NASA´s Apollo Program

Carlos González

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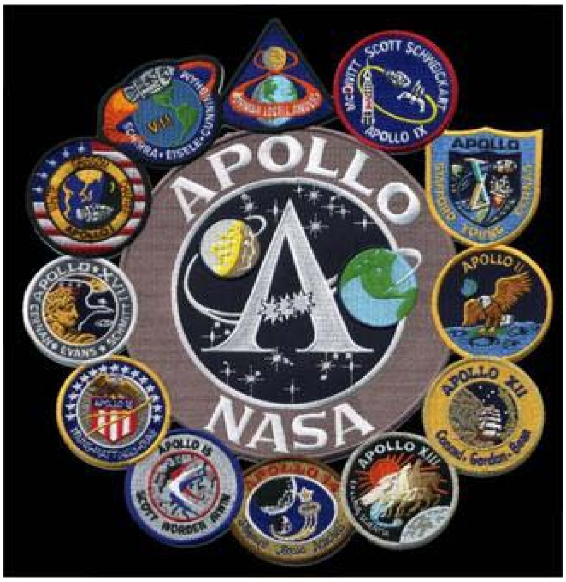
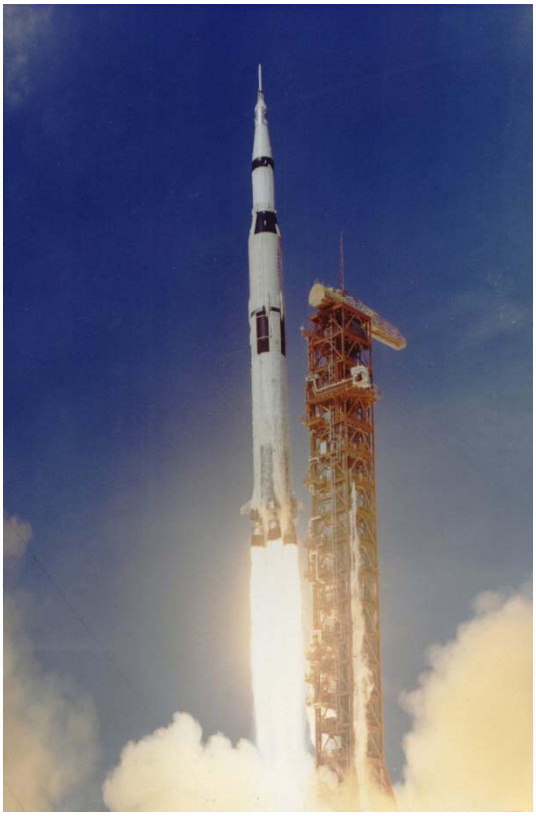
It took the professionalism, dedication and hard work of more than 400,000 persons around the world to make possible this *giant leap for mankind*

This essay is dedicated to my wife, Estrella, and daughters, Raquel and Sara, who have seldom seen me in the last months while I was busy with compiling all the available information existing on the subject and mixing it with my own memories.



Brief history of NASA´s Apollo Program

(Carlos Gonzalez. Former OPS Manager MDSCC)



Foreword

This essay couldn´t start without giving appropriate credit to the men that made the conquering of Space possible, either by dreaming of it long before it was thinkable or by making real all the theoretical studies about the subject,.
Among the dreamers: *Leonardo da Vinci, Jules Verne, H. G. Wells, Georges Mèliés, Edgar Rice Burroughs, Hugo Gersnback, Alex Raymond, Willy Ley, Chesley Bonestell, Robert McCall, etc.*
Among the theorist: *Konstantin Tsiolkovsky, Hermann Oberth, Robert H. Goddard, etc.*
And, of course, among the engineers and designers: *Wernher von Braun* and *Sergei Korolev*.

WERNHER VON BRAUN

Von Braun was the central figure in Germany´s rocket development program while in his 20s and early 30s and made possible the designing of the V-2 combat rocket during World War II.
After the war was over, Braun went to the US as part of *Operation Paperclip* to work on the *intermediate range ballistic missile* for the Army.
When NASA was created, he became director of the Marshall Space Flight Center and was the chief architect of the Saturn V vehicle that propelled the Apollo Spacecraft to the Moon.

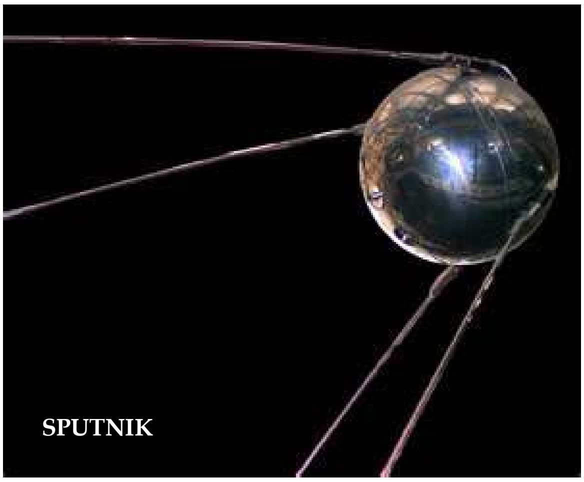
SERGEI KOROLEV

Sergei Korolev was a rocket designer and a key figure in the development of the Soviet Ballistic Missile Program.
He was appointed to lead the soviet space program and, after the success of *Sputnik* and *Vostok* projects, he was made a member of the Soviet Academy of Sciences.
By the time he unexpectedly died in 1966, his plans to compete with the United States to be the first nation to land a man on the Moon had begun to be implemented.

1. APOLLO *(The beginning)*

Why the Moon?

After World War II, the relationship between the Soviet Union and the USA was anything but friendly. There was no formal declaration of war but the antagonism had reached a peak that could only be defined as a *cold war*. Both countries were increasing their production of nuclear weapons and Intercontinental Ballistic Missiles *(ICBMs)* to carry them, *(for retaliation)*, but had not thought much about conquering Space.



SPUTNIK

Then, in 1957, the Soviets launched *Sputnik 1* and became the first nation to place a manmade object into Earth´s orbit. Although this action initiated the Space race, it was not very clear what the term exactly meant.

In 1958, the American government created the National Aeronautics and Space Administration *(NASA)* to separate defense and scientific efforts and, with this creation, the American Space Program was underway. The first project was designated *Mercury*, and it was to use an already well known launcher, *the Redstone,* which had been developed as a short range ballistic missile and deployed to defend Western Europe in case of an attack by the Soviets. At the same time, NASA had begun the process of selecting astronauts while training *Ham*, a chimpanzee, to become the first American astronaut.

LAUNCH OF A REDSTONE WITH A MERCURY CAPSULE

HAM

Long before Ham was launched, the Soviets launched a dog, *Laika,* one month after Sputnik 1, and again, became first in sending a mammal into space.

LAIKA

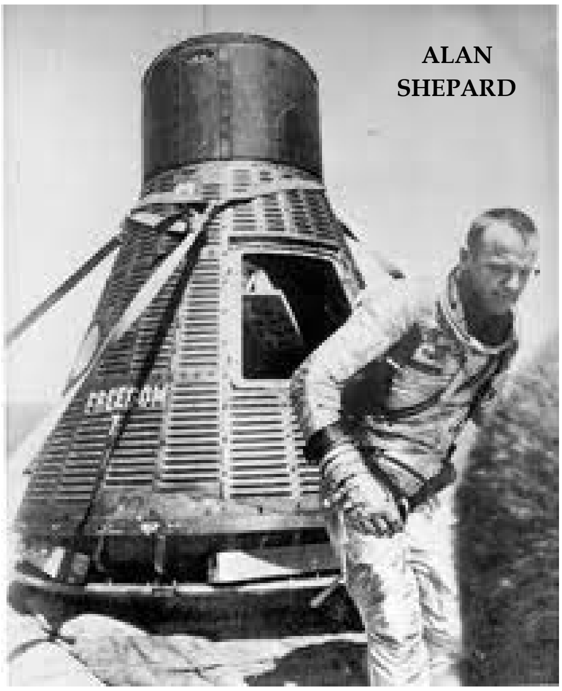
The Americans started the training of a group of astronauts in preparation for the first flight of project Mercury. Seven had been selected and became known as *The Mercury 7*. They were: *Alan Shepard Jr, Virgil (Gus) Grissom, Leroy Cooper Jr, Walter (Wally) Shirra Jr, Donald (Deke) Slayton, John Glenn Jr,* and *Malcolm Carpenter*.

THE MERCURY 7

But, here again, the Soviets were first by sending *Yuri Gagarin* into space aboard *Vostok 1* and beating *Alan Shepard*, the first American to flight, by only 23 days. In addition, Yuri completed a full orbit around the Earth while Shepard only accomplished a 16 minute suborbital flight.


YURI GAGARIN

The American pride was hurt, and the idea of putting astronauts on the Moon became a hot topic of discussion in Washington.


ALAN SHEPARD

The Americans initiated the *Vanguard* and *Explorer* projects to map the Moon in preparation for a Moon landing,

AGENA

The American president, John F. Kennedy, addressed a Joint Session of Congress on the 25th of May, 1961, and requested political support and budget to get the Americans to the Moon, *before the decade was out*, to show the world their economic and technological leadership. *Project Apollo* had begun.

In the meantime, project Mercury finally put a capsule into Earth orbit with astronaut Glenn *(1962)* by using a larger launch vehicle, an *Atlas,* while already working in the next project, *Gemini,* which would be the predecessor to Apollo.

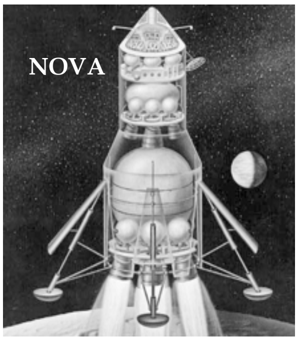
VALENTINA TERESHKOVA

The Soviets were not sleeping however, and sent the first woman, *Valentina Tereshkova* into Earth orbit *(1963)*, and also achieved the first Space walk with *Leonov (1965).* They were also busy with the design of a rocket that could get them to the Moon before the Americans.

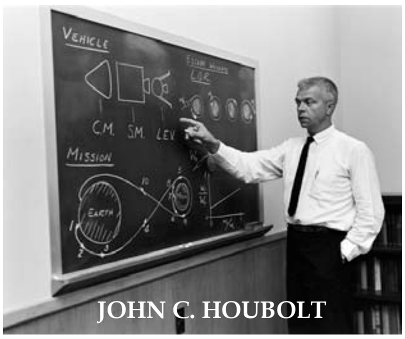
LEONOV

The American Moon project begins

The first designs for a rocket to send men to the Moon went from a missile large enough to leave Earth, land on the Moon, return to Earth and land safely at home *(NOVA)*, to the launch of two different rockets that would meet in Earth´s orbit, connect together, and continue the trip. And finally, to a *Moon rendezvous* that would comprise a large Command and Service Module *(CSM)* with a smaller Lunar Module *(LM)* attached. The former would take the astronauts to Moon´s orbit and back to Earth while the later would be used to land on the Moon and return to Moon´s orbit to *rendezvous* with the CSM. This design was proposed by *Tom Dolan* and led by *John C. Houbolt*.

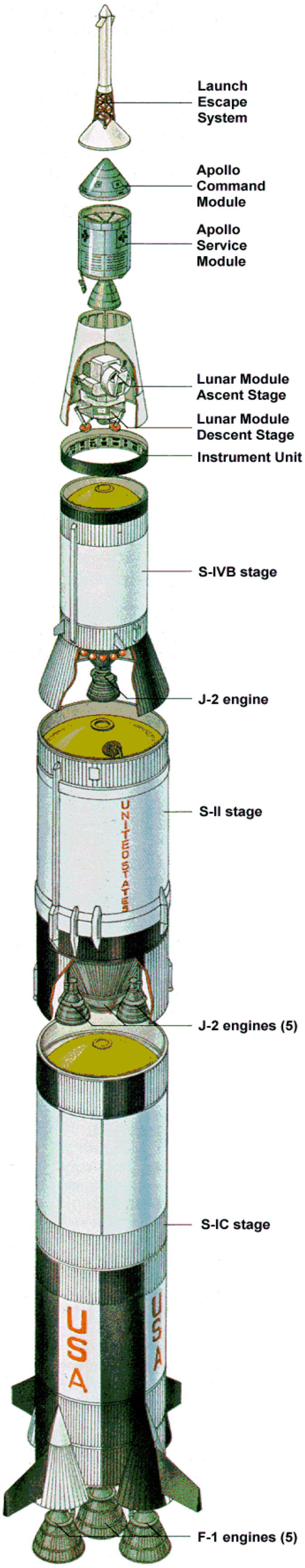


NOVA

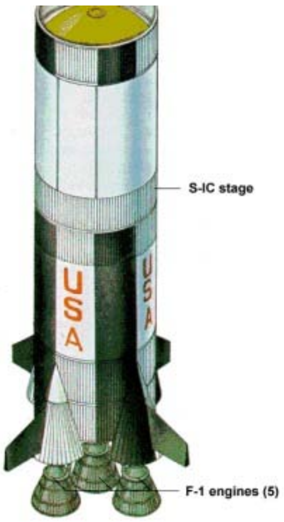


JOHN C. HOUBOLT

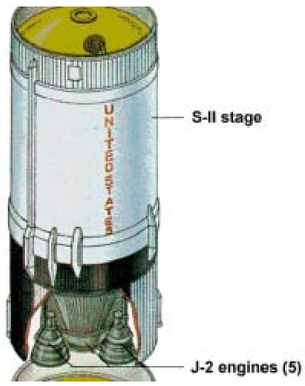
This last project was finally chosen and thus, the designing process was underway. First they needed a powerful enough launcher that would accelerate the CSM/LM combination to escape velocity so that it could leave Earth and be able to get to the Moon. And so, a giant three stage vehicle was planned and developed, the *SATURN V*.



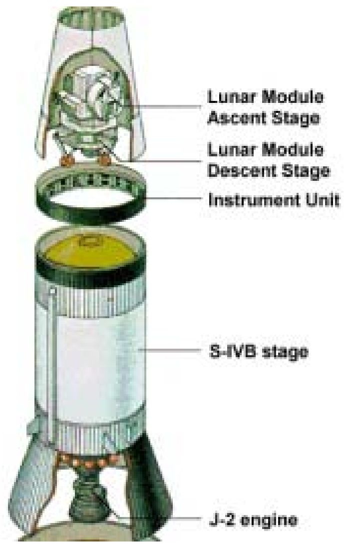
The first stage was built by Boeing in New Orleans and was called the *S-1C*. It had 5 F-1 engines, the center one being fixed while the outer four were steerable. The propellants were RP1 *(a super refined kerosene)* and liquid oxygen and was able to produce a thrust of 3.5 thousand metric tons. This first stage burned for 2.5 minutes and placed the vehicle at an altitude of 67 km and at a speed of 8,600 km/h. The ignition sequence started 8.9 seconds before liftoff with the central motor igniting first and the outside motors following sequentially, in diagonal pairs, every 300 milliseconds. Once all five engines were at full thrust the launcher was released from the launch platform. 1 minute and 20 seconds after liftoff, the astronauts experienced a dynamic pressure of 4 Gs. (1)

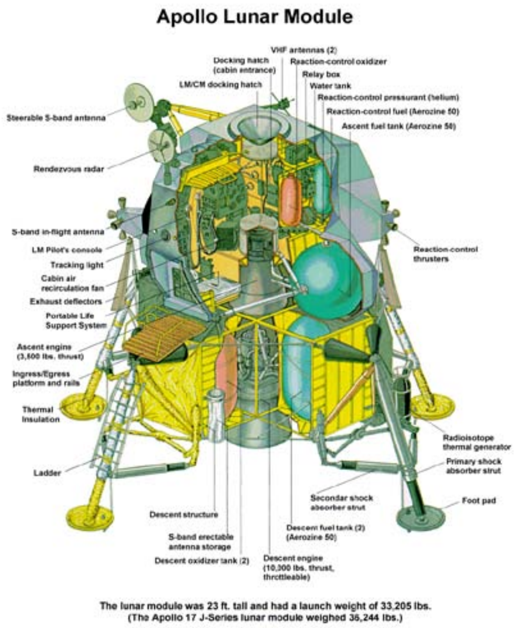


After the propellants were depleted, first stage would separate from the rest of the vehicle and the second stage would ignite. At that time, the launch escape tower was jettisoned. North American Aviation in California built the second stage, called the *S-II*, which was comprised of five J-2 motors with the center one fixed and the outer four steerable as in the first stage. The propellants were Oxygen and Hydrogen, and would burn for 6 minutes to place the rest of the vehicle at an altitude of 185 km and at a velocity of 20,600 km/h.



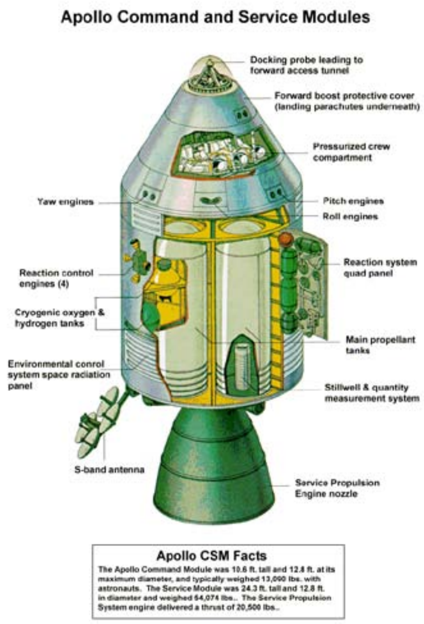
This was just a little less than needed to go into Earth´s orbit, so the second stage separated and the third ignited for 2.5 minutes giving the necessary increase in speed to achieve it. This was the *S-IVB* and was built by Douglas Aircraft in California; it used the same type of propellants of the second stage. It had a single J-2 engine which was restartable, so it could be ignited again to place the vehicle on a lunar trajectory. Atop the S-IVB there was a ring called the Instrumentation Unit *(IU)*, built by IBM; it received information from multiple sensors in the vehicle and sent commands to different parts of the launcher based on this information. After the IU, a hatch concealed the LM, built by Grumman, which had the landing legs retracted while on the trans-lunar trajectory.





The LM had two stages, landing and ascent, and used Propergol *(Mono-methyl hydrazine + Nitrogen tetroxide)* as propellant.

On top of the hatch, the CSM, built by North American Aviation, was attached. The SM used Aerozine 50 *(hydrazine + unsymmetrical di-methyl hydrazine + Nitrogen tetroxide)* as propellant.



(1) *G* is the acceleration produced by Earth's gravity and is equal to 9.8 m/s^2. A person under 4 Gs actually weights four times more than normal.

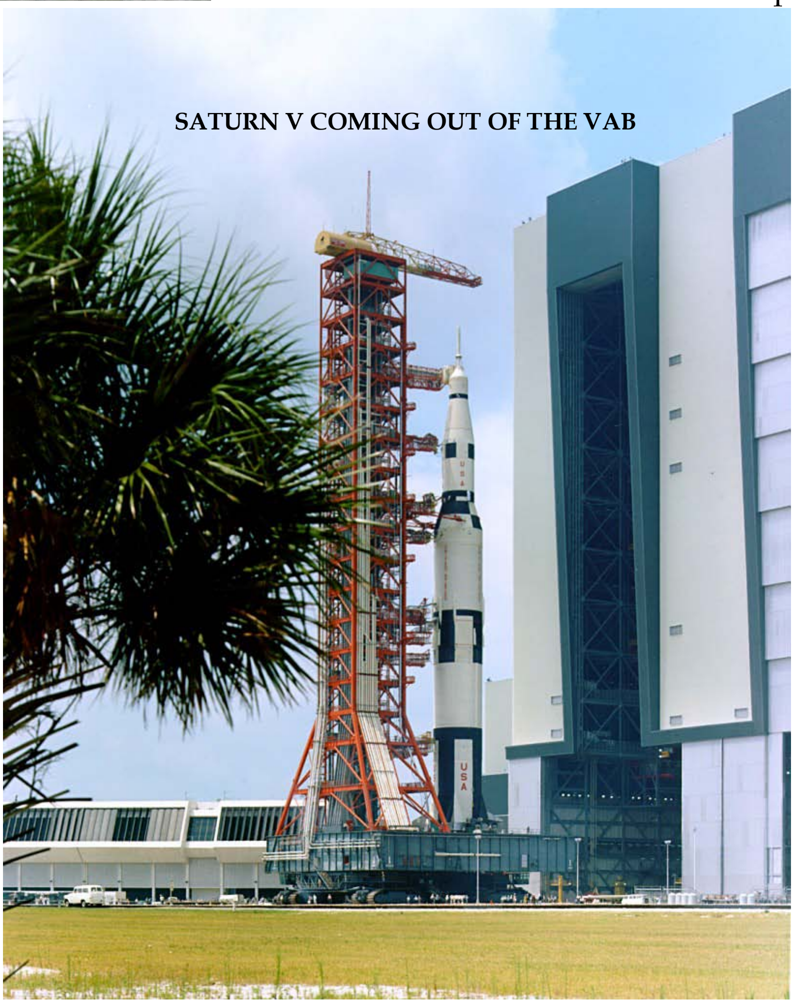
Vehicle readiness

VAB

All of these formed the huge rocket called Saturn V, but how were all these stages assembled?

This was performed at the Vehicle Assembly Building *(VAB)* which was, and still is, located on Launch Complex 39 at the Kennedy Space Center, Florida. It is the largest single-story building in the world. It was initially built to assemble the Saturn V vehicles and later used for the Shuttle. Its construction was finished by 1966.

It is 160.3 m. tall, 218.2 m. long, 157.9 m. wide and encloses 3,665,000 m^3 of space. For conditioning, it uses 125 ventilators on the roof to keep moisture under control. Nevertheless, its interior is so vast that it has its own weather, including rain clouds on very humid days. Inside air can be totally replaced in one hour.



SATURN V COMING OUT OF THE VAB

Access to this building is attained through four entries with the four largest doors in the world. Each of these doors has a height of 139 m. and need as long as 45 minutes to open or close.

Due to its location, the VAB was built to withstand hurricanes and tropical storms.

SATURN V WITH ULT GETTING READY TO ATTACH TO THE MSS

Next, the whole assembly mounted on top of a huge caterpillar and with its Umbilical Launch Tower *(ULT)* attached, left the VAB and started the trip to LC 39-A at a top speed of 2.5 km/h. When at the launch site, engineers would attach it to the Mobile Service Structure *(MSS)* and begin the launch readiness tests.

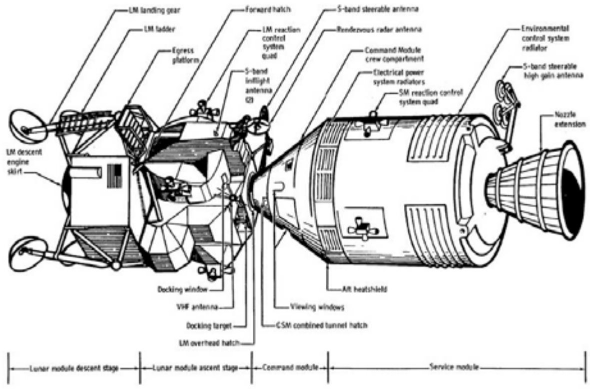
These tests verified the status of the vehicle for launch and, after they were completed, the MSS would retreat and leave the Saturn V with its ULT to continue with the launch count. At the end of the launch count sequence, the Apollo spacecraft would start its voyage to the Moon.

LAUNCH OF A SATURN V

On the way

After 2 ½ Earth orbits, and after all instruments had been checked out, it was time for the S-IVB to perform the Trans-Lunar Injection Burn *(TLI)*. This second ignition of the third stage lasted for almost 6 minutes and was able to achieve escape velocity, after which, the craft was on its way to the Moon.

NORMAL CSM/LM CONFIGURATION

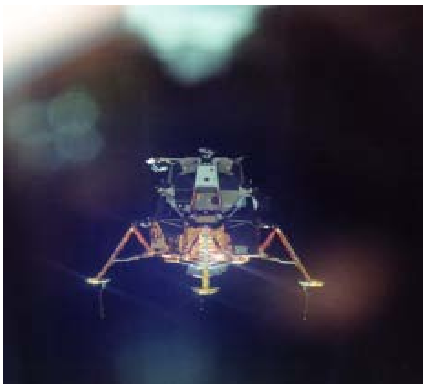


Apollo 13 space vehicle configuration.

About 40 minutes after TLI the CSM separated from the S-IVB, turned around and docked with the LM. 50 minutes later, the integrated CSM/LM separated from the S-IVB.

To prevent the S-IVB from hitting the CSM/LM, a small evasion maneuver was performed.

During the next three days things were relatively quiet aboard the CSM. The astronauts performed scheduled scientific experiments and took pictures. The CSM/LM was in a Passive Thermal Control *(PTC)* mode that prevented excessive heat buildup from the Sun by rotating the craft along its longitudinal axis.



LM AFTER SEPARATION

The trip to the Moon would normally place the CSM/LM in a free-return trajectory that would permit the astronauts the return to Earth with an easy maneuver in case of a failure, but after the course had been verified to be correct and all equipment working normally a trajectory correction was performed that would let the Moon´s gravity catch the vehicle with the aid of a small burn of the SM motor while on the backside. Normally, two firing were needed. The first one placed the craft in an elliptical orbit, and the second circularized it.

LM´S SHADOW IN THE SURFACE OF THE MOON

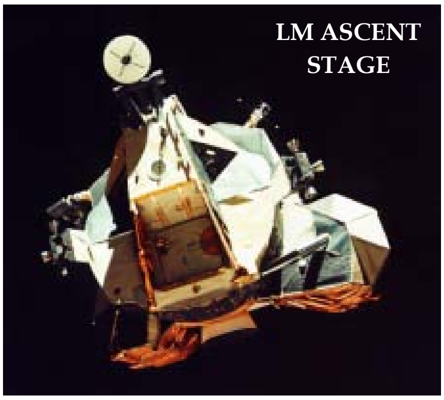
The CMDR and LM Pilot then opened the hatch, entered the LM, and turned on all the electronic equipment. A thorough checklist was then performed and LM was ready to unlatch from the CSM and start

COMING OUT OF THE LM

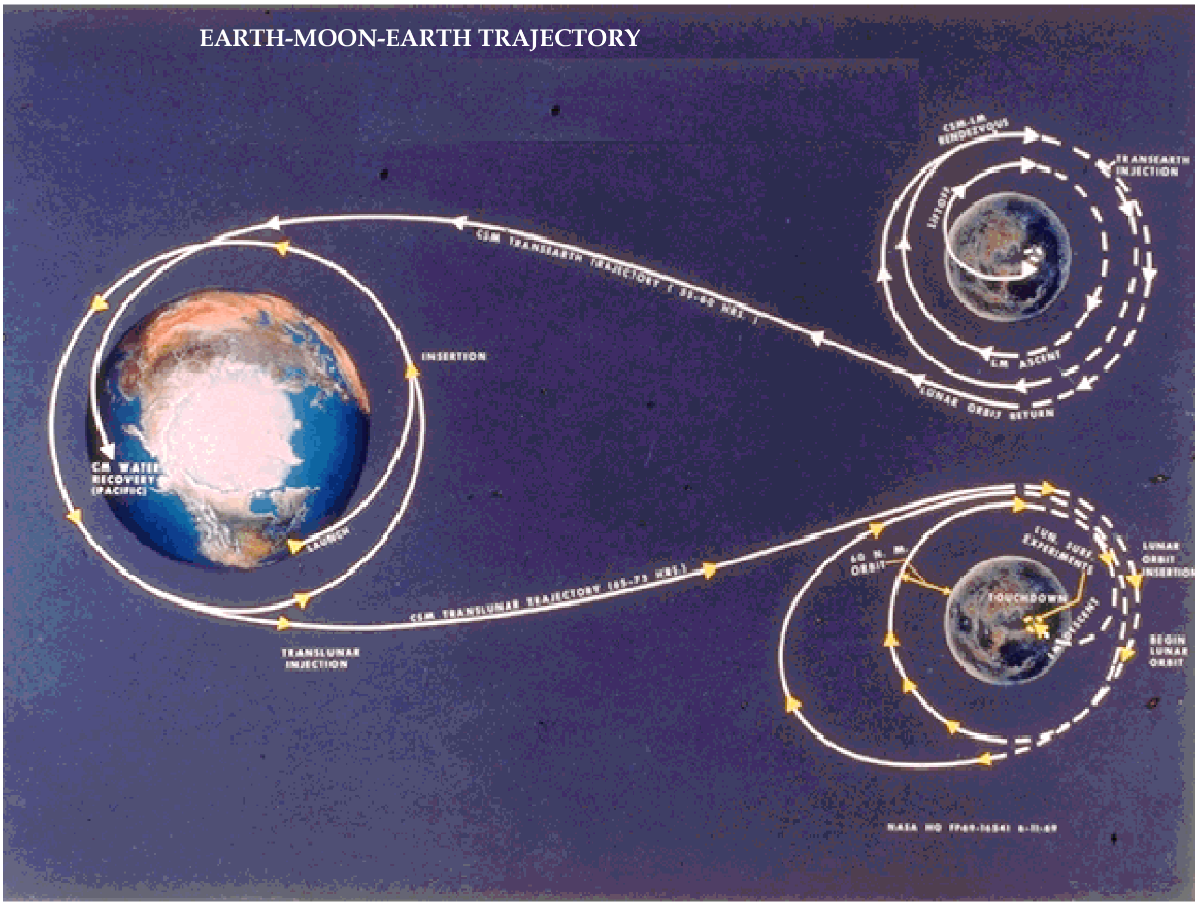

LM LIFTOFF

the landing sequence.

After the LM was in the lunar surface, there were many tasks to perform: Complete the post-landing checklist, prepare for lunar Extra Vehicular Activity *(EVA)*, and while on EVA, collect samples and inspect the surroundings for post mission reporting, etc.


LM ASCENT STAGE

Once ready to return to the CSM, they would fire the ascent stage and prepare to re-connect. The CSM was waiting in Moon´s orbit and both crafts latched together again. The Commander and the LM Pilot transferred all the samples they collected on the surface to the CSM and after everything was transferred, they would disconnect from the LM and send it on a reentry trajectory


EARTH-MOON-EARTH TRAJECTORY

to impact our satellite.

At the proper time, while behind the Moon, the SM motor was fired to provide the necessary velocity to escape Moon´s gravity and ensure an Earth-bound trajectory.

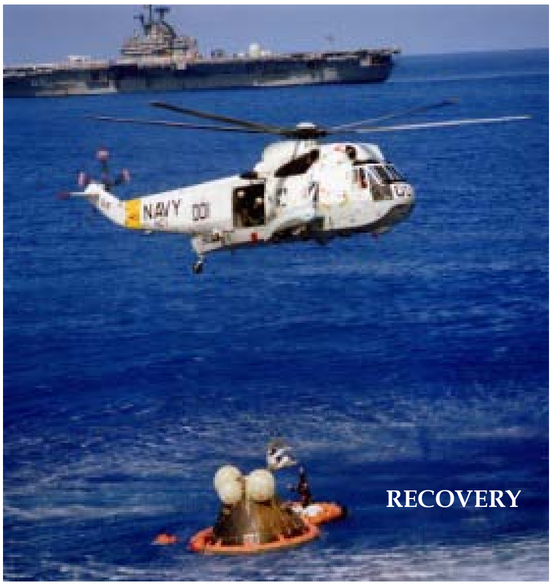
The return home

The next three days were normally uneventful and astronauts did housekeeping, took lots of photographs and prepared for reentry.

After verifying that the trajectory was adequate to place the CM in the proper window for reentry, the astronauts would don their spacesuits and jettisoned the SM.

And now, they needed to reduce the speed at which they were returning from the Moon *(approximately 40,000 km/h)* to a mere 35 km/h to splashdown into the ocean. The capsule entered Earth´s atmosphere and the friction generated a ball of fire that engulfed the CM, and the astronauts were then faced with 7 to 7½ Gs of deceleration. Meanwhile, all communications were lost during approximately 4 minutes due to this ball of fire. This *long* period was known as the *COMM BLACKOUT*.

At about 7 km altitude, the speed had been drastically reduced and the ball of fire had disappeared. A couple of conical parachutes were deployed to stabilize the craft and, later, three small parachutes were launched to extract the main ones. This occurred at an altitude of about 3 km.



The astronauts and capsule were then recovered and mission was completed.

2. APOLLO I

This was originally planned to be the first manned flight to test the capabilities of the Saturn vehicle. The launch configuration was composed of a Saturn 1B launcher carrying a Block I CSM. *(CSM 012)*. This Block I didn´t include a capability of docking with the LM as the latter had not been fully designed yet. So, the main objectives for the flight were to test launch operations, ground Tracking and Control facilities, the performance of the Apollo-Saturn launch assembly and that of the CSM. The mission designation was SA–204.

The prime crew for this flight was:

Position	**Astronaut**
Command Pilot	Virgil I. *(Gus)* Grissom
Senior Pilot	Edward H. White II
Pilot	Roger B. Chaffee

The backup crew was initially composed of: James A. McDivitt, David R. Scott and Russell L. *(Rusty)* Schweickart *(This crew later flew on Apollo IX)* but was changed to: Walter M. *(Wally)* Schirra, Donn F. Eisele and R. Walter Cunningham *(This crew later flew on Apollo VII)*.

The target launch date was November 1966 to make it coincident with the last Gemini *(12)* mission and have the two craft make a rendezvous in space but Apollo

was not ready to flight by itself, and engineers hadn´t yet developed the proper compatible docking hardware, so the date had to slip until February 21st, 1967. Within NASA, many believed that Gemini was the right module for flights to the Moon due to its reliability and experience but this soon changed to a different concept and a larger module.

Launch would take place from pad 34-A, and it would flight for up to a couple of weeks depending of the CSM performance.

Initial plans were to fly two manned missions *(204 and 205)* and then do an unmanned flight *(206)* to test the LM. The third manned flight would be a *dual* mission *(278)*. In that mission, SA-207 would be manned and use the first Block II CSM, while an unmanned mission *(208)* would launch a LM module with the purpose of performing a rendezvous and dock procedure in space.

The crew received the approval to design a mission patch with the name of *APOLLO 1* in June of 1966. The insignia was designed by the crew, with the artwork done by National Aeronautic Association *(NAA)* employee *Allen Stevens*.

The Apollo CSM spacecraft was much bigger and far more complex than any previously implemented design. In October 1963, *Joseph F. Shea* had been named Apollo Spacecraft Program Office *(ASPO)* manager and, as such, was responsible for supervising the design and construction of both, the CSM and the LM. When North

American shipped spacecraft CM-012 to Kennedy Space Center on August 26th, 1966, there were 113 significant incomplete planned engineering changes, and an additional 623 engineering change orders were made after delivery. Grissom was so frustrated with the inability of the training simulator engineers to keep up with the actual spacecraft changes, that he took a lemon from a tree by his house and hung it on the simulator (1).

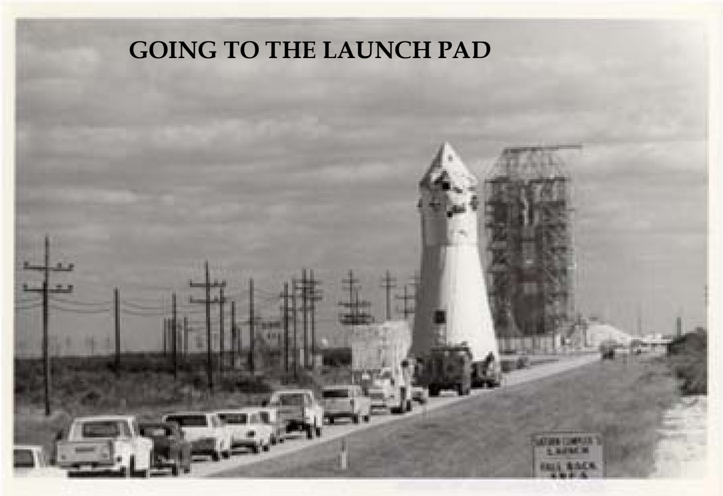
In a spacecraft review meeting held with Shea on August 19th, 1966, *(a week before delivery)*, the crew expressed concern about the amount of flammable material *(mainly nylon, netting and Velcro)* in the cabin, which the technicians found convenient for holding tools and equipment in place. Though Shea gave the spacecraft a passing grade, after the meeting they gave him a crew portrait they had posed with heads bowed and hands clasped in prayer, with the inscription:

It isn't that we don't trust you, Joe, but this time
we've decided to go over your head.

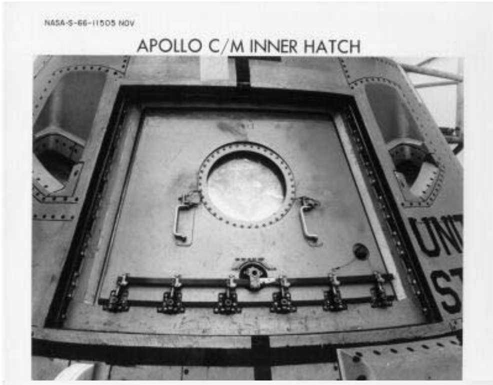
Shea gave his staff orders to tell North American to remove the flammables from the cabin, but did not supervise the issue personally.

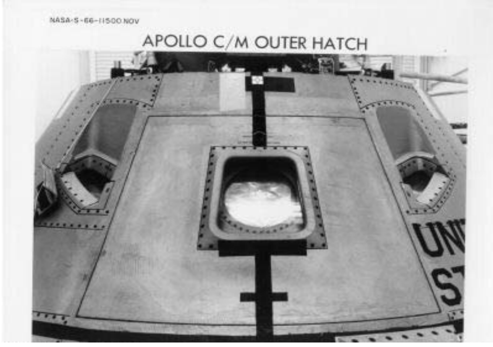
(1) Clear reference to the song *Lemon tree* by Peter, Paul and Mary
Lemon tree very pretty and the lemon flower is sweet
But the fruit of the poor lemon is impossible to eat.

The Accident



On January 27th, 1967, a launch simulation was scheduled with the vehicle already on the launch pad. This was known as a *plugs-out* test and it would determine whether the spacecraft could operate nominally on *(simulated)* internal power while detached from all cables and umbilicals. Passing this test was essential to making the February 21st launch date. The test was considered non-hazardous because neither the launch vehicle nor the spacecraft was loaded with fuel or cryogenics, and all pyrotechnic systems were disabled.





The astronauts entered into the module fully pressure-suited, and were strapped into their seats and hooked up to the spacecraft's oxygen and communication systems. Then the hatch was closed.

The hatch consisted of three parts: a removable inner hatch which stayed inside the cabin; a hinged outer hatch which was part of the spacecraft's heat shield; and an outer hatch cover which was part of the boost protective cover enveloping the entire command module to protect it from aerodynamic heating during launch and from launch escape rocket exhaust in the event of a launch abort.

There were a few minor problems that were promptly resolved and added to the lessons learned list, which was also part of the simulation exercise.

Finally, after several countdown holds, everything seemed to be fine.

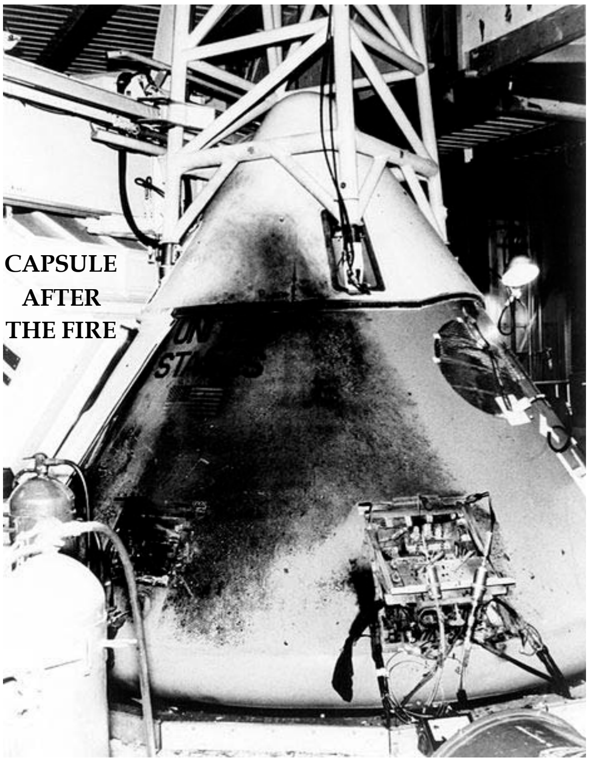
The crew members were running through their checklist again, when a voltage transient was recorded at 6:30:54 *(23:30:54 GMT)*. Ten seconds later *(at 6:31:04)*, after Chaffee said the word, *Hey!*, scuffling sounds followed for three seconds before Grissom reported a fire that began that minute. Chaffee then reported, *we've got a fire in the cockpit* while White responded to Chaffee's comment. After 12 seconds, Chaffee urged the crew to get out of the Command Module. The final voice transmission from the crew was very garbled and all transmissions ended abruptly at 6:31:21, only 17 seconds after the first indication of a fire. Then a hiss as the cabin ruptured after rapidly expanding gases from the fire over-pressurized the Command Module to 2 Atmospheres and burst the cabin interior.


RESULTS OF THE FIRE

The ground crew tried to open the hatch from the exterior but the heavy smoke coming from the capsule prevented them from helping the astronauts.

When the fire was finally extinguished the three crew members had passed away.

Obviously, an Investigation board had to be immediately assigned to find out the causes of the disaster and NASA Administrator James E. Webb obtained the approval of President Johnson to keep the results of the investigation within NASA.


CAPSULE AFTER THE FIRE

The results of the investigation were not conclusive but pointed to several problems:

a. Electrical power momentarily failed at 23:30:55 GMT, and evidence of several electric arcs in the interior equipment were found.
b. It was noted that a silver-plated copper wire running through an environmental control unit near the center couch had become stripped of its Teflon insulation and abraded by repeated opening and closing of a small access door.
c. This weak point in the wiring also ran near a junction in an ethylene glycol/water cooling line which had been prone to leaks.
d. The electrolysis of ethylene glycol solution with the silver anode was a notable hazard which could cause a violent exothermic reaction, igniting the ethylene glycol mixture in the CM's corrosive test atmosphere of pure, high-pressure oxygen.

e. The hatch had an interlock that prevented its opening until the pressures inside and outside the capsule were equalized. This would have happened fast enough had it not been for the fire inside that kept the pressure increasing constantly.
f. The hatch opened inward and didn´t have a pyrotechnic device for emergency purposes.
g. There was a too much flammable material inside the capsule.
h. The ground crew did not have the proper material to fight this situation.

The whole project was delayed for 20 months while the CM capsules went through a careful redesign. The Block I CM was only used for unmanned flights thereafter while Block II was used for manned flights.


ASTRONAUT SUIT AFTER THE FIRE

Some of the redesigns of Block II capsules were:

a. Cabin pressure during launch was nominal and contained 40% nitrogen. This would vent as the flight proceeded.
b. Nylon suits were replaced by Beta cloth.
c. The hatch opened outwards.
d. Flammable materials were replaced.
e. Plumbing and wiring were covered with protective insulation.
f. 1,407 wiring problems were corrected.

Some or all of these improvements probably saved the astronauts of APOLLO XIII three year later.

3. APOLLO II – APOLLO III

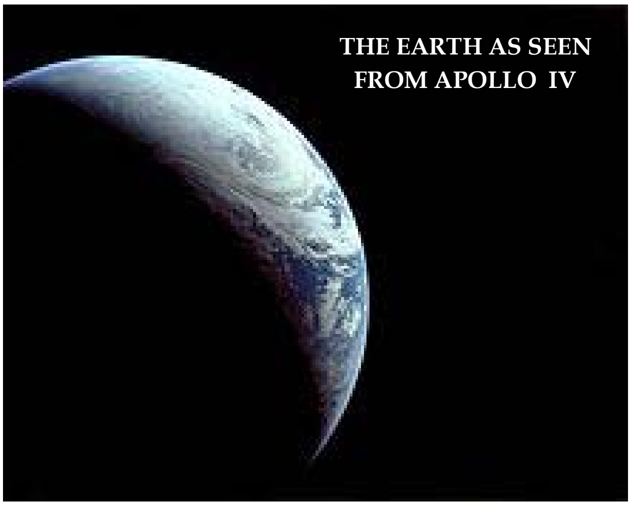
These two missions were scrubbed and the names never used.

4. APOLLO IV

The unmanned Saturn/Apollo IV *(SA-501)* mission was launched on November 9th, 1967, from launch complex 39-A, and it was the first all-up test of the three stage Saturn V rocket. It carried a payload of an Apollo Command and Service Module *(CSM)* into Earth orbit. The mission was designed to test all aspects of the Saturn V launch vehicle and also return pictures of Earth taken by the automatic Command Module apogee camera from about one hour before to one hour after apogee. Mission objectives included testing of structural integrity, compatibility

LAUNCH OF APOLLO IV

of the launch vehicle and spacecraft, heat shield and thermal seal integrity, overall reentry operations, launch loads and dynamic characteristics, stage separation, launch vehicle subsystems, the emergency detection system, and mission support facilities and operations. The mission was deemed a successful test.



Orbital insertion was achieved by ignition of the third *(S-IVB)* stage, putting the spacecraft *(S-IVB and CSM)* into a 184 x 192 km parking orbit with a period of 88.2 minutes and an inclination of 32.6 degrees. After two orbits the S-IVB was re-ignited for a simulated translunar injection burn, putting the spacecraft into an Earth-intersecting trajectory with an apogee of 17,346 km. The S-IVB stage then separated from the CSM and the service propulsion system *(SPS)* ignited for 16 seconds, raising the apogee to 18,216 km. Later the SPS was re-ignited for 271 seconds to accelerate the CSM to beyond lunar trajectory return velocities. SPS cutoff was followed by separation of the Command Module *(CM)* from the Service Module *(SM)* and orientation of the CM for reentry. Atmospheric entry at 122 km occurred at a flight path angle of 7.077 degrees with a velocity of 40,104 km/h. The CM landed near Hawaii at 20:37 GMT November 9th, 1967, about 16 km from the target landing point.

5. APOLLO V

APOLLO V AT LAUNCH PAD

The unmanned Saturn/Apollo V *(SA-204)* was the first test flight of the Lunar Module *(LM)*. Launch took place from complex 37-B on January 22nd, 1968, and the launch vehicle was a Saturn 1B.

Mission objectives were to verify the ascent and descent stages, the propulsion systems, and the restart operations, LM staging, 2nd stage *(S-IVB)* and instrument unit *(IU)* orbital performance. Also, it provided the opportunity to evaluate the spacecraft structure, which could not be tested on the ground.

After launch, the S-IVB 2nd stage ignited to insert the spacecraft into a 163 x 222 km Earth orbit with a period of 88.3 minutes and an inclination of 31.63 degrees. The nose cone was jettisoned and after a coast of 43 min 52 sec the LM was separated from the LM adapter. The LM entered a 167 x 222 km orbit with a period of 88.4 min and an inclination of 31.63 degrees.

A planned descent propulsion system *(DPS)* burn of 39 seconds was cut short after only 4 seconds. The burn was designed to simulate deceleration for descent to the lunar surface, but was stopped prematurely due to overly conservative programming of the flight software. An alternate flight plan was put into effect, in which the DPS fired for 26 seconds at 10% thrust and then for 7 seconds at maximum thrust. A third DPS firing was performed 32 seconds later, consisting of a 26 second burn at 10% thrust and 2 seconds at maximum thrust. In order to simulate an abort during the landing phase, the ascent propulsion system *(APS)* was ignited simultaneously with the DPS being shut down. The APS burn lasted 60 seconds. Later, another firing of a 6 min 23 sec of duration took place to deplete the APS fuel; this gave important information about the capabilities of the APS propellant containers. At the end of the 11 hr 10 min test period, both LM stages were left in orbit to eventually reenter and disintegrate. Despite the initial premature DPS shutdown, the mission was deemed a success and operation of all LM systems was confirmed.

6. APOLLO VI

The unmanned Saturn/Apollo VI *(SA-502)* mission was designed as the final qualification of the Saturn V launch vehicle and Apollo spacecraft for manned Apollo missions. Launch took place April 4th, 1968, from complex 39-A and the launcher carried the Apollo Command and Service Module *(CSM)* and a boilerplate Lunar Module *(LM)*. The primary objectives of the mission were to demonstrate structural and thermal integrity and compatibility of the launch vehicle and spacecraft, confirm launch loads and dynamic characteristics, and verify stage separations, propulsion, guidance and control, electrical systems, emergency detection system, and mission support facilities and operations, including Command Module recovery.


APOLLO VI LAUNCH

Three major problems occurred during the mission. Two minutes and five seconds after launch, the Saturn V structure underwent a severe pogo oscillation *(1)*, but without damage to the spacecraft structure. Due to a manufacturing flaw and unrelated to the pogo oscillations, structural panels were lost from the lunar

module adapter. Finally, after the completion of first stage firing and part way through the second stage burn, two of the five second stage J-2 engines shut down prematurely. The planned 175 km circular Earth orbit was not achieved. Instead, after completion of the third stage burn, the spacecraft was in a 172.1 x 223.1 km, 89.8 min orbit. After two orbits, the third stage failed to reignite as planned, so the Service Module propulsion system was used to boost the spacecraft to an apogee of 22,225.4 km, from which the planned lunar reentry simulation took place at 36,025 km/hr, slightly less than the planned velocity of 40,000 km/hr. The Command Module splashed down 80 km off target 9 hr 50 min after launch and was recovered in good condition.

(1) *Pogo oscillation*: This oscillation results in variations of thrust from the engines, causing variations of acceleration on the rocket's structure.

7. APOLLO VII

It was the first manned mission in the Apollo Program, and the first manned US space flight after a cabin fire killed the crew of what was to have been the first manned mission, SA-204 *(later renamed Apollo I)*, during a launch pad test in 1967. It was launched on October 11th, 1968, and it was a C type mission, *an 11-day Earth-orbital mission*, the first manned launch of the Saturn 1B launch vehicle, and the first three-person US space mission.

The prime crew for this flight was:

Position	**Astronaut**
Commander	Walter M. Schirra
CM Pilot	Donn F. Eisele
LM Pilot	R. Walter Cunningham

LM Pilot was the official title used for the third pilot position in Block II missions, regardless of whether the LM spacecraft was present or not

The backup crew was composed of Tom Stafford, John Young, and Gene Cernan

This mission carried the redesigned Block II Apollo Command/Service Module. It flew in Earth orbit so the crew could check life-support, propulsion, and control systems. Despite tension between the crew and ground controllers, the mission was a technical success, which gave NASA the confidence to launch Apollo VIII around the Moon two months later.

However, the flight would prove to be the last NASA space flight for all of its three crew members.

LAUNCH OF APOLLO VII

Even though Apollo's larger cabin was more comfortable than Gemini's, 11 days in orbit took its toll on the astronauts. Tension with Schirra began with the flight manager’s decision to launch with a less than ideal abort option for the early part of the ascent. Once in orbit, the spacious cabin may have induced some crew motion sickness, which had not been an issue in the earlier, smaller spacecraft. The crew was also unhappy with their food selections.

But the worst problem occurred when Schirra developed a severe head cold. As a result, he became irritable with requests from Mission Control and all three astronauts began *talking back* to the CapCom. *(The central point person assigned to maintain voice contact with the crew).* An early example was this exchange after Mission Control requested that a TV camera be turned on in the spacecraft:

Walter Schirra looks out the rendezvous window in front of the commander's station on the ninth day of the mission.

> *SCHIRRA: You've added two burns to this flight schedule, and you've added a urine water dump; and we have a new vehicle up here, and I can tell you at this point TV will be delayed without any further discussion until after the rendezvous.*
>
> *CapCom (Jack Swigert): Roger, copy.*
>
> *SCHIRRA: Roger.*
>
> *CapCom 1 (Deke Slayton): Apollo VII, this is CapCom number 1.*
>
> *SCHIRRA: Roger.*
>
> *CapCom 1: All we've agreed to do on this is flip it.*
>
> *SCHIRRA: ... with two commanders, Apollo VII.*
>
> *CapCom 1: All we have agreed to on this particular pass is to flip the switch on. No other activity is associated with TV; I think we are still obligated to do that.*
>
> *SCHIRRA: We do not have the equipment out; we have not had an opportunity to follow setting; we have not eaten at this point. At this point, I have a cold. I refuse to foul up our time lines this way.*

A further source of tension between Mission Control and the crew was that Schirra repeatedly expressed the view that the reentry should be conducted with their helmets off, contrary to Projects Mercury and Gemini previous experience. They perceived a risk that their eardrums might burst due to the sinus pressure from their colds, and they wanted to be able to pinch their noses and blow to equalize the pressure as it increased during reentry. This would have been impossible wearing the new Apollo helmets which were a continuous *fishbowl* type without a moveable visor, unlike previous ones.

Over the course of the mission, Schirra was instructed several times that the helmets should be worn for safety reasons. In the final exchange on the subject, Mission Control made it clear to Schirra that he would be expected to account for flouting instructions:

> *CapCom 1: Okay. I think you ought to clearly understand there is absolutely no experience at all with landing without the helmet on.*
>
> *SCHIRRA: And there no experience with the helmet either on that one.*
>
> *CapCom: That one we've got a lot of experience with, yes.*

> *SCHIRRA: If we had an open visor, I might go along with that.*
>
> *CapCom: Okay. I guess you better be prepared to discuss in some detail when we land why we haven't got them on. I think you're too late now to do much about it.*
>
> *SCHIRRA: That's affirmative. I don't think anybody down there has worn the helmets as much as we have.*
>
> *CapCom: Yes.*
>
> *SCHIRRA: We tried them on this morning.*
>
> *CapCom: Understand that. The only thing we're concerned about is the landing. We couldn't care less about the reentry. BGMT it's your neck, and I hope you don't break it.*
>
> *SCHIRRA: Thanks, babe.*
>
> *CapCom: Over and out.*

Exchanges such as this led to all three Apollo VII crew members being rejected for future missions

8. APOLLO VIII

This was the second manned mission in the Apollo Program, it was launched on December 21st, 1968, and became the first manned space craft to leave Earth orbit, reach the Earth's Moon, orbit it and return safely to Earth. The three-astronaut crew became the first humans to travel beyond low Earth orbit, the first to see Earth as a whole planet, and then the first to directly see the far side of the Moon. It was also the third flight of the Saturn V rocket and the first manned launch of the Saturn V. This was the first manned launch from LC 39-A.

The prime crew for this flight was:

Position	**Astronaut**
Commander	Frank Borman II
CM Pilot	James Lovell Jr.
LM Pilot	William Anders

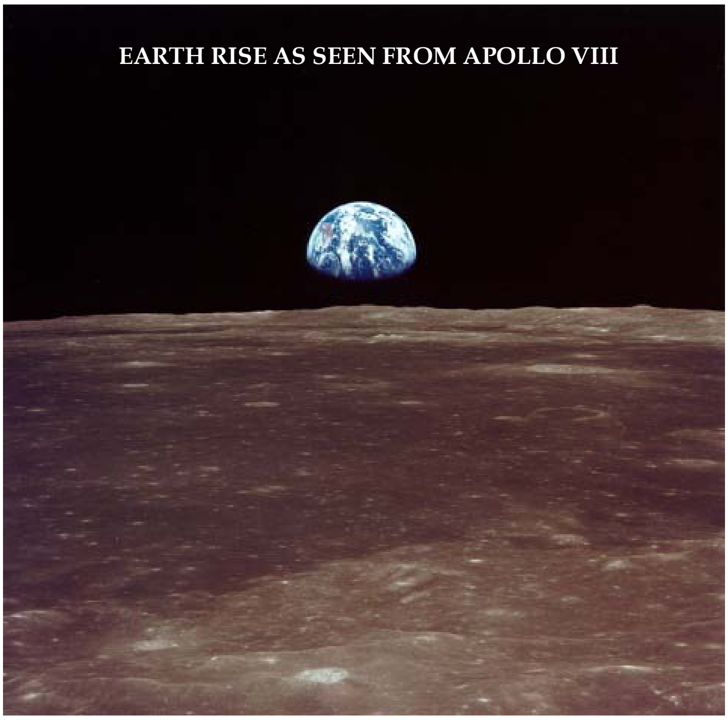
The backup crew was composed of Neil Armstrong, Buzz Aldrin, and Fred Haise

This mission was originally planned as a second Lunar Module/Command Module test in an elliptical medium Earth orbit but was changed to a more ambitious Command Module-only lunar orbital flight because the Lunar Module was not yet ready to make its first flight. This meant Borman's crew was scheduled to fly two to three months sooner than originally planned, leaving them a shorter time for training and preparation, thus placing more demands than usual on their time and discipline.

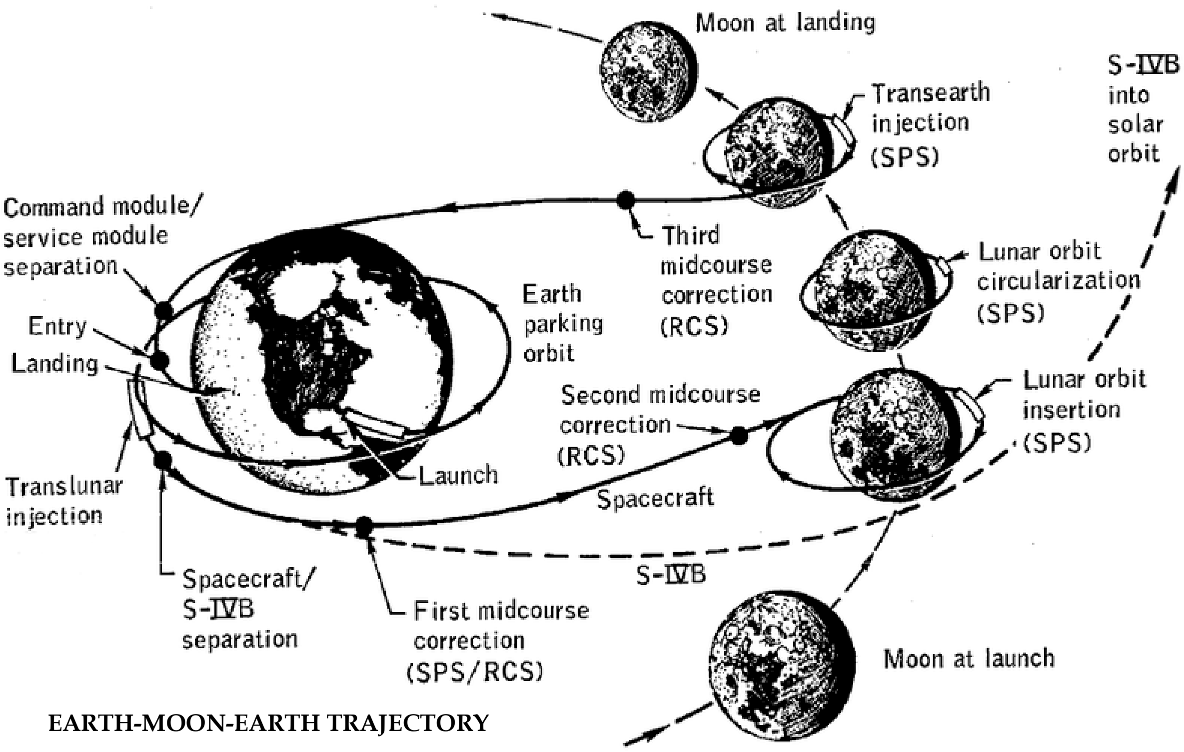
Apollo VIII took three days to travel to the Moon. It orbited ten times over the course of 20 hours, during which the crew made a Christmas Eve television broadcast and read the first 10 verses from the Book of Genesis. At the time, the broadcast was the most watched TV program ever. Apollo VIII's successful mission paved the way for Apollo XI to fulfill the goal of landing a man on the Moon before the end of the 1960s. Apollo VIII returned to Earth on December 27th, 1968, with a splash down in the Northern Pacific Ocean and a recovery by *USS Yorktown.*


APOLLO VIII LAUNCH

The Saturn V rocket used by Apollo VIII was designated SA-503, or the *03rd* model of the Saturn V *(5)* Rocket to be used in the Saturn-Apollo *(SA)* program. When it was erected in the VAB on December 20th, 1967, it was thought that the rocket would be used for an unmanned Earth-orbit test flight carrying a boilerplate Command/Service Module. Apollo VI had suffered several major problems during its April 1968 flight, including severe pogo oscillation during its first stage, two second stage engine failures, and a third stage that failed to reignite in orbit. Without assurances that these problems had been rectified, NASA administrators could not justify risking a manned mission until additional unmanned test flights proved that the Saturn V was ready.


EARTH RISE AS SEEN FROM APOLLO VIII

Teams from the Marshall Space Flight Center *(MSFC)* went to work on the problems. Of primary concern was the pogo oscillation, which would not only hamper engine performance, but could exert significant G-forces on a crew. A task force of contractors, NASA agency representatives, and MSFC researchers concluded that the engines vibrated at a frequency similar to the frequency at which the spacecraft itself vibrated, causing a resonance effect that induced oscillations in the rocket. A system using helium gas to absorb some of these vibrations was installed.



EARTH-MOON-EARTH TRAJECTORY

Of equal importance was the failure of three engines during flight. Researchers quickly determined that a leaking hydrogen fuel line ruptured when exposed to vacuum, causing a loss of fuel pressure in engine two. When an automatic shutoff attempted to close the liquid hydrogen valve and shut down engine two, it accidentally shut down engine three's liquid oxygen due to a mis-wired connection. As a result, engine three failed within one

second of engine two's shutdown. Further investigation revealed the same problem for the third-stage engine *a faulty igniter line*. The team modified the igniter lines and fuel conduits, hoping to avoid similar problems on future launches.

The teams tested their solutions in August 1968 at the Marshall Space Flight Center. A Saturn stage IC was equipped with shock absorbing devices to demonstrate the team's solution to the problem of pogo oscillation, while a Saturn Stage II was retrofitted with modified fuel lines to demonstrate their resistance to leaks and ruptures in vacuum conditions. Once NASA administrators were convinced that the problems were solved, they gave their approval for a manned mission using SA-503.

The Apollo VIII spacecraft was placed on top of the rocket on September 21st and the rocket made the slow 5 km journey to the launch pad on October 9th. Testing continued all through December until the day before launch, including various levels of readiness testing from December 5th through 11th. Final testing of modifications to address the problems of pogo oscillation, ruptured fuel lines, and bad igniter lines took place on December 18th, a mere three days before the scheduled launch.

ANNEX

This conversation shows how the most famous photo of all times was taken.

Borman: *Oh my God! Look at that picture over there! Here's the Earth coming up. Wow, that is pretty!*

Anders: *Hey, don't take that, it's not scheduled.*

Borman: *(Laughter). You got a color film, Jim?*

Anders: *Hand me that roll of color quick, will you –*

Lovell: *Oh man, that's great!*

Anders: *Hurry. Quick... Lovell: Take several of them! Here, give it to me...*

Borman: *Calm down, Lovell.*

9. APOLLO IX

This was the third manned mission in the Apollo Program and the first flight of the Command/Service Module *(CSM)* with the Lunar Module *(LM)*.

The main purpose was to test several aspects critical to landing on the Moon, including the LM engines, backpack life support systems, navigation systems, and docking maneuvers and, as such, it was only an Earth orbital flight.

The mission was the second manned launch of a Saturn V rocket.

LAUNCH OF APOLLO IX

The prime crew for this flight was:

Position	**Astronaut**
Commander	James McDivitt
CM Pilot	David Scott
LM Pilot	Rusty Schweickart

The backup crew was composed of Pete Conrad, Dick Gordon, and Alan Bean.

Launched from LC 39-A on March 3rd, 1969, the crewmen spent ten days in low Earth orbit. They performed the first manned flight of a LM, the first docking and extraction of a LM, two spacewalks, and the second docking of two manned spacecraft *(This happened two months after the Soviets performed a spacewalk crew transfer between Soyuz 4 and Soyuz 5)*. The mission finally proved that the LM was worthy of manned spaceflight. Further tests on the Apollo X mission would prepare the LM for its ultimate goal, landing on the Moon.

Apollo IX was the first space test of the complete Apollo spacecraft, including the third critical piece of Apollo hardware besides the Command/Service Module *(CSM)* and the Saturn V launch vehicle—the Lunar Module *(LM)*. It was also the first space docking of two vehicles with an internal crew transfer between them. For ten days, the astronauts put both Apollo spacecraft through their paces in Earth orbit, including an undocking and re-docking of the lunar lander with the command vehicle, just as the landing mission crew would perform in lunar orbit. Apollo IX proved that the Apollo spacecraft were up to this critical task, on which the lives of lunar landing crews would depend.

For this and all subsequent Apollo flights, the crews were allowed to name their own spacecraft *(the last spacecraft to have been named was Gemini 3)*. The gangly LM was named *Spider*, and the CSM was labeled *Gumdrop* because of the Command Module's shape, and also the blue wrapping in which the craft arrived at Kennedy Space Center. These names were required as radio call signs when the vehicles flew independently.

Schweickart and Scott performed a spacewalk *(EVA)*. Schweickart checked out the new Apollo spacesuit, the first to have its own life support system rather than being dependent on an umbilical connection to the spacecraft, while Scott filmed him from the command module hatch. Schweickart was due to carry out a more extensive set of activities to test the suit, and demonstrate that it was possible for astronauts to perform an EVA from the lunar module to the command module in an emergency, but as he had been suffering from space sickness the extra tests were scratched.

McDivitt and Schweickart later test-flew the LM, and practiced separation and docking maneuvers in Earth orbit. They flew the LM up to 179 km from Gumdrop, first using the engine on the descent stage to propel them before jettisoning it, and using the ascent stage to return. This test flight represented the first flight of a manned spacecraft that was not equipped to reenter the Earth's atmosphere.

The splashdown point was 23 deg 15 min N, 67 deg 56 min W, 290 km east of Bahamas and within sight of the recovery ship *USS Guadalcanal* and Apollo IX was the last spacecraft to splash down in the Atlantic Ocean.

10. APOLLO X

Apollo X was the fourth manned mission in the Apollo Program. It was launched May 18th, 1969. An F type mission, its purpose was to be a *dry run* for the Apollo XI, testing all of the procedures and components of a Moon landing without actually landing on the Moon itself. The mission included the second crew to orbit the Moon and an all-up test of the lunar module *(LM)* in lunar orbit. The LM came to within 15.6 km of the lunar surface during practice maneuvers.

According to the *2002 Guinness World Records,* Apollo X set the record for the highest speed attained by a manned vehicle at 39,897 km/h during the return from the Moon on May 26th, 1969.

The prime crew for this flight was:

Position	**Astronaut**
Commander	Thomas P. Stafford
CM Pilot	John W. Young
LM Pilot	Eugene A. Cernan

The backup crew was composed of Gordo Cooper, Donn Eisele, and Ed Mitchell

Due to the use of their names as call signs, the *Peanuts* characters *Charlie Brown* and *Snoopy* became semi-official mascots for the mission. Peanuts creator Charles Schulz also drew some special mission-related artwork for NASA.

Apollo X marked the only Saturn V flight from LC 39-B, as preparations for Apollo XI at LC 39-A had begun in March almost immediately after Apollo IX's launch.

Apollo X was the first of only two Apollo missions with an entirely flight-experienced crew. Stafford had flown on Gemini 6 and Gemini 9; Young had flown on Gemini 3 and Gemini 10, and Cernan had flown with Stafford on Gemini 9.

They were also the only Apollo crew all of whose members went on to fly subsequent missions aboard Apollo spacecraft: Stafford commanded the US vehicle on the ASTP *(Apollo Soyuz Test Project)*; Young commanded Apollo XVI, and Cernan commanded Apollo XVII.

The Apollo X crew holds the distinction of being the humans who have traveled to the farthest point away from home, some 408,950 km.

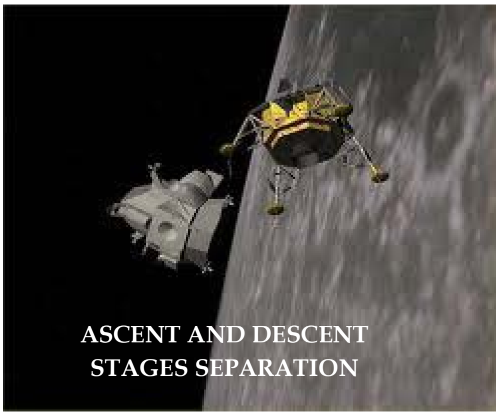
LAUNCH OF APOLLO X

They orbited the Moon at 111 km from the surface like other Apollo's, however, timing makes this distinction possible as the distance between the Earth and Moon varies by approximately 43,000 km *(between perigee and apogee)* throughout the year. Also, the Earth's rotation make the distance to Houston vary by another 12,000 km each day. The Apollo X crew reached the farthest point in their orbit around the far side of the Moon at approximately the same time Earth had rotated around putting Houston nearly a full Earth diameter away.

This dress rehearsal for a Moon landing brought Stafford and Cernan's lunar module Snoopy to 15.6 km from the lunar surface. The low approach orbit was to refine the lunar gravitational potential needed to calibrate the powered descent guidance system to within 1.9 km *(Low Range altitude update lock)* needed for a landing.

LM AFTER SEPARATION

Earth-based observations, unmanned spacecraft, and Apollo VIII respectively had allowed calibration to 370 km, 37 km, and 9.3 km. Except for that final stretch, the mission went exactly as a landing would have gone, both in space and on the ground, putting Apollo's Tracking and Control network through a dry run.



ASCENT AND DESCENT STAGES SEPARATION

Apollo X was the first to carry a color television camera inside the spacecraft, and made the first live color TV broadcasts from space.

Upon reaching lunar orbit, Young remained alone in the CM while Stafford and Cernan flew separately in the LM where they checked out their craft's radar and ascent engine, rode out a momentary gyration in the lunar lander's motion *(due to a faulty switch setting)*, and surveyed the Apollo XI landing site in the Sea of Tranquility. NASA took special precaution to ensure Stafford and Cernan would not attempt to make the first landing. According to Cernan, *A lot of people thought about the kind of people we were: Don't give those guys an opportunity to land, cause they might! So the ascent module, the part we lifted off the lunar surface with, was short-fueled. So had we literally tried to land on the Moon, we couldn't have gotten off.* The fueled Apollo X LM weighed 13,941 kg, compared to 15,095 kg for the Apollo XI LM which made the first landing.

Upon separation of the ascent stage and engine ignition, the Lunar Module began to roll violently due to the crew accidentally duplicating commands into the flight computer which took the LM out of abort mode, *(the correct configuration for the orbital separation and ignition)*. The live network broadcasts caught Cernan and Stafford uttering several expletives before regaining control of the LM. Cernan said that while the incident was downplayed by NASA, the roll was very close to being unrecoverable.

RECOVERY

Splashdown occurred in the Pacific Ocean on May 26th, 1969, at 16:52:23 GMT, approximately 740 km east of American Samoa. The astronauts were recovered by the *USS Princeton*, and subsequently flown to Pago Pago International Airport in Tafuna for a greeting and reception, before being flown on a C-141 cargo plane to Honolulu.

The LM Snoopy's descent stage was left in orbit, but eventually crashed onto the lunar surface because of the Moon's non-uniform gravitational field; its location was not tracked.

After being jettisoned, Snoopy's ascent stage flew on a trajectory past the Moon into a heliocentric orbit, making it the sole intact Lunar Module ascent stage remaining of the 10 LMs sent into space. All other ascent stages were either left in lunar orbit to eventually crash, intentionally steer into the Moon to obtain readings from seismometers placed on the lunar surface, or else burned up in Earth's atmosphere. Snoopy's location is currently unknown, but amateur astronomers still search for it.

The Command Module Charlie Brown is currently on loan to the Science Museum in London, where it is on display. Charlie Brown's Service Module was jettisoned just before re-entry and burned up in Earth's atmosphere.

After Apollo X, NASA required astronauts to choose more *dignified* names for their command and lunar module.

ANNEX

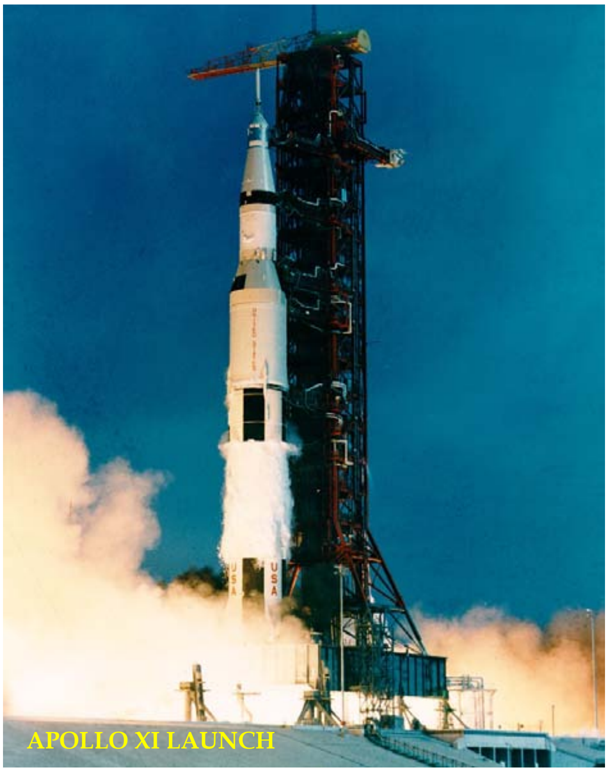
a. By the normal rotation in place during Apollo, the backup crew would have been scheduled to fly on Apollo XIII. However, Alan Shepard was given the Apollo XIII command slot instead. L. Gordon Cooper, Jr., Commander of the Apollo X backup crew was enraged and resigned from NASA. Later, Shepard's crew was forced to switch places with Jim Lovell's tentative Apollo XIV crew.
b. Deke Slayton wrote in his memoirs that Cooper and Eisele were never intended to rotate to another mission as both were out of favor with NASA management for various reasons *(Cooper for his lax attitude towards training and Eisele for incidents aboard Apollo VII and an extra-marital affair)* and were assigned to the backup crew simply because of a lack of qualified manpower in the Astronaut Office at the time the assignment needed to be made. Cooper, Slayton noted, had a very small chance of receiving the Apollo XIII command had he done an outstanding job with the assignment, which he didn't. Eisele, despite his issues with management, was always intended for future assignment to the Apollo Applications Program *(which was eventually cut down to only the Skylab component)* and not a lunar mission.

11. APOLLO XI

Apollo XI *(A trip to the Moon)*

It was the fifth Apollo Program manned mission and the first planned to actually land on the Moon.

On July 16th, 1969, 13:32:00 GMT the most powerful rocket ever built, a Saturn V *(SA-506)*, lifted off from Launch Pad 39-A at Kennedy Space Center, Florida. The mission, to set two astronauts on the surface of the Moon as the late President John F. Kennedy had urged Congress in 1961 when he said, *I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the Moon and returning him safely to the Earth.*


APOLLO XI LAUNCH

The project started early before 1960 with the two predecessor projects, Mercury and Gemini. Then, on January 27th, 1967, an accident on Apollo I *(SA-204)*, scheduled for launch February 21st, killed three astronauts while on a simulation at launch complex 34. The accident delayed the whole project for 20 months while the cause was analyzed.

The prime and backup crews for this flight were:

Prime crew:

Position	Astronaut
Commander	Neil A. Armstrong
CM Pilot	Michael Collins
LM Pilot	Edwin E. Aldrin Jr.

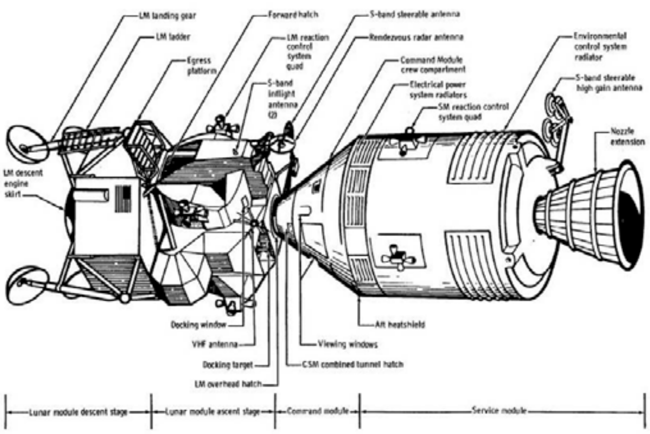
Backup crew:

Position	Astronaut
Commander	James A. Lovell Jr.
CM Pilot	William A. Anders
LM Pilot	Fred W. Haise Jr.

To the Moon

The third stage had placed the vehicle in Earth orbit, while ground Control and the astronauts verified all equipment and instruments performance. At the proper point in the trajectory, the third stage ignited again for about 6 minutes allowing the vehicle to reach escape velocity.

This last ignition was called *TLI (Trans Lunar Injection)* and Apollo was on its way to the Moon. After all the parameters, equipment and variables were checked the hatch of the third stage opened displaying the LM. The CSM made a slow evasion maneuver, turned 180° and returned to attach to the LM and retrieve it from the S-IVB.

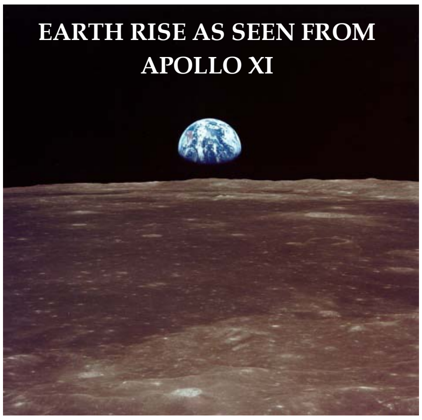


Apollo 13 space vehicle configuration.

CONFIGURACIÓN NORMAL CSM/LM

Another slow evasion maneuver and the Apollo spacecraft, composed of the SM, CM and LM, was on its *TLC (Trans Lunar Coast)* to the Moon. The S-IVB trajectory was then changed to avoid a collision with Apollo.

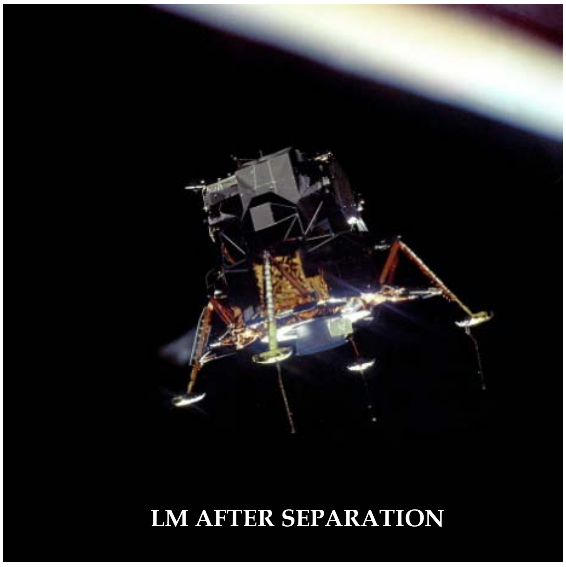
The next three and a half days were uneventful. Four mid-course correction maneuvers were scheduled but the trajectory was so accurate that only one was performed. In addition the crew performed a color TV transmission to Earth.


EARTH RISE AS SEEN FROM APOLLO XI

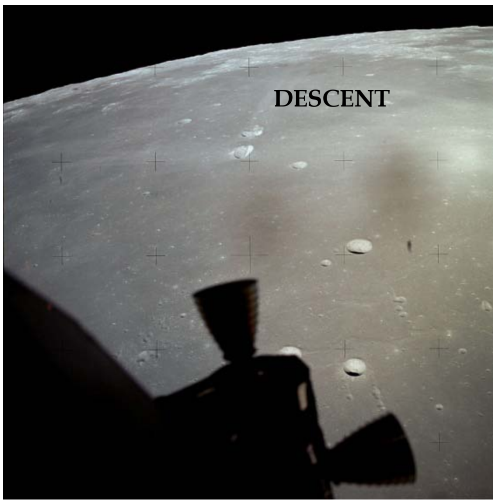
On July 18th, Armstrong and Aldrin donned space suits, went into the LM to check out the vehicle and made the second TV transmission.

On July 19th Apollo was captured by Moon´s gravity and *LOI (Lunar Orbit Insertion)* took place at a *MET (Mission Elapsed Time)* of 75 hours and 50 minutes by performing a retrograde firing of 357.5 seconds. This maneuver placed the vehicle in an elliptical orbit of about 200 by 100 km. A second firing circulated the orbit at about 100 km.

On July 20th, 1969, the lunar module *(LM) Eagle* separated from the command module *(CM) Columbia*. Michael Collins, alone aboard Columbia, inspected Eagle, as it pirouetted before him, to ensure the craft was not damaged.

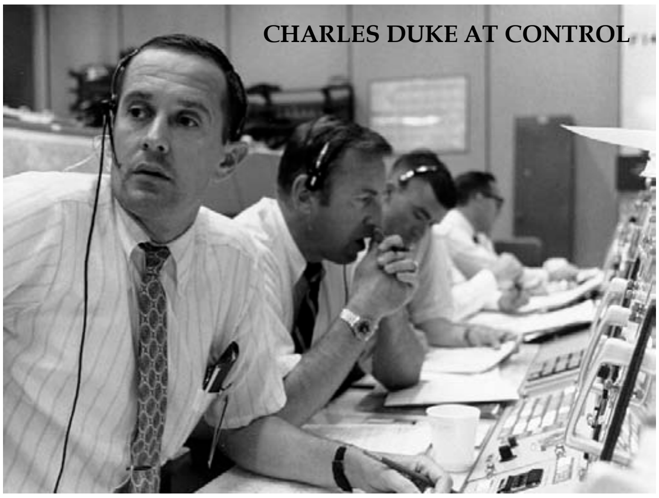

LM AFTER SEPARATION

As their descent began, Neil Armstrong and Buzz Aldrin found that they were passing landmarks on the surface 4 seconds early so they reported that they were *long* they would land kilometers west of their target point. Five minutes into the descent burn, and 1,800 m. above the surface of the Moon, the LM navigation and guidance computer produced the first of several unexpected *1202* and *1201* program alarms. The computer engineer at Mission Control Center in Houston, *Jack Garman*, told guidance officer *Steve Bales* it was safe to continue the descent. These alarms were indications of *executive overflows*, meaning the guidance computer could not complete all of its tasks in real time and had to postpone some of them.


DESCENT

When Neil Armstrong again looked outside, he saw two things, first, that the computer's landing target was in a boulder-strewn area just north and east of a 300 m. diameter crater *(later determined to be West crater)*, and, second, the landing surroundings were full of rocks. He then took semi-automatic control, and with

Buzz Aldrin calling out altitude and velocity data, landed at 20:17 GMT on July 20th, 1969, with about 17 seconds of fuel left.


CHARLES DUKE AT CONTROL

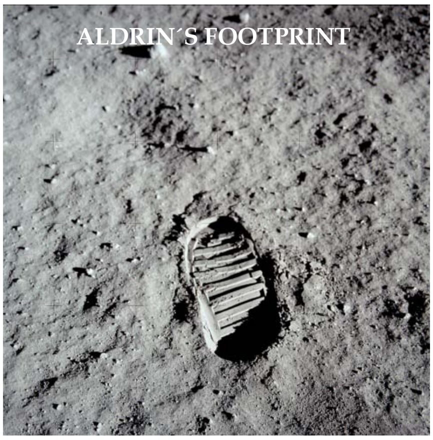
Armstrong completed the post landing checklist before calling Mission Control in Houston: *Houston, Tranquility Base here. The Eagle has landed*. Neil Armstrong´s abrupt change of call sign from *Eagle* to *Tranquility Base* caused momentary confusion at Mission Control and Charles Duke remained silent for a couple of seconds before expressing the relief of Mission Control: *Roger, Twan-- Tranquility, we copy you on the ground. You got a bunch of guys about to turn blue. We're breathing again. Thanks a lot.*


ALDRIN SALUTES FLAG

At 02:39 GMT on Monday July 21st, 1969, Neil Armstrong opened the hatch, and at 02:51 GMT began his descent to the lunar surface. The Remote Control Unit controls on his chest kept him from seeing his feet. Climbing down the nine-rung ladder, Armstrong pulled a D-ring to deploy the Modular Equipment Stowage Assembly *(MESA)*, folded against Eagle's side, activated the TV camera, and at 02:56:20 GMT he set his left foot on the surface of the Moon.


ALDRIN COMING OUT OF THE LM

After describing the surface dust as, *very fine-grained* and *almost like a powder*, Neil Armstrong stepped off Eagle's footpad and uttered his famous line *That's one small step for [a] man, one giant leap for mankind*. Buzz Aldrin joined him 13 minutes later, and described the view as *Magnificent desolation.* They collected lunar rocks and other material *(21.55 kg)*. They also, deployed a solar wind composition experiment that was later recovered. They built a scientific station *(EASEP)*, which included a passive seismic experiment and a laser ranging retro reflector, and also erected the U.S. flag. While on the surface of the Moon, they received a telephone call from U.S. President Richard Nixon who described the call as: *The most historic phone call ever made from the White House*.

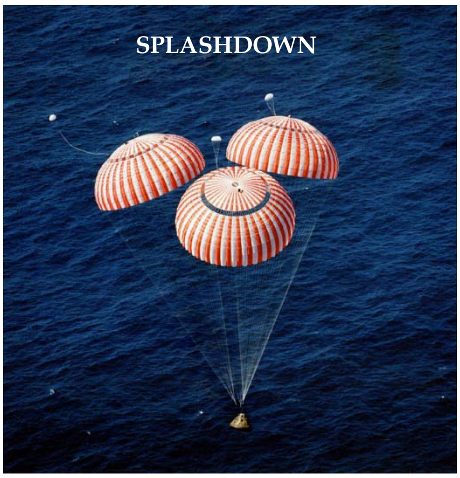


The total lunar surface stay time was 21 h 36 min and at 17:54 GMT, they lifted off in Eagle's ascent stage, carrying 21.5 kg of lunar samples with them. As they ascended, Aldrin looked up in time to see the exhaust from the engine knock over the American flag they had planted. Once in lunar orbit, the LM rendezvoused with the CSM and performed a successful docking. CMP Collins was happy to see them back aboard Columbia as he had had little to do, while they were on the surface.

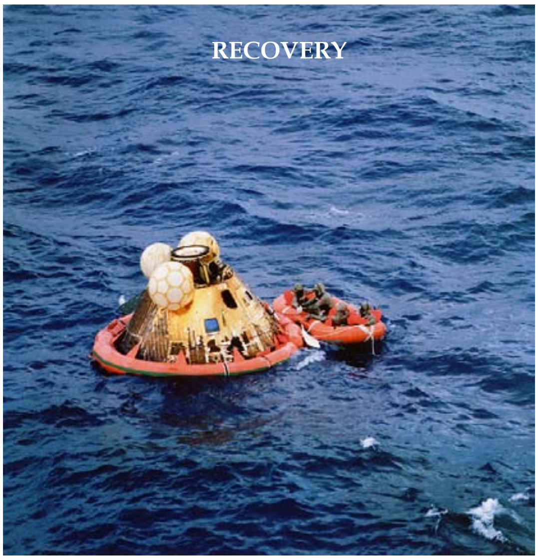
After all lunar samples had been transferred to Columbia and the hatch had been closed, Eagle was jettisoned. Now it was time to return home, and the astronauts began preparations for the trip by stowing all loose equipment, materials and the lunar samples. Then, they readied the computer and entered the ignition parameters.

The return home

After an attitude reorientation maneuver, the CSM was ready to start the return trip. While on the back side of the Moon, they performed a *TEI (Trans Earth Injection)* by firing the SM motor to acquire escape velocity. And then, another three and a half days of *TEC (Trans Earth Cost)* while in PTC *(Passive Thermal Control)* attitude.

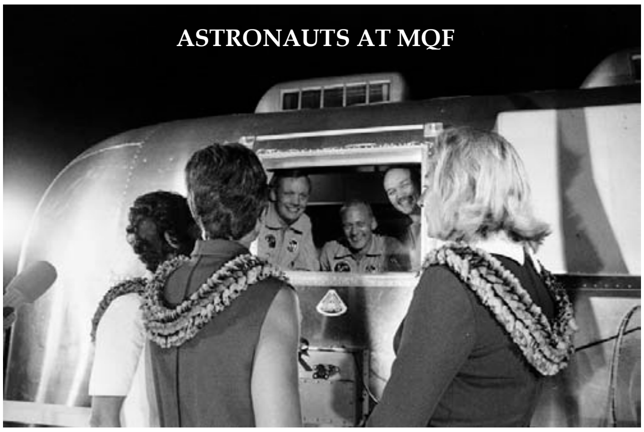


On July 23rd, the last night before splashdown, the three astronauts made a television broadcast and started the preparations for re-entry. First they donned their space suits and then, after checking the correct entry angle, they ejected the SM.


RECOVERY

On July 24th, at roughly 05:45 GMT, the drogue parachutes deployed and at 11:51 GMT the Command Module struck the Pacific Ocean. The astronauts splashed down, just before dawn, 2,660 km east of Wake Island and 24 km from the recovery ship, *USS Hornet*.

The command module landed upside down but was righted in several minutes by flotation bags triggered by the crew. *Everything's okay. Our checklist is complete. Awaiting swimmers* was Armstrong's last official transmission from the *Columbia*. A diver from the Navy helicopter hovering above attached a sea anchor to the command module to prevent it from drifting. Additional divers attached flotation collars to stabilize the module, and positioned rafts for extracting the crew. Though the chance of bringing back pathogens from the lunar surface was considered remote, it was thought possible. So, as part of the extraordinary precautions NASA required, divers provided the astronauts with Biological Isolation Garments *(BIGs)* at the recovery site which they wore until they reached isolation facilities onboard the Hornet. Additionally, they were rubbed down with a sodium-hydrochloride solution and the Command module was wiped with Betadine to remove any lunar dust that might be present. The raft containing decontamination materials was then intentionally sunk.


ASTRONAUTS AT MQF

HOUSTON CONTROL ROOM

A second Sea King helicopter hoisted the astronauts aboard one by one, where a NASA flight surgeon gave each a brief physical check during the 930 m. trip back to the Hornet.

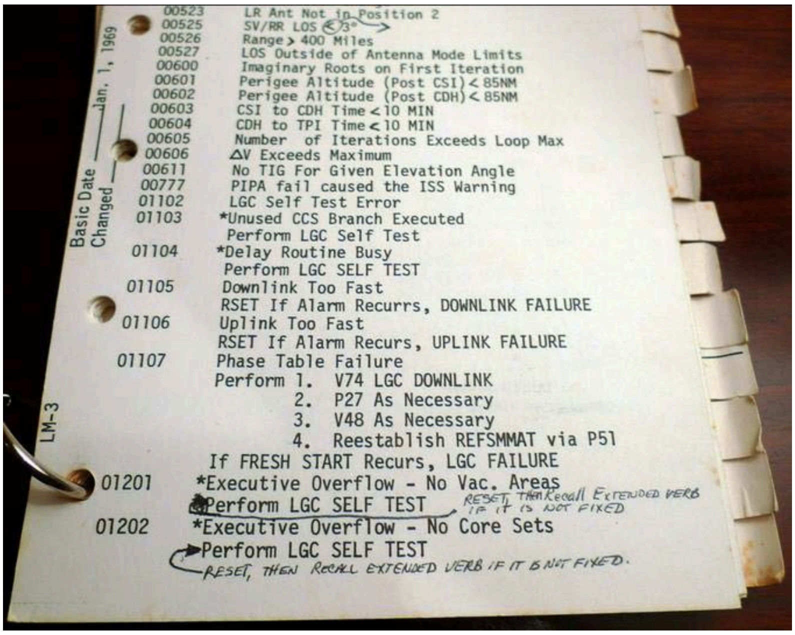
After touchdown on the Hornet, the astronauts exited the helicopter, leaving the flight surgeon and three crewmen. The helicopter and they were then lowered into hangar bay # 2 where the astronauts walked the 9.1 m. to the Mobile Quarantine Facility *(MQF)*. They would spend the next 21 days there in quarantine.

ASTRONAUTS TALKING WITH PRESIDENT NIXON

President Nixon, who had boarded the Hornet to personally welcome the astronauts back to Earth, told them, *As a result of what you've done, the world has never been closer together before*.

Additional facts of the Apollo XI flight

a. At the time of the critical translunar injection burn command computer problems onboard the tracking ship *Mercury* forced the network controller to decide on a late handover from *Redstone* to Mercury. The hand over was held until the imminent loss of signal by the Redstone. When the switch was finally made, Mercury experienced numerous signal dropouts, and the metric tracking data were virtually useless. Once again, a decision was made to carry out a contingency handover, this time to the Hawaii tracking station, which had just acquired the spacecraft signal. This whole process covered a time span of approximately three minutes.


Basic Date ——— Jan. 1, 1969
Changed ———
LM-3

00523	LR Ant Not in Position 2
00525	SV/RR LOS < 3°
00526	Range > 400 Miles
00527	LOS Outside of Antenna Mode Limits
00600	Imaginary Roots on First Iteration
00601	Perigee Altitude (Post CSI) < 85NM
00602	Perigee Altitude (Post CDH) < 85NM
00603	CSI to CDH Time < 10 MIN
00604	CDH to TPI Time < 10 MIN
00605	Number of Iterations Exceeds Loop Max
00606	ΔV Exceeds Maximum
00611	No TIG For Given Elevation Angle
00777	PIPA fail caused the ISS Warning
01102	LGC Self Test Error
01103	*Unused CCS Branch Executed Perform LGC Self Test
01104	*Delay Routine Busy Perform LGC SELF TEST
01105	Downlink Too Fast RSET If Alarm Recurrs, DOWNLINK FAILURE
01106	Uplink Too Fast RSET If Alarm Recurs, UPLINK FAILURE
01107	Phase Table Failure Perform 1. V74 LGC DOWNLINK 2. P27 As Necessary 3. V48 As Necessary 4. Reestablish REFSMMAT via P51 If FRESH START Recurs, LGC FAILURE
01201	*Executive Overflow - No Vac. Areas Perform LGC SELF TEST — RESET, THEN RECALL EXTENDED VERB IF IT IS NOT FIXED
01202	*Executive Overflow - No Core Sets Perform LGC SELF TEST RESET, THEN RECALL EXTENDED VERB IF IT IS NOT FIXED.

b. The cause of the 1202 and 1201 alarms during the mission was diagnosed as the rendezvous radar switch being in the wrong position, causing the computer to process data from both the rendezvous and landing radars at the same time.

However, in 2005, software engineer *Don Eyles* concluded in a Guidance and Control Conference paper, that the problem was actually due to a hardware design bug that had been seen previously on testing of the first unmanned LM for Apollo V.

c. The pictures that had been taken of the landing site had a resolution of 15 m., thus the reason for Armstrong seeing many rocks on the surface when he was landing the Eagle manually.
d. LM also experienced comm. problems with Houston that were minimized using the CM as a relay. LM´s high gain antenna automatic positioning system had a masking programming error that made the capsule itself to block the signal.
e. Another small problem appeared due to sloshing in the liquid fuel tanks that constantly changed the capsule´s centre of gravity confusing the computer.
f. Apollo XI landed with less fuel than other missions, and the astronauts also encountered a premature low fuel warning. This was later found to have been caused by greater propellant *slosh* than expected, which uncovered a fuel sensor. On subsequent missions, extra baffles were added to the tanks to prevent this.
g. The first landing used slow-scan television which was incompatible with commercial TV. The video was displayed on a special monitor, and a conventional TV camera viewed that monitor, significantly reducing the quality of the picture.
h. A few moments before the landing, a light informed Aldrin that at least one of the 170 cm probes hanging from *Eagle*'s footpads had touched the surface, and he said, *Contact light*. Three seconds later, *Eagle* landed and Armstrong said, *Shutdown*. Aldrin immediately said, *Okay, engine stop. ACA - out of detent.* Armstrong acknowledged, *Out of detent. Auto* and Aldrin continued, *Mode control - both auto. Descent engine command override off. Engine arm - off. 413 is in.* Charles Duke, acting as CapCom during the landing phase, acknowledged their landing by saying, *We copy you down, Eagle*.
i. Two and a half hours after landing, before preparations began for the EVA, Aldrin spoke to Mission Control and said,

> *This is the LM pilot. I'd like to take this opportunity to ask every person listening in, whoever and wherever they may be, to pause for a moment and contemplate the events of the past few hours and to give thanks in his or her own way.*

He then took communion privately. At this time NASA was still fighting a lawsuit demanding that their astronauts refrain from religious activities while in space. As such, Aldrin chose to refrain from directly mentioning this.

j. Armstrong initially had some difficulties squeezing through the hatch with his Portable Life Support System *(PLSS)*. A redesign of the LM to incorporate a smaller hatch had not been followed by a redesign of the PLSS backpack, so some of the highest heart rates recorded from Apollo astronauts occurred during LM egress and ingress.

k. Armstrong said that moving in the lunar gravity, one-sixth of Earth's, was *even perhaps easier than the simulations... It's absolutely no trouble to walk around*. Aldrin joined him on the surface and tested methods for moving around, including two-footed kangaroo hops. The PLSS backpack created a tendency to tip backwards, but neither astronaut had serious problems maintaining balance. Loping became the preferred method of movement. The astronauts reported that they needed to plan their movements six or seven steps ahead. The fine soil was quite slippery. Aldrin remarked that moving from sunlight into *Eagle*'s shadow produced no temperature change inside the suit, though the helmet was warmer in sunlight, so he felt cooler in shadow.
l. When President Nixon spoke to the astronauts while on the Moon, he originally had a long speech prepared to read during the phone call, but Frank Borman, who was at the White House as a NASA liaison during Apollo XI, convinced Nixon to keep his words brief, and to respect the lunar landing as Kennedy's legacy.
m. The astronauts had a geological hammer, but it was used only once by Aldrin as they used scoops and tongs on extension handles to collect rock samples. Many of the surface activities took longer than expected, so they had to stop documenting sample collection halfway through the allotted 34 min.
n. During this period, Mission Control used a coded phrase to warn Armstrong that his metabolic rates were high and that he should slow down. He was moving rapidly from task to task as time ran out. However, as metabolic rates remained generally lower than expected for both astronauts throughout the walk, Mission Control granted the astronauts a 15 minute extension.
o. Aldrin entered *Eagle* first. With some difficulty the astronauts lifted film and two sample boxes containing more than 22 kg of lunar surface material to the LM hatch using a flat cable pulley device called the Lunar Equipment Conveyor *(LEC)*. Armstrong reminded Aldrin of a bag of memorial items in his suit pocket sleeve, and Aldrin tossed the bag down Armstrong then jumped to the ladder's third rung and climbed into the LM. After transferring to LM life support, the explorers lightened the ascent stage for return to lunar orbit by tossing out their PLSS backpacks, lunar overshoes, one Hasselblad camera, and other equipment. They then pressurized the LM, and settled down to sleep.
p. While moving within the cabin, Aldrin accidentally broke the circuit breaker that would arm the main engine for lift off from the Moon. There was concern this would prevent firing the engine, stranding them there. Fortunately a felt-tip pen was sufficient to activate the switch. Had this not worked, the Lunar Module circuitry could have been reconfigured to allow firing the ascent engine.
q. They also left behind a memorial bag containing a gold replica of an olive branch as a traditional symbol of peace and a silicon message disk. The disk carries the goodwill statements by U.S. Presidents Eisenhower, Kennedy, Johnson and Nixon, and messages from leaders of 73 countries around the world. The disc also carries a listing of the leadership of the US Congress, a listing of members of the four committees of the House and Senate

responsible for the NASA legislation, and the names of NASA's past and present top management. *(In his 1989 book, Men from Earth, Aldrin says that the items included Soviet medals commemorating Cosmonauts Vladimir Komarov and Yuri Gagarin).* Also, according to Deke Slayton's book *Moonshot*, Armstrong carried with him a special diamond-studded astronaut pin from Slayton.

r. On their last TV broadcast Collins commented,

> *The Saturn V rocket which put us in orbit is an incredibly complicated piece of machinery, every piece of which worked flawlessly ... We have always had confidence that this equipment will work properly. All this is possible only through the blood, sweat, and tears of a number of a people ... All you see is the three of us, but beneath the surface are thousands and thousands of others, and to all of those, I would like to say, 'Thank you very much'.*

s. Aldrin added,

> *This has been far more than three men on a mission to the Moon; more, still, than the efforts of a government and industry team; more, even, than the efforts of one nation. We feel that this stands as a symbol of the insatiable curiosity of all mankind to explore the unknown ... Personally, in reflecting on the events of the past several days, a verse from Psalms comes to mind. 'When I consider the heavens, the work of Thy fingers, the Moon and the stars, which Thou hast ordained; what is man that Thou art mindful of him?'.*

t. Armstrong concluded,

> *The responsibility for this flight lies first with history and with the giants of science who have preceded this effort; next with the American people, who have, through their will, indicated their desire; next with four administrations and their Congresses, for implementing that will; and then, with the agency and industry teams that built our spacecraft, the Saturn, the Columbia, the Eagle, and the little EMU, the spacesuit and backpack that was our small spacecraft out on the lunar surface. We would like to give special thanks to all those Americans who built the spacecraft; who did the construction, design, the tests, and put their hearts and all their abilities into those craft. To those people tonight, we give a special thank you, and to all the other people that are listening and watching tonight, God bless you. Good night from Apollo XI.*

u. On the return to Earth, the Guam tracking station failed, which would have prevented communication on the last segment of the Earth return. Repair was not possible until a staff member had his ten-year old son, Greg Force, do repairs made possible by his small hands. The boy was later thanked by Armstrong himself.

12. APOLLO XII

Apollo XII was the sixth manned flight in the Apollo Program and the second to land on the Moon *(an H type mission)*. It was launched on November 14th, 1969, from LC 39-A at the Kennedy Space Center, Florida, four months after Apollo XI. The lunar surface activity occupied just over one day and seven hours, and the landing site for the mission was located in the southeastern portion of the Ocean of Storms.

The mission ended on November 24th with a successful splashdown.

The prime crew for this flight was:

Position	**Astronaut**
Commander	Charles *Pete* Conrad
CM Pilot	Richard F. Gordon
LM Pilot	Alan L. Bean

The backup crew was composed of David R. Scott, Alfred M. Worden and James E. Irwin

Unlike the first landing on Apollo XI, Conrad and Bean achieved a precise landing at their expected location, the site of the *Surveyor 3* unmanned probe, which had landed on April 20th, 1967. They carried the first color television camera to the lunar surface on an Apollo flight, but transmission was lost after Bean accidentally pointed it at the Sun and it was damaged. On one of two moonwalks, they visited the Surveyor, and retrieved some parts for return to Earth. Upon analysis, common bacterium *Streptococcus mitis* was found and it was believed to have accidentally contaminated the spacecraft's camera prior to launch and survived dormant in this harsh environment for two and a half years. However, this finding has since been disputed.

The launch took place during a rainstorm and 36 and one half seconds after lift-off the vehicle was struck by lightning. Protective circuits on the fuel cells in the service module falsely detected overloads and took all three fuel cells offline, along with much of the CSM instrumentation. A second strike at 52 seconds after launch knocked out the *8-ball* attitude indicator. The loss of all three fuel cells put the CSM entirely on batteries but they were unable to maintain normal 28V DC bus voltages into the heavy 75 amp launch loads. Then, one of the AC inverters dropped offline. These power supply problems lit nearly every warning light on the control panel and caused much of the instrumentation to malfunction.

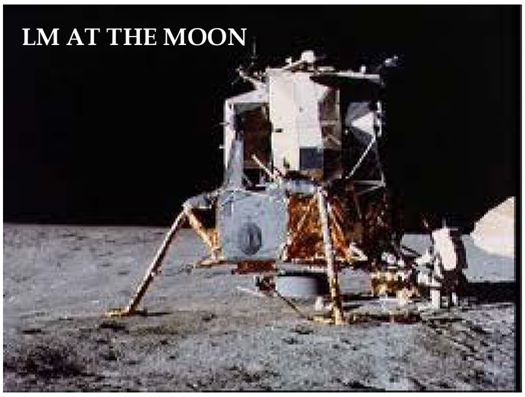
The telemetry stream at Mission Control was garbled. However, the Saturn V continued to fly correctly; the strikes had not affected the Instrument Unit.

Legendary *EECOM (Electrical, Environmental and Consumables Manager) John Aaron (the original NASA steely eyed missile man)* remembered the telemetry failure pattern from an earlier test when a power supply malfunctioned in the CSM Signal Conditioning Equipment *(SCE)*. The SCE converts raw signals from instrumentation to standard voltages for the spacecraft instrument displays and telemetry encoders.

Aaron made a call: *Try SCE to aux (going to a backup power supply)*. The switch was fairly obscure and it was not immediately recognized by the Flight Director, CapCom, or Commander Conrad. However, LM pilot Alan Bean, flying in the right seat as the CSM systems engineer, remembered the SCE switch from a training incident a year earlier when the same failure had been simulated. Aaron's quick thinking and Bean's memory saved what could have been an aborted mission. Bean put the fuel cells back on line, and with telemetry restored, the launch continued successfully.

Once in earth parking orbit, the crew carefully checked out their spacecraft before re-igniting the S-IVB third stage for TLI. The lightning strikes seemed not to have caused a serious permanent damage.

On the ground, there was fear that the lightning strike could have caused the CM's parachute mechanism to fail which would have caused the CM to crash uncontrollably into the Pacific Ocean killing the crew instantly. There was no way to determine whether this was the case, so ground controllers decided not to tell the astronauts about the possibility. The parachutes deployed and functioned normally at the end of the mission.



In this mission, the S-IVB was intended to fly into solar orbit once its part of the mission was completed. When the auxiliary propulsion system was fired however, a small error in the state vector in the Saturn's guidance system caused the S-IVB to fly past the Moon at too high an altitude to achieve earth escape velocity and it remained in a semi-stable earth orbit. It finally escaped earth orbit in 1971 but was briefly recaptured in Earth orbit 31 years later. It was discovered by amateur astronomer *Bill Yeung* who gave it the temporary designation J002E3 before it was determined to be an artificial object.

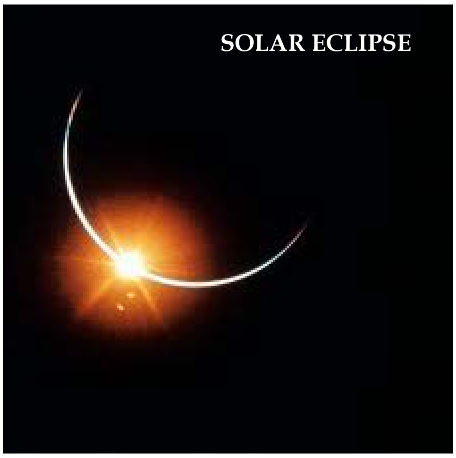
The second lunar landing was an exercise in precision targeting, using a Doppler effect radar technique developed to allow the pinpoint landings needed for future Apollo missions. Apollo XII succeeded on November 19th, in landing within walking distance of its intended target *(the Surveyor 3 probe)* which had landed on the Moon in April 1967. This was the first and, to date, only occasion in which humans have *caught up* to a probe sent to land on another world.

When Conrad, who was somewhat shorter than Neil Armstrong, stepped onto the lunar surface, his first words were, *Whoopie! Man, that may have been a small one for Neil, but that's a long one for me.* This was not an off-the-cuff remark: Conrad had made a $500 bet with reporter *Oriana Fallaci* he would say these words, after she had queried whether NASA had instructed Neil Armstrong what to say as he stepped onto the Moon. Conrad later said he was never able to collect the money.

Astronauts Conrad and Bean also collected rocks and set up equipment that took measurements of the Moon's seismicity, solar wind flux and magnetic field, and relayed the measurements to Earth. The instruments were part of the first complete nuclear-powered *ALSEP* station set up by astronauts on the Moon to relay long-term data from the lunar surface. The instruments on Apollo XI were not as extensive or designed to operate long term. The astronauts also took photographs, although by accident Bean left several rolls of exposed film on the lunar surface. Meanwhile Gordon, on board the *Yankee Clipper* in lunar orbit, took multi-spectral photographs of the surface.

The lunar plaque attached to the descent stage of *Intrepid* is unique in that unlike the other plaques, it *(a)* did not have a depiction of the Earth, and *(b)* it was textured differently *(the other plaques had black lettering on polished stainless steel while the Apollo XII plaque had the lettering in polished stainless steel while the background was brushed flat)*.

LM ascent stage was dropped *(per normal procedures)* after Conrad and Bean rejoined Gordon in orbit. It impacted the Moon on November 20th, 1969. The seismometers the astronauts had left on the lunar surface registered the vibrations for more than an hour.



The crew stayed an extra day in lunar orbit taking photographs, for a total lunar surface stay of 31 and a half hours and a total time in lunar orbit of eighty-nine hours.

On the return flight to Earth after leaving lunar orbit, the crew of Apollo XII witnessed *(and photographed)* a solar eclipse, though this one was of the Earth eclipsing the sun.

The CM returned to Earth on November 24th, 1969, at 20:58 GMT in the Pacific Ocean, approximately 800 km east of American Samoa. During splashdown, a 16 mm camera dislodged from storage and struck Bean in the forehead, rendering him briefly unconscious. He suffered a mild concussion and needed six stitches. After recovery by the *USS Hornet*, they were flown to Pago Pago International Airport in Tafuna for a reception, before being flown on a C-141 cargo plane to Honolulu.

ANNEX

a. Alan Bean smuggled a camera-shutter self-timer device on to the mission to try to take a photograph of Pete Conrad, himself and the Surveyor 3 probe in same the frame. As the timer was not part of their standard equipment, such an image would have thrown post-mission photo analysts into confusion over how the photo was taken. However, the self-timer was misplaced during the EVA and the plan was never executed.
b. As one of the many pranks pulled during the friendly rivalry between the all-Navy prime crew and the all-Air Force backup crew, the Apollo XII backup crew managed to insert into the astronauts´ lunar checklist *(attached to the wrists of Conrad's and Bean's spacesuits)* reduced-sized pictures of Playboy playmates, surprising Conrad and Bean when they looked through the checklist flip-book during their first EVA.
c. The backup crew who did this later flew to the Moon themselves on Apollo XV. Also at the back of Conrad's checklist were two pages of pre-prepared complex geological terminology, added as a joke to give him the option to sound to Mission Control like he was as skilled as a professional career geologist. The third crewmember orbiting the Moon was not left out of the Playboy prank, as a November 1969 calendar featuring DeDe Lind, Miss August 1967, had been stowed in a locker that Dick Gordon found while his crewmates were on the lunar surface. In 2011, he put this calendar up for auction. Its value was estimated by RRAuction at $12,000-$16,000.
d. Artist Forrest *(Frosty)* Myers claims to have installed the art piece *Moon Museum* on *a leg of the Intrepid landing module with the help of an unnamed engineer at the Grumman Corporation after attempts to move the project forward through NASA's official channels were unsuccessful.*
e. Alan Bean left a memento on the Moon, his silver astronaut pin. This pin signified an astronaut who completed training but had not yet flown in space; he had worn it for six years. He was to get a gold astronaut pin for successfully completing the mission after the flight and felt he wouldn't need the silver pin thereafter. Tossing his pin into a lunar crater extended the common tradition among military pilots to ceremonially dispose of their originally awarded flight wings.
f. It was the first rocket launch attended by an incumbent US president, Richard Nixon.

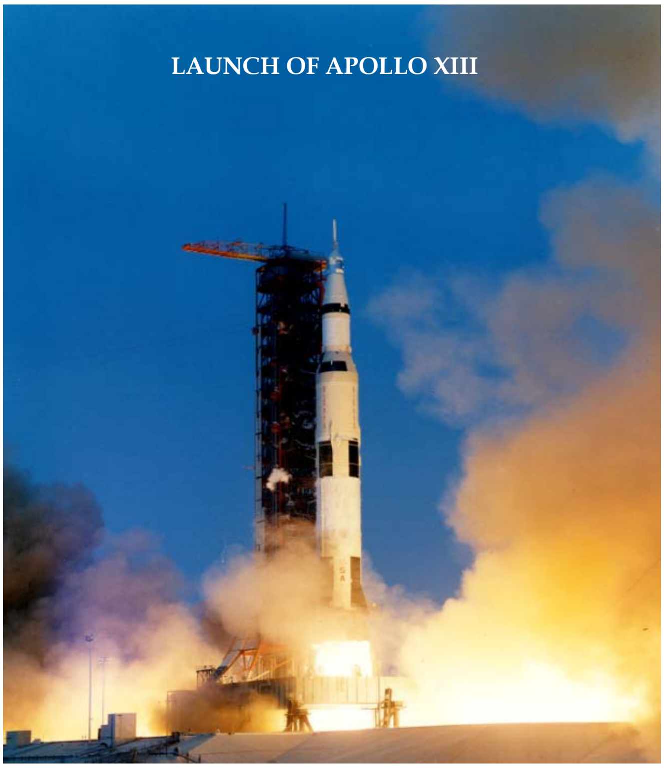
13. APOLLO XIII

Apollo XIII *(A successful failure)*

Start and breakdown

It was the seventh Apollo Program manned mission and the third planned to land on the Moon.

Launch occurred on April 11th, 1970, at 13:13 *(Houston time)*. The Moon landing was aborted due to the rupture of an oxygen tank two days after liftoff, on April 13th, which left the Service Module totally inoperative. This, in turn, affected the Command Module that also became inoperative.


LAUNCH OF APOLLO XIII

In spite of all the problems caused by the limited energy supply, the loss of cabin heat, the very low reserves of potable water and the imperative necessity of repairing the carbon dioxide extraction system, the crew returned safely to Earth on April 17th and was recovered by *USS Iwo Jima.*

The prime and backup crews for this mission were:

Prime crew:

Position	**Astronaut**
Commander	James A. Lovell, Jr.
CM Pilot	T. Kenneth Mattingly II
LM Pilot	Fred W. Haise, Jr.

Backup crew:

Position	**Astronaut**
Commander	John W. Young
CM Pilot	John L. Swigert
LM Pilot	Charles M. Duke, Jr.

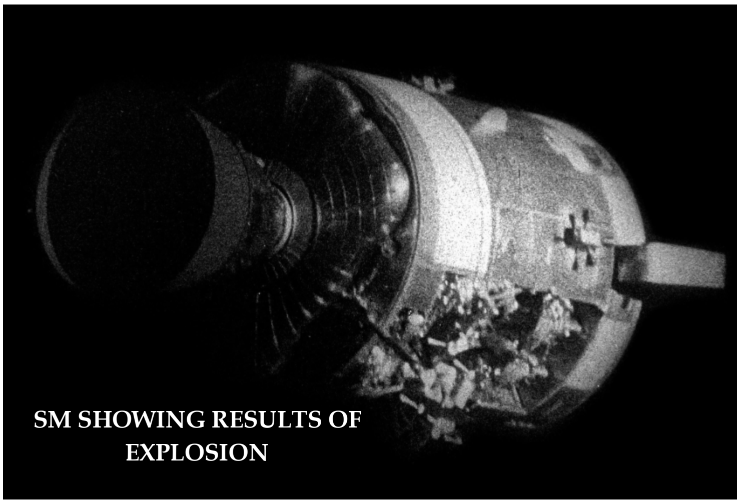
Ken Mattingly was originally selected to be the Command Module Pilot. Seven days before launch, Charles Duke was exposed to German measles by one of his sons and this exposed the virus to both of the crews as they trained together. Mattingly was found to not have suffered this illness when he was a child so he was not supposed to be immune. Three days before launch, and advised by the flight surgeon, Swigert was swapped to the prime crew. So, the crew for this mission was composed of *Lovell*, *Haise* and *Swigert*.

Mattingly never showed any symptoms of having German measles and was assigned as Command Module Pilot to Young´s crew which, afterwards, manned the Apollo XVI *(the fifth mission to land on the Moon)*.

The task assigned to Apollo XIII was to explore the *Fra Mauro* area. This area had an 80 km diameter crater in its interior, named after it, which had a special geological interest. It was believed to have been formed with the ejecta from the impact that formed *Mare Imbrium*.

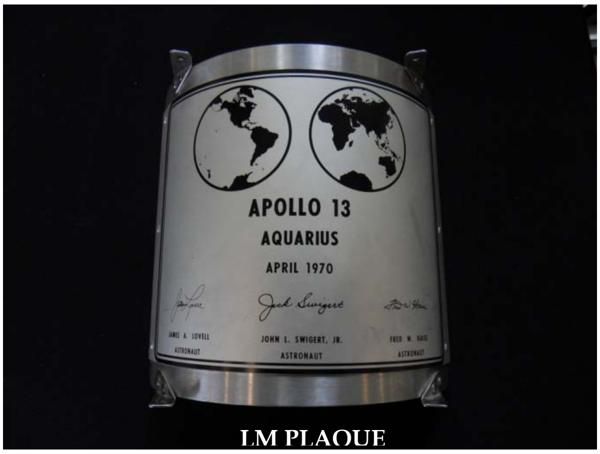
This mission started with a small incident during launch when the central motor of the second stage turned off two minutes before nominal. The four external motors kept burning to compensate for the lower thrust and the vehicle attained a nominal orbit.

At approximately 322,000 km from Earth, Mission Control requested that the crew enable the stirring fans on the oxygen and hydrogen tanks to homogenize the contents so they could obtain better pressure readouts. *(This procedure was both, periodic and usual during all Apollo fights)*. About 93 seconds afterwards, the crew heard a loud explosion-like sound followed by a strong vibration and electrical energy fluctuations. The crew initially thought that an asteroid had hit the Lunar Module.


SM SHOWING RESULTS OF EXPLOSION

But the reality was that oxygen tank number 2, one of the two tanks located inside the Service Module, had experienced a rupture due to an increase in pressure that went above the safety limits. Due to this situation, the tank itself broke open and thus, the oxygen inside expanded rapidly fulfilling the zone where the fuel cells were located. *(Sector 4)*.

The pressure, which kept increasing, broke down the nuts that were holding down the aluminum panel that covered Sector 4, expelling outside the rest of the oxygen and the broken pieces from the structure. This subsequent rupture most probably caused minor damage to the antenna which was being used for communications at the time, thus the reason for a 1.8 seconds interruption of the ground station link. The system acted automatically going from wide band to narrow band and the problem corrected itself.

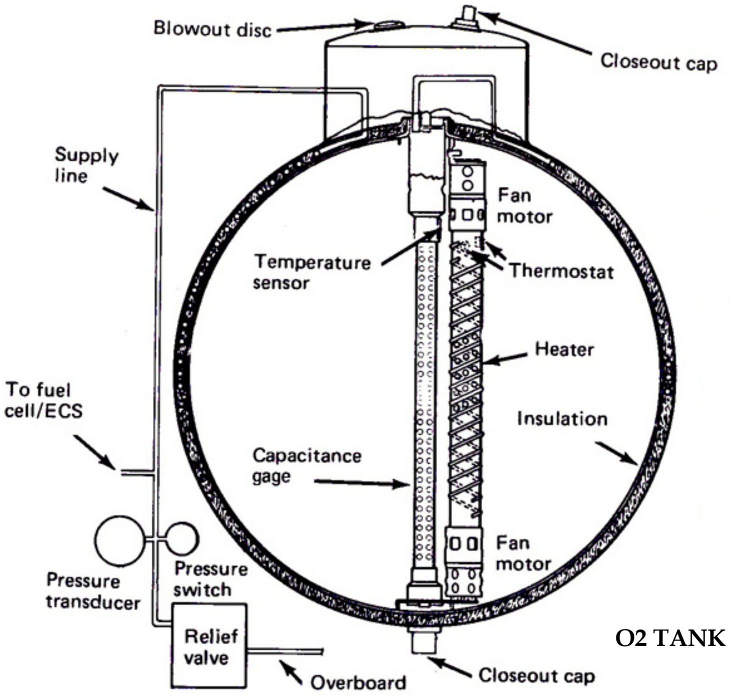


LM PLAQUE

The shock wave forced the oxygen valves of fuel cells 1 and 3 to shut down so they could only operate for 3 minutes.

One of two other things also happened. Either there was a possible partial rupture of a line that was attached to tank 1, or its through valve developed a leak, but oxygen from that tank started drifting into space during the following 130 minutes until the tank was empty and the total oxygen available to the Service Module was totally depleted.

As the fuel cells combine liquid oxygen and hydrogen to generate electricity and produce potable water, number 2 finally deactivated leaving the Apollo Command and Service Modules with the limited energy produced by the batteries. The crew was thereby forced to shut down the Command Module completely and use the Lunar Module as a life boat.

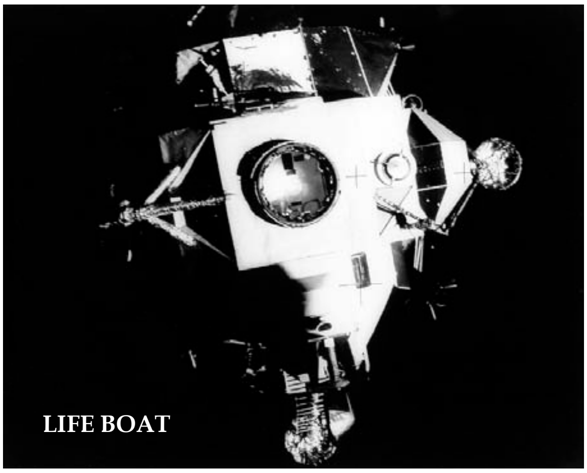


O2 TANK

This procedure had been previously suggested during a training simulation but was not considered to be a likely scenario. This solution, however, made possible the safe rescue of the crew.

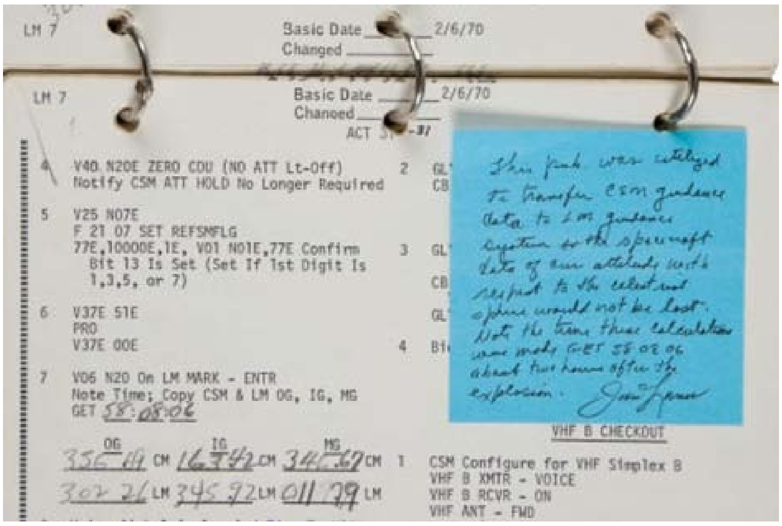
Crew Survival and the Return Trip

The failure of the Service Module aborted the planned lunar landing. The existent abort plans, developed back in 1966, were evaluated; the fastest solution was a direct abort trajectory which would require the use of the Service Module motor to obtain the necessary change in speed that would allow the craft to get in the proper course. This plan had the advantages of a faster return home and using fewer amounts of consumables, but it was rejected as being impractical due to the following:


LIFE BOAT

- It should have been done in an earlier phase of the trip, before the craft had entered the gravitational influence of the Moon and this had already happened when the problem occurred.
- There was no practical way of obtaining electrical energy to energize the motor.
- There were doubts that the motor would react normally as it could have been damaged by the oxygen tank rupture.
- Due to all these reasons, the flight director Gene Kranz and his deputy Chris Kraft decided for a free circumlunar return, using Moon´s gravity and

accelerating the craft while behind the Moon to reverse direction and send it back towards Earth. The spacecraft however, was exhibiting some strange behavior. The angular and velocity information supplied by the ground Stations while tracking the craft in auto mode differed greatly with the trajectory vector predictions that the guidance and navigation systems at Houston, GSFC *(Goddard Space Flight Centre)* and the Cape itself were calculating.



The rupture of the exterior panel acted as the ignition of a motor pushing the spacecraft away from its nominal cruise parameters. Therefore, the first order of business was to reestablish the original parameters as soon as possible by a small thrust from the Lunar Module´s propulsion system. The result was adequate and immediate but not definitive, because the leak from tank number 1 kept acting as a motor and constantly changing the trajectory, so the corrections had to take place frequently. After 130 minutes, the tank finally emptied and this constant trajectory change ceased. Once the correct course had been attained, the descent motor was used once again to get the adequate speed to place the spacecraft enrooted to Earth, and it was only used twice more for correction maneuvers.


HOUSTON CONTROL ROOM

The Lunar Module consumables had been calculated to maintain two persons during only two days and not three persons during four days. Oxygen was the least of the problems since the Lunar Module had enough to re-pressurize the capsule after each lunar activity. But different from the Command and Service modules which used the fuel cells to produce electricity and potable water as a byproduct, the Lunar module used silver oxide batteries, and the electric energy and the water *(used to cool down equipment and to drink)* were, obviously, critical consumables.

To be able to maintain the life support and the communications systems operative through return, the Lunar Module energy consumption was reduced to the lowest possible.

The limited amount of lithium hydroxide which was used to eliminate the carbon dioxide was a more serious problem. The internal Lunar Module reserves of LiOH were not sufficient to maintain the crew through return, and the remnant was kept far from reach inside the descent stage of the Lunar Module.

The Command Module had an adequate quantity of LiOH containers but there was an incompatibility with the Lunar Module. Ground engineers worked out a procedure to adapt the cube-like shape of the containers of the Command Module to the cylindrical-like shape of the Lunar Module. The astronauts called this artifact invention *the mail box*.

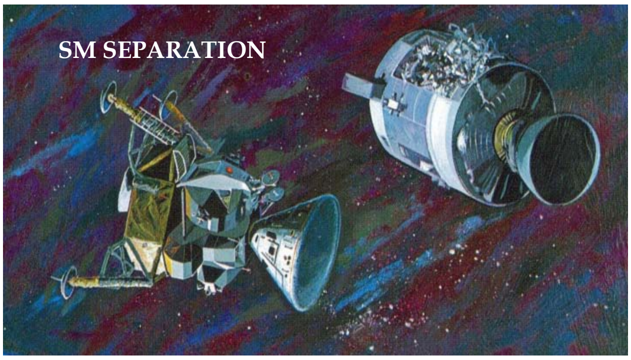
There were two trajectory corrections still remaining. First, the reentry window would place the module into the Indian Ocean where there were no USA ships to do the recovery and, second, the spacecraft would hit the atmosphere at such a shallow angle that it would probably not reenter but fly by the Earth into space. The Lunar Module motor was then used twice more to correct both of these small anomalies.

Another problem which had to be solved for a safe return was the necessity to completely repower Command Module. Flight controller John Aaron, with the help of astronaut Mattingly and a group of engineers and designers worked out a new protocol to return power to the CM with the incredible low energy level and the extremely short time.

The process was very complex because along with other problems, the very low temperature inside the Command Module had condensed the existing water vapor into droplets that covered every solid surface. There was serious concern that the electrical systems could undergo problems or failures due to the excessive moisture. Fortunately no failure occurred mostly due to the extensive improvements that had been made to the electrical circuitry as a result of lessons learned from the fire in Apollo I.

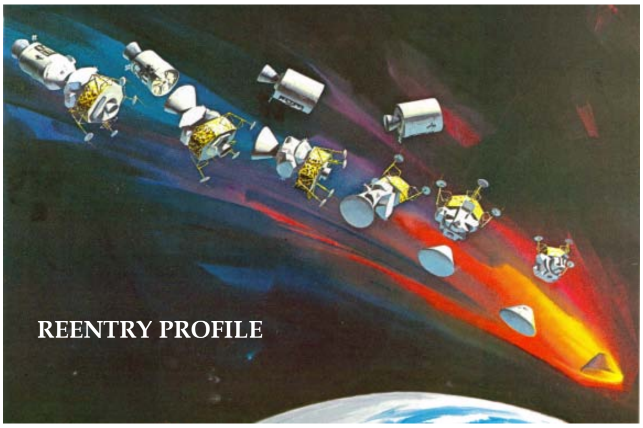
Reentry and Splashdown

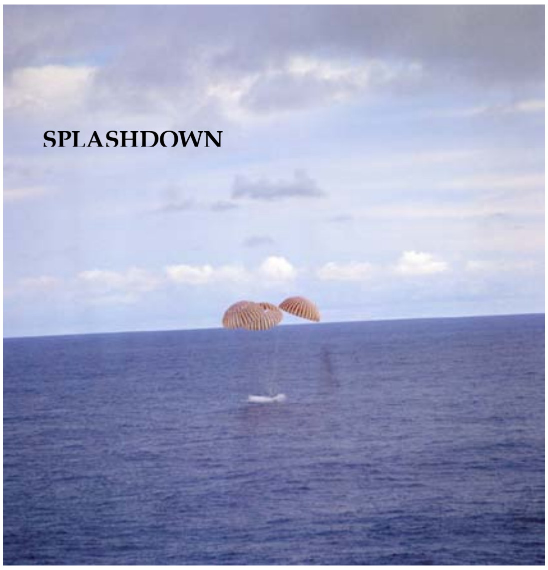
As they approached the Earth, the crew unlatched the Service Module and took several pictures to be used during later analysis. As they photographed the damage, the crew was shocked to find out that the Sector 4 panel had completely disappeared. The analysts in the ground also agreed that these pictures showed damage to the antenna.



Finally, the crew unlatched the Lunar Module, *Aquarius*, thus leaving alone the Command Module, *Odyssey*, to reenter the atmosphere.

A normal atmospheric reentry has a blackout communications period caused by atmosphere ionization around the module, which lasts approximately four minutes. The possibility that the thermal protection could have been damaged by the rupture of the section 4 cover panel worried everyone during this blackout. To make things worse, it took 33 seconds longer than normal. However, Odyssey re-established radio contact and splashed down safely in the South Pacific, south-west of American Samoa and only 6.5 km from the recovery ship.





The crew was in good condition except for Haise, who was suffering from a serious kidney infection due to lack of water.


RECOVERY

Many people classified this flight as a total failure.

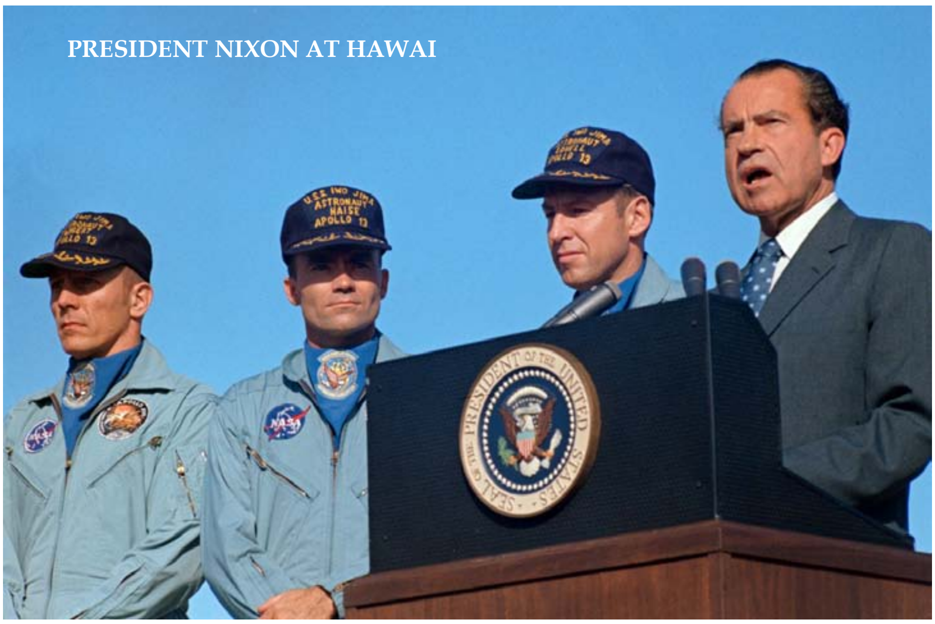
After the initial problem, the analysis showed that the probability of bringing the three astronauts safely back to Earth was very small but would increase somewhat by using the reduced return option; with this option only two astronauts would return alive. Flight director, Gene Kranz said there were no other options but bringing the three of them safely back to Earth and so, he put everyone to work to that aim.


USS IWO JIMA

Nobody had any sleep during the following four days looking for appropriate solutions. But after much hard work, the return probabilities had increased to more than 50%.


HOUSTON

The happy ending can only be classified as an absolute success and it was a demonstration of ingenuity, imagination, knowledge and perseverance.


PRESIDENT NIXON AT HAWAI

FACTS

Crew assignment

During the Apollo Program a standard procedure plan of crew rotations was implemented. Following this plan, the crew for Apollo XIII should have been the backup crew that was assigned to Apollo X and thus, the commander would have been the veteran astronaut of the Mercury and Gemini Programs, L. Gordon Cooper. Such a crew was:

- L. Gordon Cooper, Jr *(Commander)*
- Donn F. Eisele *(Command Module Pilot)*
- Edgar D. Mitchell *(Lunar Module Pilot)*

However, it was not the intention of Deke Slayton *(Director for flight crews)* to include Cooper and Eisele in other missions since both of them had issues with NASA administration for different reasons. *(Cooper due to his little interest in the training and Eisele due to some incidents during Apollo VII and for having an extra marital affair)*. Slayton assigned them as the backup crew for Apollo X only because of the need to have astronauts with flying experience so he presented the following assignment to management:

- Alan B. Shepard, Jr *(Commander)*
- Stuart A. Roosa *(Command Module Pilot)*
- Edgar D. Mitchell *(Lunar Module Pilot)*

But in this case and for the first time, Slayton´s recommendation was rejected by the administration who thought that Shepard needed more training time for a lunar flight because he had recently undergone surgery due to an equilibrium problem which had kept him grounded since the *Mercury Redstone 3*, in 1961. Finally, the assigned crew was the same that had been the backup for the historic Apollo XI flight.

Facts from the investigation committee

This mission had various *small incidents* which, in the end, contributed to the near loss of the mission and crew:

a. During initial testing, while on the launch pad, there appeared the possibility that a super-critical Helium tank used for the landing phase of the Lunar Module could have insulation problems. The solution *(?)* was to change the flight plan and enter into the Lunar Module three hours in advance of the normal script to double-check the pressure of the tank. Finally, during the trip back, the tank failed and expelled all the Helium into space causing the ship to de-stabilize. Haise had to do overtime to recover the proper attitude.

b. Oxygen tank 2 was originally in Apollo X and was replaced to implement modifications, and during those modifications it was damaged. After being repaired and tested at the factory, it was installed in Apollo XIII.
c. During 1965 the Command Module underwent a series of upgrades one of which included the change of the electrical voltage applied to the heaters from 28 to 65V DC; this change was not performed on the thermal switches however.
d. Also, during launch tests, oxygen tanks are purged to 50% and while tank 1 had no problems, tank 2 didn´t go below 92%. Flushing of the purge line and valve using high pressure gas was not successful so it was decided to boil the oxygen away with the heaters. This solution worked but the heaters remained on during 8 hours causing the Teflon insulation of the cables to become degraded due to the excess temperature.
e. As the switches had been working at 65V DC *(37 more than nominal)* for such a long time, the contacts melted and the heaters remained on permanently, increasing the pressure and finally causing the fault.

14. APOLLO XIV

The eighth Apollo Program manned mission. It was the third to land on the Moon, and the last of the *H missions*. *(Targeted landings with two-day stays on the Moon with two lunar EVAs, or moonwalks).*

APOLLO XIV LAUNCH

The Saturn V left the launch pad on its nine-day mission on January 31st, 1971, at 4:04:02 pm local time after a 40 minute and 2 second delay due to launch site weather restrictions, *(the first such delay in the Apollo Program)*. Lunar landing happened on February 5th in the Fra Mauro formation, which had originally been the target of the aborted Apollo XIII mission. During the two lunar EVAs, 42 kg of Moon rocks were collected and several surface experiments *(including seismic studies)* were performed. Shepard famously hit two golf balls on the lunar surface with a makeshift club he had brought from Earth. Shepard and Mitchell spent about 33 hours on the Moon, with about 9½ hours on an EVA.

While Shepard and Mitchell were on the surface, Roosa remained in lunar orbit aboard the CSM, performing scientific experiments and photographing the Moon. He took several hundred seeds on the mission, many of which were germinated on return resulting in the so-called Moon trees. Shepard, Roosa, and Mitchell landed in the Pacific Ocean on February 9th.

The crew for this mission was:

Position	Astronaut
Commander	Alan Shepard
CM Pilot	Stuart Roosa
LM Pilot	Edgar Mitchell

The backup crew was composed of, Eugene A. Cernan, Ronald E. Evans, Jr. and Joe H. Engle

Shepard was the oldest U.S. astronaut when he made his trip aboard Apollo XIV. He is the only *Mercury Seven* astronaut to have reached the Moon. Another of the original seven, L. Gordon Cooper, never made it due to his casual attitude toward training, along with problems with NASA hierarchy *(reaching all the way back to the Mercury-Atlas 9 flight)*.

The mission was a personal triumph for Shepard, who had battled back from Ménière's disease from 1964 to 1968. He and his crew were originally scheduled to fly on Apollo XIII, but in 1969 NASA officials switched the scheduled crews for Apollo XIII and XIV. This was done to allow Shepard more time to train for his flight, since he had been grounded for 4 years.

The Launch Control at Kennedy Space Center was visited by U.S. Vice President Spiro T. Agnew and Prince Juan Carlos of Spain.

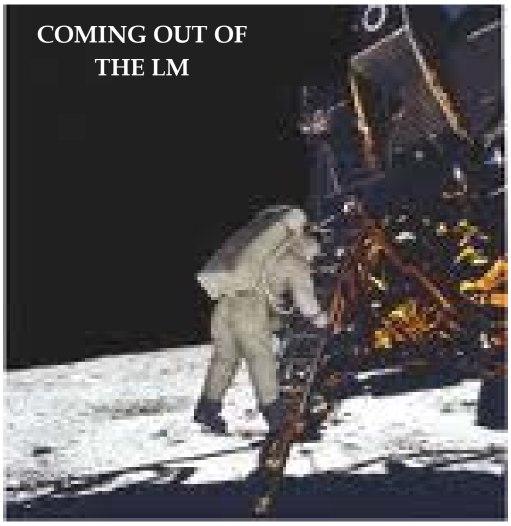
At the beginning of the mission, the CSM *Kitty Hawk* had difficulty achieving capture and docking with the LM *Antares*. Repeated attempts to dock went on for 1 hour and 42 minutes, until it was suggested that pilot Roosa hold Kitty Hawk against Antares using its thrusters, and then the docking probe would be retracted out of the way, hopefully triggering the docking latches. This attempt was successful, and no further docking problems were encountered during the mission.

LM PLAQUE

After separating from the CM in lunar orbit, the LM Antares also had two serious problems. First, the computer began getting an ABORT signal from a faulty switch.

NASA believed that the computer might be getting erroneous readings like this if a tiny ball of solder had shaken loose and was floating between the switch and the contact, closing the circuit. The immediate solution—tapping on the panel next to the switch—did work briefly, but the circuit soon closed again. If the problem recurred

after the descent engine fired, the computer would think the signal was real and would initiate an auto-abort, causing the Ascent Stage to separate from the Descent Stage and climb back into orbit. NASA and the software teams at MIT scrambled to find a solution, and determined the fix would involve reprogramming the flight software to ignore the false signal. The software modifications were transmitted to the crew via voice communication, and Mitchell manually entered the changes *(amounting to over 80 keystrokes on the LM computer pad)* just in time.



A second problem occurred during the powered descent, when the LM radar altimeter failed to lock automatically onto the moon's surface, depriving the navigation computer of vital information on the vehicle altitude and groundspeed. *(This was not a result of the modifications to the ABORT command but an unrelated bug in the radar's operation)*. After the astronauts cycled the landing radar breaker, the unit successfully acquired a signal near 5,500 m., again just in the nick of time. Shepard then manually landed the LM closer to its intended target than any of the other six moon landing missions. Mitchell believes that Shepard would have continued with the landing attempt without the radar, using the LM inertial guidance system and visual

cues. But a post-flight review of the descent data showed the inertial system alone would have been inadequate, and the astronauts probably would have been forced to abort the landing as they approached the surface.

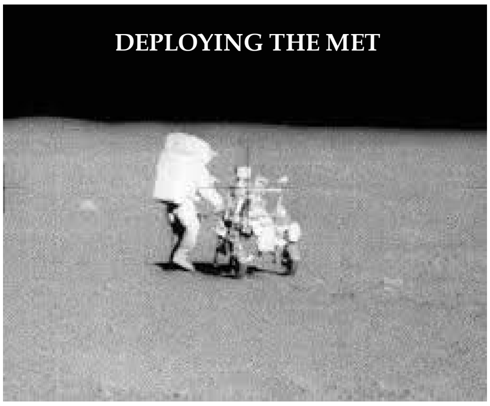
Shepard and Mitchell named their landing site *Fra Mauro Base*, and this designation is recognized by the International Astronomical Union *(depicted in Latin on lunar maps as Statio Fra Mauro)*.

Shepard's first words after stepping onto the lunar surface were, *and it's been a long way, but we're here.*

Unlike Neil Armstrong on Apollo XI and Pete Conrad on Apollo XII, Shepard had already stepped off the LM footpad and was a few meters away before he spoke.

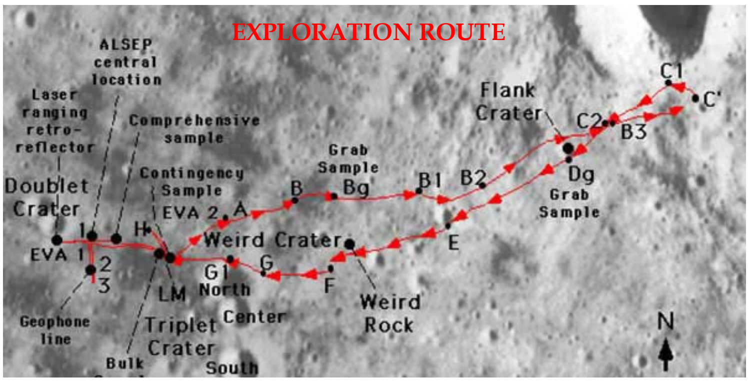

EARTH SEEN FROM THE MOON

Shepard's moon walking suit was the first to utilize red stripes on the arms and legs and on the top of the lunar EVA sunshade *hood*, to allow easy identification between the commander and the LM pilot on the surface; on previous flight pictures, it had been almost impossible to distinguish between the two crewmen, causing a great deal of confusion. This feature was included on Jim Lovell's Apollo XIII suit but was never used for obvious reasons, so Apollo XIV was the first to make use of it. This distinction was used for the remaining Apollo missions and for the EVAs of Space Shuttle flights afterwards and it is still in use today on both, the U.S. and Russian spacesuits on the International Space Station.


DEPLOYING THE MET

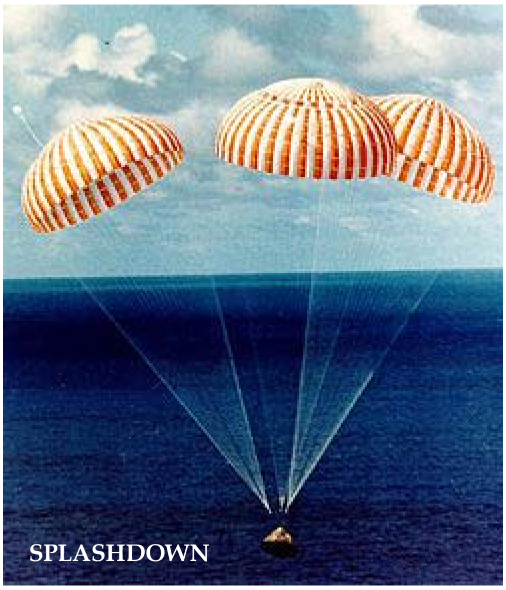

NEW SPACESUIT

After landing in the Fra Mauro formation, Shepard and Mitchell took two moon walks, adding new seismic studies to the Apollo experiment package, and using the Modular Equipment Transporter *(MET)*, a pull cart for carrying equipment and samples, referred to as a *lunar rickshaw*. Roosa, meanwhile, took pictures from on board the Command Module Kitty Hawk in lunar orbit.



EXPLORATION ROUTE

The second moonwalk, or EVA, was intended to reach the rim of the 300 m. wide Cone Crater. However, the two astronauts were not able to find the rim amid the rolling terrain of the crater's slopes. Later analysis, using the pictures that they took, determined that they had come within an estimated 20 m. of the crater's rim.



SPLASHDOWN

Shepard and Mitchell deployed and activated various scientific instruments and experiments and collected almost 45 kg of lunar samples for the return to Earth. Other Apollo XIV achievements included: the only use of MET; longest distance traversed by foot on the lunar surface; first use of shortened lunar orbit rendezvous techniques; first use of color TV with a new vidicon tube on lunar surface and the first extensive orbital science period conducted during CSM solo operations.

The astronauts also engaged in less serious activities on the Moon. Shepard smuggled on board a six iron golf club head which he could attach to the handle of a lunar excavation tool, and two golf balls, and took several one-handed swings *(due to the limited flexibility of the EVA suit)*. He exuberantly exclaimed that the second ball went *miles and miles and miles* in the low lunar gravity, but later estimated the distance as 180 to 370 m. Mitchell then threw a lunar scoop handle as if it were a javelin.

QUARANTINED

On the way back to Earth, the crew conducted the first U.S. materials processing experiments in space.

The command module *Kitty Hawk* splashed down in the South Pacific Ocean on February 9, 1971, at 21:05 GMT, approximately 1,410 km south of American Samoa. After recovery by the ship *USS New Orleans*, the crew was flown to Pago Pago International Airport in Tafuna for a reception before being flown on a C-141 cargo plane to Honolulu. The Apollo XIV astronauts were the last lunar explorers to be quarantined on their return from the Moon.

Roosa, who worked in forestry in his youth, took several hundred tree seeds on the flight. These were germinated after the return to Earth, and widely distributed around the world as commemorative Moon Trees.

This mission started a controversy among the Program followers as to whether OMEGA or ROLEX was the official NASA watch since astronauts were seen wearing ROLEX, not only in their normal life but also in the mission pictures. NASA had always advocated OMEGA as their official watch.

15. APOLLO XV

Ninth Apollo Program manned mission. This was the fourth to land on the Moon and the first of what were termed *J missions*. *(Long stays on the Moon with a greater focus on science than before)*. It was also the first mission on which the *Lunar Roving Vehicle* was used.

APOLLO XV LAUNCH

The Saturn V left the launch platform on July 26th, 1971, and splashdown happened on August 7th. At the time, NASA called it the most successful manned flight ever achieved.

The Commander and LM Pilot spent three days on the Moon, including 18½ hours outside the spacecraft on lunar extra-vehicular activity. The mission was the first not to land in a lunar mare, instead landing near Hadley Rille, in an area of the Mare Imbrium called *Palus Putredinus (Marsh of Decay)*. The crew explored the area using the first Lunar Rover, which allowed them to travel much farther from the LM than in previous missions.

The prime crew for this mission was:

Position	Astronaut
Commander	David Scott
CM Pilot	Alfred Worden
LM Pilot	James Irwin

The backup crew was composed of, Richard F. Gordon, Jr., Vance D. Brand and Harrison H. Schmitt.

They collected 77 kg of lunar surface material. At the same time, CSM Pilot Alfred Worden orbited and studied the Moon by using a Scientific Instrument Module *(SIM)* in the Service Module. This SIM had a panoramic camera, a gamma-ray spectrometer, a mapping camera, a laser altimeter and a mass spectrometer. At the end of Apollo XV's stay in lunar orbit, the crew deployed a lunar sub-satellite *(an Apollo program first)*.

Originally Apollo XV would have been an H mission like Apollo's XII, XIII and XIV. But on September 2nd, 1970, NASA announced it was cancelling what were to be the current incarnations of the Apollo XV and Apollo IXX missions. To maximize the return from the remaining missions, Apollo XV would now fly as a J mission and have the honor of carrying the first Lunar Rover.

One of the major changes in the training for XV was the geology training. Although on previous flights the crews had been trained in field geology, for the first time XV would make it a high priority. Scott and Irwin would train with *Leon Silver*, a Caltech geologist who on Earth was interested in the Precambrian era. Silver had been suggested by Harrison Schmitt as an alternative to the classroom lecturers that NASA had previously used. Among other things, Silver had made important refinements to the methods for dating rocks using the decay of uranium into lead in the late 1950s.

At first Silver would take the prime and backup crews to various geological sites in Arizona and New Mexico as if for a normal field geology lesson, but as launch time approached, these trips became more realistic. Crews began to wear mock-ups of the backpacks they would carry, and communicate using walkie-talkies to a CapCom in a tent. The CapCom was accompanied by a group of geologists unfamiliar with the area who would rely on the astronauts' descriptions to interpret the findings.


SALUTING THE FLAG

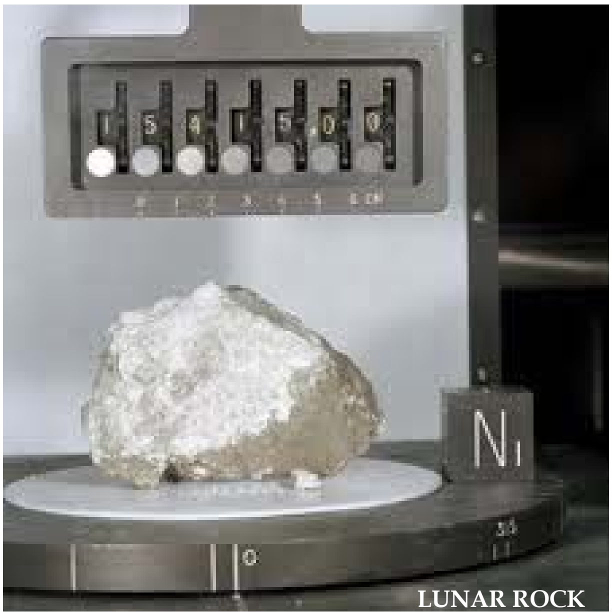
The decision to land at Hadley came in September 1970. The Site Selection Committees had narrowed the field down to two sites — Hadley Rille or the crater Marius —, near which were a group of low, possibly volcanic, domes. Although not ultimately his decision, the commander of a mission always held great sway. To Dave Scott the choice was clear, with Hadley, being *exploration at its finest*.

Command Module Pilot Al Worden undertook a different kind of geology training. Working with an Egyptian, Farouk El-Baz, he flew over areas in an airplane simulating the speed at which terrain would pass below him while in the CSM in orbit. He became quite adept at making observations as the object traveled below.


CSM AS SEEN FROM THE LM

Most of the first part of the day after arriving in lunar orbit, July 30th, was spent in preparing the Lunar Module for descent to the lunar surface later on that day. When preparations were complete, un-docking from the CSM was attempted; it did not occur, because of a faulty seal in the hatch mechanism. The CM Pilot, Al Worden, re-sealed the hatch and the LM then separated from the CSM. Dave Scott and Jim Irwin continued preparations for the descent while Al Worden remained in the CSM, returning to a higher orbit to perform lunar observations and await his crewmates' return a few days later.

Soon, Scott and Irwin began the descent. Several minutes after descent was initiated, at pitch-over and the beginning of the approach phase of the landing, the LM was 6 kilometers east of the pre-selected landing target. On learning this, Scott altered the flight path of the LM. They touched down at 22:16:29 GMT on July 30th at Hadley, within a few hundred meters of the planned landing site. While previous crews had exited the Lunar Module shortly after landing, the crew of Apollo XV elected to spend the rest of the day inside the LM, waiting until the next day to perform the first of three Extra-vehicular activities *(EVAs)*, or moonwalks, in order to preserve their sleep rhythm on a mission on which they were to spend a significantly longer time on the surface than previous crews had spent. Before they slept, Scott performed a stand-up EVA, during which the LM was depressurized and he photographed their surroundings from the top docking hatch.



LUNAR ROCK

Throughout the sleep period, Mission Control, in Houston, monitored a slow but steady oxygen leak. The data output of the onboard telemetry computers was limited during the night to conserve energy, so controllers could not determine the exact cause of the leak without awaking the crew. Scott and Irwin eventually were awakened an hour early, and the source of the leak was found to be an open valve on the urine transfer device. After the problem was solved, the crew began preparation for the first Moon walk.


DEPOYING LUNAR EXPERIMENTS

Four hours later, Scott and Irwin became the seventh and eighth humans, respectively, to walk on the Moon. After unloading the Lunar Roving Vehicle *(LRV)*, the two drove to the first moonwalk's primary destination, Elbow Crater, along the edge of Hadley Rille. On returning to the LM *Falcon*, Scott and Irwin deployed the Apollo Lunar Surface Experiments Package *(ALSEP)*. The first EVA lasted about 6½ hours.

The target of the second EVA, the next day, was the edge of Mount Hadley Delta, where the pair sampled boulders and craters along the Apennine Front. During this moonwalk, the astronauts recovered what came to be one of the more famous lunar samples collected on the Moon during Apollo, sample #15415, more commonly known as the *Genesis Rock*. Once back at the landing site, Scott continued to try to drill holes for an experiment at the ALSEP site, with which he had struggled the day before. After conducting soil-mechanics experiments and erecting a U.S. flag, Scott and Irwin returned to the LM. The EVA 2 lasted 7 hours and 12 minutes.

During EVA 3, the third and final moonwalk of the mission, the crew again ventured to the edge of Hadley Rille, this time to the northwest of the immediate landing site. After returning to the LM's location, Scott performed an experiment in view of the TV camera, using a feather and hammer to demonstrate Galileo's theory that all objects in a given gravity field fall at the same rate, regardless of mass *(in the absence of aerodynamic drag)*. He dropped the hammer and feather at the same time; because of the negligible lunar atmosphere, there was no drag on the feather, which hit the ground at the same time as the hammer.

Scott then drove the rover to a position away from the LM, where the television camera could be used to observe the lunar liftoff. Scott set up a memorial nearby to the cosmonauts and astronauts who were known to have died up to that time, with a plaque bearing their names and a *Fallen Astronaut* statuette. The EVA lasted 4 hours and 50 minutes.

In total, the two astronauts spent 18½ hours outside of the LM and collected approximately 77 kg of lunar samples.

After lifting off from the lunar surface 2 days and 18 hours after landing, the LM ascent stage rendezvoused and re-docked with the CSM with Al Worden aboard in orbit. After transferring samples and other items from the LM to the CSM, the LM was sealed off, jettisoned, and intentionally crashed into the lunar surface. After completing more observations of the Moon from orbit and releasing the sub-satellite, the three-person crew departed lunar orbit with another burn of the SPS engine.

The next day, on the return trip to Earth, Al Worden performed a spacewalk in deep space, the first of its kind, to retrieve exposed film from the SIM bay. Later on in the day, the crew set an endurance record for Apollo program, becoming the longest Apollo spaceflight to that point.

On approach to Earth the next day, August 7th, the Service Module *(SM)* was jettisoned, and the Command Module *(CM)* reentered the Earth's atmosphere. Although one of the three parachutes on the CM failed to deploy properly, only two were required for a safe landing *(one extra for redundancy)*. Upon landing in the North Pacific Ocean, the crew were recovered and taken aboard the recovery ship, the *USS Okinawa* after a mission lasting 12 days, 7 hours, 11 minutes, and 33 seconds.

ANNEX

a. Apollo XV used CSM-112, which was given the call sign *Endeavour*, named after the HM Bark *Endeavour (a Royal Navy research ship)*, and LM-10, call sign *Falcon*, named after the United States Air Force Academy mascot. If Apollo XV had flown as an H mission it would have been with CSM-111 and LM-9. That CSM was used by the Apollo Soyuz Test Project, but the LM went unused and is now on display at the Kennedy Space Center Visitor Complex.
b. The Apollo XV Saturn V carried a greater payload than the previous, so changes were made to its launch trajectory and the vehicle itself. The launch azimuth was 80–100 degrees and the Earth parking orbit 166 km. These two changes meant 500 kg more weight. The propellant reserves were reduced and the number of retrorockets on the S-IC first stage reduced from eight to four. The four outboard engines of the S-IC would be burned longer and the center engine would also burn longer before being shut down.
c. While at LC 39-A and during late June and early July 1971, the rocket and Mobile Service Structure were struck by lightning at least four times. All was well however, with only minor damage suffered.
d. During the launch, the S-IC did not completely shut off following staging, creating the possibility of the spent stage banging into the S-II engines *(the S-II exhaust also struck a telemetry package on the S-IC and caused it to fail)*. Despite this, the third stage and spacecraft reached its planned Earth parking orbit. A couple of hours into the mission, the third stage reignited to propel the spacecraft out of Earth orbit and on to the Moon.
e. The astronauts wore new spacesuits which allowed them to bend completely over and sit on the rover. Also, upgraded backpacks allowed for longer-duration moonwalks, and the CM pilot had a newer version of the old suit to let him make a *deep-space EVA* to retrieve film cartridges on the flight home.
f. Technicians at the Kennedy Space Center had many problems with the Scientific Instrument Module *(SIM)* bay in the SM because it was the first time it had flown. Some came from the fact that the instruments were designed to operate in zero gravity but were tested in the 1 G on Earth. Things like the 7.5 m. booms for the mass and gamma ray spectrometers could only be tested using railings that tried to mimic the space environment, and so they never worked particularly well. Others appeared when trying to integrate the bay into the spacecraft; data streams would not synchronize, and lead investigators of the instruments wanted to make last minute checks and changes. When it came time to test the operation of the gamma-ray spectrometer, it was necessary to stop every engine within 16 km of the test site.
g. On the LM, the fuel and oxidizer tanks were enlarged on both the descent and ascent stages, and the engine bell on the descent stage was extended. Batteries and solar cells were added for increased electrical power. All of these increased the weight of the LM to 16,330 kg. *(1,800 kg heavier than previous flights)*.
h. The Lunar Roving Vehicle, or Rover, had been in development since May 1969 with a contract awarded to Boeing. It could be folded into a space 1.5 by 0.5 m. Unloaded, it weighed 209 kg and when carrying two astronauts and their

equipment, 700 kg. Each wheel was independently driven by a ¼ horsepower *(200 W)* electric motor. Although it could be driven by either astronaut, it was the Commander who usually drove. Travelling at speeds up to 12 km/h, it meant that for the first time the astronauts could travel far afield from their lander and still have enough time to do some scientific experiments.

i. The Apollo XV sub satellite *(PFS-1)* was a small satellite released into lunar orbit from the SIM bay. The satellite acquired fields and particle data everywhere on the orbit around the Moon, while also gathering data from the magnetic field environment of the Moon and mapping the lunar gravity field. The satellite orbited the Moon and returned data from August 4th, 1971, until January 1973.

j. In later years, through a study of many lunar orbiting satellites, scientists came to discover that most low lunar orbits are unstable. Fortunately, PFS-1 had been placed, unknown to mission planners at the time, very near to one of only four Lunar *frozen orbits*, where a lunar satellite may remain indefinitely.

k. After a highly successful mission, the reputation of the crew and NASA was tarnished somewhat by a deal they made with a German stamp dealer. H. Walter Eiermann arranged for Scott to carry unauthorized commemorative postal covers in his spacesuit, in addition to the postal covers NASA had been contracted to carry for the U.S. Postal Service. Eiermann had promised each astronaut US $7,000 in the form of savings accounts in return for 100 covers signed after having returned from the Moon.

l. One final controversial event happened. The crew had contacted Belgian sculptor Paul Van Hoeydonck to create a small statuette to personally commemorate those astronauts and cosmonauts having lost their lives in the furtherance of space exploration. The small aluminum sculpture called *Fallen Astronaut* was left on the Moon next to the Rover at the end of EVA 3, along with a plaque bearing the names of the American astronauts and Soviet cosmonauts. Unknown at the time, two of the 20 cosmonauts were also deceased before Apollo XV, Valentin Bondarenko *(fire during training, March 1961)* and Grigori Nelyubov *(train accident/suicide, February 1966)*. Therefore, their names were not included on the plaque. The memorial was left while the TV camera was turned off so only Irwin knew what Scott was doing at the time. It was agreed that no replicas were to be made, but the National Air and Space Museum asked for one after they found out and Van Hoeydonck subsequently tried to sale them to the public. Under pressure from NASA, Van Hoeydonck withdrew the sale offer. NASA ultimately showed the monument on its Apollo XV mission documentary, with no mention that it was unauthorized.

m. The halo area of the Apollo XV landing site, generated by the LM's exhaust plume, was observed by a camera aboard the Japanese lunar orbiter SELENE and confirmed by photographs taken from the Apollo XV CM showing a change in surface reflectivity. This was the first visible trace of manned landings on the moon seen from space.

16. APOLLO XVI

The tenth Apollo Program manned mission. Fifth and penultimate to land on the Moon and first to land in the lunar highlands. The second of the so-called J-missions, it was launched from the Kennedy Space Center in Florida at 12:54 PM EST on April 16th, 1972, and lasted 11 days, 1 hour, and 51 minutes. Splashdown was at 2:45 PM EST on April 27th.


LAUNCH OF APOLLO XVI

John Young and Charles Duke spent 71 hours—just under three days—on the lunar surface, during which they conducted three extra-vehicular activities or moonwalks, totaling 20 hours and 14 minutes. The pair drove the Lunar Roving Vehicle *(LRV)*, the second produced and used on the Moon, 26.7 km. On the surface, Young and Duke collected 95.8 kg of samples for return to Earth while CM Pilot Ken Mattingly, who spent 126 hours and 64 revolutions in lunar orbit, performed observations. After Young and Duke rejoined Mattingly in lunar orbit, they released a sub-satellite from the Service Module. During the return trip to Earth, Mattingly performed a one-hour spacewalk to retrieve several film cassettes from the exterior of the Service Module.

The crew for this mission was:

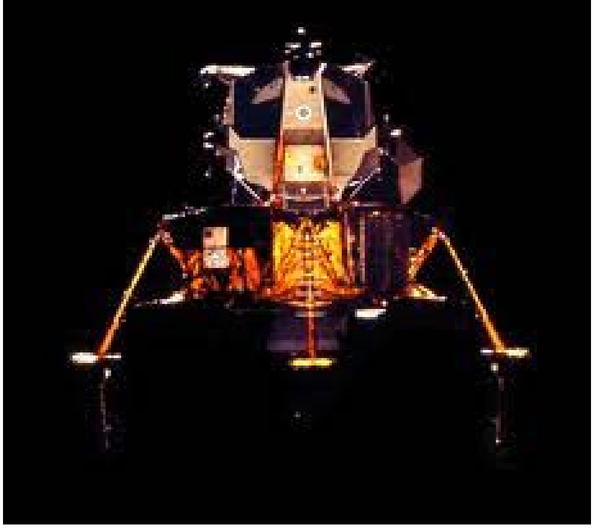
Position	Astronaut
Commander	John Young
CM Pilot	Ken Mattingly
LM Pilot	Charles Duke

Young, a captain in the United States Navy, had flown on three spaceflights prior to Apollo XVI, Gemini 3, Gemini 10 and Apollo X. One of 19 astronauts selected by NASA in April 1966, Duke had never flown in space before Apollo XVI. He served on the support crew of Apollo X and was a CapCom for Apollo XI.

The backup crew was composed of, Fred W. Haise, Jr., Stuart A. Roosa and Edgar D. Mitchell

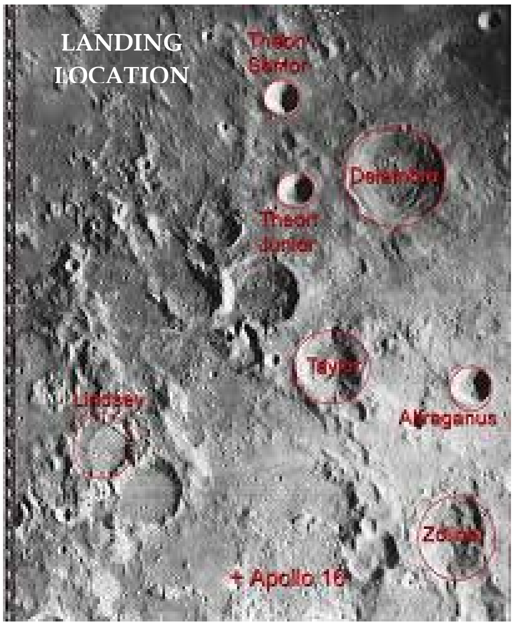
The maneuver, known as transposition, went smoothly and the LM was ejected from the S-IVB. Following docking, the crew noticed the exterior surface of the LM was giving off particles from a spot where the skin appeared torn or shredded; at one point, Duke estimated they were seeing about five to ten particles per second. The crew entered the LM through the docking tunnel to inspect its systems, and they did not spot any major issues.

LM AS SEEN FROM THE CSM



When the wake-up call was issued for flight day two, the spacecraft was about 181,000 km away from the Earth, traveling at about 5,639 km/h. They still had two days that were devoted to spacecraft maintenance and scientific research. On day two, the crew performed an electrophoresis experiment in which they attempted to prove the higher purity of particle migrations in the zero-gravity environment. Also, they performed the two-second mid-course correction burn to tweak the spacecraft's trajectory. They also went into the LM to further inspect the landing craft's systems, because they had observed additional paint peeling from a portion of the LM's outer aluminum skin but found that the spacecraft's systems were performing nominally. CM Pilot Mattingly reported a *gimbal lock* warning light, indicating the craft was not reporting an attitude, but realigning of the guidance system using the Sun and Moon cleared the problem.

On day three, the crew performed the Apollo light flash experiment, or *ALFMED*, to investigate *light flashes* that were seen by the astronauts when the spacecraft was dark, regardless of whether or not their eyes were open, on Apollo lunar flights. This was thought to be caused by the penetration of the eye by cosmic ray particles. The LM was again powered it up and checked in preparation for lunar landing.



LANDING LOCATION


EARTH FROM APOLLO XVI

On day four, the crew began preparations for lunar orbit insertion. At a distance of 20,635 km from the Moon, the SIM bay cover was jettisoned and as they passed behind the Moon, the CSM's SPS engine burned for 6 minutes and 15 seconds, braking the spacecraft into an orbit with a low point *(pericynthion)* of 108.0 km and a high point *(apocynthion)* of 315.6 km respectively. Once in lunar orbit, the Descent Orbit Insertion *(DOI)* maneuver was performed to decrease the craft's pericynthion to 19.8 km.

LM activation continued at the beginning of day five. The boom that extended the mass spectrometer out from the CSM's Scientific Instruments Bay was stuck in a semi-deployed position. It was decided that Young and Duke would visually inspect the boom after undocking from the CSM in the LM.

CSM AS SEEN FROM THE LM

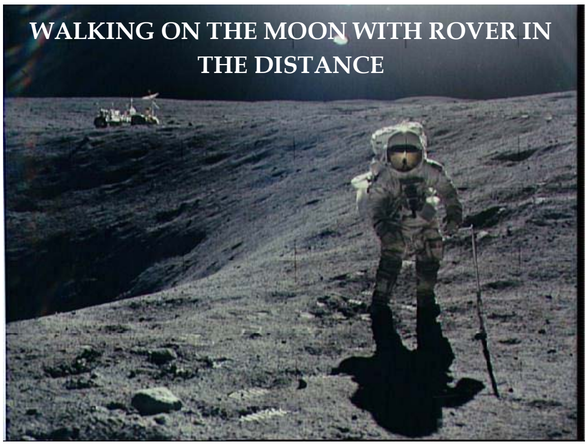
They undocked in the LM *Orion* from Mattingly in the CSM *Casper* 96 hours, 13 minutes, 13 seconds into the mission. After that, Mattingly prepared to shift Casper to a circular orbit while Young and Duke prepared Orion for the descent to the lunar surface. At this point, a malfunction occurred in the CSM engine's backup system. According to mission rules, Orion would have then re-docked with Casper, in case Mission Control decided to abort the landing and use the Lunar Module's engines for the return trip to Earth. After several hours of analysis, however, mission controllers determined that the malfunction could be worked around and Young and Duke could proceed with the landing. As a result, powered descent to the lunar surface began about six hours behind schedule and at an altitude of 20.1 km, higher than that of any previous mission. At about 4,000 m., Young was able to view the landing site in its entirety. Throttle-down of the LM's landing engine occurred on time and the spacecraft tilted forward to its landing orientation at an altitude of 2,200 m. The LM landed 270 m. north and 60 m. west of the planned landing site at 104 hours, 29 minutes, and 35 seconds into the mission, at 2:23:35 GMT on April 21st.

After landing, Young and Duke began configuring LM's systems for their three-day stay on the lunar surface, removed their spacesuits and took initial geological observations of the landing site. They then ate and configured for their first sleep period. The landing delay caused significant modifications to the mission schedule since they would spend one less day in lunar orbit after surface exploration had been completed. This in turn changed the third and final moonwalk of the mission from seven hours to five.

The next morning, Young and Duke donned and pressurized their spacesuits and depressurized the LM cabin, Young climbed out onto the *porch*, and Duke handed a jettison bag full of trash to dispose of on the surface. Young then lowered the equipment for use during the EVA *(ETB)* and descended the ladder. Upon setting foot on the lunar surface and becoming the ninth human to walk on the Moon his words were, *There you are: Mysterious and Unknown Descartes. Highland plains. Apollo XVI is gonna change your image.* Duke soon descended the ladder joining Young on the surface and becoming the tenth and youngest human to walk on the Moon, at age 36. After setting foot on the lunar surface, Duke expressed his excitement, commenting, *Fantastic! Oh, that first foot on the lunar surface is super, Tony!* The pair's first task of the moonwalk was to unload the Lunar Roving Vehicle *(LRV)*, along with other equipment, from the Lunar Module. This was done without problems. The day's next task was to deploy the ALSEP and a heat-flow experiment that had burned up with the Lunar Module *Aquarius* on Apollo XIII, and had been attempted without success on Apollo XV as a cable was inadvertently snapped after getting caught around Young's foot.

Their first Rover ride was to the first geologic stop, Plum Crater, a 36 m.-wide crater on the rim of the 290 m. across Flag Crater. There, at a distance of 1.4 km from the LM, they sampled material from the vicinity, which scientists believed penetrated through the upper regolith layer to the underlying Cayley Formation. It was there that Young retrieved, at the request of Mission Control, the largest rock returned by an Apollo mission, a breccia nicknamed Big Muley after mission geology principal investigator Bill Muehlberger.

The next stop of the day was Buster Crater, about 1.6 km from the LM. There, Duke took pictures of Stone Mountain and South Ray Crater while Young deployed a magnetic field experiment. At that point, scientists began to reconsider their pre-mission hypothesis that Descartes had been the setting of ancient volcanic activity, as the two astronauts had yet to find any volcanic material.



They returned to the LM 7 hours, 6 minutes, and 56 seconds after the start of the EVA. Once inside, they pressurized the LM cabin, went through a half-hour briefing with scientists in Mission Control, and configured the cabin for the sleep period.

On the next day, after discussing with Mission Control in Houston the day's timeline of events, they departed for *Cinco Craters*, 3.8 km from the LM. At 152 m. above the valley floor, they were at the highest elevation above the LM of any Apollo mission. Marveling at the view from the side of Stone Mountain, which Duke described as *spectacular*, the astronauts gathered samples in the vicinity and started for the second stop, the material was *a reasonable bet to be Descartes* according to geologist Don Wilhelms.

Next stop was station six, a 10 m. wide blocky crater, where they expected to find evidence of the Cayley Formation. They bypassed station seven to save time and arrived at station eight on the lower flank of Stone Mountain. There, they collected black and white breccias and smaller crystalline rocks rich in plagioclase. After gathering samples at station nine, they arrived at the final stop of the day, halfway between the ALSEP site and the LM, where they conducted several penetrometer tests. At the request of Young and Duke, the moonwalk was extended by ten minutes. They were back to the LM after 7 hours, 23 minutes, and 26 seconds of EVA time, breaking a record that had been set on Apollo XV.

On their third and final day, they were to explore North Ray Crater, the largest of any of the craters any Apollo expedition had visited. Upon arriving at the rim of the crater, they were 4.4 km away from the LM. They took pictures and obtained samples. About 1 hour and 22 minutes after arriving, they departed for station 13, a large boulder field about 0.5 km away. Here, they sampled permanently shadowed soil. After 3 hours and 6 minutes, they returned to the LM. Young drove the rover to a point about 90 m. east of the LM, known as the 'VIP site', so its television camera, controlled remotely by Mission Control, could observe Apollo XVI's liftoff from the Moon.

Six minutes after liftoff, at a speed of about 5,000 km/h, Young and Duke reached lunar orbit. The LM successfully rendezvoused and re-docked with the CSM, and transferred the samples collected on the surface. After the transfers were completed, the crew slept before jettisoning the LM ascent stage to be crashed intentionally into the lunar surface.

The next day, after final checks were completed, the expended LM ascent stage was jettisoned. The next task was to release a sub-satellite into lunar orbit from the CSM's Scientific Instrument Bay. The burn to alter the CSM’s orbit to that desired for the sub-satellite had been cancelled; as a result, the sub-satellite lasted half of its anticipated lifetime. During the CSM's 65th orbit, its Service Propulsion System main engine was reignited to return it to Earth. The SPS engine performed the burn flawlessly despite the malfunction that had delayed the lunar landing several days before.

At a distance of about 310,000 km from Earth, Mattingly performed a *deep-space* extra-vehicular activity, during which he retrieved several film cassettes from the CSM's SIM bay. While outside of the spacecraft, Mattingly set up a biological experiment, the Microbial Ecology Evaluation Device *(MEED)*. The MEED experiment was only performed on Apollo XVI.

Just over three hours before splashdown in the Pacific Ocean, the crew performed a final course correction burn, changing their velocity by 0.43 m/s, and approximately ten minutes before reentry into Earth's atmosphere the cone-shaped CM capsule separated from the expended SM, which would burn up during reentry.

The CM splashed down in the Pacific Ocean 350 km southeast of the island of Kiritimati *(or Christmas Island)*, 290 hours, 37 minutes, 6 seconds after liftoff. The spacecraft and its crew were retrieved by the *USS Ticonderoga*. They were safely aboard the Ticonderoga 37 minutes after splashdown.

ANNEX

a. The launch of Apollo XVI was delayed one month from March 17th to April 16th due to a technical problem. During the delay, the spacesuits, a spacecraft separation mechanism and batteries in the LM were modified and tested. There were concerns that the explosive mechanism designed to separate the docking ring from the CM would not create enough pressure to completely sever the ring. This, along with a dexterity issue in Young's spacesuit and fluctuations in the capacity of the LM batteries, required investigation and trouble-shooting. In January 1972, three months before the planned April launch date, a fuel tank in the CM was accidentally damaged during a routine test. The rocket was returned to the Vehicle Assembly Building and the fuel tank replaced, and the rocket returned to the launch pad in February in time for the scheduled launch.

b. The official mission countdown began on Monday, April 10th, 1972, at 8:30 a.m. At the time, the crew was participating in final training exercises in anticipation of a launch on April 16th. The astronauts underwent their final preflight physical examination on April 11th. On April 15th, liquid hydrogen and liquid oxygen propellants were pumped into the spacecraft, while the astronauts rested in anticipation of their launch the next day.

c. It was finally decided to target the Apollo XVI mission on the Descartes site while the Alphonsus site was considered for Apollo XVII. The specific landing site was between two young impact craters, North and South Ray craters, 1,000 m. and 680 m. in diameter, respectively, which provided *natural drill holes* which penetrated through the lunar regolith at the site, thus leaving exposed bedrock that could be sampled by the crew.

d. The scientific community widely suspected the site was formed by lunar volcanism, but this hypothesis was proven incorrect by the composition of lunar samples from the mission.

e. The Apollo XVI astronauts went through an extensive training program to introduce the astronauts to concepts and techniques they would use on the lunar surface. In July 1971, they went to Canada for geology training, the first time U.S. astronauts did so.

f. In addition, they also trained to use the spacesuits, adapt to the reduced lunar gravity, collect samples, maneuver in the Lunar Roving Vehicle and land and recover after the mission.

g. On first driving the lunar rover, Young discovered that the rear steering was not working. He alerted Mission Control to the problem before setting up the television camera and planting the flag of the United States with Duke. Later, while parking the Rover to deploy some experiments, the rear steering began functioning without explanation.

h. Duke set a lunar speed record, travelling at an estimated 17.1 km/h downhill.

i. Duke left a photograph of his family and a United States Air Force commemorative medallion on the surface of the Moon. The reverse of the photo is signed by Duke's family and bears the message; *This is the family of Astronaut Duke from Planet Earth. Landed on the Moon, April 1972.*

j. At the time of the LM jettison, and because of a failure by the crew to activate a certain switch before sealing it off, it initially tumbled after separation and did not execute the rocket burn necessary for the craft's intentional de-orbit. The ascent stage eventually crashed into the lunar surface nearly a year after the mission.

k. The Apollo XVI sub satellite *(PFS-2)* was similar to its sister spacecraft, PFS-1, released eight months earlier by Apollo XV. *The low orbits of both sub satellites were to be similar ellipses but, instead, something bizarre happened. The orbit of PFS-2 rapidly changed shape and distance from the Moon and in 2 ½ weeks the satellite was swooping to within a hair-raising 10 km of the lunar surface at closest approach. As the orbit kept changing, PFS-2 backed off again, until it seemed to be a safe 58 km away. But not for long: inexorably, the sub satellite's orbit carried it back toward the Moon. And on May 29th, 1972, only 35 days and 425 orbits after its release, PFS-2 crashed into the lunar surface*.

l. In later years, through a study of many lunar orbiting satellites, scientists came to discover that most Low Lunar orbits are unstable. Unfortunately, PFS-2 had been placed, squarely into one of the most unstable of orbits.

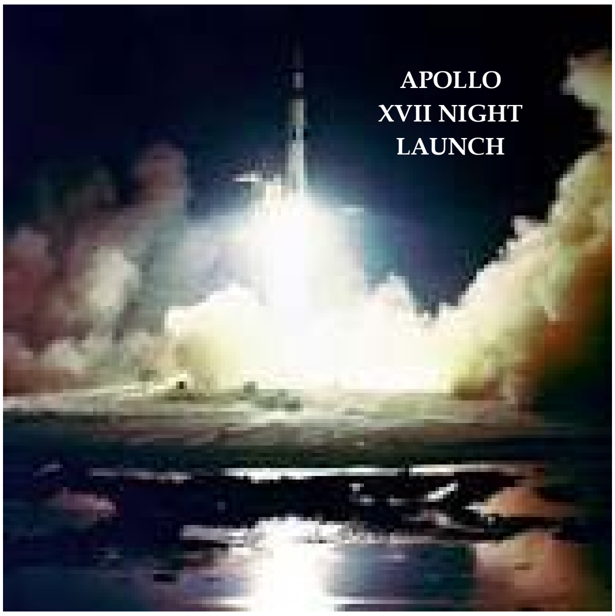
m. The aircraft carrier *USS Ticonderoga* delivered the Apollo XVI CM to the North Island Naval Air Station, near San Diego, California on Friday, May 5th, 1972. On Monday, May 8th, 1972, ground service equipment being used to empty the residual toxic reaction control system fuel in the command module tanks exploded. Forty-six people were sent to the hospital for 24 to 48 hours observation, most suffering from inhalation of toxic fumes. Most seriously injured was a technician who suffered a fractured kneecap when the GSE cart overturned on him. A hole was blown in the hangar roof 80 m. above, about 40 windows in the hangar were shattered and the Command Module suffered a three-inch gash in one panel.

n. Duke donated some flown items, including a lunar map, to Kennesaw State University in Kennesaw, Georgia. The other item was a commemorative medal issued by the United States Air Force, which was celebrating its 25th anniversary in 1972, and which he donated to the Wright-Patterson Air Force Base museum.

o. In 2006, shortly after Hurricane Ernesto affected Bath, North Carolina, eleven year-old Kevin Schanze discovered a piece of metal debris on the ground near his beach home. He and a friend discovered a *stamp* on the 91 cm flat metal sheet, which upon further inspection turned out to be a faded copy of the Apollo XVI mission insignia. NASA later confirmed the object to be a piece of the first stage of the Saturn V rocket that launched Apollo XVI into space. In July 2011, after returning the piece of debris at NASA's request, 16-year-old Schanze was given an all-access tour of the Kennedy Space Center and VIP seating for the launch of STS-135, the final mission of the Space Shuttle program.

17. APOLLO XVII

The tenth and final Apollo Program manned mission of the United States Apollo lunar landing program, it was also the sixth landing of humans on the Moon. The mission launched at 12:33 a.m. Eastern Standard Time *(EST)* on December 7th, 1972, from launch pad 39-A at the Kennedy Space Center. The launch was delayed two hours and forty minutes due to an automatic cutoff in the launch sequencer at the T-30 second mark in the countdown. The issue was quickly determined to be a minor technical error. The clock was reset and held at the T-22 minute mark while technicians worked around the malfunction in order to continue with the launch. This pause was the only launch delay in the Apollo program caused by this type of hardware failure. The count resumed, and a normal low Earth orbit was achieved.


APOLLO XVII NIGHT LAUNCH

Apollo XVII was also the first night launch of a U.S. human spaceflight and the final crewed launch of a Saturn V rocket. It was a *J-type mission*, missions including three-day lunar surface stays, extended scientific capability, and the third Lunar Roving Vehicle. The astronauts returned to Earth on December 19th after an approximately 12-day mission.

The crew for this mission was:

Position	Astronaut
Commander	Eugene Cernan
CM Pilot	Ronald Evans
LM Pilot	Harrison Schmitt

For the backup crew of this mission see the annex.

Several records set by previous flights were broken by Apollo XVII, including the longest manned lunar landing flight, the longest total lunar surface extravehicular activities, the largest lunar sample return, and the longest time in lunar orbit.

Since Apollo XVII was to be the final lunar landing of the Apollo Program, high-priority sites that had not been visited previously were given consideration for potential exploration. After eliminating a few, three sites were analyzed: Alphonsus crater, Gassendi crater, and the Taurus-Littrow valley.

The Taurus-Littrow site was selected with the prediction that old highland material from the remnants of a landslide event that occurred on the south wall of the valley and the possibility of relatively young, explosive volcanic activity in the area could be found.

Apollo XVII was the first lunar landing mission to carry the *Traverse Gravimeter Experiment (TGE)*, an experiment built by Draper Laboratory at MIT, and designed to provide relative gravity measurements throughout the landing site at various locations during the mission's moonwalks. Scientists would then use this data to gather information about the geological substructure of the site and the surrounding vicinity.

A total of twenty-six measurements were taken with the TGE during the mission's three moonwalks with productive results. As part of the ALSEP, the astronauts also deployed the Lunar Surface Gravimeter, a similar experiment, which ultimately failed to function properly.

Sector one of the Apollo XVII SM contained the SIM bay. The SIM bay housed three experiments for use in lunar orbit: a lunar sounder, an infrared scanning radiometer, and a far-ultraviolet spectrometer. A mapping camera, panoramic camera, and a laser altimeter were also included.

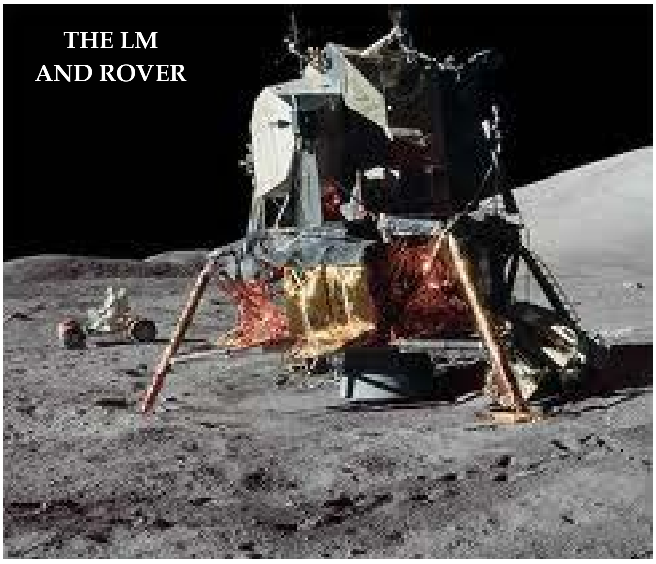
The lunar sounder beamed electromagnetic impulses toward the lunar surface with the objective of obtaining data to assist in developing a geological model of the interior of the Moon to an approximate depth of 1.3 km.

The Infrared Scanning Radiometer was designed to generate a temperature map of the lunar surface.

The Far-Ultraviolet Spectrometer would obtain data about the composition, density, and constituency of the lunar atmosphere. The spectrometer was also designed to detect far-UV radiation emitted by the Sun that was reflected off the lunar surface.

The Laser Altimeter was designed to measure the altitude of the spacecraft above the lunar surface within approximately two meters, and providing altitude information to the panoramic and mapping cameras.

Apollo XVII was also the first to include the Surface Electrical Properties *(SEP)* experiment. It included two major components, a transmitting antenna deployed near the LM and a receiving antenna located on the LRV. At different stops during the mission's traverses, electrical signals traveled from the transmitting device, through the ground, to the receiver at the LRV. The electrical properties of the lunar soil could be determined by comparison of the transmitted and received electrical signals. The results of this experiment, which are consistent with lunar rock composition, show that the top 2 km of the Moon are extremely dry.



At approximately 2:47 PM EST on December 10th, the SPS engine on the CSM ignited to slow down the CSM/LM stack into lunar orbit. Following orbit insertion and orbital stabilization, the crew began preparations for landing.

After separating from the CSM, the LM *Challenger* adjusted its orbit and began preparations for the descent. While they prepared for landing, CM Pilot remained in orbit taking observations and performing experiments.

The Apollo XVII LRV traveled a cumulative distance of approximately 35.9 km in a total drive time of about four hours and twenty-six minutes; the greatest distance traveled from the Lunar Module was about 7.6 km.

The first moonwalk of the mission began approximately four hours after landing, at about 6:55 PM on December 11th. The first task was to offload the Lunar Roving Vehicle and other equipment from the Lunar Module. While working near the rover, a fender was accidentally broken off when Gene Cernan´s hammer got caught under the right-rear fender, breaking it off. *(This same problem occurred on Apollo XVI)*. Although this was not a mission-critical issue, the loss of the fender caused Cernan and Schmitt to be covered with dust thrown up when the rover was in motion.

The crew then deployed the ALSEP, west of the immediate landing site after which they departed on the first geologic traverse of the mission. In this trip, they gathered 14 kg of samples took seven gravimeter measurements and deployed two explosive packages to test geophones that had been placed by the astronauts and seismometers that had been placed on previous Apollo missions. The EVA ended after seven hours and twelve minutes.

The second lunar excursion started on December 12th, at 6:28 PM EST. One of the first tasks was repairing the right-rear fender on the LRV. They did this by taping together four cronopaque maps with duct tape and clamping the replacement fender extension to the fender, thus providing a means of preventing dust from raining down upon them while in motion. During this EVA, they sampled several different types of geologic deposits found in the valley, including orange-colored soil. The moonwalk completed after seven hours and thirty-seven minutes. They collected 34 kg of samples, deployed three more explosive packages and took seven gravimeter measurements.

The third moonwalk, the last of the Apollo program, began at 5:26 PM EST on December 13th. During this excursion, the crew collected 66 kg of lunar samples and took nine gravimeter measurements. Before ending the moonwalk, the crew collected a rock, a breccia, and dedicated it to several different nations which were represented in the Mission Control Center at the time. A plaque located on the Lunar Module, commemorating the achievements made during the Apollo program, was then unveiled. Before reentering the LM for the final time, Gene Cernan expressed his thoughts:

I'm on the surface; and, as I take man's last step from the surface, back home for some time to come – but we believe not too long into the future – I'd like to just [say] what I believe history will record. That America's challenge of today has forged man's destiny of tomorrow. And, as we leave the Moon at Taurus-Littrow, we leave as we came and, God willing, as we shall return: with peace and hope for all mankind. Godspeed the crew of Apollo XVII.

Cernan then followed Schmitt into the LM after spending approximately seven hours and 15 minutes outside during the final lunar excursion.

Cernan and Schmitt lifted off from the lunar surface on December 14th, at 5:55 PM EST. After a successful rendezvous and docking with CSM, the crew transferred equipment and lunar samples between the LM and the CSM. Then, the LM ascent stage was sealed off and jettisoned at 1:31 AM on December 15th and deliberately crashed into the Moon in a collision recorded by seismometers deployed on Apollo XVII and previous Apollo expeditions.

On December 17th, during the trip back to Earth, at 3:27 PM EST, Ron Evans successfully conducted a one hour and seven minute spacewalk to retrieve exposed film from the instrument bay on the exterior of the CSM.

On December 19th, the crew jettisoned the no-longer-needed SM, leaving only the CM. Splashdown occurred in the Pacific Ocean at 2:25 PM, 6.4 km from the recovery ship, the *USS Ticonderoga*. Astronauts were then retrieved by a recovery helicopter and were safely aboard the recovery ship 52 minutes after landing.

In 2009 and again in 2011, the Lunar Reconnaissance Orbiter photographed the landing site from increasingly low orbits.

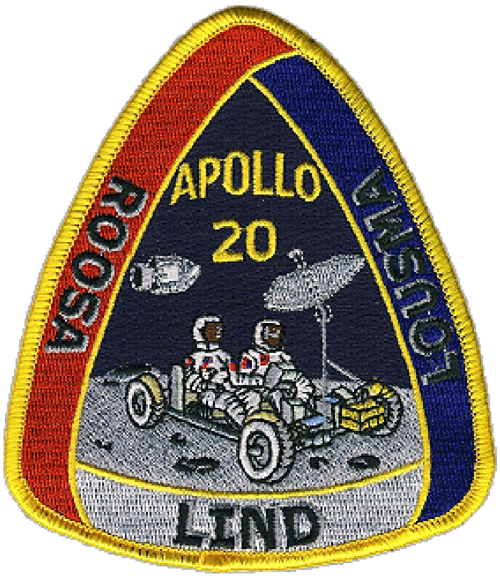
ANNEX

a. Eugene Cernan, Ronald Evans, and former X-15 pilot Joe Engle were assigned to the backup crew of Apollo XIV. Following the rotation pattern that a backup crew would fly as the prime crew three missions later, Cernan, Evans, and Engle would have flown Apollo XVII.
b. Harrison Schmitt served on the backup crew of Apollo XV and, following the crew rotation cycle, was slated to fly as Lunar Module Pilot on Apollo XVIII. However, Apollo XVIII was cancelled in September 1970 and following this decision, the scientific community pressured NASA to assign a geologist to an Apollo landing. In light of this pressure, Schmitt, a professional geologist, was assigned the LM Pilot position on Apollo XVII.
c. Subsequent to the decision to assign Schmitt to Apollo XVII, there remained the question of which crew *(the full backup crew of Apollo XV, Dick Gordon, Vance Brand, and Schmitt, or the backup crew of Apollo XIV)* would become prime crew of the mission. NASA Director of Flight Crew Operations Deke Slayton ultimately assigned the backup crew of Apollo XIV *(Cernan and Evans)*, along with Schmitt, to the prime crew of Apollo XVII.
d. Throughout the Apollo lunar missions, the crew members observed light flashes that penetrated closed eyelids. These flashes, described as *streaks* or *specks* of light, were usually observed by astronauts while the spacecraft was darkened during a sleep period. These flashes, while not observed on the lunar surface, would average about two per minute and were observed by the crew members during the trip out to the Moon, back to Earth, and in lunar orbit.
e. The Apollo XVII crew conducted an experiment, also conducted on Apollo XVI, with the objective of linking these light flashes with cosmic rays. As part of an experiment conducted by NASA and the University of Houston, one astronaut wore a device that recorded the time, strength, and path of high-energy atomic particles that penetrated the device. Analysis of the results concluded that the evidence supported the hypothesis that the flashes occurred when charged particles travelled through the retina in the eye.
f. Some media call *Apollo XVIII* the vehicle that was used for the Apollo-Soyuz mission *(ASTP)* but this is was never an official NASA release.
g. A total of 382 Kg of lunar samples were collected by the Apollo missions that landed on the Moon.

18. APOLLO XVIII – APOLLO XX

NASA had established, back in 1968, an Apollo Applications Program *(AAP)* taking advantage of Apollo's XVIII through XX for the purpose of increasing scientific lunar exploration and to pave the way for a permanent lunar base.

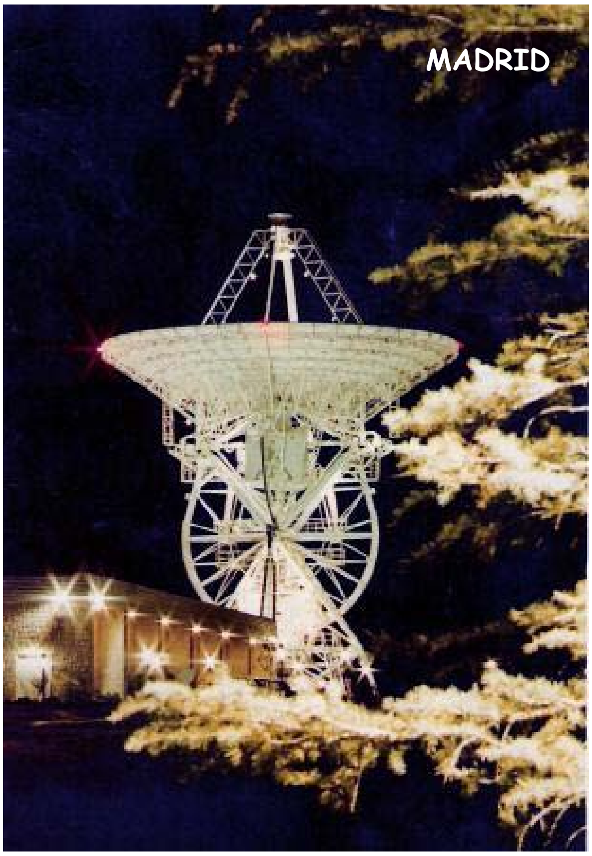
Shortage of funds and little interest by the tax payers did away with the project. Several insignias had been made for these last Apollo's however. Here are some of them:



19. TRACKING NETWORK

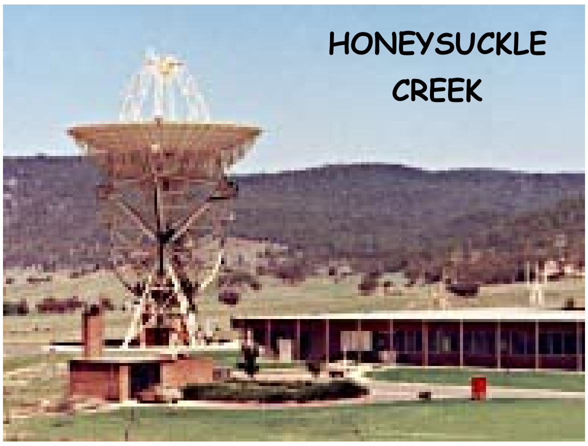
The Apollo Program was the most aggressive, intuitive, work demanding and brain teasing/storming of the decade of the 60s. It ended up as an unprecedented success; many times due to pure luck but most of the times due to human ingenuity and knowledge.

But this Program would not have been possible without the ***MSFN*** *(Manned Space Flight Network)*. These comprised the use of ground tracking stations



throughout the world, tracking ships, tracking aircraft and the most complex communications network ever configured for a specific task.

The principal elements of NASA's ground support system were the 26 m.



antennas at Madrid, Spain; Honeysuckle Creek, Australia; and Goldstone, California. These stations were supplemented by their DSN *(Deep Space*

Network) counterparts, who resided in the same countries, and acted as *WING SITES (backups)*.

Also, NASA had three *AIS (Apollo Instrumentation Ships) Mercury, Redstone,* and *Vanguard*, all equipped with several 9 m. antennas, and a Missile Range Instrumentation Ship, *Huntsville.*

There were also, four Apollo Range Instrumentation Aircraft *(ARIA)*, which originally were Boeing C-135 Stratolifter cargo aircraft and were latter modified by a contract among NASA, DoD, McDonnell Douglas and Bendix to include a steerable 2.1 m. antenna dish in its distinctive *Droop Snoot* or *Snoopy Nose*. The EC-135N ARIA became operational in January 1968.

The rest of the network was composed of several 9 m. land antennas with S-Band capabilities located around the globe plus several more locations which had VHF or UHF or C-Band Radar or some or all of them.

A few of the most known due to the amount of contacts with Apollo space craft were:

1. Related to launch and early orbit: MERRITT ISLAND *(MILA)*, BERMUDA *(BDA)*, CORPUS CHRISTI *(TEX)*, and CANARY ISLANDS *(CYI)*.

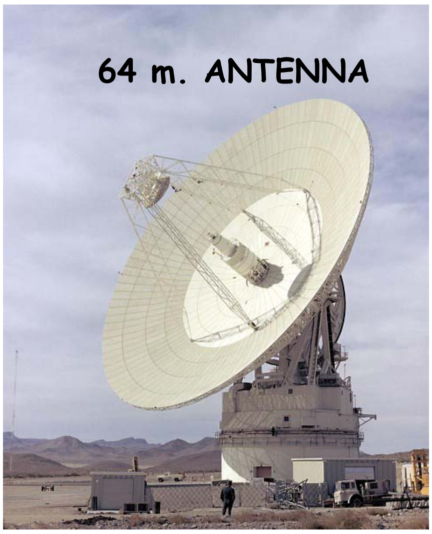
2. Related with orbital operations and reentry: ANTIGUA *(ANG)*, ASCENSION ISLAND *(ACN)*, CORPUS CHRISTI *(TEX)*, GRAND BAHAMA ISLAND *(GBM)*, GUAM *(GWM)*, GUAYMAS *(GYM)*, and KAUAI *(HAW)*,

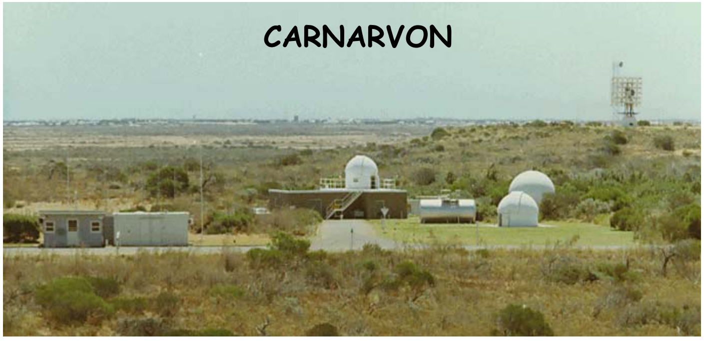
In addition, the 64 m. antenna of the Jet Propulsion Laboratory station at Goldstone and the 64 m. antenna of the Australian Commonwealth Scientific and Industrial Research Organization at Parkes, Australia, were used in support of the actual lunar landing and extravehicular activities whenever possible.

Voice and data communications to all these stations from MCC were routed through the Goddard Space Flight Center in Maryland and subsequently through subsidiary switching centers at Canberra, London, Madrid, and Honolulu.

Not directly related to tracking but to prevent astronaut accidents due to excessive radiation was the *SPAN (Solar Particle Alert Network)*. The three NASA multiple-telescope observatories were spaced approximately 120° around the world and maintained a continuous monitor of Sun flare activity. These observatories were: Boulder, USA; Canary Islands, Spain; and Carnarvon, Australia.

And finally, some of the 9 m. locations having S-Band systems, also had X-Band and C-Band radars and were used as Range Safety Stations. These were used to ensure that a launch vehicle malfunction would not cause any danger to the general population. The Range Safety Officer *(RSO)* had the responsibility of aborting or destroying a vehicle that flew outside of its normal path and could endanger people. During Apollo, some of these stations were: The Bahamas and Antigua, though NASA also received information on range safety from Argentina, Newfoundland; Wallops Island, Virginia; or the Kennedy Space Center *(KSC)*.





20. ACKNOWLEDGEMENTS

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22. GLOSSARY OF TERMS

AAP	Apollo Applications Program
AIS	Apollo Instrumentation Ship
ALFMED	Apollo Light Flash Experiment
ALSEP	Apollo Lunar Surface Experiments Package
APS	Ascent Propulsion System
ARIA	Apollo Range Instrumentation Aircraft
ASPO	Apollo Spacecraft Program Office
ASTP	Apollo-Soyuz Test Program
CapCom	Capsule Communicator
CM	Command Module
CMDR	Commander
CMP	Command Module Pilot
CSM	Command and Service Module
DoD	Department of Defense
DOI	Descent Orbit Insertion
DPS	Descent Propulsion System
DSN	Deep Space Network
EASEP	Early Apollo Scientific Experiment Package
EECOM	Electrical, Environmental and Consumables Manager
EMU	Extra Vehicular Mobility Unit
EST	Eastern Standard Time
ETB	Equipment Transfer Bag
EVA	Extra Vehicular Activity
GMT	Greenwich *Mean Time*
GSFC	Goddard Space Flight Centre

GSE	**Ground Support Equipment**
ICBM	**Inter Continental ballistic missiles**
IU	**Instrumentation Unit**
LC	**Launch Complex**
LM	**Lunar Module**
LMP	**Lunar Module Pilot**
LRV	**Lunar Roving Vehicle**
MCC	**Mission Control Centre**
MDSCC	**Madrid Deep Space Communications Complex**
MEED	**Microbial Ecology Evaluation Device**
MET	**Modular Equipment Transporter**
MIT	**Massachusetts Institute of Technology**
MSFN	**Manned Space Flight Network**
MSS	**Mobile Service Structure**
NAA	**National Aeronautic Association**
NASA	**National Aeronautics and Space Administration**
OPS	**Operations**
PFS	**Particles and Fields Sub satellite**
PLSS	**Portable Life Support System**
PTC	**Passive Thermal Control**
RSO	**Range Safety Officer**
SA-XYY	**Saturn/Apollo**
	X = Saturn type
	YY = Model of Saturn used (X)
	E.G. AS-503 (03rd model of a Saturn V for Saturn/Apollo)
SCE	**Signal Conditioning Equipment**

SEP	**Surface Electrical Properties**
SIM	**Scientific Instrument Module**
SM	**Service Module**
SPAN	**Solar Particle Alert Network**
SPS	**Service Propulsion System**
STS	**Space Transportation System**
S-IC	**First Stage of a Saturn V Vehicle**
S-II	**Second Stage of a Saturn V Vehicle**
S-IVB	**Third Stage of Saturn V**
TEC	**Trans Earth Coast**
TEI	**Trans Earth Injection**
TGE	**Traverse Gravimeter Experiment**
TLI	**Trans Lunar Injection**
TLC	**Trans Lunar Coast**
TONY	**Anthony Wayne (Tony) England (EVA CapCom)**
ULT	**Umbilical Launch Tower**
VAB	**Vehicle Assembly Building**