APOLLO BY THE NUMBERS

A statistical reference for the manned phase of Project Apollo

by

Richard W. Orloff

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Introduction

The purpose of this work is to provide researchers, students, and space enthusiasts with a comprehensive reference for facts about Project Apollo, America's effort to put men on the moon.

Research for this work started in 1988, when the author discovered that, despite the number of excellent books that focused on the drama of events that highlighted Apollo, there were none that focused on the drama of the numbers.

It may be impossible to produce the perfect Apollo fact book. For a program of the magnitude of Apollo, many NASA centers and contractors maintained data files for each mission. As a result, the same types of measurements from different sources vary, sometimes significantly. In addition, there are notable errors and conflicts even within official NASA and contractor documents. In order to minimize conflicts, the author sought original documents to create this work. Some documents were previously unavailable to the public, and were released only following the author's petitions through the Freedom of Information Act.

Trivia buffs will have a field day with the data published here, and it's a sure bet that a few readers will disagree with some of it. However, it is a start. Enjoy!

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Comments and documented potential corrections are welcomed, and should be addressed to the author via Internet e-mail at orloff@injersey.com

Richard W. Orloff
June, 1996

Acknowledgments

The information contained in the mission summaries in this work was derived primarily from uncopyrighted NASA and contractor mission reports, and, in some cases, is quoted verbatim from the original text without attribution. Readers interested in specific sources will find them listed in the bibliographies which appear at the end of each mission summary. In a few cases, it was necessary to include information from other copyrighted works, and the author acknowledges those cases as follows:

The source for some of the astronaut biographical data is *Who's Who In Space: The International Space Year Edition*, by Michael Cassutt, although most information was derived from NASA biographies.

The primary source for descriptions of the mission emblems is the official NASA text that accompanied each emblem. However, additional information has been used from *Space Patches From Mercury to the Space Shuttle*, written by Judith Kaplan and Robert Muniz. Another source is Dick Lattimer's unpublished draft of *Astronaut Mission Patches and Spacecraft Callsigns,* available at Rice University's Fondren Library.

The source for the COSPAR designations for the various Apollo spacecraft and launch vehicle stages once on orbit is the *R. A. E. Table of Earth Satellites 1957-1986*.

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Notes

For the convenience of the reader, event times are expressed mostly as GMT (Greenwich Mean Time) and GET (Ground Elapsed Time). Local U.S. Eastern time, in which all missions were launched, is also included only for significant events. In regular usage, GMT does not use a colon between the hours and minutes; however for the convenience of readers of this work, most of whom are in the United States, where time is expressed as “00:00”, the colon is included.

The term “GET” (Ground Elapsed Time), used for manned U.S. spaceflights prior to the space shuttle, was referenced to “Range Zero,” the last integral second before liftoff. With the first launch of the shuttle, NASA began using the term “MET” (Mission Elapsed Time), which begins at the moment of solid rocket booster ignition. The format for GET used here is hhh:mm:ss.sss (e.g., hours:minutes:seconds). Example: 208:23:45.343, with “GET” excluded and assumed in order to avoid confusion with GMT.

Some other abbreviations used frequently in this work include:

B. S.: Bachelor of Science degree
CM: Command Module
CSM: Command and Service Module(s) (combined structure)
GH_2: Gaseous Hydrogen
LH_2: Liquid Hydrogen
LM: Lunar Module
LOX: Liquid Oxygen
LRV: Lunar Rover Vehicle (used on Apollos 15, 16, and 17)
M. S.: Master of Science degree
MET: Modular Equipment Transport (used only on Apollo 14)
NASA: National Aeronautics and Space Administration
Ph. D.: Doctor of Philosophy degree
Sc. D.: Doctor of Science degree
S-IB: Saturn IB launch vehicle
S-IVB: Saturn IV-B launch vehicle
SM: Service Module

APOLLO 13

The seventh mission:
The third manned lunar landing attempt.

Apollo 13 Summary

Figure 1: Original Apollo 13 crew, (l. to. r.) Jim Lovell, Ken Mattingly, Fred Haise (NASA S69-62224).

Figure 2: Crew after Mattingly was replaced (l. to. r.) Lovell, Jack Swigert, Haise (photo taken after mission) (NASA S70-36485).

Background

Apollo 13 was planned as a Type H mission, a precision manned lunar landing demonstration and systematic lunar exploration. It was, however, aborted during translunar flight because of the loss of all the oxygen stored in two tanks in the service module.

The primary objectives were:

- to perform selenological inspection, survey, and sampling of materials in a preselected region of the Fra Mauro formation;
- to deploy and activate an Apollo lunar surface experiments package;
- to further develop man's capability to work in the lunar environment; and
- to obtain photographs of candidate exploration sites.

The crewmen were Captain James Arthur Lovell, Jr. (USN), commander; Jack Leonard "Jack" Swigert, Jr. [SWY-girt], command module pilot; and Fred Wallace Haise, Jr., lunar module pilot. Swigert was backup command module pilot, but Lt. Commander Thomas Kenneth "Ken" Mattingly, II (USN), the prime command module pilot, had been exposed to rubella (German measles) by a member of the backup crew[1] eight days before the scheduled launch date, and results of his pre-mission physical examination revealed he had no immunity to the disease. Consequently, on the day prior to launch, and after several days of intense training with the prime crew, Swigert was named to replace Mattingly.

Selected as an astronaut in 1962, Lovell was making his fourth spaceflight and second trip to the moon, the first person ever to achieve those milestones. He had been pilot of Gemini 7, command pilot of Gemini 12, and command module pilot of Apollo 8, the first manned mission to the Moon. Lovell was born March 25, 1928 in Cleveland, Ohio, and was 42 years old. He received a B. S. from the U. S. Naval Academy in 1952. His backup for the mission was Commander John Watts Young (USN).

The original command module pilot, Mattingly would have been making his first spaceflight. He was born March 17, 1936 in Chicago, Illinois, and was 34 years old. He received a B. S. in Aeronautical Engineering from Auburn University in 1958, and was selected as an astronaut in 1966.

Swigert was making his first spaceflight. He was born August 30, 1931 in Denver, Colorado, and was 38 years old. Swigert received a B. S. in Mechanical Engineering from the University of Colorado in 1953, an M. S. in Aerospace Science from Rensselaer Polytechnic Institute in 1965, and an MBA from the University of Hartford in 1967, and was selected as an astronaut in 1966.[2]

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[1]Major Charles Moss Duke, Jr., USAF.

[2]Swigert died of complications from bone marrow cancer treatments on December 27, 1982 in Washington, D. C.

Haise was also making his first spaceflight. He was born November 14, 1933 in Biloxi, Mississippi, and was 36 years old. Haise received a B. S. in Aeronautical Engineering from the University of Oklahoma in 1959, and was selected as an astronaut in 1966. His backup was Major Charles Moss Duke, Jr. (USAF).

The capsule communicators (CAPCOMs) for the mission were Joseph Peter Kerwin, M. D.; Vance DeVoe Brand; Major Jack Robert Lousma (USMC); Young; and Mattingly. The support crew were Lousma; Brand; and Major William Reid Pogue (USAF). The flight directors were Milton L. Windler (first shift); Gerald D. Griffin (second shift); Eugene F. Kranz (third shift); and Glynn S. Lunney (fourth shift).

The Apollo 13 launch vehicle was a Saturn V, designated SA-508. The mission also carried the designation Eastern Test Range #3381. The CSM was designated CSM-109, and had the call-sign "Odyssey." The lunar module was designated LM-7, and had the call-sign "Aquarius."

Launch Preparations

The terminal countdown was picked up at T-28 hours at 05:00:00 GMT on April 10. Scheduled holds were 9 hours 13 minutes at T-9 hours and one hour duration at T-3 hours 30 minutes.

At launch time, a cold front extended from a low pressure cell in the North Atlantic, becoming stationary through northern Florida and along the Gulf Coast to a low pressure area located in southern Louisiana. The frontal intensity was weak in northern Florida but became stronger in the northwestern Gulf of Mexico-Louisiana area. Surface winds in the Cape Kennedy area were light and variable. Generally, winds in the lower part of the troposphere were light, permitting the sea breeze to switch the surface wind to the east southeast by early afternoon. Altocumulus clouds covered 40% of the sky (base 19,000 feet) and cirrostratus 100% (base 26,000 feet); the temperature was 75.9° F; the relative humidity was 57%; and the barometric pressure was 14.676 lb/in^2. The winds, as measured by the anemometer on the light pole 60.0 feet above ground at the launch site measured 12.2 knots at 105° from true north.

Ascent Phase

Apollo 13 was launched from Kennedy Space Center Launch Complex 39, Pad A, at a Range Zero time of 19:13:00 GMT (02:13:00 p.m. EST) on April 11, 1970. The planned launch window extended to 22:36:00 GMT to take advantage of a sun elevation angle on the lunar surface of 10.0°.

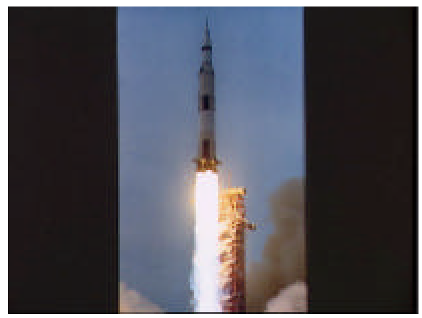

Figure 3: Apollo 13 lifts off from Kennedy Space Center Pad 39 A (NASA S70-34855).

Between 000:00:12.6 and 000:00:32.1, the vehicle rolled from a launch pad azimuth of 90° to a flight azimuth of 72.043°. The S-IC engine shut down at 000:02:43.60, followed by S-IC/S-II separation, and S-II engine ignition. Due to high amplitude oscillations in the propulsion/structural system, the S-II center engine shut down at 000:05:30.64, two minutes and 12 seconds earlier than planned. The early shutdown caused considerable deviations from the planned trajectory. The altitude at shutdown was 10.7 n. mi. lower and the velocity was 5,685.3 ft./sec. slower than expected.

Figure 4: Ken Mattingly (l.), original Apollo 13 CMP, monitors communications during liftoff with CAPCOM Joe Kerwin (NASA S70-34628).

The S-II engine shut down at 000:09:52.64 followed by separation from the S-IVB, which ignited at 000:09:56.90, both 34 seconds late. The first S-IVB engine cutoff occurred 44 seconds late, at 000:12:29.83, with deviations from the planned trajectory of only -1.9 ft./sec. In velocity and only 0.2 n. mi. in altitude.

The S-IC stage impacted the Atlantic Ocean at 000:09:06.9 at latitude 30.177° north and longitude 74.065° west, 355.3 n. mi. from the launch site. The S-II stage impacted the Atlantic Ocean at 000:20:58.1 at latitude 32.320° north and longitude 33.289° west, 2,452.6 n. mi. from the launch site.

The maximum wind conditions encountered during ascent were 108.13 knots at 252° from true north at 44,540 feet, and a maximum wind shear of 0.0166 sec^{-1} at 50,610 feet.

Despite the early shutdown of the S-II center engine, parking orbit conditions at insertion, 000:12:39.83 (S-IVB cutoff plus 10 seconds to account for engine tailoff and other transient effects), showed a nearly nominal apogee and perigee of 100.3 by 99.3 n. mi., a period of 88.19 minutes, an inclination of 32.547°, and a velocity of 25,565.9 ft./sec. The apogee and perigee were based upon a spherical Earth with a radius of 3,443.934 n. mi.

The international designation for the CSM upon achieving orbit was 1970-029A and the S-IVB was designated 1970-029B. After undocking prior to Earth entry, the LM would be designated 1970-029C.

After orbital insertion, all launch vehicle and spacecraft systems were verified and preparations made for translunar injection. Onboard television was initiated at 001:35 for about 5-1/2 minutes.

The 350.75-second translunar injection maneuver (second S-IVB firing) was performed at 002:35:46.30. The S-IVB engine shut down at 002:41:37.15 and translunar injection occurred ten seconds later, after 1.5 Earth orbits lasting 2 hours 29 minutes 7.3 seconds, at a velocity of 35,562.7 ft./sec.

Translunar Phase

At 003:06:38.9, the CSM was separated from the S-IVB stage and onboard television was initiated at 003:09 for about 72 minutes to show the docking, ejection, and interior and exterior views of the CM. Transposition and docking with the LM occurred at 003:19:08.8. The docked spacecraft were ejected from the S-IVB at 004:01:00.8, and an 80.2-second separation maneuver was initiated by the S-IVB auxiliary propulsion system at 004:18:00.6.

On previous lunar missions, the S-IVB stage had been maneuvered by ground command into a trajectory such that it would pass by the Moon and go into a solar orbit. For Apollo 13, the S-IVB was targeted to hit the Moon so that the vibrations resulting from the impact could be sensed by the Apollo 12 seismic station and telemetered to Earth for study.

A 217.2-second lunar impact maneuver was made at 005:59:59.5. The S-IVB impacted the lunar surface at 077:56:39.7. The seismic signals lasted three hours 20 minutes, and were so strong that the Apollo 12 seismometer gain had to be reduced to keep the recording on the scale. The suprathermal ion detector recorded a jump in the number of ions from zero at impact to 2,500 and then back to zero. It was theorized that the impact drove particles from the lunar surface up to 200,000 feet above the moon, where they were ionized by sunlight. The impact point was latitude 2.5° south and longitude 27.9° west, 35.4 n. mi. from the target point and 75 n. mi. from the Apollo 12 seismometer. At impact, the S-IVB weighed 29,599 pounds and was traveling 2,579 ft./sec.

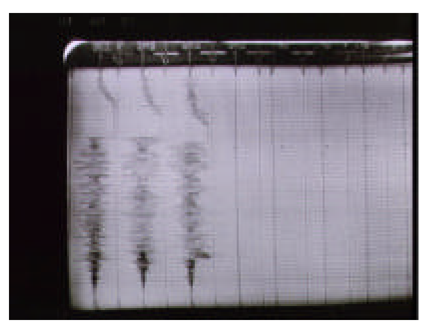

Figure 5: Seismic recording of the S-IVB stage impacting the lunar surface (NASA S70-34985).

Good quality television coverage of the preparations and performance of the second midcourse correction burn was received for 49 minutes beginning at 030:13.

Photographs of the Earth were taken during the early part of translunar coast to support an analysis of atmospheric winds. At 030:40:49.65, a 3.49-second midcourse correction lowered the closest point of spacecraft approach to the Moon to an altitude of 60 miles. Before this maneuver, the spacecraft had been on a free-return trajectory, in which the spacecraft would have looped around the Moon and returned to Earth without requiring a major maneuver.

Through the first 46 hours of the mission, telemetered data and crew observations indicated that the performance of oxygen tank no. 2 was normal. At 046:40:02, the crew routinely turned on the fans in oxygen tank 2. Within three seconds, the oxygen tank no. 2 quantity indication changed from a normal reading of about 82 percent full to an obviously incorrect reading “off-scale high,” of over 100 percent. Analysis of the electrical wiring of the quantity gauge shows that this erroneous reading could have been caused by either a short circuit or an open circuit in the gauge wiring or a short circuit between the gauge plates. Subsequent events indicated that a short was the more likely failure mode.

At 047:54:50 and at 051:07:44, the oxygen tank no. 2 fans were turned on again, with no apparent adverse effects. The quantity gauge continued to read off-scale high.

Following a rest period, the Apollo 13 crew began preparations for activating and powering up the LM for checkout. At 053:27, the commander and lunar module pilot were cleared to enter the LM to commence inflight inspection of the LM. A television transmission of the spacecraft interior started at 055:14 and ended at 055:46. The crew moved back into the CM and the LM hatch was closed at 055:50.

At 055:52:31, a master alarm on the CM caution and warning system alerted the crew to a low pressure indication in the cryogenic hydrogen tank no. 1. This tank had reached the low end of its normal operating pressure range several times previously during the flight. At 055:52:58, flight controllers requested the crew to turn on the cryogenic system fans and heaters.

The command module pilot acknowledged the fan cycle request at 55:53:06, and data indicate that current was applied to the oxygen tank no. 2 fan motors at 055:53:20, followed by a power transient in the stabilization control system.

About 90 seconds later, at 055:54:53.555, telemetry from the spacecraft was lost almost totally for 1.8 seconds. During the period of data loss, the caution and warning system alerted the crew to a low voltage condition on DC main bus B. At about the same time, the crew heard a loud “bang” and realized that a problem existed in the spacecraft

When the crew heard the bang and got the master alarm for low DC main bus B voltage, the commander was in the lower equipment bay of the command module, stowing the television camera which had just been in use. The lunar module pilot was in the tunnel between the CSM and the LM, returning to the CSM. The command module pilot was in the left-hand couch, monitoring spacecraft performance. Because of the master alarm indicating low voltage, the command module pilot moved across to the right-hand couch where CSM voltages can be observed. He reported that voltages were “looking good” at 055:56:10 and also reported hearing “…a pretty good bang…” a few seconds before. At this time, DC main bus B had recovered and fuel cell 3 did not fail for another 90 seconds. He also reported fluctuations in the oxygen tank no. 2 quantity, followed by a return to the off-scale high position.

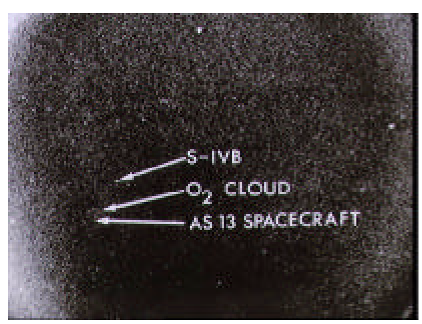

Figure 6: Telescopic photograph showing the Apollo 13 spacecraft, S-IVB stage and oxygen cloud formed following the SM accident (NASA S70-34857).

The commander reported, "…We're venting something…into space…" at 056:09:07, followed at 056:09:58 by the lunar module pilot's report that fuel cell 1 was off-line. Less than half an hour later, he reported that fuel cell 3 was also off-line.

When fuel cells 1 and 3 electrical output readings went to zero, the ground controllers could not be certain that the cells had not somehow been disconnected from their respective busses and were not otherwise all right. Attention continued to be focused on electrical problems.

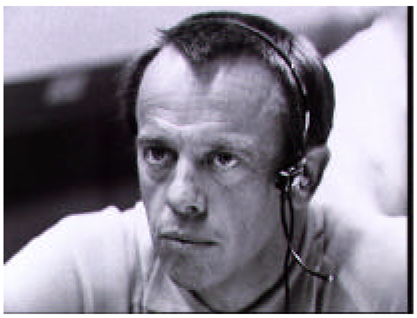

Figure 7: Astronaut Alan Shepard, scheduled to command Apollo 14, monitors communications between crew and ground regarding oxygen cell failure. (NASA S70-34904)

Five minutes after the accident, controllers asked the crew to connect fuel cell 3 to DC main bus B in order to be sure that the configuration was known. When it was realized that fuel cells 1 and 3 were not functioning, the crew was directed to perform an emergency powerdown to lower the load on the remaining fuel cell. Fuel cell 2 was shut down at 058:00, followed ten minutes later by powerdown of the CM computer and platform.

Observing the rapid decay in oxygen tank no. 1 pressure, controllers asked the crew to switch power to the oxygen tank no. 2 instrumentation. When this was done, and it was realized that oxygen tank no. 2 had failed, the extreme seriousness of the situation became clear.

Several attempts were then made to save the remaining oxygen in the oxygen tank no. 1, but the pressure continued to decrease. It was obvious by about 1-1/2 hours after the accident that the oxygen tank no. 1 leak could not be stopped and that shortly it would be necessary to use the LM as a "lifeboat" for the remainder of the mission. The resultant loss of oxygen made the three fuel cells inoperative. This left the CM batteries, normally used only during reentry, as the sole power source and the only oxygen was contained in a surge tank and repressurization packages used to repressurize the CM after cabin venting. The LM became the only source of sufficient electrical power and oxygen to permit a safe return to Earth, and led to the decision to abort the Apollo 13 mission. By 058:40, the LM had been activated, the inertial guidance reference transferred from the CSM guidance system to the LM guidance system, and the CSM systems were turned off.

Figure 8: From l. to r., Director of Flight Crew Operations Deke Slayton and astronauts Ken Mattingly, Vance Brand, jack Lousma, and John Young evaluate Apollo 13's situation.

The remainder of the mission was characterized by two main activities – planning and conducting the necessary propulsion maneuvers to return the spacecraft to Earth, and managing the use of consumables in such a way that the LM, which is designed for a basic mission with two crewmen for a relatively short duration, could support three men and serve as the actual control vehicle for the time required.

Figure 9: Crater IAU 221 on lunar farside (center of photo on horizon) (NASA AS13-62-8918).

A number of propulsion options were developed and considered. It was necessary to return the spacecraft to a free-return trajectory and to make any required midcourse corrections. Normally, the SM service propulsion system would be used for such maneuvers. However, because of the high electrical power requirements for that engine, and in view of its uncertain condition and the uncertain nature of the structure of the SM after the accident, it was decided to use the LM descent engine if possible.

The spacecraft was then maneuvered back into a free-return trajectory at 061:29:43.49 by firing the LM descent engine for 34.23 seconds. It then looped behind the Moon and was out of contact with the Earth tracking stations between 077:08:35 and 077:33:10, a total of 24 minutes 35 seconds.[3]

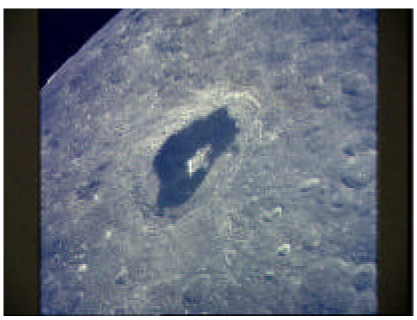

Figure 10: Lunar farside, showing crater Tsiolkovsky (NASA AS13-60-8659)

Flight controllers calculated that the minimum practical return time for Apollo 13 was 133 hours total mission time to the Atlantic Ocean, and the maximum was 152 hours to the Indian Ocean. Since recovery forces were deployed in the Pacific, a return path was selected for splashdown there at 142:40.

A 263.82-second transearth injection maneuver using the LM descent propulsion system was executed at 079:27:38.95 to speed up the return to Earth by 860.5 ft./sec. after the docked spacecraft had swung around the far side of the Moon.

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[3]Source of lunar occultation times unknown, but appear to be more accurate expressions of times in *Apollo 13 Mission Operations Report*, p. III-26. 1992 *Guinness Book Of World Records*, page 118, states that Apollo 13 holds the record for farthest distance traveled from Earth: 248,655 st. mi. at 1:21 a.m. British Daylight Time April 15, 1970 at 158 miles above the moon, the equivalent of 216,075 n. mi. 00:21 GMT April 15 (08:21 p.m. EST April 14) at an apolune of 137 n. mi.

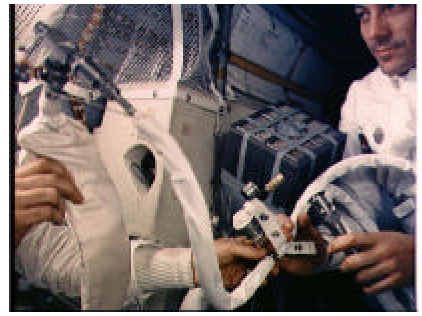

Figure 11: Swigert with temporary hose connections and apparatus required when the crew moved from the CM to the LM (NASA AS13-62-9004).

Guidance errors during the transearth injection maneuver necessitated a 14-second transearth midcourse correction of 7.8 ft./sec. Using the descent propulsion system at 105:18:42.0 to bring the projected entry flight-path angle within the specified limits. During the transearth coast period, the docked spacecraft were maneuvered into a passive thermal control mode.

Figure 12: View of Mission Operations Control Room (MOCR) during transearth flight (NASA S70-34986).

The most critical consumables were water, used to cool the CSM and LM systems during use; CSM and LM battery power, the CSM batteries being for use during reentry and the LM batteries being needed for the rest of the mission; LM oxygen for breathing; and lithium hydroxide (LiOH) filter canisters used to remove carbon dioxide from the spacecraft cabin atmosphere.

These consumables, and in particular the water and LiOH canisters, appeared to be extremely marginal in quantity shortly after the accident, but once the LM was powered down to conserve electric power and to generate less heat and thus use less water, the situation improved greatly. Engineers in Houston developed a method which allowed the crew to use materials on board to fashion a device allowing use of the CM LiOH canisters in the LM cabin atmosphere cleaning system . At splashdown, many hours of each consumable remained available.

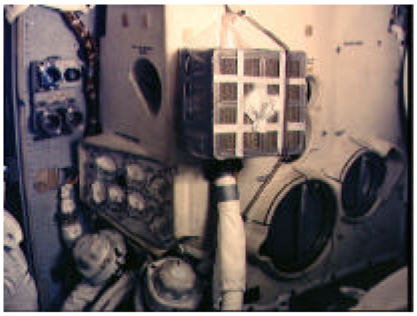

Figure 13: Box used to house CM lithium hydroxide canisters to purge carbon dioxide from the LM "lifeboat" (NASA AS13-62-8929).

The unprecedented powered-down state of the CM required several new procedures for entry. The CM was briefly powered up to assess the operational capability of critical systems. Also, the CM entry batteries were charged through the umbilical connectors that had supplied power from the LM while the CM was powered down.

Approximately six hours before entry, the passive thermal control mode was discontinued, and a final midcourse correction was made using the LM reaction control system to refine the flight-path angle slightly. The 21.50-second maneuver of 3.0 ft./sec. was made at 137:40:13.00.

Figure 14: View of Earth during transearth flight. Visible are parts of southwestern U. S. and northwestern Mexico. Baja California is clearly seen (NASA AS13-60-8588).

Figure 15: Flight controllers gather around console of Shift 4 Flight Director Glynn Lunney to review weather maps of the proposed splashdown site in the south Pacific (NASA S70-35014).

Less than half an hour later, at 138:01:48.0, the service module was jettisoned, which afforded the crew an opportunity to observe and photograph the damage caused by the failed oxygen tank.

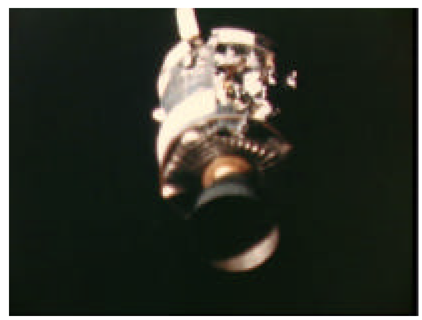

Figure 16: View of damaged Service Module taken from 16 mm film (NASA S70-35703).

The crew viewed the SM and reported that an entire panel was missing near the S-band high-gain antenna, the fuel cells on the shelf above the oxygen shelf were tilted, and the high-gain antenna damaged, and a great deal of debris was hanging out.

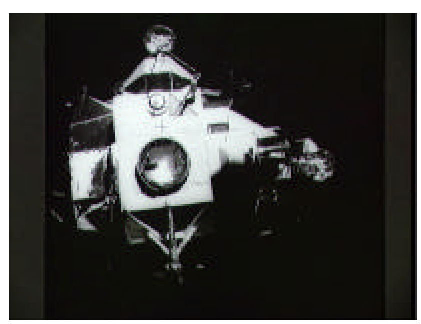

Figure 17: View of LM following jettison, about an hour prior to splashdown (NASA AS13-59-8562).

The LM was retained until 141:30:00.2, about 70 minutes before entry, to minimize usage of CM electrical power. At undocking, normal tunnel pressure provided the necessary force to separate the two spacecraft. All other events were the same as a normal mission.

Recovery

The command module reentered the Earth's atmosphere (400,000 feet altitude) at 142:40:45.7 at a velocity of 36,210.6 ft./sec., following a transearth coast of 63 hours 08 minutes 42.9 seconds. Some pieces of the LM survived entry and projected trajectory data indicated that they struck the open sea between Samoa and New Zealand.

Figure 18:After a harrowing mission, the Apollo 13 CM finally splashes down in the Pacific (NASA S70-35638).

The parachute system effected splashdown of the CM in the Pacific at 18:07:41 GMT (01:07:41 p.m. EST) on April 17. Mission duration was 142:54:41.

Figure 19: Swigert (l.) and Haise (center) in life raft as Navy team assists crew from the CM. Lovell is exiting from hatch (NASA S70-35610).

The impact point was about 1.0 n. mi. from the target point and 3.5 n. mi. from the recovery ship U. S. S. *Iwo Jima*. The splashdown site was at latitude 21.63° south and longitude 165.37° west. After splashdown, the CM assumed an apex-up flotation attitude.

The crew was retrieved by helicopter and aboard the recovery 45 minutes after splashdown.

Figure 20: Crew exits recovery helicopter aboard U. S. S. Iwo Jima (NASA S70-35614).

The CM was recovered 43 minutes later. The estimated CM weight at splashdown was 11,133 pounds, and the estimated distance traveled for the mission was 541,103 n. mi.

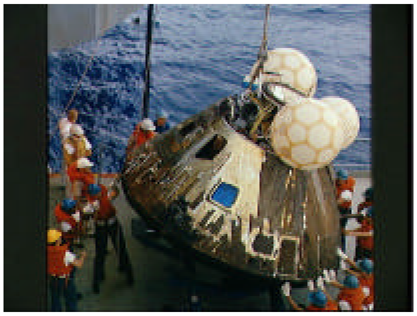

Figure 21: CM is loaded aboard the recovery ship (NASA S70-35632).

The crew departed the *Iwo Jima* by aircraft at 18:20 GMT on April 18 and arrived in Houston 03:30 GMT on April 20. The *Iwo Jima* arrived with the CM at Hawaii at 19:30 GMT on April 24. Deactivation was completed on April 26.

Figure 22: (l. to. r.) Former Apollo Program Director Lt. Gen. Sam Phillips; NASA Administrator Dr. Thomas Paine; and Dr. George Low celebrate safe return of Apollo 13 crew (NASA S70-35148).

The CM was delivered to the North American Rockwell Space Division facility in Downey, California, for postflight analysis, arriving at 14:00 GMT on April 27.

Figure 23: Lovell reads newspaper account of Apollo 13 recovery (NASA S70-15501).

Conclusions

The Apollo 13 accident was nearly catastrophic. Only outstanding performances on the part of the crew, ground support personnel and the excellent performance of the LM systems made the safe return of the crew possible.

Figure 24: President Richard M. Nixon awards Presidential Medal of Freedom to crew at Hickam AFB, Hawaii (NASA S70-15511)

The following conclusions were made from an analysis of post-mission data:

1. The mission was aborted because of the total loss of primary oxygen in the service module. This loss resulted from an incompatibility between switch design and pre-mission procedures, a condition which, when combined with an abnormal pre-mission detanking procedure, caused an inflight shorting and a rapid oxidation within one of two redundant storage tanks. The oxidation then resulted in a loss of pressure integrity in the related tank and eventually in the remaining tank.

2. The concept of a backup crew was proven for the first time when, three days prior to launch, the backup command module pilot was substituted for his prime crew counterpart, who was exposed and found susceptible to rubella (German measles).

3. The performance of lunar module systems demonstrated an emergency operational capability. Lunar module systems supported the crew for a period twice their intended design lifetime.

4. The effectiveness of pre-mission crew training, especially in conjunction with ground personnel, was reflected in the skill and precision with which the crew responded to the emergency.

5. Although the mission was not a complete success, a lunar flyby mission, including three planned experiments (lightning phenomena, Earth photography, and S-IVB lunar impact), were completed and data were derived with respect to the capabilities of the lunar module.

Report of the Apollo 13 Review Board

On April 17, 1970, NASA Administrator Thomas O. Paine established the Apollo 13 Review Board, naming Edgar M. Cortright, director of the NASA Langley Research Center, as chairman. Cortright’s eight-member panel met for nearly two months, and submitted their final report on June 15. Neil Armstrong, commander of the recent Apollo 11 mission, was the only astronaut on the board. William Anders, lunar module pilot of Apollo 8, and executive secretary of the National Aeronautics and Space Council, was one of three observers.

The evidence pointed strongly to an electrical short circuit with arcing as the initiating event. About 2.7 seconds after the fans were turned on in the SM oxygen tanks, an 11.1-ampere current spike and simultaneously a voltage-drop spike were recorded in the spacecraft electrical system. Immediately thereafter, current drawn from the fuel cells decreased by an amount consistent with the loss of power to one fan. No other changes in spacecraft power were being made at the time. No power was on the heaters in the tanks (the quantity gauge and temperature sensor were very low power devices). The next anomalous event recorded was the beginning of a pressure rise in oxygen tank no. 2 thirteen seconds later. Such a time lag was possible with low-level combustion at the time. These facts pointed to the likelihood that an electrical short circuit with arcing occurred in the fan motor or its wires to initiate the accident sequence. The energy available from the short circuit was probably 10 to 20 joules. Tests conducted during the investigation showed that this energy is more than adequate to ignite Teflon of the type contained within the tank. This likelihood of electrical initiation is enhanced by the high probability that the electrical wires within the tank were damaged during abnormal tanking operations at KSC prior to launch.

Data were not adequate to determine precisely the way in which the oxygen tank no. 2 system lost its integrity. However, available information, analyses, and tests performed during this investigation indicate that most probably combustion within the pressure vessel ultimately led to localized heating and failure at the pressure vessel closure. It is at this point, the upper end of the quantity probe, that the ½-inch Inconel conduit is located, through which the Teflon-insulated wires enter the pressure vessel. It is likely that the combustion progressed along the wire insulation and reached this location where all of the wires come together. This, possibly augmented by ignition of the metal in the upper end of the probe, led to weakening and failure of the closure or the conduit, or both.

Failure at this point would lead immediately to pressurization of the tank dome, which is equipped with a rupture disc rated at about 75 psi. Rupture of this disc or of the entire dome would then release oxygen, accompanied by combustion products, into bay 4. Spacecraft accelerations recorded at this time were probably caused by this release.

Release of the oxygen then began to pressurize the oxygen shelf space of bay 4. If the hole formed in the pressure vessel were large enough and formed rapidly enough, the escaping oxygen alone would be adequate to blow off the bay 4 panel. However, it is also quite possible that the escape of oxygen was accompanied by combustion of Mylar and Kapton (used extensively as thermal insulation in the oxygen shelf compartment and in the tank dome) which would augment the pressure caused by the oxygen itself. The slight temperature increases recorded at various SM locations indicate that combustion external to the tank probably took place. The ejected panel then struck the high-gain antenna, disrupting communications from the spacecraft for the 1.8 seconds.

<u>How The Problem Occurred</u>

Following is a list of factors that led to the accident:

- After assembly and acceptance testing, the oxygen tank no. 2 which flew on Apollo 13 was shipped from Beech Aircraft Corporation to North American Rockwell (NR) in apparently satisfactory condition.

- It is now known, however, that the tank contained two protective thermostatic switches on the heater assembly, which were inadequate and would subsequently fail during ground test operations at Kennedy Space Center (KSC).

- In addition, it is probable that the tank contained a loosely fitting fill tube assembly. This assembly was probably displaced during subsequent handling, which included an incident at the prime contractor’s arc plant in which the tank was jarred.

- In itself, the displaced fill tube assembly was not particularly serious, but it led to the use of improvised detanking procedures at KSC which almost certainly set the stage for the accident.

- Although Beech did not encounter any problem in detanking during acceptance tests, it was not possible to detank oxygen tank no. 2 using normal procedures at KSC. Tests and analyses indicated that this was due to gas leakage through the displaced fill tube assembly.

- The special detanking procedures at KSC subjected the tank to an extended period of heater operation and pressure cycling. These procedures had not been used before, and the tank had not been qualified by test for the conditions experienced. However, the procedures did not violate the specifications which governed the operation of the heaters at KSC.

- In reviewing these procedures before the flight, officials of NASA, NR, and Beech did not recognize the possibility of damage due to overheating. Many of these officials were not aware of the extended heater operation. In any event, adequate thermostatic switches might have been expected to protect the tank.

- A number of factors contributed to the presence of inadequate thermostatic switches in the heater assembly. The original 1962 specifications from NR to Beech Aircraft Corporation for the tank and heater assembly specified the use of 28 V DC power, which is used in the spacecraft. In 1965, NR issued a revised specification which stated that the heaters should use a 65 V DC power supply for tank pressurization; this was the power supply used at KSC to reduce pressurization time. Beech ordered switches for the Block II tanks but did not change the switch specifications to be compatible with 65 V DC.

- The thermostatic switch discrepancy was not detected by NASA, NR, or Beech in their review of documentation, nor did tests identify the incompatibility of the switches with the ground support equipment at KSC, since neither qualification nor acceptance testing required switch cycling under load as should have been done. It was a serious oversight in which all parties shared.

- The thermostatic switches could accommodate the 65 V DC during tank pressurization because they normally remained cool and closed. However, they could not open without damage with 65 V DC power applied. They were never required to do so until the special detanking. During this procedure, as the switches started to open when they reached their upper temperature limit, they were welded permanently closed by the resulting arc and were rendered inoperative as protective thermostats.

- Failure of the thermostatic switches to open could have been detected at KSC if switch operation had been checked by observing heater current readings on the oxygen tank heater control panel. Although it was not recognized at that time, the tank temperature readings indicated that the heaters had reached their temperature limit and switch opening should have been expected.

- As shown by subsequent tests, failure of the thermostatic switches probably permitted the temperature of the heater tube assembly to reach about 1,000° F in spots during the continuous 8-hour period of heater operation. Such heating has been shown by tests to severely damage the Teflon insulation on the fan motor wires in the vicinity of the heater assembly. From that time on, including pad occupancy, the oxygen tank 2 was in a hazardous condition when filled with oxygen and electrically powered.

- It was not until nearly 56 hours into the mission, however, that the fan motor wiring, possibly moved by the fan stirring, short circuited and ignited its insulation by means of an electric arc. The resulting combustion in the oxygen tank probably overheated and failed the wiring conduit where it enters the tank, and possibly a portion of the tank itself.

- The rapid expulsion of high-pressure oxygen which followed, possibly augmented by combustion of insulation in the space surrounding the tank, blew off the outer panel to bay 4 of the SM, caused a leak in the high-pressure system of oxygen tank no. 1, damaged the high-gain antenna, caused other miscellaneous damage, and aborted the mission.

Apollo 13 Objectives

Spacecraft
Primary Objectives

1. To perform selenological inspection, survey, and sampling of materials in a preselected region of the Fra Mauro formation. *Not attempted.*

2. To deploy and activate an Apollo lunar surface experiments package. *Not attempted.*

3. To further develop man's capability to work in the lunar environment. *Not attempted.*

4. To obtain photographs of candidate exploration sites. *Not attempted.*

Detailed Objectives

B. Television coverage. *Not attempted.*

C. Contingency sample collection. *Not attempted.*

D. Selected sample collection. *Not attempted.*

E. Landing accuracy improvement techniques. *Not attempted.*

F. Photographs of candidate exploration sites. *Not attempted.*

G. Extravehicular communication system performance. *Not attempted.*

H. Lunar soil mechanics. *Not attempted.*

I. Dim light photography. *Not attempted.*

J. Selenodetic reference point update. *Not attempted.*

K. CSM orbital science photography. *Not attempted.*

L. Transearth lunar photography. *Not attempted.*

M. EMU water consumption measurement. *Not attempted.*

N. Thermal coating degradation. *Not attempted*

Experiments

1. ALSEP III: Apollo Lunar Surface Experiments Package. *Not Attempted.*

   a. Passive seismic experiment.

   b. Heat flow experiment.

   c. Charged particle lunar environment experiment.

   d. Cold cathode gauge experiment.

   e. Lunar dust detection.

2. S-059: Lunar field geology. *Not attempted.*

3. S-080: Solar wind composition. *Not attempted.*

4. S-164: S-band transponder exercise. *Not attempted.*

5. S-170: Downlink bistatic radar observations of the Moon. *Not attempted.*

6. S-178: Gegenschein from lunar orbit. *Not attempted.*

7. S-184: Lunar surface close-up photography. *Not attempted.*

8. T-029: Pilot describing function. *Achieved.*

Launch Vehicle Objectives

1. To launch on a flight azimuth between 72° and 96° and insert the S-IVB/instrument unit/spacecraft into the planned circular Earth parking orbit. *Achieved.*

2. To restart the S-IVB during either the second or third revolution and inject the S-IVB/instrument unit/spacecraft into the planned translunar trajectory. *Achieved.*

3. To provide the required attitude control for the S-IVB/instrument unit/spacecraft during transposition, docking, and ejection. *Achieved.*

4. To perform an evasive maneuver after ejection of the command and service module/lunar module from the S-IVB/instrument unit. *Achieved.*

5. To attempt to impact the S-IVB/instrument unit on the lunar surface within 350 kilometers (189 nautical miles) of latitude 3° south, longitude 30° west. *Achieved.*

6. To determine actual impact point within 5.0 kilometers (2.7 nautical miles) and time of impact within one second. *Achieved.*

7. To vent and dump the remaining gases and propellants to safe the S-IVB/instrument unit. *Achieved.*

Apollo 13 Spacecraft History

EVENT	DATE
Individual and combined CM and SM systems test completed at factory.	03/16/69
Integrated CM and SM systems test completed at factory.	04/08/69
LM #7 final engineering evaluation acceptance test at factory.	05/18/69
LM #7 integrated test at factory.	05/18/69
Saturn S-IVB stage #508 delivered to KSC.	06/13/69
Saturn S-IC stage #8 delivered to KSC.	06/16/69
Saturn S-IC stage #8 erected on MLP #3.	06/18/69
LM ascent stage #7 ready to ship from factory to KSC.	06/24/69
CM #109 and SM #109 ready to ship from factory to KSC.	06/25/69
LM descent stage #7 ready to ship from factory to KSC.	06/25/69
CM #109 and SM #109 delivered to KSC.	06/26/69
LM ascent stage #7 delivered to KSC.	06/27/69
LM descent stage #7 delivered to KSC.	06/28/69
Saturn S-II stage #8 delivered to KSC.	06/29/69
CM #109 and SM #109 mated.	06/30/69
CSM #109 combined systems test completed.	07/07/69
Saturn V instrument unit #508 delivered to KSC.	07/07/69
LM ascent stage #7 and descent stage #7 mated.	07/15/69
Saturn S-II stage #8 erected.	07/17/69
Spacecraft/LM adapter #16 delivered to KSC.	07/18/69
LM #7 combined systems test completed.	07/22/69
Saturn S-IVB stage #508 erected.	07/31/69
Saturn V instrument unit #508 erected.	08/01/69
Launch vehicle electrical systems test completed.	08/29/69
CSM #109 altitude tests completed.	09/12/69
LM #7 altitude tests completed.	09/20/69
Launch vehicle propellant dispersion/malfunction overall test completed.	10/21/69
Launch vehicle service arm overall test completed.	12/04/69
CSM #109 moved to VAB	12/09/69
Spacecraft erected.	12/10/69
Space vehicle and MLP #3 transferred to launch complex 39A.	12/15/69
CSM #109 integrated systems test completed.	01/05/70
LM #7 combined systems test completed.	01/05/70
CSM #109 electrically mated to launch vehicle.	01/18/70
Space vehicle overall test #1 (plugs in) completed.	01/20/70
LM #6 flight readiness test completed.	02/24/70
Space vehicle flight readiness test completed.	02/26/70
Saturn S-IC stage #8 RP-1 fuel loading completed.	03/16/70
Space vehicle countdown demonstration test (wet) completed.	03/25/70
Space vehicle countdown demonstration test (dry) completed.	03/26/70

Apollo 13 Ascent Phase

Event	GET (hhh:mm:ss)	Altitude (n mi)	Range (n mi)	Earth Fixed Velocity (ft/sec)	Space Fixed Velocity (ft/sec)	Event Duration (sec)	Geocentric Latitude (deg N)	Longitude (deg E)	Space Fixed Flight Path Angle (deg)	Space Fixed Heading Angle (E of N)
Liftoff	000:00:00.61	0.032	0.000	0.9	1,340.7		28.4470	-80.6041	0.04	90.00
Mach 1 achieved	000:01:08.4	4.394	1.310	1,095.2	2,087.5		28.4533	-80.5804	27.34	85.14
Maximum dynamic pressure	000:01:21.3	6.727	2.829	1,550.6	2,566.2		28.4608	-80.5529	28.98	82.96
S-IC center engine cutoff*	000:02:15.18	23.464	24.266	5,162.8	6,328.2	141.9	28.5677	-80.1654	23.612	76.609
S-IC outboard engine cutoff	000:02:43.60	36.392	50.991	7,787.3	9,002.5	170.3	28.6989	-79.6810	19.480	75.696
S-IC/S-II separation*	000:02:44.3	36.739	51.815	7,820.8	9,036.3		28.7029	-79.6660	19.383	75.693
S-II center engine #5 cutoff	000:05:30.64	86.183	298.100	11,566.6	12,859.6	164.64	29.8167	-75.1433	4.158	76.956
S-II to complete CECO*	000:07:42.6	97.450	580.109	15,583.8	16,904.3	132.00	30.8785	-69.8409	0.77	79.40
S-II outboard engine cutoff	000:09:52.64	102.112	964.578	21,288.0	22,610.8	426.64	31.9133	-62.4374	0.657	83.348
S-II/S-IVB separation*	000:09:53.50	102.150	967.505	21,301.6	22,624.5		31.9193	-62.3805	0.650	83.380
S-IVB 1st burn cutoff	000:12:29.83	103.469	1,533.571	24,236.4	25,560.4	152.93	32.5241	-51.2552	0.004	89.713
Earth orbit insertion	000:12:39.83	103.472	1,572.300	24,242.1	25,566.1		32.5249	-50.4902	0.005	90.148

Apollo 13 Earth Orbit Phase

Event	GET (hhh:mm:ss)	Space Fixed Velocity (ft/sec)	Event Duration (sec)	Velocity Change (ft/sec)	Apogee (n mi)	Perigee (n mi)	Period (mins)	Inclin-ation (deg)
Earth orbit insertion	000:12:39.83	25,566.1		35,538.4	100.3	99.3	88.19	32.547
S-IVB 2nd burn ignition	002:35:46.30	25,573.2						
S-IVB 2nd burn cutoff	002:41:37.15	35,562.6	350.85	10,039.0				31.818

Apollo 13 Translunar Phase

Event	GET (hhh:mm:ss)	Altitude (n mi)	Space Fixed Velocity (ft/sec)	Event Duration (sec)	Velocity Change (ft/sec)	Space Fixed Flight Path Angle (deg)	Space Fixed Heading Angle (E of N)
Translunar injection	002:41:47.15	182.445	35,538.4			7.635	59.318
CSM separated from S-IVB	003:06:38.9	3,778.582	25,029.2			45.030	72.315
CSM docked with LM/S-IVB	003:19:08.8	5,934.90	21,881.4			51.507	79.351
CSM/LM ejected from S-IVB	004:01:00.8	12,455.83	16,619.0			61.092	91.491
Midcourse correction ignition (CM SPS)	030:40:49.65	121,381.93	4,682.5			77.464	112.843
Midcourse correction cutoff	030:40:53.14	121,385.43	4,685.6	3.49	23.2	77.743	112.751
Midcourse correction ignition (LM DPS)	061:29:43.49	188,371.38	3,065.8			79.364	115.464
Midcourse correction cutoff	061:30:17.72	188,393.19	3,093.2	34.23	37.8	79.934	116.54

Apollo 13 Transearth Phase

Event	GET (hhh:mm:ss)	Altitude (n mi)	Space Fixed Velocity (ft/sec)	Event Duration (sec)	Velocity Change (ft/sec)	Space Fixed Flight Path Angle (deg)	Space Fixed Heading Angle (E of N)
Transearth injection ignition (LM DPS)	079:27:38.95	5,465.26	4,547.7			72.645	-116.308
Transearth injection cutoff	079:32:02.77	5,658.68	5,020.2	263.82	860.5	64.784	-117.886
Midcourse correction ignition (LM DPS)	105:18:28.0	152,224.32	4,457.8			-79.673	114.134
Midcourse correction cutoff	105:18:42.0	152,215.52	4,456.6	14.00	7.8	-79.765	114.242
Midcourse correction ignition (LM RCS)	137:39:51.5	37,808.58	10,109.1			-72.369	118.663
Midcourse correction cutoff	137:40:13.00	37,776.05	10,114.6	21.50	3.2	-72.373	118.660
SM separation	138:01:48.0	35,694.93	10,405.9			-71.941	118.824
LM jettisoned	141:30:00.2	11,257.48	17,465.9			-60.548	120.621

Apollo 13 Timeline

Event	GET (hhh:mm:ss)	GMT Time	GMT Date
Terminal countdown started at T-28 hours.	-028:00:00	05:00:00	10-Apr-70
Scheduled 9-hour 13-minute hold at T-9 hours.	-009:00:00	00:00:00	11-Apr-70
Countdown resumed at T-9 hours.	-009:00:00	09:13:00	11-Apr-70
Scheduled 1-hour hold at T-3 hours 30 minutes.	-003:30:00	14:43:00	11-Apr-70
Countdown resumed at T-3 hours 30 minutes.	-003:30:00	15:43:00	11-Apr-70
Guidance reference release.	-000:00:16.961	19:12:43	11-Apr-70
S-IC engine start command.	-000:00:08.9	19:12:51	11-Apr-70
S-IC engine ignition (#5).	-000:00:06.7	19:12:53	11-Apr-70
All S-IC engines thrust OK.	-000:00:01.4	19:12:58	11-Apr-70
Range zero.	000:00:00.00	19:13:00	11-Apr-70
All holddown arms released (1st motion) (1.06 g).	000:00:00.3	19:13:00	11-Apr-70
Liftoff (umbilical disconnected).	000:00:00.61	19:13:00	11-Apr-70
Tower clearance yaw maneuver started.	000:00:02.3	19:13:02	11-Apr-70
Yaw maneuver ended.	000:00:10.0	19:13:10	11-Apr-70
Pitch and roll maneuver started.	000:00:12.6	19:13:12	11-Apr-70
Roll maneuver ended.	000:00:32.1	19:13:32	11-Apr-70
Mach 1 achieved.	000:01:08.4	19:14:08	11-Apr-70
Maximum bending moment achieved (69,000,000 lbf-in).	000:01:16	19:14:16	11-Apr-70
Maximum dynamic pressure (651.63 lb/ft2).	000:01:21.3	19:14:21	11-Apr-70
S-IC center engine cutoff command.	000:02:15.18	19:15:15	11-Apr-70
Pitch maneuver ended.	000:02:43.3	19:15:43	11-Apr-70
S-IC outboard engine cutoff.	000:02:43.60	19:15:43	11-Apr-70
S-IC maximum total inertial acceleration (3.83 g).	000:02:43.70	19:15:43	11-Apr-70
S-IC maximum Earth-fixed velocity.	000:02:44.10	19:15:44	11-Apr-70
S-IC/S-II separation command.	000:02:44.3	19:15:44	11-Apr-70
S-II engine start command.	000:02:45.0	19:15:45	11-Apr-70
S-II ignition.	000:02:46.0	19:15:46	11-Apr-70
S-II aft interstage jettisoned.	000:03:14.3	19:16:14	11-Apr-70
Launch escape tower jettisoned.	000:03:21.0	19:16:21	11-Apr-70
Iterative guidance mode initiated.	000:03:24.5	19:16:24	11-Apr-70
S-IC apex.	000:04:31.7	19:17:31	11-Apr-70
S-II center engine cutoff (S-II engine #5 cutoff 132.36 seconds early).	000:05:30.64	19:18:30	11-Apr-70
S-II command to complete CECO.	000:07:42.6	19:20:42	11-Apr-70
S-II maximum total inertial acceleration (1.66 g).	000:08:57.00	19:21:57	11-Apr-70
S-IC impact (theoretical).	000:09:06.9	19:22:06	11-Apr-70
S-II outboard engine cutoff (34.53 seconds later than planned).	000:09:52.64	19:22:52	11-Apr-70
S-II maximum Earth-fixed velocity; S-II/S-IVB separation command.	000:09:53.50	19:22:53	11-Apr-70
S-IVB 1st burn start command.	000:09:53.60	19:22:53	11-Apr-70
S-IVB 1st burn ignition.	000:09:56.90	19:22:56	11-Apr-70
S-IVB ullage case jettisoned.	000:10:05.4	19:23:05	11-Apr-70
S-II apex.	000:10:32.2	19:23:32	11-Apr-70
S-IVB 1st burn cutoff (9 seconds later than planned).	000:12:29.83	19:25:29	11-Apr-70
S-IVB 1st burn maximum total inertial acceleration (0.58 g).	000:12:30.00	19:25:30	11-Apr-70
S-IVB 1st burn maximum Earth-fixed velocity.	000:12:30.50	19:25:30	11-Apr-70
Earth orbit insertion.	000:12:39.83	19:25:39	11-Apr-70
Maneuver to local horizontal attitude started.	000:12:50.1	19:25:50	11-Apr-70
Orbital navigation started.	000:14:10.4	19:27:10	11-Apr-70
S-II impact (theoretical).	000:20:58.1	19:33:58	11-Apr-70
TV transmission started.	001:37	20:50	11-Apr-70
TV transmission ended.	001:43	20:56	11-Apr-70
S-IVB 2nd burn restart preparation.	002:26:08.10	21:39:08	11-Apr-70
S-IVB 2nd burn restart command.	002:35:38.10	21:48:38	11-Apr-70
S-IVB 2nd burn ignition.	002:35:46.30	21:48:46	11-Apr-70
S-IVB 2nd burn cutoff.	002:41:37.15	21:54:37	11-Apr-70
S-IVB 2nd burn maximum total inertial acceleration (1.43 g).	002:41:37.23	21:54:37	11-Apr-70
S-IVB safing procedures started.	002:41:37.9	21:54:37	11-Apr-70
Translunar injection.	002:41:47.15	21:54:47	11-Apr-70
Maneuver to local horizontal attitude and orbital navigation started.	002:44:08	21:57:08	11-Apr-70
S-IVB 2nd burn maximum Earth-fixed velocity.	002:53:53.6	22:06:53	11-Apr-70
Maneuver to transposition and docking attitude started.	002:56:38.3	22:09:38	11-Apr-70
CSM separated from S-IVB.	003:06:38.9	22:19:38	11-Apr-70
TV transmission started.	003:09	22:22	11-Apr-70
CSM docked with LM/S-IVB.	003:19:08.8	22:32:08	11-Apr-70
CSM/LM ejected from S-IVB.	004:01:00.8	23:14:00	11-Apr-70
S-IVB maneuver to evasive APS burn attitude.	004:09:00	23:22:00	11-Apr-70

Apollo 13 Timeline

Event	GET (hhh:mm:ss)	GMT Time	GMT Date
S-IVB APS evasive maneuver ignition.	004:18:00.6	23:31:00	11-Apr-70
S-IVB APS evasive maneuver cutoff.	004:19:20.8	23:32:20	11-Apr-70
TV transmission ended.	004:20	23:33	11-Apr-70
S-IVB maneuver to LOX dump attitude initiated.	004:27:40.0	23:40:40	11-Apr-70
S-IVB lunar impact maneuver - CVS vent opened.	004:34:39.4	23:47:39	11-Apr-70
S-IVB lunar impact maneuver - LOX dump started.	004:39:19.4	23:52:19	11-Apr-70
S-IVB lunar impact maneuver - CVS vent opened.	004:39:39.4	23:52:39	11-Apr-70
S-IVB lunar impact maneuver - LOX dump ended.	004:40:07.4	23:53:07	11-Apr-70
Maneuver to attitude for final S-IVB APS burn initiated.	005:48:07.8	01:01:07	12-Apr-70
S-IVB lunar impact maneuver - APS ignition.	005:59:59.5	01:12:59	12-Apr-70
S-IVB lunar impact maneuver - APS cutoff.	006:03:36.7	01:16:36	12-Apr-70
Earth weather photography started.	007:17:14	02:30:14	12-Apr-70
Unsuccessful passive thermal control attempt.	007:43:02	02:56:02	12-Apr-70
Earth weather photography ended.	011:17:19	06:30:19	12-Apr-70
2nd S-IVB transposition maneuver (unplanned) initiated by launch vehicle digital computer.	013:42:33	08:55:33	12-Apr-70
Unplanned S-IVB velocity increase of 5 feet per second which altered lunar impact trajectory closer to target point.	019:29:10	14:42:10	12-Apr-70
TV transmission started.	030:13	01:26	13-Apr-70
Midcourse correction ignition (SPS) - transfer to hybrid non-free return trajectory.	030:40:49.65	01:53:49	13-Apr-70
Midcourse correction cutoff.	030:40:53.14	01:53:53	13-Apr-70
TV transmission ended.	031:02	02:15	13-Apr-70
Photograph Comet Bennett.	031:50	03:03	13-Apr-70
Unsuccessful passive thermal control attempt.	032:21:49	03:34:49	13-Apr-70
Crew turned on fans in oxygen tank #2 (routine procedure).	046:40:02	17:15	13-Apr-70
Cryogenic oxygen tank #2 quantity gauge indicated "off-scale high," of over 100% (probably due to short circuit). First indication of a problem.	046:40:05	17:18:05	13-Apr-70
Cryogenic oxygen tank #2 quantity probe short circuited.	046:40:08	17:21:08	13-Apr-70
Oxygen tank #2 fans turned on again with no apparent adverse affects. Quantity gauge continued to read "off-scale high."	047:54:50	19:03:50	13-Apr-70
Oxygen tank #2 fans turned on again with no apparent adverse affects. Quantity gauge continued to read "off-scale high."	051:07:44	22:57:44	13-Apr-70
CDR and LMP cleared to enter the LM to commence inflight inspection.	053:27	00:40	14-Apr-70
LMP entered LM.	054:20	01:33	14-Apr-70
CDR entered LM.	054:35	01:48	14-Apr-70
LM system checks.	054:40	01:53	14-Apr-70
TV transmission started.	055:14	02:27	14-Apr-70
CDR and LMP entered LM.	055:30	02:43	14-Apr-70
TV transmission ended.	055:46	02:59	14-Apr-70
Tunnel hatch closed.	055:50	03:03	14-Apr-70
Master caution and warning triggered by low hydrogen pressure in tank #1. Alarm turned off after 4 seconds.	055:52:31	03:05:31	14-Apr-70
CAPCOM: "13, we've got one more item for you, when you get a chance. We'd like you to stir up your cryo tanks. In addition, I have shaft and trunnion..."	055:52:58	03:05:58	14-Apr-70
LMP (Swigert): "Okay."	055:53:06	03:06:06	14-Apr-70
CAPCOM: "...for looking at the Comet Bennett, if you need it."	055:53:07	03:06:07	14-Apr-70
LMP: "Okay. Stand by."	055:53:12	03:06:12	14-Apr-70
Oxygen tank #1 fans on.	055:53:18	03:06:18	14-Apr-70
Oxygen tank #1 pressure decreased 8 psi due to normal destratification. Spacecraft current increased by 1 ampere.	055:53:19	03:06:19	14-Apr-70
Oxygen tank #2 fans on. Stabilization control system electrical disturbance indicated a power transient.	055:53:20	03:06:20	14-Apr-70
Oxygen tank #2 pressured decreased 4 psi.	055:53:21	03:06:21	14-Apr-70
Electrical short in tank #2 (stabilization control system electrical disturbance indicated a power transient.)	055:53:22.718	03:06:22	14-Apr-70
1.2-volt decrease in AC bus #2 voltage.	055:53:22.757	03:06:22	14-Apr-70
11.1 ampere “spike” recorded in fuel cell #3 current followed by drop in current and rise in voltage typical of removal of power from one fan motor, indicating opening of motor circuit.	055:53:22.772	03:06:22	14-Apr-70
Oxygen tank #2 pressure started to rise for 24 seconds.	055:53:36	03:06:36	14-Apr-70
11-volt decrease in AC bus #2 voltage for one sample.	055:53:38.057	03:06:38	14-Apr-70
Stabilization control system electrical disturbance indicated a power transient.	055:53:38.085	03:06:38	14-Apr-70
22.9-ampere “spike” recorded in fuel cell #3 current, followed by drop in current and rising voltage typical of one fan motor, indicating opening of another motor circuit.	055:53:41.172	03:06:41	14-Apr-70

Apollo 13 Timeline

Event	GET (hhh:mm:ss)	GMT Time	GMT Date
Stabilization control system electrical disturbance indicated a power transient.	055:53:41.192	03:06:41	14-Apr-70
Oxygen tank #2 pressure rise ended at a pressure of 953.8 psia.	055:54:00	03:07:00	14-Apr-70
Oxygen tank #2 pressure started to rise again.	055:54:15	03:07:15	14-Apr-70
Oxygen tank #2 quantity dropped from full scale (to which it had failed at 046:40) for two seconds and then read 75.3% full. This indicated the gauge short circuit may have corrected itself.	055:54:30	03:07:30	14-Apr-70
Oxygen tank #2 temperature started to rise rapidly.	055:54:31	03:07:31	14-Apr-70
Flow rate of oxygen to all three fuel cells started to decrease.	055:54:43	03:07:43	14-Apr-70
Oxygen tank #2 pressure reached maximum value of 1,008.3 psia.	055:54:45	03:07:45	14-Apr-70
Oxygen tank #2 temperature rises 40 F° for one sample (invalid reading)	055:54:48	03:07:48	14-Apr-70
Oxygen tank #2 quantity jumped to off-scale high and then started to drop until the time of telemetry loss, indicating a failed sensor.	055:54:51	03:07:51	14-Apr-70
Oxygen tank #2 temperature read -151.3 F. Last valid indication.	055:54:52	03:07:52	14-Apr-70
Oxygen tank #2 temperature suddenly went off-scale low, indicating a failed sensor.	055:54:52.703	03:07:52	14-Apr-70
Last telemetered pressure from oxygen tank #2 before telemetry loss was 995.7 psia.	055:54:52.763	03:07:52	14-Apr-70
Sudden accelerometer activity on X, Y, and Z axes.	055:54:53.182	03:07:53	14-Apr-70
Body-mounted roll, pitch, and yaw rate gyros showed low-level activity for 1/4 second.	055:54:53.220	03:07:53	14-Apr-70
Oxygen tank #1 pressure dropped 4.2 psi.	055:54:53.323	03:07:53	14-Apr-70
2.8-amp rise in total fuel cell current.	055:54:53.5	03:07:53	14-Apr-70
X, Y, and Z accelerations in CM indicate 1.17 g, 0.65 g, and 0.65 g.	055:54:53.542	03:07:53	14-Apr-70
Telemetry loss for 1.8 seconds. Master caution and warning triggered by DC main bus B undervoltage. Alarm turned off in 6 seconds. Indications were that the cryogenic oxygen tank #2 lost pressure during this time period and the panel separated.. It was at this time that the crew heard a loud bang.	055:54:53.555	03:07:53	14-Apr-70
Nitrogen pressure in fuel cell #1 went off-scale low indicating a failed sensor.	055:54:54.741	03:07:54	14-Apr-70
Telemetry recovered.	055:54:55.35	03:07:55	14-Apr-70
Service propulsion system engine valve body temperature started a rise of 1.65 F° in 7 seconds. DC main bus A decreased 0.9 volt to 28.5 volts and DC main bus B decreased 0.9 volt to 29.0 volts. Total fuel cell current was 15 amps higher than the final value before telemetry loss. High current continued for 19 seconds. Oxygen tank #2 temperature read off-scale high after telemetry recovery, probably indicating failed sensors. Oxygen tank #2 pressure read off-scale low following telemetry recovery, indicating a broken supply line, a tank pressure below 19 psia, or a failed sensor. Oxygen tank #1 pressure read 781.9 psia and started to drop steadily. Pressure drops over a period of 130 minutes to the point at which it was insufficient to sustain operation of fuel cell #2.	055:54:56	03:07:56	14-Apr-70
Oxygen tank #2 quantity read off-scale high following telemetry recovery indicating a failed sensor.	055:54:57	03:07:57	14-Apr-70
The reaction control system helium tank C temperature began a 1.66 F° increase in 36 seconds.	055:54:59	03:07:59	14-Apr-70
Oxygen flow rates to fuel cells #1 and #3 approached zero after decreasing for 7 seconds.	055:55:01	03:08:01	14-Apr-70
Surface temperature of SM oxidizer tank in bay #3 started a 3.8 F° increase in a 15-second period. Service propulsion system helium tank temperature started a 3.8 F° increase in a 32-second period.	055:55:02	03:08:02	14-Apr-70
DC main bus A voltage recovered to 29.0 volts. DC main bus B recovered to 28.8.	055:55:09	03:08:09	14-Apr-70
LMP: "Okay, Houston, we've had a problem here."	055:55:20	03:08:20	14-Apr-70
CAPCOM: "This is Houston. Say again, please."	055:55:28	03:08:28	14-Apr-70
CDR (Lovell): "Houston, we've had a problem. We've had a main B bus undervolt."	055:55:35	03:08:35	14-Apr-70
CAPCOM: "Roger. Main B bus undervolt."	055:55:42	03:08:42	14-Apr-70
Oxygen tank #2 temperature started steady drop lasting 59 seconds, indicating a failed sensor.	055:55:49	03:08:49	14-Apr-70
CMP (Haise): "Okay. Right now, Houston, the voltage is - is looking good. And we had a pretty large bang associated with the caution and warning there. And as I recall, main B was the one that had an amp spike on it once before."	055:56:10	03:09:10	14-Apr-70
CAPCOM: "Roger, Fred."	055:56:30	03:09:30	14-Apr-70
Oxygen tank #2 quantity became erratic for 69 seconds before assuming an off-scale-low state, indicating a failed sensor.	055:56:38	03:09:38	14-Apr-70
CMP: "In the interim here, we're starting to go ahead and button up the tunnel again."	055:56:54	03:09:54	14-Apr-70
CMP: "That jolt must have rocked the sensor on - see now - oxygen quantity 2. It was oscillating down around 20 to 60 percent. Now it's full-scale high."	055:57:04	03:10:04	14-Apr-70
Master caution and warning triggered by DC main bus B undervoltage. Alarm was turned off in six seconds.	055:57:39	03:10:39	14-Apr-70
DC main bus B dropped below 26.25 volts and continued to fall rapidly.	055:57:40	03:10:40	14-Apr-70

Apollo 13 Timeline

Event	GET (hhh:mm:ss)	GMT Time	GMT Date
CDR: "Okay. And we're looking at our service module RCS helium 1. We have - B is barber poled and D is barber poled, helium 2, D is barber pole, and secondary propellants, I have A and C barber pole." AC bus fails within two seconds.	055:57:44	03:10:44	14-Apr-70
Fuel cell #3 failed.	055:57:45	03:10:45	14-Apr-70
Fuel cell current started to decrease.	055:57:59	03:10:59	14-Apr-70
Master caution and warning caused by AC bus #2 being reset.	055:58:02	03:11:02	14-Apr-70
Master caution and warning triggered by DC main bus A undervoltage.	055:58:06	03:11:06	14-Apr-70
DC main bus A dropped below 26.25 volts and in the next few seconds leveled off at 25.5 volts.	055:58:07	03:11:07	14-Apr-70
CMP: "AC #2 is showing zip."	055:58:07	03:11:07	14-Apr-70
CMP: "Yes, we got a main bus A undervolt now, too, showing. It's reading about 25 and a half. Main B is reading zip right now."	055:58:25	03:11:25	14-Apr-70
Master caution and warning triggered by high hydrogen flow rate to fuel cell #2.	056:00:06	03:13:06	14-Apr-70
CDR: "...It looks to me, looking out the hatch, that we are venting something. We are venting something out into the - into space."	056:09:07	03:22:07	14-Apr-70
LMP reported fuel cell #1 off line.	056:09:58	03:22:58	14-Apr-70
Emergency power-down.	056:33:49	03:46:49	14-Apr-70
LMP reported fuel cell #3 off line.	056:34:46	03:47:46	14-Apr-70
CDR and LMP entered LM.	057:43	04:56	14-Apr-70
Shutdown of fuel cell #2.	058:00	05:13	14-Apr-70
CM computer and platform powered down.	058:10	05:23	14-Apr-70
CSM systems powered down. LM systems powered up.	058:40	05:53:00	14-Apr-70
Midcourse correction ignition to free-return trajectory (LM DPS).	061:29:43.49	08:42:43	14-Apr-70
Midcourse correction cutoff.	061:30:17.72	08:43:17	14-Apr-70
LM systems powered down.	062:50	10:03	14-Apr-70
Lunar occultation entered.	077:08:35	00:21:35	15-Apr-70
Lunar occultation exited.	077:33:10	00:46:10	15-Apr-70
S-IVB impact on lunar surface.	077:56:39.7	01:09:39	15-Apr-70
LM systems powered up.	078:00	01:13	15-Apr-70
Abort guidance system to primary guidance system aligned.	078:10	01:23	15-Apr-70
Transearth injection ignition (LM DPS).	079:27:38.95	02:40:39	15-Apr-70
Transearth injection cutoff.	079:32:02.77	02:45:02	15-Apr-70
LM systems powered down.	082:10	05:23	15-Apr-70
Apparent short-circuit in LM electrical system, accompanied by a "thump" in vicinity of descent stage and observation of venting for several minutes in area of LM descent batteries #1 and #2.	097:13:53	20:26:53	15-Apr-70
LM configured for midcourse correction.	100:00	23:13	15-Apr-70
CSM power configuration for telemetry established.	101:20	00:33	16-Apr-70
CM powered up.	101:53	01:06	16-Apr-70
LM systems powered up.	104:50	04:03	16-Apr-70
Midcourse correction ignition (LM DPS).	105:18:28.0	04:31:28	16-Apr-70
Midcourse correction cutoff.	105:18:42.0	04:31:42	16-Apr-70
Passive thermal control started.	105:20	04:33	16-Apr-70
LM systems powered down.	105:50	05:03	16-Apr-70
LM power transferred to CSM.	112:05	11:18	16-Apr-70
Battery A charge initiated.	112:20	11:33	16-Apr-70
Battery A charge terminated. Battery B charge initiated.	126:10	01:23	17-Apr-70
Battery B charge terminated.	128:10	03:23	17-Apr-70
LM systems powered up.	133:35	08:48	17-Apr-70
Platform aligned.	134:40	09:53	17-Apr-70
Preparation for midcourse correction.	136:30	11:43	17-Apr-70
Midcourse correction ignition (LM RCS).	137:39:51.5	12:52:51	17-Apr-70
Midcourse correction cutoff.	137:40:13.00	12:53:13	17-Apr-70
SM separation.	138:01:48.0	13:14:48	17-Apr-70
SM photographed.	138:15	13:28	17-Apr-70
CM powered up.	140:10	15:23	17-Apr-70
Platform aligned.	140:40	15:53	17-Apr-70
LM maneuvered to undocking attitude.	140:50	16:03	17-Apr-70
LM jettisoned.	141:30:00.2	16:43:00	17-Apr-70
Entry.	142:40:45.7	17:53:45	17-Apr-70
Drogue parachute deployed			
S-band contact with CM established by recovery aircraft.	142:48	18:01	17-Apr-70
Visual contact with CM established by recovery helicopters.	142:49	18:02	17-Apr-70

Apollo 13 Timeline

Event	GET (hhh:mm:ss)	GMT Time	GMT Date
Visual contact with CM established by recovery ship. Voice contact with CM established by recovery helicopters.	142:50	18:03	17-Apr-70
Main parachute deployed.			
Splashdown (went to apex-up).	142:54:41	18:07:41	17-Apr-70
Swimmers deployed to retrieve main parachutes.	142:56	18:09	17-Apr-70
1st swimmer deployed to CM.	143:03	18:16	17-Apr-70
Flotation collar inflated.	143:11	18:24	17-Apr-70
Life preserver unit delivered to lead swimmer.	143:18	18:31	17-Apr-70
CM hatch opened for crew egress.	143:19	18:32	17-Apr-70
Crew egress.	143:22	18:35	17-Apr-70
Crew aboard recovery helicopter.	143:29	18:42	17-Apr-70
Crew aboard recovery ship.	143:40	18:53	17-Apr-70
CM aboard recovery ship.	144:23	19:36	17-Apr-70
Flight crew departed recovery ship via Samoa and Hawaii.	167:07	18:20	18-Apr-70
Flight crew arrived in Hawaii	199:22	02:35	19-Apr-70
Flight crew arrived in Houston.	224:17	03:30	21-Apr-70
Recovery ship arrived in Hawaii.	312:17	19:30	24-Apr-70
Safing of CM pyrotechnics completed.	343:22	02:35	26-Apr-70
Deactivation of fuel and oxidizer completed.	360:15	19:28	26-Apr-70
CM arrived at contractor's facility in Downey, CA.	378:47	14:00	27-Apr-70

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