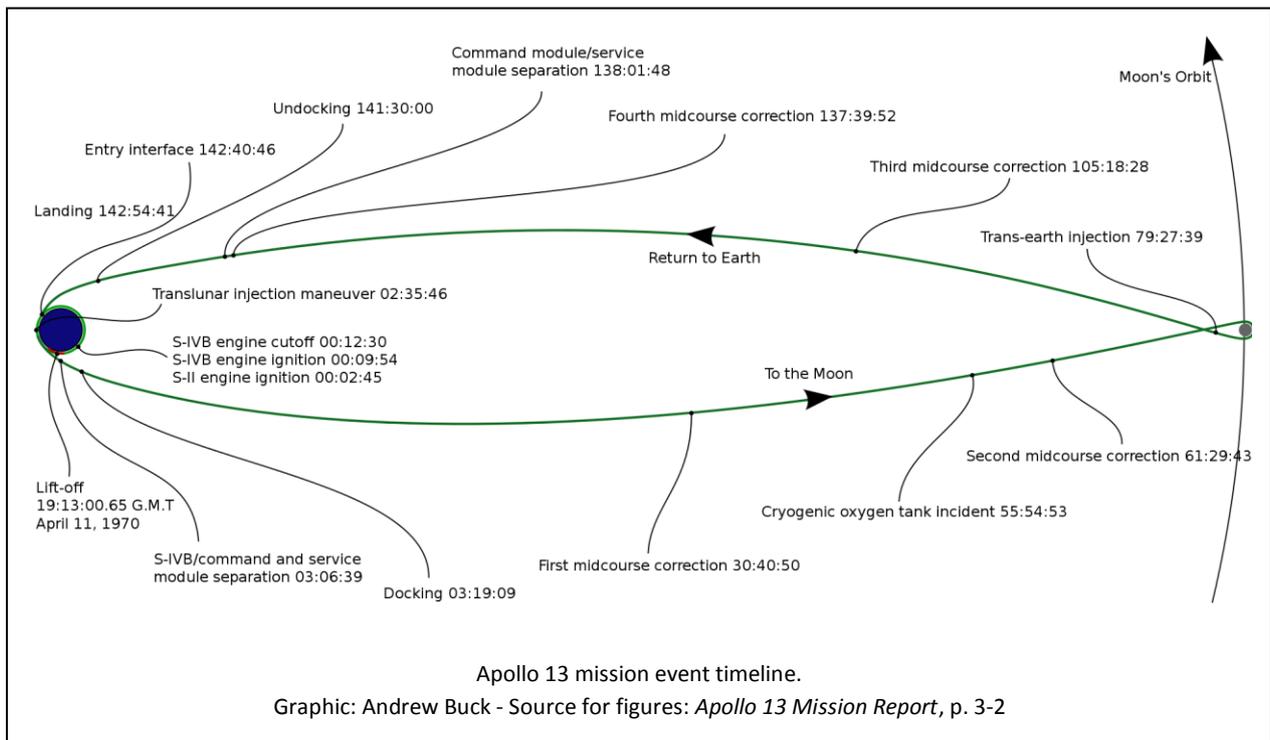
The fate of Apollo 13 and its crew was now riding on the two bare wires sealed in Oxygen Tank #2.

Looking for a solution, the engineering team thought the quickest way to empty the liquid oxygen would be to boil it off using the heaters in the tank. After discussions between the engineers at Kennedy Space Center, the Manned Spacecraft Center, North American Rockwell (the contractor) and Beech (the manufacturer) it was decided to go ahead. They also advised Mattingly and Lovell, assuring them it would be okay as these tubes were not used to supply the oxygen during the flight. Lovell queried the implications of putting a new tank in. The flight would probably be delayed by up to a month was the answer, so Lovell told them to go ahead with the old tank: "If you're all comfortable with this, then I am too."

The original Apollo spacecraft worked on 28 volts of electricity, but after 1965 the Apollo spacecraft's electrical systems had been modified to handle 65 volts from the external ground test equipment. Unfortunately Beech, the manufacturer of the tank, did not advise the manufacturer of the thermostat of the change, so the bi-metal thermostat switches installed in these tanks were still the 28 volt models, so when the heaters were switched on to boil the oxygen off after the CDDT test, the higher voltage caused arcing in the bi-metal thermostat and welded the contacts together. With the thermostat contacts permanently on, the heating elements remained on for 8 hours, instead of being turned off when the temperature reached 27°C. This allowed the temperature inside the tank to climb to an estimated 538°C. As the temperature gauge on the ground test panel only went to 29.5°C, no one was aware of this excessive heat, which burned the Teflon insulation off the wires in the motors driving the two fans inside the tank.

Perhaps the first clue of a problem in the Service module was at 0318 AEST 14 April when oxygen tank #2 quantity indicated off scale high,

eight hours before Lovell and Haise entered the LM to conduct some system checks, but nobody took notice of it.



But now, on board *Odyssey*, 322,000 kilometres from Earth, the relaxed complacency of the crew and ground teams around the world was to be suddenly interrupted when Swigert switched the fans on in the oxygen tanks.

When Swigert switched the fans on in O₂ Tank #2 at 55:53:18 GET, (1306:18 AEST on 14 April), some of the liquid oxygen in tank had been used, exposing the bare wiring. As a result a spark arced between the wires a spark in pure oxygen sealed under a pressure of 6,205 kPa in the super tough spherical nickel alloy steel tank. It took less than 20 seconds for the resulting pressure to blow the tank apart shock the feed valves to two of the three fuel cells causing their failure within seconds.....wreck the adjacent equipment in Bay 4 of the Service Module and blow the external side panel out..... which clipped the main antenna as it hurtled out into space. Langley Research Center estimated the explosion was equivalent to 3.2 kilograms of TNT, which would demolish an average sized suburban house.

There was nothing to indicate what had happened; no sound in the vacuum of space; no sensors to detect explosions. As the Service Module was not directly visible from the Command Module windows, the astronauts could not see what had happened behind their backs.

Just a shudder from the spacecraft.



Alan Foster

At Goldstone Tracking Station the prime receiver's usually steady white "Signal in Lock" light suddenly blinked out and the alarms began their two-tone singing.

The servo operator immediately switched to Program Track (antenna under computer control) and the receiver operators began trying to reacquire the signal but were only able to find a weak signal coming from the spacecraft.

Alan Foster on the Honeysuckle Creek receivers remembers what it was like once the Moon had risen at the site:

"The signal level dropped right down to about minus 140 db, I can remember struggling with it – it was pretty grim but we managed to keep in lock. They also went on to emergency voice and became hard to hear."

Lovell:

"Fred was still in the Lunar Module. Jack was back in the Command Module in the left hand seat. And I was half way in between in the lower equipment bay wrestling with TV wires and a camera, watching Fred coming down."

Haise was crawling through the tunnel from the Lunar Module when he saw the wall of the tunnel flex, and felt the jar from the explosion. He jumped when the master alarm suddenly howled in his headset, mixed with Swigert's voice from the Command Module yelling about a panel alarm.

Lovell:

"Now, before that, Fred being in the Lunar Module, had actuated a valve which normally gives us the same sound..... since he didn't tell us about it, we all rather jumped. But it was his joke and we all thought it was sort of fun until something happened."

"It wasn't me!" Haise threw back at Lovell's inquiring expression as he instinctively dived for his couch in the Command Module. Swigert tried to slam the hatch shut behind him, thinking the jolt might have come from the Lunar Module being hit by something. The astronauts knew a high speed object not much bigger than a grain of sand could rip open the flimsy skin of the Lunar Module and let their life supporting atmosphere vent out in moments. Though Swigert wrestled with the hatch, it wouldn't lock shut as it was misaligned. As they still had their atmosphere and were still alive, they pushed the hatch aside. All three astronauts' pulse rates shot up to over 130.

Lovell:

"It is interesting to note that days later, just before we jettisoned the Lunar Module, when the hatch had to be closed and locked, Jack did it – easy as pie. That's the kind of flight it was."

Swigert admitted,

"It shook the spacecraft and scared the hell out of me. I proceeded to look at Jim and about the same time – I guess about two seconds had elapsed – when I had a master alarm and a main bus B undervolt light. I told Houston we had a problem and proceeded to go over to the right hand side of the spacecraft to look at the voltage..."

He saw the B bus voltage supplying half the power to drive the spacecraft, drop right out. Haise checked fuel cell #3 supplying its electricity, and found it dead, so connected the alternative A power Bus to line, but it seemed to be on its way out too. A quick check of fuel cell #1 showed it was as dead as #3. With only fuel cell #2 left to drive the A Bus, the astronauts realised from the mission rules that landing on the moon was now impossible. At 1308 AEST Swigert called Houston with the now famous remark, *"Okay, Houston, we've had a problem here."*

Capcom Jack Lousma, *"This is Houston – say again, please."*

"Houston – we've had a problem. We've had a Main B Bus undervolt," Lovell explained.

"Roger. Main B undervolt. ... Okay, stand by, Thirteen, we're looking at it." Capcom Lousma answered for the Mission Control team.

In the Apollo 13 spacecraft, launched at 1313 hours (Houston time on Saturday, April 11), it was 9:08 pm on April 13. At Honeysuckle Creek it was 1308 hours (1:08 pm) on April 14.

At Houston it was just after 2100 local on a pleasant clear evening. With three friends, Andy Saulietis had rigged up a telescope connected to a black and white television set on a roof of the Manned Spacecraft Center. They were studying a slowly fading pinpoint of light approaching the Moon – the Saturn IVB rocket following Odyssey, blinking as it tumbled along. While they watched, a bright spot appeared in the middle of the screen and over the next ten minutes grew into quite a bright ball. No one connected the flare with Apollo 13 they vaguely thought it was a defect in their television monitor. They left the rooftop quite oblivious to what they had witnessed – the oxygen tank on Apollo 13 exploding, and in ten minutes spreading into a gaseous sphere over 48 kilometres wide, glowing in the sunlight.

Inside the Mission Control Center none of the Flight Controllers sitting at their consoles were aware of what had happened either, until some of them began seeing abnormal indications coming down their telemetry channels – strange readings from temperatures, pressures, voltages, and the status of various pieces of equipment. They were overwhelmed by reports of loss of the High Gain Antenna, spacecraft



Charlie Dumas (left) speaks with Gerry Griffin at the EECOM console. Sy Liebergot, smoking a pipe, is at right.
From 16mm NASA footage several minutes before the explosion. Screenshot by Colin Mackellar.

computer restarts, random thruster firings, and multiple system failures. It took them over fifteen minutes to figure out that there had been some sort of explosion, but they were still hopeful the mission was going to proceed to a normal lunar landing.

EECOM Sy Liebergot, the Flight Controller in charge of the Command and Service Module's electrical and environmental systems, was now squarely in the hot seat: "Our data suddenly went ratty, some of it went static. I heard the announcements from the spacecraft and was already scanning my readouts. Nothing made sense. I called Kranz, 'We may have an instrumentation problem, Flight. Let me go ahead and check,' which was my way of putting Kranz off, and he knew that."

"Rog." Kranz replied.

Liebergot never saw the pressure spike in the oxygen tank that caused the explosion:

"You look away, you blink, and it's gone. That's exactly what happened. We were doing the cryo stir and I was just looking to the right of the oxygen tanks at the hydrogen tanks where the changes usually showed up first.

Everybody was looking at the hydrogen, which was about two inches over. When I looked back the spike had already gone.

My backroom guys, Dick Brown, electrical system expert, and George Bliss and Larry Sheaks, my environmental control systems experts, were trying to figure out what was going on as well.



[OK, Houston, we've had a problem here.](#)

Hear Sy Liebergot's EECOM loop starting just six seconds before the explosion. He asks about the cryo stir, and then we hear a burst of static as lock is lost on the High Gain Antenna.

We hear the team beginning to troubleshoot the problem.

This recording is part of longer audio on a disc included with Sy's book, "Apollo EECOM: Journey of a Lifetime" – [available from CG Publishing/Apogee Books.](#)

This audio clip is also available on [Sy's website.](#)

Used with kind permission of, and with thanks to, Sy Liebergot.

1.1MB mp3 / 2 minutes 12 seconds.

Clip starts at 055:54:49GET.

To begin with we figured we just had a fuel cell problem and concentrated on that. Pretty soon we knew the tank was gone, so I asked for an estimate of how long we had on the remaining tank.”

Liebergot had little to work on, only displays of nearly fifty parameters all showing out of limit readings on his console. This was so sudden, without any warning, that he felt overwhelmed. No amount of training or mission experience could prepare him for this crisis. Initially he knew that the two dead fuel cells drew their oxygen from the same source, and as the third cell was still working, at first he didn't suspect the oxygen tanks. He was working on a Fuel Cell #3 leak, and trying to isolate it. Also, he was still trying to figure out why two fuel cells would fail. Then he saw that oxygen tank #2 was showing empty. Its contents had all gone! Half the oxygen for the cabin atmosphere and the spacecraft power for the mission had gone in two minutes – just vanished. They hadn't even reached the moon.

All their training and simulations had always relied on backup systems to keep the mission going, nobody had been game enough to introduce a complete failure of all the power systems into the simulations. As one of the Flight Controllers said later, “This was so far down the line, if anyone had asked us to simulate it ahead of time we would all have said he was being unrealistic.”

Liebergot:

“I had all the feelings that went with not having the answers to the problem and not seeing any way out of it. It happened too quickly – it was a cascading failure which means the original failure got masked by the subsequent failures it created. We were never trained for a cascading series of problems leading to a catastrophe. That's not training. It was like saying the structure of the spacecraft was going to fail.”

A minute or so after the explosion Alan Glines, the communications engineer (INCO), reported to Kranz that the signal from the spacecraft had



Capcom Jack Lousma speaks with the crew onboard Apollo 13 after the explosion. Astronaut John Young is seated next to him. From 16mm NASA footage, screenshot by Colin Mackellar.

switched to the smaller omni antennas, which was probably due to the side panel hitting the big antenna on its way past. The weaker signal combined with the erratic behaviour of the spacecraft caused the receiver operators at Goldstone and Honeysuckle Creek and the other stations difficulty in holding onto the weak, fluctuating signal for the rest of the mission.

Then Lovell announced the voltage on the A Bus was beginning to drop. An uneasy silence fell on the voice loops...

"Okay, Houston, are you still reading Apollo 13?" Lovell couldn't contain his anxiety any longer.

"That's affirmative," replied Lousma, *"We are reading you. We're trying to come up with some good ideas here for you."*

He looked appealingly at Kranz: "What can I tell them?" Kranz did not have an answer. Nobody had an answer.

Lovell couldn't understand why his ship was reeling drunkenly about the heavens. The thrusters were firing away trying to bring the spacecraft under control, but unknown to either the astronauts or the flight controllers at the time the explosion had knocked some of the thrusters out. Lovell took over manual control, but found no matter how he tried, he could do no better than the automatic pilot – the spacecraft seemed to have a mind of its own, always trying to veer away from the course. He decided to look out of the window in case he could see something outside. As he swung himself onto the left seat and peered out, the sight that met his inquiring eyes formed a knot in his stomach – the sun was shining on a powerful stream of gas spurting out of the side of the Service Module.

Sixteen minutes after the explosion, at 1322 AEST, Lovell remembers, "I happened to look out of the left hand window, and saw the final evidence pointing toward potential catastrophe. *'We are venting something out into the into space,'* I reported to Houston."

"Roger, we copy you are venting," acknowledged Lousma.

In Mission Control a report of gas venting into space spread among the consoles like wildfire, and put a whole new dimension on the

situation. Liebergot: "I ignored that, I couldn't deal with that. I needed to go and find what I could do about it."

Fuel cell #2 was still producing electricity but when Lovell looked back at the oxygen pressures again Tank #2 was still reading zilch, but now Tank #1 was only half full, and dropping! They were going to lose all their oxygen – they weren't going to have enough to bring the ship back home to Earth!

This was it! Lovell knew they were in trouble. But how serious was it? Was it only oxygen gas squirting out into space? How long did they have? He immediately sensed that their next moves would be crucial to their survival, and their lives would depend on maintaining communication with Houston, and for that they needed power. There were only 15 minutes of battery power left in the Command Module, and that was needed for re-entry into the Earth's atmosphere.

The Earth was over 90 hours away

Lovell:

"The knot in my stomach tightened, and all regrets about not landing on the moon vanished. Now it was strictly a case for survival. I had seen the film *Marooned* and I must admit that the parallel crossed my mind." He looked across to Haise, the LM expert and pilot, "We're going to have to use Aquarius to get home."

Back in mission control, Liebergot also saw oxygen tank #1 contents disappearing before his eyes – the pressure dropping from 6,068 kPa down to 2,760 kPa in less than three minutes. Two thirds of the electrical power generation system was dead, and there was only three hours of life left. Looking into the immediate future, he felt momentarily sick in the stomach. He grabbed the security handles on his console to steady himself down. Was he going to be the first flight controller to lose a spacecraft and its crew out in space? "In all my life I have never felt so alone, as I did then. I didn't have the answers. It seemed we were on the point of losing everybody and everything."

What had to be done before the Command Module completely died? Would this crippled combination of a dead Command Service Module and a Lunar Module only designed to go down to the lunar surface and back with two people cope with demands and manoeuvres

they were never designed for? There was little time left to make any plans.....

Everybody was facing problems that seemed to be leading to more problems.

..... except the Lunar Module systems people..... they were standing by with a fully operational spacecraft, powered down waiting to arrive at the moon. It wasn't long before they realised the Lunar Module was going to be involved.

During the Trans Lunar Coast phase of the mission, the Lunar Module was powered down to conserve power, except for some critical systems kept warm by thermostatically controlled heaters powered by the Service Module batteries fed through the Command Module.

Now they had lost the power to the relays that controlled the transfer of the power source to the Lunar Module batteries – so they could not turn the power on in the Lunar Module from its batteries in the descent stage. That was the first big problem to be overcome.

Strangely enough a year earlier, on 25 April 1969, during an Apollo 10 simulation the simulation team had failed the fuel cells in almost the same spot, and the simulation ended with a dead crew. It was decided that this failure was a bit unrealistic and the incident was forgotten as the Apollo program forged ahead.

Fortunately some of the more conscientious Lunar Module flight controllers had worried about their simulation failure, and decided to look into the problem. Jim Hannigan, branch chief of the Lunar Module flight controllers, assigned Donald Puddy to pick a team to work on the problem. Bill Legler, one of the key members of the team (who had been present during the Apollo 10 simulation) worked out some procedures that could reverse the power flow to go from the Lunar Module back into the Command Module and energise the power transfer relays.

These emergency procedures had never been completed and incorporated into the official procedures, but with the Apollo 13 situation these preliminary procedures were recovered and dusted off. They gave the Lunar Module controllers a head start.

The engineer in charge of the electrical and environmental systems of the Lunar Module was Bill Peters:

“I had just unplugged from the console and only taken two steps away when Bob Heselmeyer called out ‘You’d better come back here, I think something’s going on.’ I figured out pretty quickly it looked like a major disaster, and one of the plans in cases like this was to close all the telephone lines in and out of the Control Center so just in case I called my wife real quick and told her not to expect me home that night – turn on the TV to find out why – and hung up.”

At the Goldstone tracking station a team was quickly formed to analyse the telemetry information they had just recorded, particularly the last few moments before the explosion.

Bill Wood, lead USB Engineer:

“We were able to read all bits up to signal loss by recording the data at a high speed of 60 inches per second and playing it back at 3½ inches per second. Then we rolled the chart paper onto the control room floor and counted the frames of data by eye to find out what each parameter was reading up to the signal loss, and what things looked like right after the signal was reacquired. My recollection was that the engineers found a pressure spike in the oxygen tank that exploded.”

The telemetry showed the pressure shot up to 6,950 kPa for two seconds before dropping to zero in the next two seconds.

Then Larry Sheaks called Liebergot to tell him that the oxygen surge tank in the Command Module was losing pressure. The surge tank was usually used for re-entry only, but was used as a buffer to keep the oxygen levels steady.

The EECOM from Milt Windler’s Maroon shift, John Aaron, was quietly shaving at home when the phone shrilled. It was Arnold Aldrich, his office manager, at Mission Control.

Aaron:

“Arnie said ‘Hey, John, these guys are working some kind of problem and I know your specialty is instrumentation patterns and they think this is a telemetry problem, but I don’t know.’ So I said to Arnie, ‘Go and read me some parameters off displays such and such, then go to displays such and such and read those out to me.’



Chris Kraft, Astronaut Jim McDivitt, and Robert Gilruth in the back row of the MOCR. Behind them is the glass window of the VIP viewing room. From 16mm NASA footage, screenshot by Colin Mackellar.

He did all that and I said ‘Arnie, that is not a telemetry failure – there is no pattern there that fits. Tell those guys they’ve got a real problem and I’ll be right there.

By the time I came in, I got in on the tail end of analysing what had happened there, and started convincing the guys that they ought to power down the Command Module and save the batteries, because we were using battery power to troubleshoot the problem, and I knew these were the same batteries that were going to bring us home.

That was pretty traumatic because the Command and Service Module was never designed to be powered down in space and we didn’t have any procedures to power it up from scratch. Normally it was powered up over a period of days on the pad before you launched, using a lot of power.”

Forty six minutes after the explosion George Bliss informed Liebergot that there was only 1 hour 54 minutes left in O₂ Tank #1, when the last fuel cell would die. Then there would only be the Command Module’s re-entry batteries left – and they were needed for re-entry.

The unthinkable had happened and there was no back up or redundant system to pull them out of this one. They were facing a major disaster in space. Liebergot announced on the intercom loop: “Flight, the pressure in O₂ tank 1 has dropped all the way down to 297 (psi) (2048 kPa) and we’d better think about getting into the LM.”

Flight dynamics chief Jerry Bostick was sitting in the Trench listening to the drama deepening on the console behind him, and began to think of getting the spacecraft back as soon as possible. He and his team soon discarded the immediate turn-around (direct abort which would bring them home in 34 hours) using the main SPS engine because the LM ‘lifeboat’ would have to be cast off, and doubt about the integrity of the Service Module – that is, how much damage had been done to the internal systems of the Service Module? Was the engine damaged? Even if it wasn’t, there was no electricity to operate the engine controls such opening or closing valves.

The alternative was to carry on and sling around the Moon. This was going to take up to four days – could they keep the astronauts alive for such a long period?



Astronauts Gene Cernan (left), Deke Slayton (coat) and Ed Mitchell look on as Jack Lousma sits at his Capcom console.
From 16mm NASA footage, screenshot by Colin Mackellar.

That was up to the LM systems controllers. The Trench waited for the Flight Directors to make up their minds. Ken Mattingly slid alongside Lousma and plugged his headset in. He wanted to help his mates if he could.

Kranz said this was his toughest call on Apollo 13. “My team was pretty much split down the middle. Many of my systems controllers wanted to get home in the fastest fashion possible.” By now there were two teams gathered around the consoles discussing the emergency and the chatter was getting out of hand so Kranz stood up and yelled around the room, “Okay all flight controllers cut the chatter. I want every member of the White team to settle down and get back on the voice loops – the rest of you shut up.”

Still damp from being called from a shower at home, Chris Kraft had arrived by now and joined the intercom conversation at his Director’s console, just before thirty three year old Glynn Lunney was due to take over the next shift. Leader of the Maroon team, Milt Windler, also joined the group. Lunney had been discussing the return options with Bostick and an intense discussion developed between the Flight Directors on the best course of action, ending

with Kranz addressing Kraft, “Our only real option is to go around the Moon.”

Kraft agreed, “When do you want to do the burn?” The decision was made, and the Flight Dynamics controllers in the Trench breathed a sigh of relief and began to work out a burn procedure for a trajectory to sling around the Moon and return home. So 53 minutes after the explosion, an emergency plan began to evolve.

Lunney:

“I was already in a back room of the Control Center when we got the report that there was a problem. We were due on shift at about 10:00 pm (USCST) that night. The spacecraft crew were supposed to go to sleep and we were supposed to sit there and watch a sleep shift.

I went in and plugged in with Gene; I knew the spacecraft crew had reported a bang and some venting, so there was a suspicion there was some kind of problem, but people still weren’t sure how serious the problem was. There were a set of confusing indicators – we had lost the oxygen in one tank so we lost the fuel cell that was plugged to it, and that fuel cell was plugged to the B electrical Buss. The RCS thrusters were split between main Bus A and Main Bus B, so we

had lost half the thrusters which gave us these attitude control problems.

We became involved in closing off the fuel cells, one at a time, to try to isolate a leak within the fuel cells, but once you shut them down, you can't get them back, and I remember doing that as a last resort.

We had a number of situations to deal with. We were on a non free-return trajectory.

Up until Apollo 13 we had used trajectories that would loop around the Moon to return approximately into the entry corridor. Here we were not going to come back to any safe kind of Earth entry at all.

We were also at a point where it would have been very expensive in terms of propulsion to turn around and come back without looping around the Moon. That was considered for a while, but the only way we knew how to do that was to dump the descent stage of the Lunar Module and use all of the Service Propulsion fuel, but the two problems with that were we couldn't power the Service Module up any

more, we were only down to batteries, so we couldn't sustain a power load to run the Service Propulsion engine, and we didn't want to dump the descent stage of the Lunar Module because it was our lifeboat where most of the batteries, water and so on were stored.

Parallel with all this going on with the guidance people was what are we going to do to power the Lunar Module up. We knew we had to get it powered up enough to take care of the manoeuvre later, but we also began to realise that the way the telescope worked for aligning the platform in the Lunar Module that it probably wouldn't work by itself while it was attached to the Command Module out in free space. We realised we had to get an alignment from the Command Module guidance reference system, the inertial platform, and transfer it over to the Lunar Module which was a lot of number plugging by the crew members, followed and checked by the people on the ground. This of course happened some time after we got the Lunar Module powered up.



Glynn Lunney (left) and Milt Windler, take stock of the situation.
Behind them, in the background, is Robert Gilruth. Deke Slayton is in the foreground.
From 16mm NASA footage, screenshot by Colin Mackellar.



Here's a view of the MOCR during Glynn Lunney's shift, after the accident.
Panorama assembled from 16mm NASA footage by CM.

We got the Lunar Module powered up but as we went through it we were trying to figure out what we didn't have to bring up because we knew we were going to be power limited and water coolant limited to get home.

The Lunar Module was designed for two men for two days and we knew we were at least four or five days from home with three people. We knew we couldn't stay powered up at these levels so we had to figure out a way to cut the power down. We also knew we had limited amounts of consumables on board.

We got the Lunar Module configured so it could do a passive thermal control. Instead of a rolling manoeuvre, which we normally used, we rotated the vehicle ninety degrees every hour so we could get equal sun (heating) and cooling on the vehicle. As we could watch this on the ground the crew didn't have to worry about it.

Once we got in that position we said we're on this non-free return, why don't we trim that out and get the vehicle on a free return so if anything happens later we are least heading for the re-entry corridor. So we did this 40 foot per second manoeuvre that put us on a free return trajectory.

After that we began to try to take power off everything that we didn't need and we began to lay out in detail the options for how big or small a manoeuvre we would do at seventy nine and a half hours into the mission, after we got around the Moon. We settled on a manoeuvre that wasn't quite maximum but would get us

back by about 142 hours. We had also figured out how to husband the consumables.

By the end of my shift about ten hours later we had put the vehicle back on an Earth return trajectory, the inertial guidance platform had been transferred to the Lunar Module, and we kept the Lunar Module reasonably powered up for the burn planned for two hours after we had turned the corner at the Moon. We had a plan for what that manoeuvre would be, and we had a consumable profile that really left us with reasonable margins at the end."

Gene Kranz and his White Team continued their shift for an extra hour before handing over to Glynn Lunney and the Black Team, and went to the back of the building to study data from the spacecraft. Kranz decided to step out of the Houston shift sequence and head a Tiger Team to concentrate on the engineering and procedures to get the crippled spacecraft and its crew back home.

Kranz:

"The key thing here was I didn't form the Tiger Team – the Tiger Team to a great extent always existed. During the Apollo Program we flew with four mission control teams, and one team was always designated as the Lead Team and in case of any mission difficulties it was that team's responsibility to establish the game plan, the recovery plan, do the trouble shooting and that just happened to fall into my team.

We had many problems here – we had a variety of survival problems, we had electrical management, water management, and we had to figure out how to navigate because the stars were occluded by the debris cloud surrounding the spacecraft. Basically we had to turn a two day spacecraft into a four and a half day spacecraft with an extra crewmember to get the crew back home. We were literally working outside the design and test boundaries of the spacecraft so we had to invent everything as we went along. There were many lead people, but the three people I would name were Arnie Aldrich who handled the checklist, John Aaron with the power management, and Bill Peters who looked at the Lunar Module and tried to figure out how it could be most effective as a lifeboat.”

There were no official procedures to refer to even the emergency procedures didn't cover losing all three Command Module fuel cell power sources and using the Lunar Module in lieu of the Command Module.

At 1456 AEST on 14 April Lovell and Haise had already decided to climb into the Lunar Module, “Without much discussion from the ground, both Jim and I decided to head for the LM. At this point we only had one choice and took it,” Haise explained. Swigert was left to wind down the Command Module.

The last oxygen tank was nearly empty. Capcom Jack Lousma told the astronauts, *“Thirteen, Houston. We'd like you to start making your way over to the LM now.”*

Swigert replied: *“Fred and Jim are in the LM.”* Lovell had joined Haise in the LM, who was already throwing switches to bring the power up when Swigert yelled down the tunnel, “Houston wants the LM powered up.”

Haise advised Houston, *“.....and Jack, I got LM power on.”*

Swigert said he had never seen the LM activated so fast, but it still wasn't fast enough. He had to turn the re-entry battery in the Command Module on to keep the navigation



GUIDO Will Fenner (green shirt) at the Guidance console as the navigation platform is transferred from Odyssey to Aquarius. From 16mm NASA footage, screenshot by Colin Mackellar.

guidance system going until the crucial settings were transferred to the Lunar Module system. Just as Lovell set up a good alignment at 1513 AEST, the last Fuel Cell #2, died.

Lovell:

“Getting that transfer was the first big turning point.”



[Powering up Aquarius.](#)

395kb mp3. PAO commentary and air/ground audio. Starting at 058:00:02GET.

Houston told Swigert to close the Command Module down. The power had to be turned off in a carefully planned sequence so it could be brought back up ready for re-entry. At 1553 he turned off the last switch, looked around the lifeless cabin – no cosy lights, no friendly voices from the radio, no gurgling from pipes or whirring of fans their cheerful home of a moment ago was just dark and dead 333,125

empty kilometres from Earth, and racing away from it at 3,380 kilometres per hour!

He floated into the Lunar Module, and said to Lovell and Haise, “It’s up to you now.” He suddenly felt lost. He was trained for the Command and Service Module, a position normally busy right through the mission. Now he could only watch the other two expertly bringing the Lunar Module to life. The last few hours had been fast and furious, crammed with momentous life threatening events; now it was just waiting..... for what?

Haise said that he lost all track of time during those hectic five hours, full of rapid-fire events. It was more like a dream than reality because of the jolt from the security of comfort and order to the onslaught of unexpected events and fleeting images and feeling very vulnerable to the hostile environment of empty space. Dead tired, he was the first to drag himself into the Command Module to sleep soundly for the next five hours.



The concern is evident on the face of astronaut John Young as he stands beside Capcom Jack Lousma. Behind him is astronaut Tom Stafford. From 16mm NASA footage, screenshot by Colin Mackellar.

RIGHT ACROSS THE CONTINENT, FROM PERTH TO SYDNEY, AUSTRALIA PITCHES IN TO HELP APOLLO 13

Author:

"I heard Swigert send his problem call, and then listened as the flight controllers sent a barrage of instructions up to the spacecraft, punctuated by terse responses from the astronauts. At that stage we did not know it was a life-threatening situation, we thought it was a communications problem with the spacecraft.

The first indication of the seriousness of the crisis to us at Honeysuckle Creek was when Mission Control in Houston called the Operations Supervisor at Honeysuckle Creek and asked, 'How long would it take to get Parkes up?' Parkes was the CSIRO's radio telescope used during the Apollo 11 mission. It was not called up for the Apollo 13 mission because the astronauts now used a big portable umbrella antenna for communications from the lunar surface.

I knew the situation was really serious as you don't just casually ask to use the 64 metre radio astronomy antenna at Parkes without making

high level arrangements with plenty of warning."

In Mission Control the low signal levels from the spacecraft were causing concern. Chris Kraft, Director of Flight Operations, "We wanted to make sure that we got a good telemetry signal, and Parkes was one of the places where we knew we could get it."

"Parkes isn't committed to this mission," Mike Dinn informed them.

"Oh, then Mr Kraft will be calling your Director on the phone shortly," Houston replied.

Honeysuckle Creek Station Director Don Gray:

"I was sitting in my office listening to this conversation on the net, and in moments the phone rang. Chris Kraft said to me 'We have a serious problem on the spacecraft; it looks like we are going to have to power down and will need all the antennas we can get. Do what you can to get Parkes up as soon as possible.'



Don Gray, Station Director, in his office at Honeysuckle Creek. Photo: Hamish Lindsay.



Dr John Bolton, Director of Parkes. Photo from a 1967 ABC publication, via John Sarkissian.

First of all I called Tom Reid, the Director at Tidbinbilla, to organise a crew to go to Parkes, then I rang John Bolton at Parkes to find he was already aware of the problem and was prepared to change the antenna over to support the NASA signals.”

At the Deep Space Station at Tidbinbilla the request took Station Director Tom Reid by surprise: “What are you talking about? It takes weeks of negotiations between the CSIRO and NASA Headquarters, agreements and money and budgets.’ Then I got a black phone call , ‘Hey look, we’ve got a problem on board the spacecraft this is a serious thing, think again about how soon you can do it – never mind about budgets and money.’

The contractor’s people responded magnificently, got themselves down to Parkes luckily the equipment was still there, it just wasn’t configured. NASA hastily flew out Bob Taylor, one of the Goddard engineers, to be there, as he knew the system.”

Dr. John Bolton, Director of Parkes:

“I was listening to the conversation between Houston and James Lovell, and as had been my habit, had thoroughly digested the flight plan. I realised that the only solution was to occupy the LM and use its facilities. The very low power

(signal from the spacecraft) and the fact that the journey would be in Parkes coverage time meant we would certainly be called in. I rang Tom Reid, the Director of Tidbinbilla, with whom I had an excellent relationship, to ask for the NASA crew to be sent in; I rang Taffy (Dr. E.G. Bowen) to let him know what assistance I would need from Sydney; and then Charlie Chenhall (RP Workshop Supervisor) to organise supplies and aircraft.

Fortunately Radhakrishnan (Venkataraman Radhakrishnan, Director of the Raman Research Institute, Bangalore, India) was conducting a special experiment on the telescope and a number of engineers were on hand. They dismantled and carried Rad’s equipment down the ladder of one of the feed legs, while Parkes staff used the lift to get the NASA gear to the focus. We accomplished in 10 hours what normally took close to a week.”

Bruce Window, Tidbinbilla USB Supervisor:

“It was about 6 pm. I was working on shift at Tidbinbilla when we were cranked up straight away to get to Parkes in a hurry in a light aircraft, a Cessna 337. It was a hairy trip. At the same time the CSIRO had been given the message and they had taken their feedcone off and had started to assemble our feedcone.

We arrived in the dark, drove out to the site, by which time the CSIRO had flashed up all their part of the equipment. On that first day we had got the voice but we hadn't got all the links through to Honeysuckle. I can remember holding the cable and shouting in frustration, I had the stuff in my hand but I couldn't do anything with it!

Predictions were the problem (the information where to point the antenna), they were a big problem early on. We just had to rely on predictions from NASA. John Bolton and his boys had to work around them as much as they could. We didn't get any really good data from Parkes that first night. They were relying heavily on us because of the improved quality of signal they were able to up the bit rate by one step with our signal from what they were getting from the 26 metre dishes (such as Honeysuckle) that was why they needed us at Parkes. We worked 16 hour days."

Kevyn Westbrook, Officer in Charge of the Deakin Switching Centre in Canberra:

"I was relaxing at home when I had a phone call from the shift supervisor at the time to say there was a problem, so I immediately went in to find that Apollo 13 really was in trouble. Next there was a call from the Network Manager in the United States to say they wanted two things immediately they wanted to activate the lines to Parkes, and the second one, which was a bit more difficult, was to get some kind of broadband communication between the Carnarvon OTC Earth station and the Carnarvon Tracking Station. They wanted everything they could get.

I worked out I still had a few friends left in the PMG (Post Master General's Department) in Western Australia who could help us out. So, by 4 o'clock in the morning I dragged one of my friends out of bed, and he said, 'Oh, I think I have got an OB (Outside Broadcast) link we could use, I'll see what I can do give me a call back in an hour.'

When I called him back he said, 'Yes, I've organised it, two OB vans will be leaving the depot in Perth for Carnarvon at 8 o'clock this morning, as soon as the guys get to work.' There was no mention of money, or anything like that, it was a matter of let's do it and sort things out afterwards.

At the same time I got cracking with the PMG. Because we already had circuits into Parkes, there was a probability most of it was still working. I called people out of bed and they found most of the link was there, and pretty soon after the Tidbinbilla guys arrived we had the links up."

Trevor Gray, PMG technician:

"We worked non-stop through the night to get the links going. After Apollo 11 we had trouble with the connections exploding when we switched the equipment on because of the high voltage and moisture getting in, so we had left the equipment switched on, but then all the electronic valves had deteriorated, and we were frantically trying to find the sick valves and change them before we could get the links going."

Wilfred Laing, Senior Technical Officer at the Redfern Microwave Terminal in Sydney was interrupted by the phone ringing:

"It was the City South Control to say they needed Parkes up in a hurry. I phoned through to Parkes to find they were already setting their end up.

Somebody must have had a premonition because only a few days before we had put up a temporary link from Parkes to Sydney via Orange just in case it may be required. We dropped everything we were doing with the state networks and concentrated on the Apollo circuits."

Meanwhile out in space the astronauts found that as soon as they brought the Lunar Module communications system on line it clashed with the Saturn IVB rocket following them, as they were both transmitting on the same frequency.

Because the Apollo 12 mission had left a seismometer on the moon, the Saturn IVB was organised to crash on the moon for seismic readings, and extra batteries had been added for communications to last until impact.

Normally, this should occur well before the Lunar Module was fired up. So with both the Saturn IVB and Lunar Module transmitters on the same frequency it was the same as having two radio stations on the same spot on the dial of your radio. Which one does it try to lock onto?

Bill Wood at the Goldstone Tracking Station:

“The Flight Controllers at Houston wanted us to move the signal from the Lunar Module across to the other side of the Saturn IVB signal to allow for expected doppler changes. Tom Jonas, our receiver-exciter engineer, yelled at me, ‘that’s not going to work! We will end up locking both spacecraft to one up-link and wipe out the telemetry and voice contact with the crew.’

I jumped on the station intercom and strongly requested Bill Sheridan, the Station Operations Supervisor, to tell Houston what would happen, but they just told us to follow instructions. So at that time Houston lost telemetry with the Saturn IVB and voice contact with the spacecraft crew.

Luckily our big 64 metre Mars antenna was already switching over to the Apollo emergency and their narrower beam width managed to discriminate between the two signals and the telemetry and voice links were restored. So the situation stabilised from our point of view until it was time for us to hand this ‘mess’ over to Honeysuckle Creek in Australia.”

Honeysuckle Creek was tracking with its smaller 26 metre antenna.

Deputy Director Mike Dinn:

“This was where the receiver operators earned their money. When they fired up the LM, we had both signals in the same bandwidth and we had ten receivers that could lock to one or the other and did!

Before the mission I had foreseen the possibility of our having to cope with the Saturn IVB and the LM together. There was nothing written down in the procedures and I remember calling Goddard Space Flight Center in Maryland, our technical advisors, to discuss what we might do, and we agreed there would be no difficulty in “pulling” the frequencies apart by tuning the station transmitters appropriately. I was used to this procedure in the Deep Space Network in the early years of lunar and planetary exploration. Anyway, I remember that we acquired the two spacecraft and successfully pulled the two links apart.

Then Houston asked us to tune the frequency of one transmitter and I immediately recognised this would bring all the frequencies back



Reaching to punch up a communication loop is Supervisor John Mitchell, at right in the SB1 position. Behind him is Peter Cohn at the Antenna Position Programmer/ Tracking Data Processor.

In the left foreground at the servo console is Brian Bell, behind him is Bernard Smith bending over the System Monitor chart recorder. Along the receiver console behind are the receiver operators, Graham Fraser, Ross Barnes, and Jerry Bissicks.

Photo: Hamish Lindsay. The exact date is unknown.

together again. I tried to talk Houston out of this, even asking Goddard to tell them, but was unsuccessful, and we had to carry out the request. The problems we knew would happen, occurred.”

John Mitchell, Honeysuckle USB Shift Supervisor:

“Back when Apollo 1 had the fire, during the long suspension period that followed we used to hire a Cessna 210 and practice handovers and that sort of thing. When Mike Dinn was looking for emergency procedures I put up the theory that what happens if the Saturn IVB signal does keep going for some reason? So I proposed the theory of getting the LM to switch off and we practiced that time and time again with the aircraft. I told Mike Dinn that this was the way to go.”

From his previous discussions with Goddard, **Dinn agreed:**

“I advised Houston that the only way out of this mess was to ask the astronauts in the LM to turn off its signal so we could lock on to the Saturn IVB, then turn the LM back on and pull it away from the Saturn signal.”

Mitchell:

“They came back in an hour and told us to go ahead, and Houston transmitted the instructions up to the astronauts ‘in the blind’ hoping the astronauts could hear, as we couldn’t hear them at that moment. The downlink from the spacecraft suddenly disappeared, so we knew they got the message. When we could see the Saturn IV downlink go way out to the prescribed frequency, we put the second uplink on, acquired the LM, put the sidebands on, locked up and tuned away from the Saturn IVB. Then everything worked fine.”

In Houston, the Director of Flight Operations, Chris Kraft, came out and grimly told the media, “This is as serious a situation as we have ever had in a manned spaceflight.”

People around the world, already blasé about moon missions, suddenly became engrossed in this gripping drama from space as the world’s media wound themselves up for this journalists’ manna from the Apollo program. Everybody was wondering would they come back alive?



Director of Flight Operations, Chris Kraft, speaks to the media at a midnight press conference in the MSC Auditorium. Courtesy Spacecraft Films.

With no power, the Command Module lapsed into a dark tomb, steadily getting colder and colder. Beads of moisture formed over all the surfaces, crusting the windows. Occasional flashes of sunlight through the windows pierced the darkness lit only by their torches. Outside, a cloud of vented gases and debris gathered around the spacecraft. Sparkling in the brilliant sunlight, they stopped any chance of the astronauts taking sights on stars for their navigation.

Lovell:

“The spacecraft was doing things I had never seen before. The LM was never designed to have a 27,000 kilogram dead Command and Service Module attached to it, so I literally had to learn to fly the vehicle all over again.”

Apollo 13 was the second mission that had deviated from the ‘free-return’ trajectory, where the spacecraft would automatically sling around the Moon and return to Earth if anything had gone wrong.

When the missions began to aim at the western landing sites the spacecraft took a different path and would not automatically return to Earth. Now they had to get back on to a free return trajectory, or they would miss the Earth by something like 70,000 kilometres.

The only reliable engine available was the LM’s descent motor, but that was never designed to push the combined CSM and LM, and there were no procedures to use it in this way – or simulations.

Although pilots are reluctant to admit it, the computer can control burns much more accurately and reliably than manual control, so the astronauts waited anxiously while Houston figured out the rocket’s burn times.



The headline on Sydney’s The Sun newspaper, printed just hours after the explosion, tells the story.

Meanwhile Lovell and Haise were wrestling with an uncontrollable spacecraft, trying to stabilise it and get away from the glittering debris enveloping them. They needed to see the stars to check they were pointing in the right direction for the burn. Every ruse failed. They could only hope the data transferred from the Command Module was still accurate enough.

“Roger, Aquarius, You are go for the burn,” Capcom Lousma finally announced. Haise commented, “This was yet untried. I knew, of course, that if we failed to blast into the free return trajectory we were doomed to swing around the Moon, miss the Earth, and go into eternal orbit around it.”

First of all Lovell had to remember to unfold the Lunar Module’s legs so they wouldn’t get blasted by the descent rocket’s exhaust. Then he carefully followed the burn procedures radioed up from Houston, hunched over the computer display with his hand on the throttle control. At 1842:43 AEST Tuesday 14 April the engine burned for 34.23 seconds, just over the scheduled 30 seconds. “Auto shutdown.” Lovell

 [Possible Atlantic landing site.](#) 235kb mp3.

Fred Haise calls Capcom Jack Lousma, to ask about plans for the return flight. Starting at 059:17:53GET

 [Possible burn foreshadowed.](#) 795kb mp3.

PAO commentary from 059:51GET.

 [Comms problems.](#) 520kb mp3.

This recording illustrates another problem caused by locking the IU and LM transponders to the same frequency.

Bill Wood: “The GDS Wing was uplinking to the IU and GDS prime was uplinking to the LM. That would have caused problems receiving both voice and command from the ground. While there was only one 30 kHz voice subcarrier from the GDS Prime, the presence of two uplink carriers would have caused the interference that the crew was hearing.”

Clip starts at 059:59:05GET.

advised Houston and everyone hung anxiously onto the trajectory displays. Was the Lunar Module's motor able to do the job? Was Apollo 13 coming home?

Soon the tracking data showed that the burn was perfect. Apollo 13 was going to round the moon at about 209 kilometres instead of 97 kilometres above the surface and would return to Earth into the Indian Ocean. "Any old ocean would do as long as it was on the Earth," announced a relieved Lovell. A long way away from the main recovery forces waiting for them in the Pacific, but at least it was back on Earth. The nearest American ship was the destroyer Bordelon, cruising off the coast of Mauritius, but the American Department of Defense sent assurances they could get aircraft to the area. Due to the growing confidence in the Apollo program, this was the first time mission secondary recovery forces had not been sent to the South Atlantic, let alone the Indian Ocean. Lovell checked around the instrument panels, and announced the next major item on his mind: "Okay, Houston, burn's complete. Now we have to talk about powering down."

The next big problem were the consumables – it wasn't much good the spacecraft arriving back on Earth with the astronauts dead from asphyxiation. The Lunar Module was only designed for two people for 45 hours, now it was going to have to support three bodies jammed in it for 90 hours. There just wasn't enough water or power to last the voyage back to Earth. Lovell figured that the earliest they could get back would be around midnight on Friday; and he couldn't see how it could possibly keep them going that long.

In the Lunar Module Haise was looking at the situation. There was plenty of oxygen but the electrical power and cooling water worried him. The LM had no fuel cells, only batteries for two days of normal operation, and the water used for cooling the electronic systems would run out about 5 hours before re-entry by his calculations. Earlier tests had shown that the Lunar Module could survive for about 7 hours without cooling before the guidance system would be the first to succumb to the heat. Haise waited for Mission Control's assessment.

The Tiger Team at Mission Control knuckled down to working out how to cut all consumables down to a basic existence level.

John Aaron:

"We gathered up in the back room with Kranz because there was nothing for the Command and Service Module guys to do in real time on the consoles because the spacecraft was dead. Kranz started talking about the strategy, what we were going to do going around the Moon and when we get back close to Earth we will power the spacecraft up and do the re-entry..... and I said, 'Kranz – you can't do that because you don't have the power' and he said, 'Okay John Aaron, you're in charge of power – if anybody wants any power you go and see John Aaron.'

So I said, 'Tell you what guys, I've got some ideas, but let me put them down a piece of paper and come back in an hour and I'll show you a way we might be able to do this.' So they came back in about an hour, and I had sketched out a rough profile and I told them, 'Okay guys, this is all the power we've got so we'll have to do the guidance system and all this stuff this way.....' and everybody started saying 'Oh my God, you can't do that - we've got to have this, we've got to have that' – and that started a whole sequence of the brokerage process between me allocating subsystems and switch turn-ons and circuit breakers and keeping track of the power profile. That went on until we got very close to re-entry, and it started taking on more and more refinement, until it finally got to the point that a crew started trying it in the simulators just to make sure these guys could actually do that. It was an endless iteration of brokerages across those days, and you have to remember all the power analysis was done on arithmetic and slide rules – we never had any calculators."

Bill Peters, Lunar Module TELMU, or electrical and environmental systems engineer:

"We had developed some off-line computer programs that gave a time line power profile output. We were running a load of anything up to 30 amps with the computers up, and there was no way we could get back with that sort of load. I figured if we could get down to about 12 amps we would be okay. We only knew this from our ground computations. Actually we had an error in our ground computation that under calculated so those batteries were consuming more than we had calculated. The first time I felt we could make it home was when we went

around the Moon and did the real LM power down and the numbers came up on the screen. Before that there was a possibility they would not make it. Once we hit the 12 amps I was convinced we had it made. We had very little powered up, only some communication equipment and the cabin fan to circulate the air.

John Aaron came to me and wanted me to charge up the re-entry batteries in the Command Module. We had concocted a scheme where we ran two CSM to LM umbilical cables backwards – they were designed for the CSM to send power to the LM – to heaters to keep some components warm while travelling to the Moon. This powered the Command Module’s inverters to charge its batteries. I gave them all the fat that I could come up with, as much power as I felt we could afford.”

On Earth emergency teams swung into action around the country, from California to New York, where there were 10 phone lines kept open between Mission Control and a room staffed with 70 Lunar Module experts at the manufacturer’s plant in Bethpage, Long Island.

On 14 April the US Senate adopted a resolution urging all communications media and businesses to pause at 2100, their local time, to “permit persons to join in prayer for the safety of the astronauts.” On the same day President Nixon cancelled his appointments and drove out to the Goddard Space Flight Centre in Maryland, accompanied by Apollo 11 astronaut Michael Collins, at the time Assistant Secretary of State for Public Affairs, to find out the details of how the mission was progressing.

Despite the Cold War, the Russians ordered four ships to the splashdown area, and Premier Aleksei Kosygin sent a message, “I want to inform you the Soviet Government has given orders to all citizens and members of the armed forces to use all necessary means to render assistance in the rescue of the American astronauts.”



[Free return manoeuvre planned for 61:30GET.](#)

5 min 30s / 1.4MB mp3. Starting at 060:22:53GET.



[Voice of America Commentary.](#)

6 min 47s / 1.4MB mp3. This is 12 hours after the explosion and the comms is now much better. Starting at 066:35GET.

Wednesday 15 April 1970

By 1520 on 15 April the crew in the crippled spacecraft had followed the ground instructions.

Lovell:

“We shut off all those exotic electronic devices that we would not normally be caught without out there the guidance systems, the computer, the auto pilot. We only had the radio for communications and a little fan to circulate the atmosphere.”

Haise:

“For most of the first two days after the explosion we split shifts I was awake in the LM alone while Jim and Jack slept in the CSM and vice versa. So there was no crowding during that period. It finally became so cold that we all just stayed in the LM. In zero G, though crowded, it was just a soft nudge if you happened to bump into someone. Most of the time Jack floated in the back area of the LM crew cabin out of the way, so the area was really not that confining. And it was good to have the three of us together in the same vehicle. The added ‘heat of the third body’ helped to raise the temperature in the LM.”

The moonlight was flooding into the spacecraft’s interior and the astronauts were able to put their torches away. They had cut their consumption of water down to 170 grams per day. As Houston told them to save the Lunar Module’s water for cooling, Lovell told Swigert to transfer all the drinking water from the Command Module to the Lunar Module, which he did using plastic juice bags, but he sloshed some of the water into his boots, and suffered the misery of cold wet feet for the rest of the trip. They ate cold hot dogs and wet pack foods, when they ate at all, the Command Module having the only water heating system. All the food and drinks were cold refrigerator cold! They didn’t get very thirsty and became quite dehydrated. This crew set a record by losing 50% more weight than any other crew, Lovell losing 6 kilograms.

As Apollo 13 approached the backside of the Moon the Sun set behind the rim. An eerie darkness enveloped the spacecraft. The glinting, blinding debris surrounding them vanished and the surrounding velvet blackness was studded with an illimitable sea of bright stars – stars in

every direction. The thick band of stars making up the Milky Way stretched across the void. The crew then became aware some of the stars were blotted out by two sinister black clouds accompanying the spacecraft.

Lovell, *"I can't for the life of me figure out what that dark stuff is."*

Haise, *"Yes – did you look at it, Jack?"*

Swigert, *"Yes, okay.....see it there like two black clouds."*

They decided it was the debris from the explosion. They became subdued as they remembered the crisis-laden moments of the explosion until a voice from Earth broke the spell, *"Aquarius, Houston."*

"Go ahead Houston."

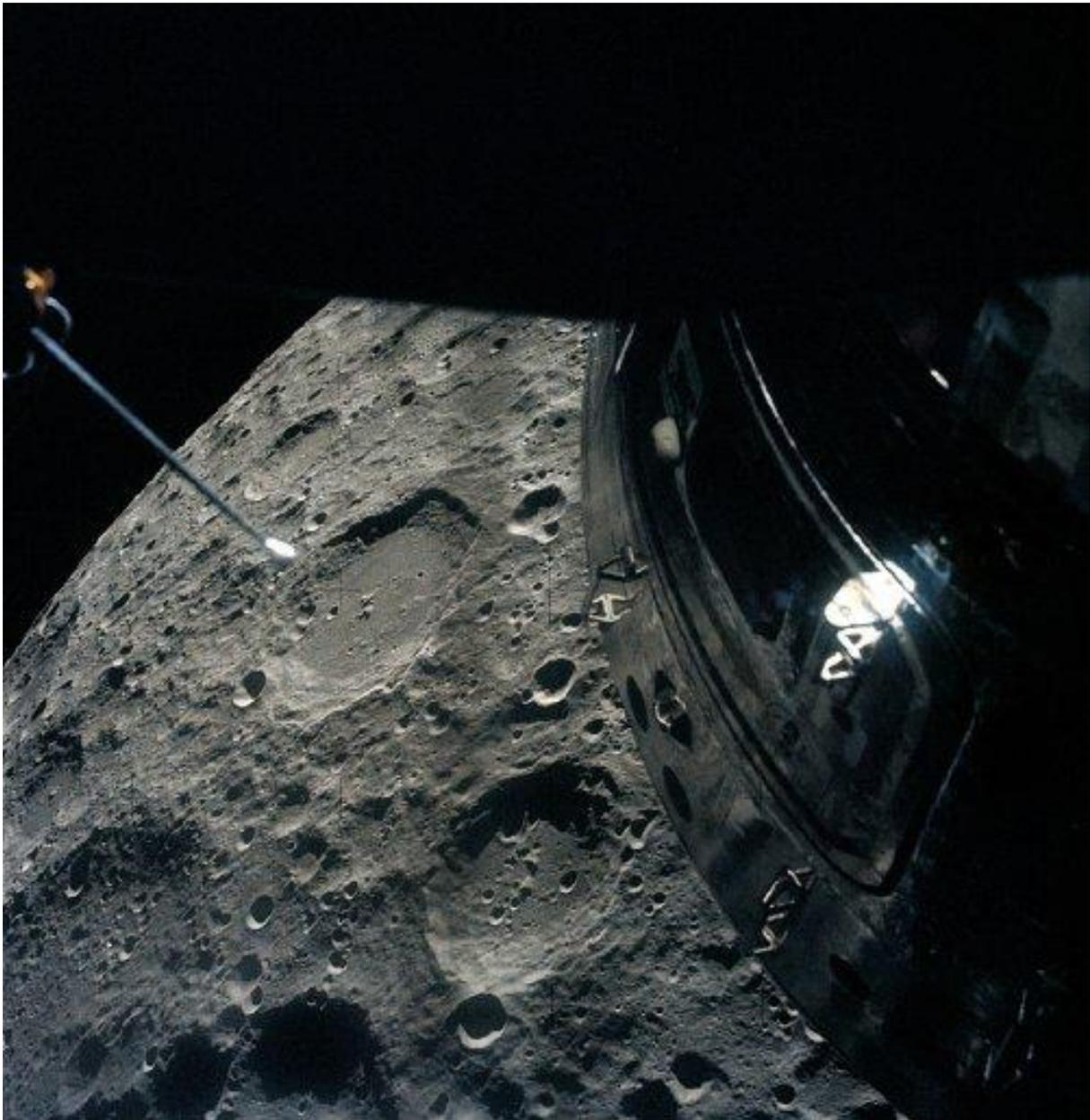
"Okay, Jim, we have a little over two minutes until loss of signal and everything's looking good here."

Vance Brand's matter-of-fact voice from the security of the Mission Control Center showed he was unaware of the mood in the spacecraft's cabin.

"Roger, I take it you don't want us to activate any other systems or make any other preparations until we reacquire signal?" Lovell checked.

"Roger – that's correct."

"Okay, we'll just sit tight, then. See you on the other side."



Apollo 13 rounds the Moon
View from Aquarius, with the Command Module at right. NASA JSC scan via the ALSJ. AS13-62-8909.

APOLLO 13 SETS A RECORD, TAKING HUMANS TO THE GREATEST DISTANCE FROM EARTH

At 1021:35 AEST on Wednesday 15 April (GET 77:08:35) Apollo 13 coasted behind the Moon and lost contact with the tracking stations on Earth for about 24 minutes 35 seconds. As they looped around the back of the Moon, at a maximum height of 253.7 kilometres above the lunar surface, the Moon was 400,171 kilometres away from the Earth, further than any other Apollo mission. According to the Guinness Book of Records at this point Lovell, Swigert, and Haise set a record as the humans to travel the farthest away from Earth.

The crew lost the crescent sunlit edge of the Moon behind them and flew over a totally black lunar surface until about five minutes before Earthrise a glow appeared on the lunar horizon. Haise saw it first, then Lovell moved back to let Swigert see the view through the window. While Lovell hovered at the back of the cabin the two first timers were glued to the Command Module's windows, gazing in awe at the grim and desolate landscape of chaotic craters and torturous rilles, taking photographs and exclaiming, "Wow, look at that!"

"Hey, you guys come on we've got a burn to do. If we don't get this right you won't get your pictures developed!" Lovell had seen it all before on Apollo 8.

"It's all right for you – you've been here before – we haven't." They still couldn't take their eyes from the passing spectacle.



[Apollo 13 rounds the Moon](#). 205kb mp3.

AOS. Starting at 077:35:39GET.

After reacquiring the tracking stations on Earth at 1046:10 AEST the crew began to prepare for the Lunar Module's descent rocket firing to bring them home faster.



[PC+2 burn](#). 1.2MB mp3. As heard live via the Voice of America, Rhett Turner reporting. 79:28GET.

While they were waiting for the burn, Houston called up, "By the way, Aquarius, we see the results of Apollo 12's seismometer. Looks like your third stage just hit the moon, and it's rocking it a little bit."



Mare Moscoviense. View from Aquarius. AS13-62-8922. From the Apollo Image Atlas of the Lunar and Planetary Institute.

Lovell answered, "Well, at least something worked on this flight. Sure glad we didn't have a LM impact too!"

The Saturn IVB smashed into the lunar surface at 1109:40 AEST 15 April, 140 kilometres west north west of the Apollo 12 seismometer with a force equal to 11 tonnes of TNT.

Dr. Gary Latham, principal investigator of the experiment, commented:

"The Apollo 12 Lunar Module's signal only lasted for about 55 minutes. This signal (from the Apollo 13 Saturn IVB) arrived about 30 seconds after impact, the peak amplitude was a factor of 20 to 30 times larger than the LM, and lasted for 4 hours, which was astounding to us."

Choosing the safest option of the three available, one that did not require the Service Module to be dropped off, but took the longest time, Houston told the crew they could shorten the trip by 10 hours with a PC+2 burn, or a burn 2 hours after Pericyynthion, the closest point they would come to the Moon. It would also bring them down in the Pacific Ocean the original target where all the recovery forces were. Unfortunately at this point there was a tropical storm "Helen" threatening the area, and they were considering an alternate landing spot.

Due to the software in the LM not being able to accommodate the attached dead bulk of the CSM, Lovell had to fire the engine manually.

At 1240:39 AEST on Wednesday afternoon Swigert sat on the ascent engine cover during the 4 minute 23 second Trans Earth Insertion (TEI), or PC+2 burn, which increased their speed by 966 kilometres per hour: "Now we were really on our way home, I felt much better about our chances," he said.

Now it became a matter of waiting. And how the time dragged!

Lovell:

"It was very quiet very quiet. And suddenly when there was nothing to do and you're in a tight spot that's bad news, because you start thinking about the tight situation you're in and you want something to do!"

In the computer room at Honeysuckle Creek it was anything but quiet.

Geoff Seymour, Computer Supervising Engineer:

"We had an intermittent hardware problem in the telemetry computer. Prior to the launch we had experienced this problem and at one stage they were anticipating delaying the launch until we could fix the problem, but the computer managed to stay up long enough for the launch to go ahead.

Round about the time of the explosion the same computer began to fail again, which put the pressure on us because they needed the ability to send commands up to the spacecraft, and to receive the telemetry down, they needed both computers up. We began to troubleshoot this computer and managed to narrow it down to three printed circuit boards on one chassis. We replaced those, but it didn't solve the problem. I stayed on site, sleeping in one of the bedrooms below until we fixed it. As the spacecraft rounded the moon and was coming back the NASA engineers decided to ship out a chassis from the computer in the training facility in Goddard and strapped it into a first class seat on an airliner.

We believed we could fix it before the chassis arrived from the States. The only thing left for us to do was to take the chassis out of the computer and we removed several hundred printed circuit boards, we cleaned every socket in the chassis, we cleaned every pin on every printed circuit board we could remove – we put it all back in, and from that day onwards the intermittent problem just went away."

Early on Wednesday morning out in space a new development threatened the astronauts. A light warned them that the carbon dioxide had built up to a dangerous level, and in the confines of the Lunar Module they would have eventually gone to sleep and died, poisoned by their own breath.

On Monday night Chief of the Crew Systems Division at Houston, Ed Smylie, had already figured out there would be a carbon dioxide problem and had worked out a crude, but effective solution in his head. He joined his assistant, Jim Correale, to devise a system to join the Command Module's square lithium canisters, which clean the carbon dioxide from the air, to the Lunar Module's round system using only the materials available on board such as tape, plastic, and cardboard. Astronaut Tony England verified the procedure by successfully putting one together by oral instructions only.



Jim Lovell (left) and Jack Swigert (right) work with temporary hose connections inside Aquarius.
In the background is the contraption holding the carbon dioxide scrubbers.

This photo is a combination of AS13-62-9003 and 9004, both taken by Fred Haise.

Source images courtesy of the Lunar and Planetary Institute, composite image by Colin Mackellar, 2018. (Some objects in the photo have been slightly shortened due to changed perspectives. Here is the [single frame](#) previously used.)

Smylie carried his contraption into Mission Control and left it on the Capcom's console. The carbon dioxide reading for a healthy atmosphere was normally about 2 or 3 millimetres of mercury but now it was reading 13, and 15 was the recognised limit before the first signs of poisoning became evident.

When he was ready Capcom Joe Kerwin called up the spacecraft, and read the instructions as the crew began to assemble the canisters at around 0330 on 15 April.

Lovell: "Jack and I put it together it wasn't very handsome, but it worked."

In the Australian Senate, Apollo 13 caused enough concern to be raised as questions on April 15 and April 16.

Senator Anderson:

"It is interesting to be able to tell the Senate and the people of Australia that a small army of dedicated Australians worked throughout the night to install microwave links enabling the 64 metre radio telescope of the Commonwealth Scientific and Industrial Research Organisation at Parkes to assist the return voyage of the Apollo 13 spacecraft. Parkes, within hours after a request by the National Aeronautics and Space Administration, established voice communication with the astronauts at about 8:30 pm last night.

Teams from the Post Master General's Department and the Australian Broadcasting Commission, assisted by personnel from Amalgamated Wireless (Australasia) Ltd., installed temporary microwave circuits from Parkes to Coonambro and from Red Hill in

Canberra via Williamsdale to Honeysuckle Creek. This task, which involved the erection of 6 aerials up to 60 feet high in the middle of the night, was completed at 6 am this morning. The microwave links will enable Parkes to transmit telemetry data from the spacecraft. Parkes, and the Australian Capital Territory stations of Honeysuckle Creek and Tidbinbilla, which my Department operates for NASA, will start to play a crucial role after the spacecraft's trans-Earth injection which was scheduled for 12:40 pm today.

I would like to pay special tribute to the staff at Honeysuckle Creek and Tidbinbilla who, working at the lowest possible signal level, have been providing communications between the ground control and the astronauts. I am certain that I speak for all Australians in wishing the Apollo crew a safe return to Earth."

Thursday 16 April 1970

At 0626:53 AEST during the morning of 16 April, not long after they had entered the influence of the Earth's gravity field, everyone at Mission Control slid to the edge of their seats and grappled with another heart stopping report from Haise: "I just heard a little thump, sounded like down in the descent stage, and I saw a new shower of snowflakes come up." Another explosion! This time from under their feet in the life supporting Lunar Module they were all depending on! More debris gathered around the two stricken spacecraft.

It was battery #2 in the Lunar Module's descent stage. Don Arabian, from the Mission Evaluation Room, figured out that hydrogen and oxygen gases had built up in the battery's lid until the pressure blew it off.

Bill Peters, the Lunar Module's electrical engineer:

"After it made its "pop and snowflakes" as people say, we looked at the data and it had a spike in the current data, that's all we saw in real time, but that battery continued to run for a long time before it failed to contribute electricity and I turned it off." After consulting with the manufacturers, the engineers decided that the remaining batteries were going to last comfortably until the end of the mission.

Mission Control began working on correcting some errors derived from the TEI burn with

another burn of 14 seconds of the Lunar Module's descent motor at 1431:28 AEST on 16 April. Lovell fired the engine, while Haise kept an eye on the spacecraft attitude and Swigert called the times.

Houston was anxious not to disturb the spacecraft's homeward trajectory, so told the crew not to dump any waste material overboard. This meant they had to find a way to store their urine on board. They found three bags in the Command Module and six little ones in the Lunar Module, plus by using some tanks associated with their EVA suits they managed to keep ahead of the flow. "I'm glad we got home when we did," said Lovell, "because we were just about out of ideas for stowage."

Friday 17 April 1970

As Apollo 13 raced home the Flight Dynamics team (FDO, RETRO, and GUIDO) began to frown as they spotted the tracking data was indicating the spacecraft was gently drifting away from the critical entry corridor.

What was causing this insidious drift? Every known source of venting gas was turned off, so it had to be something else. After the mission ended, it was concluded that the small thrust causing the drift came from a 'non-propulsive' water boiler vent in the Lunar Module's cooling system, which under normal circumstances would not have been noticed in the short dash down to the moon's surface and back. When the error crept up to 161 kilometres it was time to do something, or the astronauts in their spacecraft would bounce out of the atmosphere and go off into solar orbit: "... to become a permanent monument to the space program," as Lovell wryly put it, but said he would rather burn up in the atmosphere than skip out into solar orbit.

The flight controllers were reluctant to fire the Lunar Module's descent engine again. Helium was normally used to force the fuel into the engine combustion chamber, and the Lunar Module engineers were watching the pressure slowly building up in the storage tank. At 12,411 kPa a safety membrane would blow out to relieve the pressure. Once that happened there was no guarantee the engine would work, so the correction burn had to happen before the

helium blew. Late during Wednesday evening when Capcom Vance Brand called Apollo 13:

"We don't want to power up the spacecraft completely, so that means no computer or mission timer.

We'll simply go with a manual burn, with you controlling the engine with the Start and Stop switches. For attitude, what we're going to want to do is manually orient the spacecraft to place the Earth in the centre of your window. If you hold it there throughout the burn, the attitude will be correct. Got that?"

"Roger, I think so," Lovell confirmed thoughtfully, remembering back in Apollo 8 they had tried just such an exercise to see if they could steer the spacecraft into the re-entry corridor with no help from the navigation systems. Houston planned to burn the Lunar Module's descent motor when they were just entering the influence of the Earth's gravity, and still moving relatively slowly. Using Swigert's wrist watch, from 1431:28 AEST 16 April, they timed the burn manually for 14 seconds at 10% power, during which Lovell and Haise steered the spacecraft to keep the crosshair of the optical sight in their windows parallel with the Earth's terminator, or sunset line, which meant they should be aiming straight for the re-entry corridor again.

Three and a half hours later the helium pressure reached 13,245 kPa and blew the safety membrane out, sending another thump through the spacecraft and a shower of sparkling crystals to join the cloud of debris shepherding Apollo 13 through space. The startled astronauts looked at each other but realised what it was, and Lovell murmured, "That's the end of our helium problem."

It became so cold in Odyssey that sleep was impossible. Lovell:

"When we turned off the electrical systems, we lost our source of heat, and the sun streaming in the windows didn't help much. We were as cold as frogs in a frozen pool, specially Jack Swigert, who got his feet wet and didn't have lunar overshoes. It wasn't simply that the temperature dropped down to 1.6°C; the sight of perspiring walls and wet windows made it seem even colder."

The Command Module had been referred to as "the bedroom", but by the last day they were

calling it "the refrigerator". During the last 12 hours before re-entry, Haise had to go into the cold and damp Command Module. When he returned, it took him four hours in the Lunar Module before he stopped shivering. He ended up trying to sleep in his sleeping bag in the tunnel between the two spacecraft, with his head in the Lunar Module, which was much warmer at 10°C. Even after the fiery re-entry and warm 27°C Pacific waters they could still see their frosty breath inside the cabin.



[It's cold in here.](#)

Honeysuckle is prime during this recording of Jim Lovell describing the cold – the 39 second recording, made at Honeysuckle Creek, begins at 132:53GET.

This clip (254kb mp3 file) was recorded by Hamish Lindsay.

Lovell commented:

"We had a dead Service Module, we had a Command Module but it had no power in it, and we had a Lunar Module that was a wonderful vehicle but it didn't have a heat shield."

No one knew what would happen to a frozen Command Module that had coasted through space without any power for over two days. "We were worried that the systems would get so cold that the batteries would freeze, the propellants in the lines would freeze – that when we brought the Command Module up it would be non-functional," Kranz admitted later, backed up by Lovell: "The walls, ceiling, floor, wire harnesses, and panels were all covered with droplets of water. The chances of short circuits caused us apprehension, to say the least. But thanks to the safeguards built into the Command Module after the disastrous fire in January, 1967, no arcing took place. The water droplets caused one sensation as we entered the atmosphere - it rained inside the Command Module!"

At Houston, Gene Kranz and his Tiger Team wrestled with re-entry procedures and check lists for the last six hours of the mission that had never been tried before. Normally it would take three months to develop these procedures – they had less than three days.

John Aaron:

"Basically we planned to power up the vehicle in reverse, we had the crew turn the guidance system on in the blind, then right at the end I

allowed them to turn on the telemetry system so that we could see it and verify it was all on okay. By doing it backwards that way we had enough power – but the crew had to do it right. Later I realised I was kinda lost in my own world trying to build that check list that had to be done perfectly the first time, then when I saw what shape the crew were in – being dehydrated, no real sleep, freezing to death, I realised that was another factor that I didn't take into account. But they executed that check list perfectly, it was just amazing.

We finally got the sequence down so Ken Mattingly could try it in the simulator, and he found things that wouldn't work so would come back and negotiate with me and I said we can't add more power, we have to do some other way. And of course the crew was getting kinda anxious, they were trying to be subtle, but not too subtle, and kept saying, 'Hey Houston, we're looking out the window and the Earth's getting bigger and bigger – where's that check list?'"

It was Thursday evening in Houston when Arnold Aldrich and Gene Kranz escorted Aaron into the Mission Control Center, hugging the checklist to his chest: "I had one hand type-written copy with the latest changes in it, we didn't have word processors in those days, and I said 'Okay Flight - here it is, read it to the crew.'"

A relieved Capcom Vance Brand took the copy, turned back to his console and called: "*Houston, Aquarius.*"

"*Go, Houston,*" replied Lovell.

"*Okay, we are ready to read you the first checklist instalment*"

"*All right, Vance. I'm going to get Jack on the line, so stand by.*"

Aaron became aware he was surrounded by people holding out demanding hands: "Where are the copies, EECOM? I need a copy." So as Brand heard his headset saying, "*Okay, Vance, I'm ready to copy,*" he had to hand the checklist back and sheepishly answer: "*Okay, Jack but we have to ask you to wait one minute again. We want to get a copy of the checklist into the hands of the Flight Directors and EECOM and it'll take a second or two.*"

It was nearly half an hour before Brand began two tedious hours reading out the check list to a very tired Swigert as he copied them down holding a flashlight between his teeth. Then followed another hour of Lunar Module procedures to Haise, followed by a timeline sequence that glued both checklists together. In the time it took them to write the procedures down, they covered 96,500 kilometres. Swigert finished writing down the last entry just over 12 hours before they were due to start using it – there was no time for corrections or a second chance it had to be right the first time as the spacecraft hurtled towards that narrow door into the Earth's atmosphere with its speed building up to a maximum of 38,623 kilometres per hour.

Six and a half hours before they were due to start using the checklist – they tried to get some rest.

Lovell reported:

"Haise is lying in the tunnel with his head on the ascent engine cover, Swigert is lying on the floor in a sleep restraint."

They had been averaging three hours of disturbed sleep a day.

Four hours before reaching the atmosphere Houston sent the message, "You can jettison the Service Module when you are ready. No big rush, but any time." Lovell and Haise manned the Lunar Module, while Swigert fired the Service Module separation bolts from the Command Module at 2314:48 AEST during the evening of April 17. Lovell had suggested to Swigert that he put a label over the switch to jettison the Lunar Module in case he threw the wrong switch, and sent his mates off to be incinerated in the brief meteor the Lunar Module was to become!

Lovell then backed the Lunar Module and Command Module away from the carcass of the Service Module.

Swigert tried each of the Command Module windows but saw nothing. Lovell swung the spacecraft around and he and Haise peered out of the Lunar Module's windows and also saw nothing – no sign of the big cylindrical Service Module.

ONE WHOLE SIDE OF THE SPACECRAFT IS MISSING

Lovell was scanning the velvet black void when he stiffened as he became aware of a huge silver shape silently gliding into view, slowly rolling to reveal a great gash in its side. Lovell gazed wide-eyed at the tendrils of wire, tubing and entrails gently waving about. Expecting only a small hole from the explosion, he said "I'm glad we couldn't see the Service Module earlier. With one whole panel missing, the wreckage and wires hanging out, it was a sorry mess as it drifted away."

Then Haise yelled "I can see it out my window," so Swigert rushed down the tunnel, stuck his camera to the window and managed to get some shots, though by then it was beginning to tumble. Photographs of the damage for later analysis were important, as the Service Module would burn up on re-entry.

Jim Lovell exclaims, "There's one whole side of that spacecraft missing."



[One whole side of that spacecraft missing.](#)

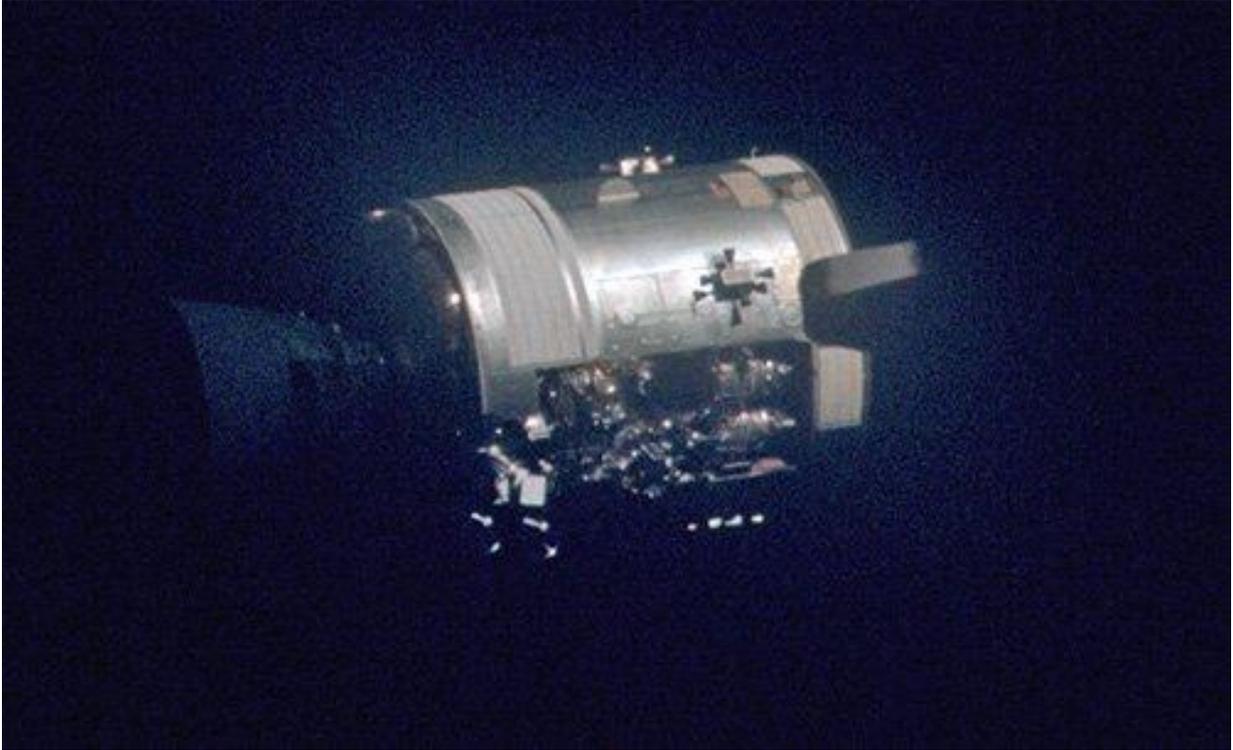
Jim Lovell exclaims, "There's one whole side of that spacecraft missing." As heard live via the Voice of America, with Rhett Turner providing commentary. 4.7MB mp3 / 9 minutes.

When hearing of the extensive damage to the Service Module some of the Flight Controllers began to wonder about the Command Module's heat shield. Had it been damaged in the explosion? Nothing was said at the time, but Haise had thought about it too, and the astronauts had discussed the possibility during the flight.

During the mission they had filled the Command Module with all their rubbish in plastic bags, and now Haise had to transfer them all back to the LM as they prepared for the homecoming. He commented: "*Boy, you wouldn't believe this LM right now! There's nothing but bags from floor to ceiling!*"



The damaged Service Module drifts away.



Here's another view. AS13-58-8464, via the Lunar & Planetary Institute in Houston.

[The photo](#) has been cropped and considerably brightened.

Click [here](#) to watch a 3.1MB MPEG4 video file

Animation assembled by Colin Mackellar from images courtesy of the [Lunar and Planetary Institute](#).

Saturday 18 April 1970

At 0400 USCST on Friday April 17 the members of the Tiger Team entered Mission Control and spread around the consoles for the final moments of the saga. John Aaron took over from Sy Liebergot at the EECOM console and around 1000 he felt ready for the Command Module power up procedure and called on the intercom,

"Flight, EECOM."

"Go EECOM," returned Kranz.

"Ready for power up any time the crew is."

"Roger EECOM – Capcom Flight."

"Go Flight," answered Joe Kerwin.

"EECOM says the Command Module can come on line anytime."

"Roger Flight," Kerwin keyed his air/ground switch, "*Aquarius, Houston.*"

"Go Houston," Lovell responded tersely.

"*You're go to start powering up Odyssey.*"

Swigert felt a useful member of the crew again as at 0123 AEST Saturday April 18 he began to power up the Command Module using its normal three re-entry batteries, which had

been topped up from the Lunar Module's batteries. "Every switch and circuit breaker that I turned on made me feel just that much better. I forgot about being tired and didn't even notice the cold."

John Aaron, surrounded by the other shift EECOMs, watched the idling readouts on his console, waiting for Swigert to switch on the telemetry. He was looking for a maximum current drain of 43 amps. If it was much more the batteries might not last to splashdown. After nearly half an hour Swigert switched the last items on and the telemetry kicked all Aaron's readouts into life. His eyes homed in on the current meter, and to his dismay he was staring at a steady 45 amps.

"What the hell are those two rogue amps doing there?" he angrily questioned anybody on the intercom or within earshot. Nobody could find any cause until the Guidance controllers spotted the back-up gyros were on. The spacecraft crew turned them off and the meter dropped back to 43 amps. Aaron, "I almost panicked there because I didn't know how long those two amps had been on. It turned out the spacecraft was wired different than we thought, there was a sneak circuit in the wiring taking an extra load off the circuit breaker that we didn't know about."

Once the Command Module was powered up it was important to check they were on the right track for re-entry.

Capcom Joe Kerwin:

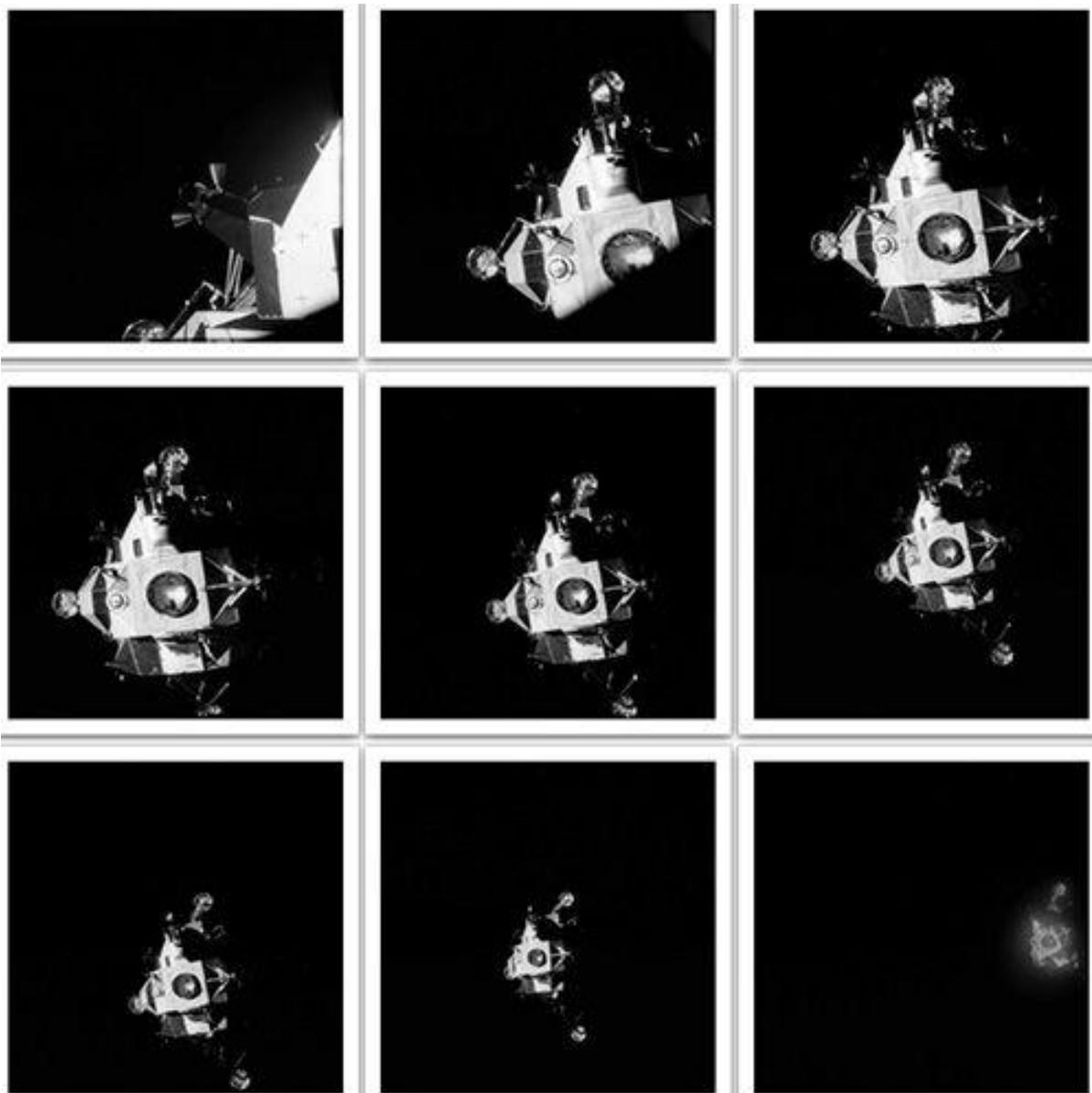
“This was the tense time for me. Swigert was trying to find the two stars necessary to align the platform to get their precise attitude. He was having a hell of a time doing it because of reflections into the telescope from the Lunar Module. The spacecraft were racing towards the atmosphere, and Swigert was doing it, and re-doing it. What we would have had to do was to say ‘Okay, Jack it's time to knock that off – we'll take an approximate attitude – it's time to jettison the LM – we have to get on with it.

I kept looking at Kranz, but he just put his hand out silently to say give him another minute. Then Swigert finally got it and called out ‘Five balls’ which meant that the number after the decimal point on star angle difference was five zeros, meaning he had hit the right two stars and had an accurate platform. From there on everything just went nominally from my point of view.”

Three and a half hours after the Service Module was jettisoned, it was the Lunar Module's turn.

Lovell, *“Ten seconds.”*

Swigert *“Five..... LM Jettison,”*



“Farewell Aquarius, and we thank you.”

The ‘Age of Aquarius’ ends at 0243AEST on April 18th.

Assembled from images AS13-59-8559, 61, 62, 63, 65, 66, 68, 71, 73, courtesy of the [Lunar and Planetary Institute](http://www.lpi.usra.edu).



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At 0243 AEST 18 April the faithful "lifeboat" Aquarius was released and pushed off with 20.7 kPa air pressure from the tunnel. Sadly they watched it drift away to begin a slow forward somersault. Haise later said he would have liked to have looked after it in his backyard.

"Okay, copy that. Farewell Aquarius, and we thank you," Kerwin called out from Houston.

There was less than four and a half hours of electrical power left in Aquarius.

 [LM jettison.](#)

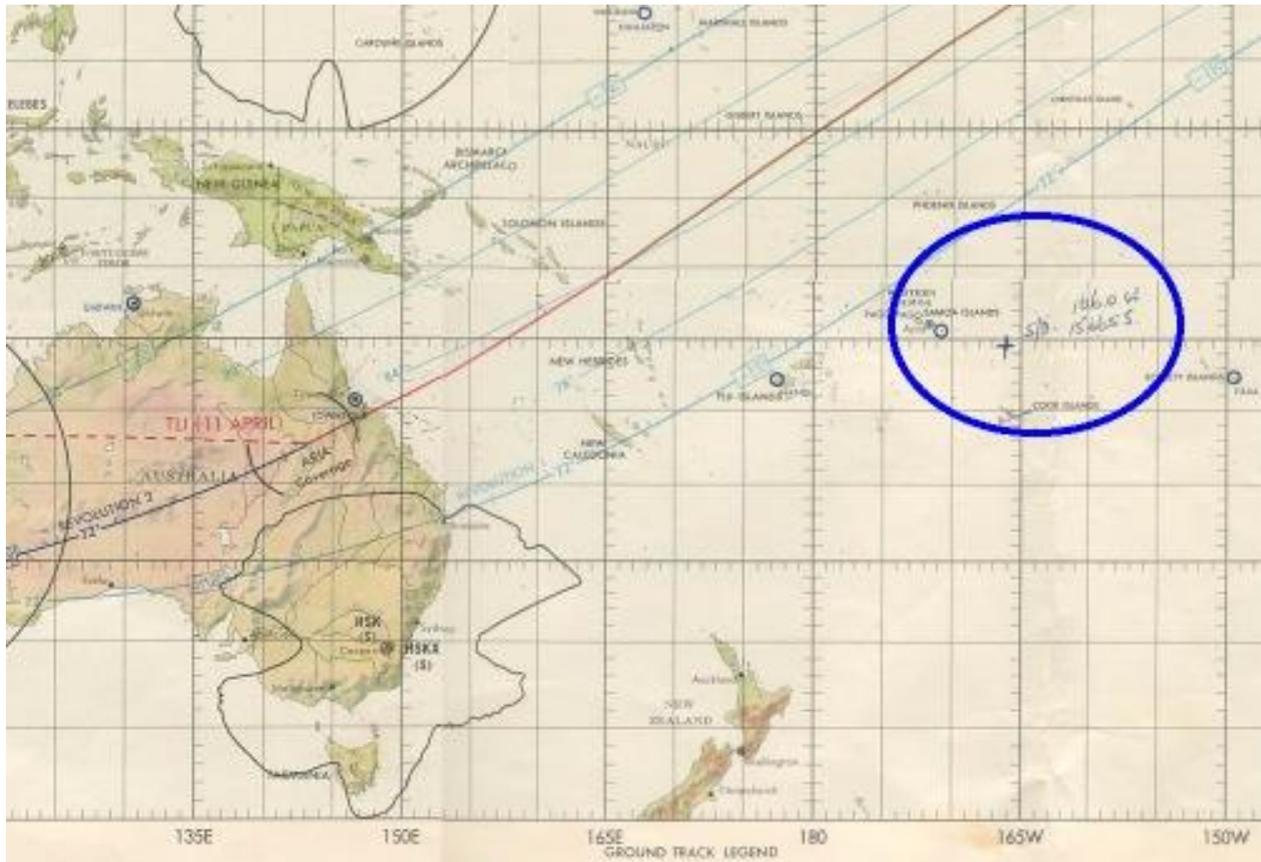
340kb mp3. Aquarius is jettisoned. Voice of Apollo as heard via ABC Radio.

Paul Oats at Carnarvon:

"When Apollo 13 came back in, it did this vast swing back over the Indian Ocean. Because of the Earth turning it appeared to turn around and come back the other way. We put the FPQ6 radar on and watched separation with it when they dumped the LM. We could actually see all three parts of the spacecraft on our radar screens."

John Saxon at Honeysuckle Creek:

"We were the last site, as we generally were, to track the re-entry phase of the mission when they entered the Earth's atmosphere. We were tracking both the Command Module and the Lunar Module.



Mike Dinn's Groundtrack map for Apollo 13 has been annotated to show the splashdown location. Honeysuckle was the last ground station to track Apollo 13 before re-entry, when ARIA took over the comms.

[Click here](#) to get a 730kb scan of the entire map.

There was a great deal of interest in where the LM came down because it had a package to be installed on the Moon which had a radio isotope power supply, and there was a concern that had it entered over land there might have been a radioactive contamination problem. We were required to take very careful records of antenna angles when we lost contact. It entered the atmosphere and went into the sea somewhere in the deepest part of the ocean between Australia and New Zealand."

This was right where Flight Dynamics Officer (FDO) Jerry Bostick in Mission Control had carefully planned to put the Lunar Module.

Paul Mullen, antenna driver at Honeysuckle:

"We lost the LM at the end – it was going too fast for our 3° per second antenna speed – it just dived out of sight ahead of our antenna."

Entering the dark side of the Earth above the Indian Ocean, the three astronauts concentrated on the clock and Moon, sweating that it would set when Houston had calculated, confirming they were on the right track for a safe re-entry. At precisely the right second a

black notch bit into the bottom of the Moon, and it sank below the Earth's horizon.

The Commander looked at his crew: "Gentlemen, we're about to re-enter. I suggest you get ready for a ride."

Kerwin, "Odyssey, Houston standing by. Over."

Swigert, "You have a good bedside manner, Joe."

Kerwin, "That's the nicest thing anybody's said. How about that?"

Swigert: "Sure wish I could go to the FIDO (Flight Dynamics) party tonight."

Kerwin, "Yes it's going to be a wild one.....Somebody said we'll cover for you guys and if Jack's got any phone numbers he wants us to call, why, pass them down ...

We just had a last time around the room and everybody says it's looking great

 [One last time around the room.](#) 140kb mp3

Welcome home."

Swigert, "Thank you."

 [Welcome home](#). 220kb mp3.

Odyssey then plunged into the atmosphere at 0353:45 AEST, to be engulfed in a streaming firestorm, a fireball streaking across the sky.

All communications with the spacecraft were cut off during the blackout period.

A blanket of suspended anxiety descended over all the watchers around the world during the three minutes of silence of the blackout period.

 [Audio onboard ARIA 4](#) (page)
Searching for a signal from Apollo 13 – [Re-entry section](#).

The seconds flicked away with no response from the spacecraft. Unable to do any more for the mission now, the Houston Flight Controllers

could only watch the recovery forces at work on their large television screens and listen for the spacecraft to respond to their Capcom. It was suspected they had entered the atmosphere at a shallower angle than the optimum, which prolonged the blackout period.

The tension built up..... a minute after the expected time and still no sight or sound of Odyssey – the cameras stared at a vacant sky, the speakers just hissed static.

Joe Kerwin called out from Houston, "Odyssey, Houston standing by."

Suddenly Swigert's voice filled the airwaves over the Pacific, "Okay, Joe!" and at 0402 AEST three healthy parachutes were seen.

 [Okay Joe](#).
205kb mp3. Audio from NASA Public Affairs.

Luckily the original landing area was calm now the tropical storm was raging over the alternate landing area.



Joe Kerwin on the Capcom console, earlier in the mission.
From 16mm NASA footage, screenshot by Colin Mackellar.



The Apollo 13 crew arrive on the Iwo Jima.

Photo courtesy of Kipp Teague's Apollo Image Gallery. NASA image: ap13-KSC-70PC-0130

Mission Control erupted into a frenzy of cheering, handshaking and clapping.

John Aaron:

“Since I had designed the re-entry sequence, Kranz put me on the console as it came in and that worked out fine, but that sure was something when they made it through the blackout and out came the chutes. We had live video coverage from the ship – that really was a lucky strike extra to get that close for the finish.”

So how close was it to three fatalities? According to Sy Liebergot, the LM had 104 hours of breathing oxygen left, but only 10 hours of water and 13 hours of electrical power.

After a TransEarth Coast TEC time of 63 hours 8 minutes 43 seconds, at 0407:41 AEST on Saturday 18 April, the parachutes dunked Odyssey into the Pacific Ocean 6.5 kilometres from the USS Iwo Jima, and the crew were greeted by cheering sailors, a brass band, and

Rear Admiral Donald Davis with, “We’re glad you made it, boys.”

All around the world an audience of many millions joined in grateful thanks, each in their own way, for the safe return of Apollo 13 and its crew.

Nine doctors checked them out to be in reasonable shape considering their ordeal, except for a urinary tract infection for Haise, brought on by not drinking enough fluids, which allowed the toxins to build up. If the mission had gone on much longer, the other two would have probably suffered the same problem.

Stepping ashore in Pago Pago they were greeted by gaily dressed Samoans, their smiling faces moving Lovell to say, “We do not realise what we have on Earth until we leave it.”

rescue ships or aircraft. And stretching credibility a bit the astronauts first names of James, Fred, and Jack add up to 13 letters, the launch date of 4/11/70 add up to 13 from pad 39 which is 3 x 13. Even German Measles has 13 letters. Not surprisingly the Horoscope for Aquarius from the Houston Post of April 13 1970 said 'Do surprises turn you on? Then this is the day for the unexpected.'

Was Apollo 13 good luck or bad luck? Probably good luck because it brings up a lot of "What ifs...?" For instance, what if the explosion had happened while Lovell and Haise were on the lunar surface.....!!?

Lovell said:

"To get Apollo 13 home required a lot of innovation. Most of the material written about our mission described the ground-based activities, however I would be remiss not to state that it really was the teamwork between the ground and the flight crew that resulted in a successful return. Some people would call the Apollo 13 mission a \$375 million failure. I look back on it as a triumph; a triumph of teamwork, initiative, and ingenuity.

Nobody believes me, but during this six day odyssey we had no idea what an impression Apollo 13 made on the people of Earth. We never dreamed a billion people were following us on television and radio, and reading about us in banner headlines of every newspaper published. We still missed the point on board

the carrier Iwo Jima which picked us up because the sailors had been as remote from the media as we were. Only when we reached Honolulu did we comprehend our impact."

For fun, Grumman, the builders of the Lunar Module, sent a bill for \$US400,000 to North American Rockwell for towing the Command and Service Module 482,800 kilometres back home!

Jack Swigert said after the mission:

"I knew that no matter how dark the situation looked, we had a lot of help from the ground. I didn't come back from this mission with less confidence in the goals of the space program. I came back with more."

Chris Kraft:

"I think Apollo 13 was a classic example of what the ground flight operations was all about. It proved that the ground was worthwhile. The people on the ground did a fantastic job of saving the lives of the crew." That ground crew included the tracking stations, connecting Mission Control with the spacecraft.

President Nixon summed up this dramatic odyssey with:

"The three astronauts did not reach the moon, but they reached the hearts of millions of people in America and in the world."



ACRONYMS

AEST	Australian Eastern Standard Time.
ACN	Ascension Island Tracking Station in the south east Atlantic Ocean.
Acq	Acquisition (of spacecraft signal).
ALSEP	Apollo Lunar Surface Experiments Package, the scientific instruments left behind by the Moon landings.
AOS	Acquisition of signal from the spacecraft (the downlink).
APP	Antenna Position Programmer, computer controlling the antenna.
Capcom	Capsule Communicator, the voice of Mission Control, always an astronaut.
CRO	Carnarvon Tracking Station, Western Australia.
CM	Command Module.
CSM	Command and Service Module.
CT	US Central Saving Time.
DOWNLINK	The signal sent from the spacecraft back to the tracking stations on Earth.
DSKY	Guidance computer keypad.
DSS	Deep Space (Tracking) Station.
EECOM	Emergency, Environmental, and Consumables Management.
ET	US Eastern Time.
GDS	Goldstone Tracking Station in California.
GET	Mission Ground Elapsed Time, time in hours/minutes/seconds from launch.
GWM	Guam Tracking Station in the north west Pacific Ocean.
HSK	Honeysuckle Creek Tracking Station, Canberra, Australia.
HSKX	Canberra Deep Space Communications Complex at Tidbinbilla, also called the Wing.
IU	Instrumentation Unit, electronic system part of the Saturn IVB rocket.
LM	Lunar Module, the spacecraft that landed on the Moon in later missions.
LOI	Lunar Orbit Insertion.
LOS	Loss of the downlink signal from the spacecraft.
MAD	Madrid Tracking Station, Spain.
MOCR	Mission Operations Control Room in Houston.
MSFN	Worldwide Manned Space Flight Network of tracking stations.
NASA	National Aeronautics and Space Administration.
NET-1	Phone line between Mission Control Capcom and astronauts in spacecraft.
OMNI	Multiple antennas around the spacecraft.
PGNS	Primary Guidance and Navigation System.
PSI	Pounds per square inch pressure.
PTC	Passive Thermal Control – spinning the spacecraft to even temperatures around it.
RCS	CSM Reaction Control System for controlling the attitude of the spacecraft.
REFSMMAT	Reference to Stable Member Matrix or a mathematical means of determining navigation angles using the stars as a reference.
S-IC	First stage of the Saturn V launch booster rocket.
S-II	Second stage of the Saturn V

SIVB	Saturn IVB, third and final stage of the Saturn V launch rocket
SAS	Space Adaption Syndrome, or motion sickness.
SPS	Service Propulsion System – Service Module rocket motor.
SRT	Site Readiness Test. Tracking station equipment tests before each group of passes.
TEC	Trans Earth Coast – the voyage back to Earth.
TEI	Trans Earth Injection – the rocket motor burn to send spacecraft back to Earth.
TLC	Trans Lunar Coast – the voyage out to the Moon.
TLI	Trans Lunar Injection – the rocket motor burn to send spacecraft toward the Moon.
UPLINK	The signal sent from the tracking station up to the spacecraft.
USB	Unified S-Band, the tracking station system
UT	Universal Time, also known as Greenwich Mean Time (GMT).

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Chris Kraft, Gene Kranz, Glynn Lunney, Fred Haise, Jerry Bostick, John Aaron, Sy Liebergot, Bill Peters, Joe Kerwin, Bill Wood, Don Gray, Tom Reid, Mike Dinn, John Saxon, Neil Eyre, John Mitchell, Bruce Window, Kevyn Westbrook, Trevor Gray, Wilfred Laing.

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Hamish Lindsay's classic photo of Honeysuckle Creek.
Above is a cropped version of Hamish's [full image available here](#). 1mb file.

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ABOUT THE AUTHOR

Hamish Lindsay worked at the Muchea, Carnarvon, and Honeysuckle Creek space tracking stations between 1963 and 1981.

He has written many essays on the history of human spaceflight and is the author of the book *Tracking Apollo to the Moon*.

