APOLLO BY THE NUMBERS

A statistical reference for the manned phase of Project Apollo

by

Richard W. Orloff

APOLLO BY THE NUMBERS

A statistical reference for the manned phase of Project Apollo

© 1996
Richard W. Orloff

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!

****

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*.

The author gratefully acknowledges the assistance of the following people for helping to locate original NASA documents, photographs, and other information.

Bunda L. Dean, formerly Lyndon B. Johnson Space Center
Joan Ferry and Lois Morris, Fondren Library, Rice University, and
Philip N. French and Jonathan Grant, formerly NASA Center for Aerospace Information
Robert W. Fricke, Jr., Lockheed Martin/Lyndon B. Johnson Space Center
Becky Fryday, formerly Media Services, Lyndon B. Johnson Space Center
Mike Gentry, Media Services, Lyndon B. Johnson Space Center
Dale Johnson, George C. Marshall Space Flight Center
Janet Kavocevich, Lyndon B. Johnson Space Center
Joey Pellarin Kuhlman, formerly Lyndon B. Johnson Space Center
Florastela Luna, Lyndon B. Johnson Space Center
Kenneth Nail, John F. Kennedy Space Center
Lee Saegesser, NASA Headquarters
Lisa Vazquez, formerly Media Services, Lyndon B. Johnson Space Center
Oma Lou White, formerly George C. Marshall Space Flight Center

Special thanks for proofing, comments and last-minute help go to:

Robert Sutton, Marshall, VA
David Ransom, Jr., Rancho Palos Verdes, CA

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 1

The fire.

Apollo 1 Fire Summary

Figure 1: The Apollo 1 Crew -- (l. to r.) Ed White, Gus Grissom, Roger Chaffee (NASA S66-30236).

Background

The first manned Apollo mission, was scheduled for launch on February 21, 1967 at Cape Canaveral launch complex 34. However, the death of the prime crew in a command module fire during a practice session on January 27 put America's lunar landing program on hold.

The crewmen were Lt. Colonel Virgil Ivan "Gus" Grissom (USAF), command pilot; Lt. Colonel Edward Higgins White, II (USAF), senior pilot; and Lt. Commander Roger Bruce Chaffee (USN), pilot.

Selected in the astronaut group of 1959, Grissom had been pilot of MR-4, America's second and last suborbital flight, and command pilot of the first two-man flight, Gemini 3. He was born April 3, 1926 in Mitchell, Indiana and was 40 years old. Grissom received a B. S. in Mechanical Engineering from Purdue University in 1950. His backup for the mission was Captain Walter Marty "Wally" Schirra (USN).

White had been pilot for the Gemini 4 mission, during which he became the first American to walk in space. He was born November 14, 1930 in San Antonio, Texas, and was 36 years old. He received a B. S. from the U. S. Military Academy at West Point in 1952, an M. S. in Aeronautical Engineering from the University of Michigan in 1959, and was selected as an astronaut in 1962. His backup was Major Donn Fulton Eisele (USAF).

Chaffee was training for his first spaceflight. He was born February 15, 1935 in Grand Rapids, Michigan and was 31 years old. He received a B. S. in Aeronautical Engineering from Purdue University in 1957, and was selected as an astronaut in 1963. His backup was Ronnie Walter "Walt" Cunningham.

The Accident

The accident occurred during the Plugs Out Integrated Test. The purpose of this test was to demonstrate all space vehicle systems and operational procedures in as near a flight configuration as practical and to verify systems capability in a simulated launch.

Figure 2: Grissom being checked out in Apollo 1 pressure suit (NASA S66-40760).

The test was initiated at 12:55 GMT on January 27, 1967. After initial system tests were completed, the flight crew entered the command module at 18:00 GMT. The command pilot noted an odor in the spacecraft environmental control system suit oxygen loop and the count was held at 18:20 GMT while a sample of the oxygen in this system was taken. The count was resumed at 19:42 GMT with hatch installation and subsequent cabin purge with oxygen beginning at 19:45 GMT. (The odor was later determined not to be related to the fire.)

Communication difficulties were encountered and the count was held at approximately 22:40 GMT to troubleshoot the problem. The problem consisted of a continuously live microphone that could not be turned off by the crew. Various final countdown functions were still performed during the hold as communications permitted.

By 23:20 GMT, all final countdown functions up to the transfer to simulated fuel cell power were completed and the count was held at T-10

minutes pending resolution of the communications problems.

Figure 3: Grissom, Chaffee, and White during Apollo 1 training. (NASA S66-49181).

From the start of the T-l0 minute hold at 23:20 GMT until about 23:30 GMT, there were no events that appear to be related to the fire. The major activity during this period was routine troubleshooting of the communications problem; all other systems were operating normally. There were no voice transmissions from the spacecraft from 23:30:14 GMT until the transmission reporting the fire which began at 23:31:04.7 GMT.

During the period beginning about 30 seconds before the report, there were indications of crew movement. These indications were provided by the data from the biomedical sensors, the command pilot's live microphone, the guidance and navigation system, and the environmental control system. There was no evidence as to what this movement was or that it was related to the fire.

The biomedical data indicated that just prior to the fire report the senior pilot was performing essentially no activity until about 23:30:21 GMT when a slight increase in pulse and respiratory rate was noted. At 23:30:30 GMT, the electrocardiogram indicated some muscular activity for several seconds. Similar indications were noted at 23:30:39 GMT. The data show increased activity but are not indicative of an alarm type of response. By 23:30:45 GMT, all of the biomedical parameters had reverted to the baseline "rest" level.

Beginning at about 23:30 GMT, the command pilot's live microphone transmitted brushing and tapping noises which were indicative of movement. The noises were similar to those transmitted earlier in the test by the live microphone when the command pilot was known to have been moving. These sounds ended at 23:30:58.6 GMT

Any significant crew movement would result in minor motion of the command module was detected by the guidance and navigation system; however, the type of movement could not be determined. Data from this system indicated a slight movement at 23:30:24 GMT, with more intense activity beginning at 23:30:39 GMT and ending at 23:30:44 GMT More movement began at 23:31:00 GMT and continued until loss of data transmission during the fire.

Increases of oxygen flow rate to the crew suits also indicated movement. All suits had some small leakage, and this leakage rate varied with crew positions. Earlier in the Plugs Out Test, the crew reported that a particular movement, the nature of which was unspecified, provided increased flow rate. This was also confirmed from the flow rate data records. The flow rate showed a gradual rise at 23:30:24 GMT which reached the limit of the sensor at 23:30:59 GMT

At 23:30:54.8 GMT, a significant voltage transient was recorded. The records showed a surge in the AC Bus 2 voltage. Several other parameters being measured also showed anomalous behavior at this time.

Beginning at 23:31:04.7 GMT, the crew gave the first verbal indication of an emergency when they reported a fire in the command module.

Emergency procedures called for the senior pilot, occupying the center couch, to unlatch and remove the hatch while retaining his harness buckled. A number of witnesses who observed the television picture of the command module hatch window discerned motion that suggested that the senior pilot was reaching for the inner hatch handle. The senior pilot's harness buckle was found unopened after the fire, indicating that he initiated the standard hatch-opening procedure. Data from the Guidance and Navigation System indicate considerable activity within the command module after the fire was discovered. This activity was consistent with movement of the crew prompted by proximity of the fire or with the undertaking of standard emergency egress procedures.

Personnel located on adjustable level 8 adjacent to the command module responded to the report of the fire. The Pad Leader ordered crew egress procedures to be started and technicians started toward the White Room which surrounded the hatch and into which the crew would step upon egress. Then, at 23:31:19 GMT, the command module ruptured.

All transmission of voice and data from the spacecraft terminated by 23:31:22.4 GMT, three seconds after rupture. Witnesses monitoring television showing the hatch window report that flame spread from the left to the right side of the command module and shortly thereafter covered the entire visible area.

Flames and gases flowed rapidly out of the ruptured area, spreading flames into the space between the command module pressure vessel and heat shield, through access hatches and into levels A-8 and A-7 of the service structure. These flames ignited combustibles, endangered pad personnel, and impeded rescue efforts. The burst of fire, together with the sounds of rupture, caused several pad personnel to believe that the command module had exploded or was about to explode.

The immediate reaction of all personnel on level A-8 was to evacuate the level. This reaction was promptly followed by a return to effect rescue. Upon running out on the swing arm from the umbilical tower, several personnel obtained a fire extinguisher and returned along the swing arm to the White Room to begin rescue efforts. Others obtained fire extinguishers from various areas of the service structure and rendered assistance in fighting the fires.

Three hatches were installed on the command module. The outermost hatch, called the boost protective cover (BPC) hatch, was part of the cover which shielded the command module during launch and was jettisoned prior to orbital operation. The middle hatch was termed the ablative hatch and became the outer hatch when the BPC was jettisoned after launch. The inner hatch closed the pressure vessel wall of the command module and was the first hatch to be opened by the crew in an unaided crew egress. The outer or BPC hatch was in place but not fully latched because of distortion in the BPC caused by wire bundles temporarily installed for the test. The middle hatch and inner hatch were in place and latched after crew ingress.

Although the BPC hatch was not fully latched it was necessary to insert a specially-designed tool into the hatch in order to provide a hand-hold for lifting it from the command module. At this time the White Room was filling with dense, dark smoke from the command module interior and from secondary fires throughout level A-8. While some personnel were able to locate and don operable gas masks, others were not. Some proceeded without masks while others attempted without success to render masks operable. Even operable masks were unable to cope with the dense smoke present because they were designed for use in toxic rather than dense smoke atmospheres.

Visibility in the White Room was virtually zero. It was necessary to work essentially by touch since visual observation was limited to a few inches at best. A hatch removal tool was in the White Room. Once the small fire near the BPC hatch had been extinguished and the tool located the Pad Leader and an assistant removed the BPC hatch. Although the hatch was not latched removal was difficult.

The personnel who removed the BPC hatch could not remain in the White Room because of the smoke. They left the White Room and passed the tool which was necessary to open each hatch to other individuals. A total of five individuals took part in opening the three hatches and each made several trips into the White Room and out for breathable air.

The middle hatch was removed with less effort than was required for the BPC hatch.

The inner hatch was unlatched and an attempt was made to raise it from its support and to lower it to the command module floor. The hatch could not be lowered the full distance to the floor and was instead pushed to one side. When the inner hatch was opened intense heat and a considerable amount of smoke issued from the interior of the command module.

When the Pad Leader ascertained that all hatches were open, he left the White Room, proceeded a few feet along the swing arm, donned his headset and reported this fact. From

a voice tape it has been determined that this report came approximately five minutes, twenty-seven seconds after the first report of the fire. The Pad Leader estimates that his report was made no more than thirty seconds after the inner hatch was opened. Therefore, it was concluded that all hatches were opened and the two outer hatches removed approximately five minutes after the report of fire or at about 23:36 GMT.

Medical opinion, based on autopsy reports, concluded that chances of resuscitation decreased rapidly once consciousness was lost (about 15 to 30 seconds after the first suit failed) and that resuscitation was impossible by 23:36 GMT. Loss of consciousness was due to cerebral hypoxia due to cardiac arrest resulting from myocardial hypoxia. Factors of temperature, pressure and environmental concentrations of carbon monoxide, carbon dioxide, oxygen and pulmonary irritants were changing extremely rapidly. It was impossible to integrate these variables on the basis of available information with the dynamic physiological and metabolic conditions they produced in order to arrive at a precise time when consciousness was lost and death supervened. The combined effect of these environmental factors dramatically increased the lethal effect of any factor by itself.

Visibility within the command module was extremely poor. Although the lights remained on, they could be perceived only dimly. No fire was observed. Initially, the crew was not seen. The personnel who had been involved in removing the hatches attempted to locate the crew without success.

Throughout this period, other pad personnel were fighting secondary fires on level A-8. There was considerable fear that the launch escape tower, mounted above the command module, would be ignited by the fires below and destroy much of the launch complex.
Shortly after the report of the fire, a call was made to the fire department. From log records, it appeared that the fire apparatus and personnel were dispatched at about 23:32 GMT. After hearing the report of the fire, the doctor monitoring the test from the blockhouse near the pad proceeded to the base of the umbilical tower.

The exact time at which firemen reached Level A-8 is not known. Personnel who opened the hatches unanimously stated that all hatches were open before any firemen were seen on the level or in the White Room. The first firemen who reached Level A-8 stated that all hatches were open, but that the inner hatch was inside the command module, when they arrived. This placed arrival of the firemen after 23:36 GMT. It was estimated, on the basis of tests, that seven to eight minutes were required to travel from the fire station to the launch complex and to ride the elevator from the ground to Level A-8. Thus, the estimated time of firemen arrival at level A-8 was shortly before 23:40 GMT

When the firemen arrived, the positions of the crew couches and crew could be perceived through the smoke but only with great difficulty. An unsuccessful attempt was made to remove the senior pilot from the command module.

Initial observations and subsequent inspection revealed the following facts. The command pilot's couch (the left hand couch) was in the "170 degree" position, in which it was essentially horizontal throughout its length. The foot restraints and harness were released and the inlet and outlet oxygen hoses were connected to the suit. The electrical adapter cable was disconnected from the communications cable. The command pilot was lying supine on the aft bulkhead or floor of the command module, with his helmet visor closed and locked and with his head beneath the pilot's head rest and his feet on his own couch. A fragment of his suit material was found outside the command module pressure vessel five feet from the point of rupture. This indicated that his suit had failed prior to the time of rupture (23:31:19.4 GMT) allowing convection currents to carry the suit fragment through the rupture.

The senior pilot's couch (the center couch) was in the "96 degree" position in which the back portion was horizontal and lower portion in the raised position. The buckle releasing the shoulder straps and lap belts was not opened. The straps and belts were burned through. The suit oxygen outlet hose was connected but the inlet hose was disconnected. The helmet visor was closed and locked and all electrical connections were intact. The senior pilot was lying transversely across the command module just below the level of the hatchway.

The pilot's couch (the right hand couch) was in the "264 degree" position in which the back portion was horizontal and the lower portion dropped toward the floor. All restraints were disconnected, all hoses and electrical connections were intact and the helmet visor was closed and locked. The pilot was supine on his couch.

From the foregoing, it was determined that in all probability the command pilot left his couch to avoid the initial fire, the senior pilot remained in his couch as planned for emergency egress, attempting to open the hatch until his restraints burned through and the pilot remained in his couch to maintain communications until the hatch could be opened by the senior pilot as planned. With a slightly higher pressure inside the command module than outside, opening the inner hatch was impossible because of the resulting force on the hatch. Thus the inability of the pressure relief system to cope with the pressure increase due to the fire made opening the inner hatch impossible until after cabin rupture. After rupture, the intense and widespread fire together with rapidly increasing carbon monoxide concentrations further prevented egress.

Whether the inner hatch handle was moved by the crew cannot be determined because the opening of the inner hatch from the White Room also moves the handle within the command module to the unlatched position. Immediately after the firemen arrived, the Pad Leader on duty was relieved to allow treatment for smoke inhalation. He had first reported over the headset that he could not describe the situation in the command module. In this manner he attempted to convey the fact that the crew was dead to the Test Conductor without informing the many people monitoring the communication channels. Upon reaching the ground the Pad Leader told the doctors that the crew was dead. The three doctors proceeded to the White Room and arrived there shortly after the arrival of the firemen. The doctors estimate their arrival to have been at 23:45 GMT. The second Pad Leader reported that medical support was available at approximately 23:43 GMT. The three doctors entered the White Room and determined that the crew had not survived the heat, smoke, and thermal burns. The doctors were not equipped with breathing apparatus, and the command module still contained fumes and smoke. It was determined that nothing could be gained by immediate removal of the crew. The firemen were directed to stop removal efforts.

When the command module had been adequately ventilated, the doctors returned to the White Room with equipment for crew removal. It became apparent that extensive fusion of suit material to melted nylon from the spacecraft would make removal very difficult. For this reason it was decided to discontinue efforts at removal in the interest of accident investigation and to photograph the command module with the crew in place before evidence was disarranged.

Photographs were taken, and the removal efforts resumed at approximately 00:30 GMT, January 28. Removal of the crew took approximately 90 minutes and was completed about seven and one-half hours after the accident.

Chronology of the Fire

It was most likely that the fire began in the lower forward portion of the left-hand equipment bay, to the left of the command pilot, and considerably below the level of his couch.

Once initiated, the fire burned in three stages. The first stage, with its associated rapid temperature rise and increase in cabin pressure, terminated 15 seconds after the verbal report of fire. At this time, 23:31:19 GMT, the command module cabin ruptured. During this first stage, flames moved rapidly from the point of ignition, traveling along debris traps installed in the command module to prevent items from dropping into equipment areas during tests or flight. At the same time, Velcro strips positioned near the ignition point also burned.

The fire was not intense until about 23:31:12 GMT. The slow rate of buildup of the fire during the early portion of the first stage was consistent with the opinion that ignition occurred in a zone containing little combustible material. The slow rise of pressure could also result from absorption of most of the heat by the aluminum structure of the command module.

Figure 4: Apollo 1 Command Module after fire (NASA S90-35348).

The original flames rose vertically and then spread out across the cabin ceiling. The debris traps provided not only combustible material and a path for the spread of the flames but also firebrands of burning molten nylon. The scattering of these firebrands contributed to the spread of the flames.

By 23:31:12 GMT, the fire had broken from its point of origin. A wall of flames extended along the left wall of the module, preventing the command pilot, occupying the left hand couch, from reaching the valve which would vent the command module to the outside atmosphere.

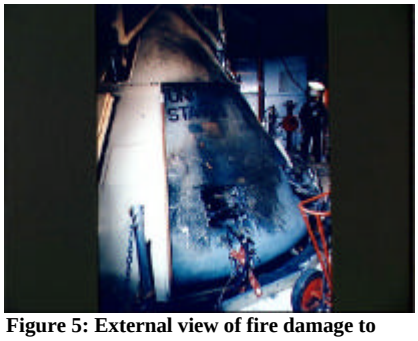

Figure 5: External view of fire damage to Apollo 1 Command Module (NASA S67-21295).

Although operation of this was the first step in established emergency egress procedures, such action would have been to no avail because the venting capacity was insufficient to prevent the rapid build-up of pressure due to the fire. It was estimated that opening the valve would have delayed command module rupture by less than one second.

The command module was designed to withstand an internal pressure of approximately 13 pounds per square inch above external pressure without rupturing. Data recorded during the fire showed that this design criterion was exceeded late in the first stage of the fire and that rupture occurred at about 23:31:19 GMT. The point of rupture was where the floor or aft bulkhead of the command module joined the wall, essentially opposite the point of origin of the fire. About three seconds before rupture, the final crew communication began at 23:31:16.8 GMT. This communication ended shortly after rupture at 23:31:21.8 GMT, followed by loss of telemetry at 23:31:22.4 GMT.

Rupture of the command module marked the beginning of the brief second stage of the fire. This stage was characterized by the period of greatest conflagration due to the forced convection that resulted from the outrush of gases through the rupture in the pressure vessel. The swirling flow scattered firebrands throughout the crew compartment spreading fire. This stage of the fire ended at approximately 23:31:25 GMT. Evidence that the fire spread from the left hand side of the command module toward the rupture area was found on subsequent examination of the module and crew suits. Evidence of the intensity of the fire includes burst and burned aluminum tubes in the oxygen and coolant systems at floor level.

This third stage was characterized by rapid production of high concentrations of carbon monoxide. Following the loss of pressure in the command module and with fire now throughout the crew compartment, the remaining atmosphere quickly became deficient in oxygen so that it could not support continued combustion. Unlike the earlier stages where the flame was relatively smokeless, heavy smoke now formed and large amounts of soot were deposited on most spacecraft interior surfaces as they cooled. The third stage of the fire could not have lasted more than a few seconds because of the rapid depletion of oxygen. It was estimated that the command module atmosphere was lethal by 23:31:30 GMT, five seconds after the start of the third stage.

Figure 6: Internal view of fire damage to Apollo I Command Module (NASA S67-21294).

Although most of the fire inside the command module was quickly extinguished because of a lack of oxygen, a localized, intense fire lingered in the area of the environmental control unit. This unit was located in the left hand equipment bay, near the point where the fire was believed to have started. Failed oxygen and water/glycol lines in this area continued to supply oxygen and fuel to support the localized fire that melted the aft bulkhead and burned adjacent portions of the inner surface of the command module heat shield.

The Investigation

Immediately after the accident, additional security personnel were positioned at Launch Complex 34 and the complex was impounded. Prior to disturbing any evidence, numerous external and internal photographs were taken of the spacecraft After crew removal, two experts entered the command module to verify switch positions. Small groups of NASA and North American Aviation management, Apollo 204 Review Board members, representatives and consultants inspected the exterior of Spacecraft 012.

Figure 7: Grissom (l.) inspects CM during visit to North American Aviation, 1966 (NASA S66-40760).

A series of close-up stereo photographs of the command module was taken to document the as-found condition of the spacecraft systems. After the couches were removed, a special false floor with removable 18-inch transparent squares was installed to provide access to the entire inside of the command module without disturbing evidence. A detailed inspection of the spacecraft interior was then performed followed by the preparation and approval by the Board of a command module disassembly plan.

Command module 014 was shipped to KSC on February 1, 1967 to assist the Board in the investigation. This command module was placed in the Pyrotechnics Installation Building and was used to develop disassembly techniques for selected components prior to their removal from command module 012. By February 7, 1967, the disassembly plan was fully operational. After the removal of each component, photographs were taken of the exposed area. This step-by-step photography was used throughout the disassembly of the spacecraft. Approximately 5,000 photographs were taken.

All interfaces such as electrical connectors, tubing joints, physical mounting of components, etc. were closely inspected and photographed immediately prior to, during, and after disassembly. Each item removed from the command module was appropriately tagged, sealed in clean plastic containers and transported under the required security to bonded storage.

On February 17, 1967, the Board decided that removal and wiring tests had progressed to a point which allowed moving the command module without disturbing evidence. The command module was moved to the Pyrotechnics Installation Building at KSC, where better working conditions were available.

With improved working conditions, it was found that a work schedule of two eight-hour shifts per day for six days a week was sufficient to keep pace with the analysis and disassembly planning. The only exception to this was a three-day period of three eight-hour shifts per day used to remove the aft heat shield, move the command module to a more convenient work station and remove the crew compartment heat

shield. The disassembly of the command module was completed on March 27, 1967.

Cause of the Apollo 1 Fire

Although the Board was not able to determine conclusively the specific initiator of the Apollo 204 fire, it identified the conditions which led to the disaster. These conditions were:

1. A sealed cabin, pressurized with an oxygen atmosphere.

2. An extensive distribution of combustible materials in the cabin.

3. Vulnerable wiring carrying spacecraft power.

4. Vulnerable plumbing carrying a combustible and corrosive coolant.

5. Inadequate provisions for the crew to escape.

6. Inadequate provisions for rescue or medical assistance.

Having identified the conditions that led to the disaster, the Board addressed itself to the question of how these conditions came to exist. Careful consideration of this question lead the Board to the conclusion that in its devotion to the many difficult problems of space travel, the Apollo team failed to give adequate attention to certain mundane but equally vital questions of crew safety. The Board's investigation revealed many deficiencies in design and engineering, manufacture and quality control.

As a result of the investigation, major modifications in design, materials, and procedures were implemented, including:

- The two-piece hatch was replaced by a single quick-operating, outward opening crew hatch made of aluminum and fiberglass. The new hatch could be opened from inside in seven seconds and by a pad safety crew in 10 seconds. Ease of opening was enhanced by a gas-powered counterbalance mechanism.

- The launch pad spacecraft cabin atmosphere for pre-launch testing was changed from 100% oxygen to a mixture of 60% oxygen and 40% nitrogen in order to reduce support of any combustion. The crew suit loops still carried 100% oxygen. After launch, the 60%-40% mix was gradually replaced with pure oxygen until cabin atmosphere reached 100% oxygen at five pounds per square inch. This "enriched air" mix was selected after extensive flammability tests in various percentages of oxygen at varying pressures.

Other changes included: substituting stainless steel for aluminum in high-pressure oxygen tubing; armor plated water-glycol liquid line solder joints; protective covers over wiring bundles; stowage boxes built of aluminum; replacement of materials to minimize flammability; installation of fireproof storage containers for flammable materials; mechanical fasteners substituted for gripper cloth patches; flameproof coating on wire connections; replacement of plastic switches with metal ones; installation of an emergency oxygen system to isolate the crew from toxic fumes; and the inclusion of a portable fire extinguisher and fire-isolating panels in the cabin.

Safety changes were also made at Launch Complex 34. These included structural changes to the white room for the new quick-opening spacecraft hatch; improved firefighting equipment; emergency egress routes; emergency access to the spacecraft; purging of all electrical equipment in the white room with nitrogen; installation of a hand-held water hose for fire fighting, and a large exhaust fan to draw smoke and fumes from the white room; fire-resistant paint; relocation of certain structural members to provide easier access to the spacecraft and faster egress; addition of a water spray system to cool the launch escape system (the solid propellants could be ignited by extreme heat); and the installation of additional water spray systems along the egress route from the spacecraft to ground level.

Apollo 1 Spacecraft History

Event	Date
Fabrication of spacecraft 012 at North American Aviation, Downey, CA.	Aug., 1964
Basic structure completed.	Sept., 1965
Installation and final assembly of subsystems completed. Critical design reviews completed. Check-out of all subsystems initiated, followed by integrated testing of all spacecraft subsystems.	Mar., 1966
Customer acceptance readiness review completed. NASA issued Certificate of fight worthiness and authorized spacecraft to be shipped to KSC.	Aug., 1966
Command module received at KSC.	Aug. 26, 1966
CM-012 mated with service module in altitude chamber and alignment, subsystems and system certification tests and functional checks performed.	Sept., 1966
First combined systems tests completed.	Oct. 1, 1966
First manned test at sea level pressure to verify total spacecraft system operation completed.	Oct. 13, 1966
Unmanned test at altitude pressures using oxygen to verify spacecraft system operation.	Oct. 15, 1966
Manned test with flight crew completed.	Oct. 19, 1966
Second manned altitude test, with backup crew, initiated but discontinued when failure occurred in oxygen system regulator in spacecraft environmental control system. Regulator removed and found to have design deficiency.	Oct. 21, 1966
Design certification document issued which certified design as flightworthy, pending satisfactory resolution of open items.	Oct. 7, 1966
Apollo program director conducted recertification review which closed out majority of open items remaining from previous reviews.	Dec. 21, 1966
Sea level and unmanned altitude tests completed.	Dec. 28, 1966
Manned altitude test with backup flight crew completed.	Dec. 30, 1966
Command module removed from altitude chamber.	Jan. 3, 1967
Spacecraft mated to launch vehicle at launch complex 34. Various tests and equipment installations and replacements performed.	Jan. 6, 1967

Apollo 1 Fire Timeline

Event	Date	Time (GMT)
Plugs Out Test initiated when power applied to spacecraft.	Jan. 27, 1967	12:55
Following completion of initial verification tests of system operation, command pilot entered spacecraft, followed by pilot and senior pilot.		18:00
Count held when command pilot noted odor in spacecraft environmental control system suit oxygen. Sample taken.		18:20
Count resumed after hatch installed.		19:42
Cabin purged with oxygen.		19:45
Open microphone first noted by test crew.		22:25
Count held while communication difficulties checked. Various final countdown functions performed during hold as communications permitted.		22:40
From this time until about 23:53 GMT, flight crew interchanged equipment related to communications systems in effort to isolate communications problem. During troubleshooting period problems developed in ability of various ground stations to communicate with one another and with crew.		22:45
Final countdown functions up to transfer to simulated fuel cell power completed and count held at T-10 minutes pending resolution of communications problems. For next 10 minutes, no events related to fire. Major activity was routine troubleshooting of communications problem. All other systems operated normally during this period.		23:20
First indication by either cabin pressure or battery compartment sensors of a pressure increase.		23:21:11
Command Pilot live microphone transmitted brushing and tapping noises, indicative of movement. Noises similar to those transmitted earlier in test by live microphone when command pilot was known to be moving.		23:30
No voice transmissions from spacecraft from this time until transmission reporting fire.		23:30:14
Slight increase in pulse and respiratory rate noted from senior pilot.		23:30:21
Data from guidance and navigation system indicated undetermined type of crew movement. Gradual rise in oxygen flow rate to crew suits began, indicating movement. Earlier in Plugs Out Test, crew reported that an unspecified movement caused increased flow rate.		23:30:24
Senior Pilot’s electrocardiogram indicated muscular activity for several seconds.		23:30:30
Additional electrocardiogram indications from senior pilot. Data show increased activity but were not indicative of alarm type of response. More intense crew activity sensed by guidance and navigation system.		23:30:39

Apollo 1 Fire Timeline

Event	Date	Time (GMT)
Crew movement ended.	Jan. 27, 1967	23:30:44
All of senior pilot's biomedical parameters reverted to "rest" level.		23:30:45
Variation in signal output from gas chromatograph.		23:30:50
First voice transmission ended.		23:31:10
Fire broke from its point of origin. Evidence suggests a wall of flames extended along left wall of module, preventing command pilot, occupying left hand couch, from reaching valve which would vent command module to outside atmosphere. Original flames rose vertically and spread out across cabin ceiling. Scattering of firebrands of molten burning nylon contributed to spread of flames. It was estimated that opening valve would have delayed command module rupture by less than one second.		23:31:12
Cabin pressure exceeded range of transducers, 17 pounds per square inch absolute (psia) for cabin and 21 psia for battery compartment transducers. Rupture and resulting jet of hot gases caused extensive damage to exterior.		23:31:16
Beginning of final voice transmission from crew. Entire transmission garbled. Sounded like "They're fighting a bad fire - Let's get out. Open 'er up." Or, "We've got a bad fire - Let's get out. We're burning up." Or "I'm reporting a bad fire. I'm getting out." Transmission ended with cry of pain, perhaps from pilot.		23:31:16.8
Command module ruptured, start of second stage of fire. First stage marked by rapid temperature rise and increase in cabin pressure. Flames had moved rapidly from point of ignition, traveling along net debris traps installed to prevent items from dropping into equipment areas. At same time, Velcro strips positioned near ignition point also burned.		23:31:19
End of final voice transmission.		23:31:21.8
All spacecraft transmissions ended. Television monitors showed flame spreading from left to right side of command module and shortly covered entire visible area. Telemetry loss made determination of precise times of subsequent occurrences impossible.		23:31:22.4
Third stage of fire characterized by greatest conflagration due to forced convection from outrush of gases through rupture in pressure vessel. Swirling flow scattered firebrands, spreading fire. Pressure in command module dropped to atmospheric pressure five or six seconds after rupture.		23:31:25
Command module atmosphere reached lethal stage, characterized by rapid production of high concentrations of carbon monoxide. Following loss of pressure, and with fire throughout crew compartment, remaining atmosphere quickly became deficient in oxygen and could not support continued combustion. Heavy smoke formed and large amounts of soot deposited on most spacecraft interior surfaces. Although oxygen leak extinguished most of fire, failed oxygen and water/glycol lines supplied oxygen and fuel to support localized fire that melted aft bulkhead and burned adjacent portions of inner surface of command module heat shield.		23:31:30

Apollo 1 Fire Timeline

Event	Date	Time (GMT)
Fire apparatus and personnel dispatched.	Jan. 27, 1967	23:32
Attempts to remove hatches.		23:32:04
Pad leader reported that attempts had started to remove hatches.		23:32:34
Hatches opened; outer hatches removed. Resuscitation of crew impossible.		23:36
Pad leader ascertained all hatches open, left white room, proceeded a few feet along swing arm, donned headset and reported this fact.		23:36:31
Firemen arrived at Level A-8. Positions of crew couches and crew could be perceived through smoke but only with great difficulty. Unsuccessful attempt to remove senior pilot from command module.		23:40
Doctors arrived.		23:43
Photographs taken, and removal efforts started.	Jan. 28, 1967	00:30
Removal of crew completed, about seven and one-half hours after accident.		07:00
Command module 014 shipped to KSC to develop disassembly techniques for selected components prior to their removal from command module 012.	Feb. 1, 1967	
Disassembly plan fully operational.	Feb. 7, 1967	
Command module moved to pyrotechnics installation building at KSC, where better working conditions available.	Feb. 17, 1967	
Disassembly of command module completed.	Mar. 27, 1967	

Apollo 1 Fire Bibliography

Akens, Davis S, editor, *Saturn Illustrated Chronology: Saturn's First Ten Years, April 1957 Through April 1967*, MHR-5, August 1, 1968, George C. Marshall Space Flight Center, National Aeronautics and Space Administration

Apollo Program Summary Report, National Aeronautics and Space Administration, Lyndon B. Johnson Space Center, Houston, Texas, April 1975 (JSC-09423) (NTIS N75-21314)

Bilstein, Roger E., *Stages To Saturn: A Technological History of the Apollo/Saturn Launch Vehicles*, Scientific and Technical Information Branch, National Aeronautics and Space Administration, November, 1980 (NASA SP-4206)

Brooks, Courtney G., James M. Grimwood, and Loyd S. Swenson, Jr., *Chariots For Apollo: A History of Manned Lunar Spacecraft*, The NASA History Series, Scientific and Technical Information Branch, National Aeronautics and Space Administration, Washington, DC, 1979 (NASA SP-4205) (NTIS N79-28203)

Cassutt, Michael, *Who's Who in Space: The International Edition*, MacMillan Publishing Company, New York, 1993.

Compton, William David, *Where No Man Has Gone Before: A History of Apollo Lunar Exploration Missions*, The NASA History Series, Office of Management, Scientific and Technical Information Division, National Aeronautics and Space Administration, Washington, D.C., 1989 (NASA SP-4214)

Ertel, Ivan D., and Roland W. Newkirk, *The Apollo Spacecraft: A Chronology*, Volume IV, January 21, 1966 - July 14, 1974, Scientific and Technical Information office, National Aeronautics and Space Administration, Washington DC, 1978 (NASA SP-4009)

Ezell, Linda Neuman, *NASA Historical Data Book, Volume II, Programs and Projects 1958-1968*, The NASA Historical Series, Scientific and Technical Information Division, National Aeronautics and Space Administration, Washington, DC, 1988 (NASA SP-4012)

Ezell, Linda Neuman, *NASA Historical Data Book, Volume III, Programs and Projects 1958-1968*, The NASA Historical Series, Scientific and Technical Information Division, National Aeronautics and Space Administration, Washington, DC, 1988 (NASA SP-4012)

First Americans In Space: Mercury to Apollo-Soyuz, National Aeronautics and Space Administration (undated)

Kaplan, Judith and Robert Muniz, *Space Patches From Mercury to the Space Shuttle*, Sterling Publishing Co., New York, 1986

Lattimer, Dick, *Astronaut Mission Patches and Spacecraft Callsigns*, unpublished draft, July 4, 1979, Lyndon B. Johnson Space Center History office

NASA Information Summaries, PM 001 (KSC), National Aeronautics and Space Administration, November 1985

The Early Years: Mercury to Apollo-Soyuz, PM 001 (KSC), NASA Information Summaries, National Aeronautics and Space Administration, November 1985

Thompson, Floyd, Chairman, *Report of the Apollo 204 Review Board*, National Aeronautics and Space Administration, April 5, 1967