
# America's Greatest Projects and their Engineers – VIII – Part 1

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# I. Tragedy and Death Before the First Apollo Flight

Everything seemed to be going well for the Apollo Project, the third in a series of space projects by the United States intended to place an American astronaut on the Moon before the end of the 1960's decade. Apollo 1, known at that time as AS (Apollo Saturn)-204 would be the first manned spaceflight of the Apollo program, and would launch a few months after the flight of Gemini 12, which had occurred on 11 November 1966. Although Gemini 12 was a short duration flight, Pilot Buzz Aldrin had performed three extensive EVA's (Extra Vehicular Activities), proving that Astronauts could work for long periods of time outside the spacecraft.

The three U. S. Astronauts were in the Block 1 Command Service Module at the Kennedy Space Flight Center on Launch Pad Complex No. 34. They had been putting the CSM through a rigorous test in preparation for what would be their journey into outer space on 21 February 1967. The astronauts, Commander Gus Grissom and Pilots Roger Chaffee and Ed White, outfitted in their shiny new spacesuits, had just about completed their pre-launch activities for the day.

Suddenly, a spark (believed to have come from a loose terminal connection) ignited a bundle of wires in the oxygen-saturated CSM, and the fire quickly spread throughout the module. Even though the CSM had two escape hatches (the three-part main hatch and a boost hatch), neither could be opened in less than ninety seconds, and the new nylon spacesuits, rather than offering any type of fire protection, likely contributed to the deaths of the Astronauts. The fatal date of that tragic fire was **27 January 1967**.

## A. The Three Lives that Were Lost

On that tragic day in January of 1967, those killed in this fatal fire, the first to take the life of a U. S. astronaut during an actual spaceflight mission, were:

**Lt. Colonel Virgil "Gus: Grissom:** age 41, from Mitchell, Indiana with a BS in Mechanical Engineering from Purdue University. Grissom flew 100 combat missions in the Korean War and was a test pilot at the Wright-Patterson Air Force Base near Dayton Ohio. Selected as one of the first seven U. S. Astronauts in 1959, Grissom flew in the Mercury Project (MA-4) and became the second American in space. He was also the Command Pilot for Gemini 3, was the first of the corps of U. S. astronauts to fly in space twice, and might have become the first American to walk on the Moon if not for his untimely death.

**Lt. Colonel Edwin H. White:** age 36, from San Antonio, Texas, received a BS degree from the U. S. Military Academy, and later received his MS degree in Aeronautical Engineering from the University of Michigan. White spent three and a half years in West Germany, flying in the

22nd Fighter Day Squadron in defense of our NATO allies. He earned his credentials as a test pilot at the Wright-Patterson Air Force Base, logging more than 2,200 hours in jet aircraft. He was a member of NASA's second Group of Nine Astronauts, and quickly moved up the pecking order due to his knowledge and intellect. He was the Pilot on Gemini 4, which completed 66 Earth orbits, and became the first American to walk in space, for approximately 20 minutes. This accomplishment helped the United States overcome the Soviet Union's early lead in the Space Race.

**Lt. Commander Roger B. Chaffee:** age 32, from Grand Rapids, Michigan, received his BS in Aeronautical Engineering, also from Purdue University. A Naval Aviator, Chaffee flew over 100 missions to Guantanamo Bay during the time of the Cuban Missile Crisis brought on by the Soviet Union. Along with thirteen other pilots, Chaffee was selected to be an astronaut as part of NASA's Group 3 in 1963. Although he never flew in the Gemini program, he served as Capsule Communicator for both the Gemini 3 and Gemini 4 missions, being the only one allowed to directly communicate with the crew of those spaceflights. Chaffee finally received his first spaceflight assignment in 1966, which was to be on Apollo 1.

# B. Investigation, Findings & Recommendations

## Investigation

Following the fire, NASA immediately formed a Review Board that consisted of seven members, and began meeting the next day after the fire. Included on the Board were such distinguished NASA personnel as Maxime Faget, the principal designer of the one-man and two-man capsules used in the Mercury Project and Project Gemini. Also named to the Board was Lt. Colonel Frank Borman, who had been selected by NASA in the second astronaut group and had set a fourteen-day spaceflight endurance record on Gemini 7. The Board was chaired by Dr. Floyd L. Thompson and was charged with the responsibility to review the evidence related to the fire and to recommend changes to reduce the hazards within the CSM as well as those inherent in the Apollo Program. The Board met almost daily, often twice daily, for two months following the fire. Both houses of the U.S. Congress conducted their own hearings in an attempt to oversee the Review Board's investigation.

**Dr. Floyd L. Thompson (1898–1976)** was the third Director of NASA Langley Research Center, serving in that capacity from 1960 to 1968. Born in Salem, Michigan, he served four years in the United States Navy following graduation from high school. After his military service, he entered the University of Michigan and was awarded a Bachelor of Science degree in Aeronautical Engineering in June 1926.

He was an outstanding Research Center leader during the challenging beginning of the crewed space flight era. He guided research leading to programs of international importance, including Project Mercury as well as the concept of erectable space vehicles which led to the development of *Echo*, the world's first passive communications satellite. He was also responsible for the solid-fueled launch vehicle, Scout, which was used to propel a satellite into orbit.

He began his career at the NACA (National Advisory Committee Aeronautics) Langley Memorial Aeronautic Laboratory after graduation, where he specialized in flight instrumentation and operations, and pressure and loads measurements. Thompson progressed through various assignments to become Langley's Chief of Research, was appointed Associate Director in charge of all research, and became Director of Langley in May 1960. Thompson had been awarded honorary doctorate degrees for his outstanding career in the flight sciences and for his development of the space flight teams necessary for the Mercury Project and Project Gemini by both the University of Michigan and the College of William and Mary.

As the chairman of the Apollo 204 (later Apollo 1) Review Board, Thompson and his committee were tasked with determining the causes of the tragedy and the recommendations for preventing anything close to a similar occurrence in the future. Because of the critical nature of the fire and the politics of the Space Race, they first met on 28 January 1967 and usually twice daily thereafter to review proposed plans, to determine requirements for testing and analysis of the data, and to provide basic direction. Witnesses were interviewed and film and other evidence was thoroughly reviewed. Command Module 012, as it was known to the NASA Administration before it became forever known as part of Apollo 1, was taken apart at the launch complex. When the Review Board determined that tests had progressed to a point where the Command Module could be removed without disturbing the evidence, CM 012 was transferred to the Pyrotechnic Installation Building on 17 February 1967.

## Time Was a Major Factor

Command Module 014, originally scheduled to be flown as Apollo 7, had been shipped to the Kennedy Space Center on 01 February 1967 to establish exact location and condition of all components prior to the accident. CM 012 was painstakingly taken apart component by component and studied closely, with any and all components that showed evidence of abnormal fire effects being examined both internally and externally. Disassembly was completed two months after the fire by the end of March 1967.

In just slightly over two months from the time of the tragedy (can you just imagine how long that investigation would take today?), he and the Review Board presented their findings and recommendations to James E. Webb, NASA's Administrator, on 05 April 1967. Although nearly a dozen findings and recommendations were offered, some of them were redundant or inconclusive, but all of them were sincere and illustrated deep concern about astronaut safety as well as that of the entire NASA support staff.

Numerous witnesses were called to testify before the Review Board, nearly all of them NASA department heads and engineers, during the two-month investigation. One of the most compelling testimonies was given by **Dr. Joseph F. Shea**, at the time the head of the Apollo

Spacecraft Program Office. A Bronx native, Dr. Shea received his Ph. D. in Engineering Mechanics from the University of Michigan. He went to work for NASA in 1961 and played a key role in shaping the course of the Apollo Program. He had been a leading proponent in NASA's decision which favored lunar orbit rendezvous, and supported design and testing of the Saturn V rocket which would carry astronauts into outer space and to the Moon. Unfortunately for Dr. Shea, who was considered by many to be the top "systems engineer" of his time, he apparently became too personally and too deeply involved in the investigation. After urging his colleagues to move quickly with the investigation and to implement the necessary changes in order to put some distance between the USA and the Soviet Union regarding the "Space Race", he suffered a nervous breakdown. Subsequently, the stress of the tragedy caused NASA to replace him in late 1967, and he left NASA shortly thereafter.

A condensed synopsis of those findings and recommendations is listed below:

### Finding 1:

The CSM had a momentary power failure. Return of power quite likely caused an electrical arcing, possibly in more than one location.

### Recommendation:

A sub-committee listed the many fire hazards that were present at the instant that the fire erupted. However, there was no mention of backup or redundant power, shielding, grounding, surge protection or even fire suppression. They did identify the most probable location as the ECS (Environmental Control System) where the initial arcing occurred, and they did offer the statement that "No evidence was discovered that suggested sabotage." Many of the NASA engineers and astronauts were disappointed with this inconclusive determination.

### Finding 2:

The CSM contained many types and classes of combustible material in areas contiguous to possible ignition sources. That included notebooks, test reports and other non-inflammable materials near the astronauts' couches. Tests were performed in the full oxygen environment to which the three astronauts had been subjected. This verified that the CSM test conditions were extremely hazardous.

### Recommendation:

The amount and location of combustible materials in the Command Module must be severely restricted and controlled.

## Finding 3:

Due to internal pressure, the Command Module inner hatch could not be opened prior to rupture of the Command Module. The crew was never capable of effecting emergency egress because of the pressurization before rupture and their loss of consciousness soon after rupture. The astronauts' rescue was prevented by the **plug door hatch**, which could not be opened against the higher internal pressure of the cabin. The door was designed, similar to that typically used on an aircraft, to seal itself by taking advantage of the higher pressure on the inside of the module, forcing the wedge-shaped door into its socket, making a good seal and preventing it from being opened until the pressure was released. There was also a failure to identify the test as hazardous since the rocket was unfueled, thus leading to the erroneous assumption that emergency preparedness would not be a priority.

## Recommendation:

That the time required for egress of the crew be reduced and the operations necessary for egress be simplified. The problem with hatches had been prevalent since the first capsule design, and much time and engineering effort would be dedicated to better and quicker hatch openings and closings.

## Finding 4:

Adequate safety precautions were neither established nor observed for this test. The organizations responsible for the planning, conduct and safety of this test failed to identify it as being hazardous. No procedures for this type of emergency had been established.

## Recommendation:

Those responsible must continually monitor CSM activities and have contingency plans for escape or rescue. Emergency fire, rescue and medical teams must be in attendance, and service structures and umbilical towers must be modified to facilitate emergency operations.

## Conclusion:

Two of the findings were mostly directed to the actual design deficiencies of the space capsule (CSM) by it manufacturer, North American Aviation. The first dealt with the Environmental Control System and its reliance on a pure oxygen system, recommending either a diluent gas or a well-monitored two-gas system be used instead. The second finding directed at North American Aviation was in regard to the deficiencies which existed in their Command Module design, workmanship and quality control. They were cited for having nearly 100 items on a punch list which had not been corrected.

While there could be no rational excuse for the fatal tragedy which occurred, the Block 1 CSM did not seem to have the same safety priorities as the Block 2 CSM. The former was to be considered as the prototype design spacecraft, and would only be used for low Earth orbit flights, whereas the Block 2 would be the lunar-capable version. Block 2 would have a docking hatch and would incorporate weight reduction and lessons learned in Block I. Note: you will learn more about the differences between Block 1 and Block 2 CSM's later in this course.

Detailed design of the docking capability depended on design of the LEM (Lunar Excursion Module), which had been contracted to the Grumman Aircraft Corporation. Corrections of the problems which caused the fire were applied to the Block II spacecraft, which was ultimately used for all manned missions. Although the Congressional hearings cleared them of liability for the fatal accident, NAA received such heavy criticism following the fatal fire on 27 January 1967 that they were required to seek some financial relief in order to survive. In March, 1967 NAA merged with Rockwell-Standard, and the merged company became known as North American-Rockwell. While American astronauts had been killed in pre-training, not one astronaut had ever perished during either the preliminary space travel training or in actual space travel, whether the astronauts were in a one-man space capsule (Mercury Project) or a two-man spacecraft (Project Gemini).

# II. Beginning of the Man on the Moon Concept

## A. Plans to Land on the Moon

The Apollo program was actually conceived during the Eisenhower administration in the early Spring of 1960. This was to be the follow-up to Project Mercury, which the United States was desperate to achieve. Project Mercury would be a means to catch up to the Soviet Union in the "Space Race", which had begun in October of 1957 when the Soviets launched Sputnik 1. The program was named by NASA's long-time manager of research, Abe Silverstein. He had also been credited with naming Project Mercury, and he chose the name early in 1960, because he felt "Apollo, the Greek God of light, music, and sun riding his chariot across the Sun was appropriate to the grand scale of the proposed program."

In July 1960, NASA Deputy Administrator Hugh L. Dryden announced the Apollo program to industry representatives at a series of Space Task Group conferences. Project Mercury was already well underway, and NASA had named their first seven astronauts who would be the first Americans to go into outer space. Much of the political process surrounding the U. S. presidential election of 1960 had centered around the seemingly great advantage that the Soviet Union had over America. The "Space Race" had continued to grow more intense with the public.

Initially, the issue of the "Space Race" took a back seat to the more pressing needs of the new Kennedy administration in early 1961. That ended abruptly on **12 April 1961** when Soviet

Cosmonaut Yuri Gagarin on a Vostok spacecraft became not only the first human in outer space but also the first to orbit the Earth before parachuting to a safe landing on a farm in Western Russia. The U. S. did launch a flight less than three weeks later on **05 May 1961** with Astronaut Alan Shepard piloting Freedom 7, it was a suborbital, short-duration flight that traveled only three hundred miles. While this was the first space flight of the U. S., President Kennedy was distraught over the Soviets increasing their lead in the "Space Race", and requested Vice President Lyndon Johnson to set up a meeting with NASA administrators.

In that meeting, that included James E. Webb, the NASA administrator, Dryden suggested that manned flight to the Moon was the best way to "catch up" with the Soviet Union in the "Space Race". Although historians would have a difficult time trying to determine who first conceived the idea of landing an American on the Moon and returning him safely to Earth, the proposition took hold. President Kennedy, who saw the Soviets as a major "Cold War" threat and had grown frustrated over the constant barrage of their space exploits, made his now-famous announcement to a joint meeting of the U. S. Congress. On 25 May 1961, twenty days after the Freedom 7 spaceflight, Kennedy proposed the manned Moon landing, and suggested that the U. S. should "commit to achieving the goal of landing a man on the Moon and returning him safely to Earth" by the end of the decade (1960's). Kennedy's speech became the Genesis for the Apollo Project.

## B. Design Considerations and Decisions

Project Mercury had realistically begun in the Spring of 1959 when the first seven American astronauts were selected. While the Mercury spacecraft was a module that could only support one astronaut on a limited Earth orbital mission, the spacecraft for the Apollo Project would need to carry at least three astronauts. Plans for the Apollo program included transporting astronaut crews to and from a **Space Station**, developing **circumlunar flights**, and eventually carrying out **manned lunar landings**. Landing men on the Moon by the end of 1969 would require an enormous composite of technological creativity, and would undoubtedly be the largest financial commitment of resources since World War II. The ultimate cost would prove to be more than $25 billion, a large commitment by the U. S. during peacetime. At its peak, the Apollo program would employ nearly 400,000 personnel, and would require the support of several thousand industrial firms and dozens of universities.

## 1. Rockets - Launch Vehicles

There were several options which were being considered in order to eventually land an American on the Moon; to compound the early dilemma with the project, some in NASA did not think that the mission was possible, and many more had serious doubts the project would accomplish its goal by the end of the 60's. Early options for placing a man on the Moon included the following:

1. Direct flight from the Earth to the Moon

2. Earth Orbit Rendezvous (EOR)

3. Lunar Orbit Rendezvous (LOR)

1. The Space Task Group, which was responsible for Project Mercury and the Headquarters Office of Launch Vehicle Programs, favored using the Nova rocket for a direct flight from Earth to the Moon. Landing the entire spacecraft on the lunar surface, as would be necessary with a direct flight approach, would have required a large increase in rocket thrust. This would mean a much heavier load of fuel tanks and fuel, which NASA estimated at nearly one hundred tons.

2. Marshall Space Flight Center advocated an Earth Orbit Rendezvous. This method would require the use of several smaller Saturn launch vehicles to rendezvous in a Low Earth Orbit LEO). One of the vehicles would then be refueled in orbit for the long flight to the Moon.

3. Key members of the Langley Research Center advocated the LOR. Its premise was to have one spacecraft launched from Earth, travel and orbit the Moon’s surface, and detach a separate spacecraft, known as an LEM (Lunar Excursion Module), down to the Moon’s surface. The LEM would then rendezvous and re-attach to the Moon-orbiting spacecraft.

We do know that NASA authorized several serious studies on a direct landing method for the Apollo program, but dropped the ideas because they would require too big a rocket. After much review by NASA administrators and engineers, the LOR method was selected. The payload for the LOR was estimated to be just slightly over 45 tons. In addition, the LOR method would require only one large booster instead of the two required for either of the other two options. At the time the decision to not need so big a rocket was very logical; the Atlas rocket for the Mercury Project was still in development, which had necessitated that the smaller Redstone rocket be used to launch the first American astronaut (Alan Shepard) into space. Furthermore, the Titan I and Titan II rockets, which would eventually be used for the manned spaceflights of Project Gemini, were still on the drawing board at Aerojet General since the “bridge project” between Mercury (Gemini) and Apollo had yet to be announced.

## Rocket Requirements - Saturn Family

During the month of January 1961, a committee headed by George Low, Program Chief for Manned Space Flight, examined the manned lunar landing program. The committee concluded in its 7 February report that both direct ascent and earth-orbital-rendezvous methods were feasible. Using the Saturn C-2, the latter could be achieved at an earlier date (1968-69), but posed a high launch rate in a short period of time (six or seven C-2s for the 8,000 lb. spacecraft) and a mastery of rendezvous techniques. The direct ascent mode would take two years longer, depending on the development of the super rocket which had been named the Nova rocket.

On 01 July 1960, NASA had established the George C. Marshall Space Flight Center in Huntsville, Alabama. The history of the MSFC dated back to shortly after the end of World War II. 127 missile specialists led by Dr. Wernher von Braun signed work contracts with the U. S. Army's Ordnance Corps. Most of them had worked on the V-2 missile development under von Braun at Peenemunde, Germany. Von Braun and the other Germans were moved around the U.S. over the next several years, before settling at the Redstone Arsenal in Huntsville. In October 1948, the Chief of Ordnance for the Army Ballistic Missile Agency (ABMA) designated Redstone Arsenal as the center of research and development activities in free-flight rockets and related items, and the following June, the Ordnance Rocket Center was opened.

Beginning in April 1950, about 1,000 persons were involved in the transfer to Huntsville, including von Braun's group. At this time, R&D responsibility for guided missiles was added, and studies began on a medium-range guided missile that eventually became the Redstone rocket. Although this rocket was primarily intended for military purposes, von Braun kept outer space firmly in his mind, and published a widely read article on this subject in 1952. That year he used a WAC Corporal rocket as a second stage for a V-2; the combination, called Bumper, reached a record-breaking 250 miles altitude. Von Braun was appointed Chief of the Guided Missile Development Division later that year.

The Army's official role in the U.S. space satellite program was delayed, however, after higher authorities elected to use the Vanguard rocket then being developed by the Naval Research Laboratory (NRL). While competition for U. S. space travel supremacy was being waged among the three military branches in the Department of Defense, the Soviet Union launched Sputnik 1, the first man-made earth satellite, on **04 October 1957**. This was followed on 03 November with the second satellite, Sputnik 2. The United States attempted a satellite launch on 06 December, using the NRL's Vanguard rocket, but it barely struggled off the launch pad, then fell back and exploded. After finally receiving permission to proceed despite the fact that their missile was part of a military defense program, von Braun and the ABMA space development team combined a Jupiter C in a Juno 1 configuration. By incorporating a fourth stage to the rocket, they were able to successfully place Explorer 1, the first American satellite, into orbit around the earth on **31 January 1958**.

Finally, the U.S. Army Ordnance Missile Command (AOMC), was established at Redstone Arsenal, and they were permitted by ABMA to develop a large space booster of approximately 1.5 million-pounds thrust using a cluster of available rocket engines. In early 1959, this vehicle was first designated as Saturn. The U.S. manned satellite space program, using the Redstone as a booster, was officially named Project Mercury on 26 November 1958. There followed a typical political squabble over the next eighteen months, when the Air Force proposed a Super Nova rocket that would be better and cheaper than the Saturn. However, its development was barely in the design stage, whereas the Saturn had construction drawings and parts on the ground. NASA solved the infighting by absorbing the ABMA. Effective 01 July 1960, 4,670 civilian employees, about $100 million worth of buildings and equipment, and 1,840 acres of land transferred from AOMC/ABMA to NASA's George C. Marshall Space Flight Center in Huntsville, Alabama. MSFC was named in honor of General George C. Marshall, U. S. Army Chief of Staff during World War II, U. S. Secretary of State, and Nobel Prize winner for his world-renowned Marshall Plan, which was the rebuilding of war-torn Europe.

The United States launched 32 Saturn rockets between 1961 and 1975. The Saturn family of rockets included the Saturn 1 (10 launches), Saturn 1B (9 launches), the three-stage Saturn V (12 launches), and the two-stage Saturn V (1 launch). Although some flights experienced significant problems, no Saturn rocket would ever fail catastrophically in flight. In addition to Saturn rockets being used in support of the Apollo lunar missions, they would also be used later for the launch of the Skylab space station, ferrying crews to and from Skylab, and to launch the American half of the Apollo-Soyuz Test Project.

## Saturn 1

The U.S. Army Ballistic Missile Agency (ABMA), under the direction of Wernher von Braun, began developing the Saturn I rocket in 1957. The unique first stage was composed of a cluster of eight Redstone booster rockets around a Jupiter tank. This clustering of smaller boosters, rather than manufacturing larger rockets, allowed the use of tooling from the Redstone and Jupiter missile programs. The first Saturn rocket to fly was the Saturn I, which had a thrust capacity of about 200,00 lbf, and was the first launch vehicle that was capable of carrying more than 20,000 pounds into outer space and propelling the load into a Low Earth Orbit (LEO). Designed specifically to launch larger payloads, most of the rocket's power came from a clustered lower stage consisting of boosters taken from older rocket designs strapped together to make a single large booster. Its design proved sound and very flexible. Although it served only for a brief period for NASA, ten Saturn I rockets were flown before it was replaced by the Saturn 1B, its successor, which featured a more powerful upper stage and improved instrumentation.

America's ambitious manned space travel plans included the design of a heavy-lift launch vehicle by a team headed by Dr. von Braun and his V-2 engineers. Chrysler Corporation had opened a Huntsville operation in the 1950's, which was designated as their Space Division. It became Marshall Space Flight Center's prime contractor for the first stage of both the Saturn 1 and Saturn 1B rocket versions. The design, based on this cluster of boosters from the Redstone as well as the Jupiter missiles, was actually the first nuclear-tipped, medium-range ballistic missile (MRBM). Chrysler built them for the early Apollo program at their huge Michoud Assembly Plant, one of the largest manufacturing plants in the world, in East New Orleans. Between October 1961 and July 1965, all of Chrysler's missiles and boosters were successful and NASA never suffered a launch failure.

Figure 1. Saturn-1 on 27 January 1961

SA-1 was the first flight of the Saturn 1 space launch vehicle and first mission of the Apollo program. The rocket was launched on 27 October 1961 from Cape Canaveral, Florida. The flight was suborbital, reaching an apogee of just over eighty-five miles. The SA-I first stage was powered by eight H-1 rocket engines, four smaller rockets in a cluster at the center and four larger rockets 90 degrees apart near the outer perimeter. The rockets burned RP-1 (refined petroleum) fuel with liquid oxygen (LOX) as the oxidizer. The four outboard engines were mounted on single-axis gimbals, allowing them to be steered to guide the rocket. On later versions of the Saturn rockets (SA-5 through SA-10), eight fins provided aerodynamic stability in the flight through the atmosphere. The size and other statistics of the SA-1 were also extremely impressive. SA-1 through SA-5 were each about 180 feet in height and weighed in excess of 560 tons, including stage three which was never actually used. Three more S-1 test rockets were launched from Cape Canaveral, two in 1962 and one in March of 1963. Each carried a dummy stage 2 rocket that was never fired, but the rocket carried no payload. The first four Saturn I missions were called Block 1-capable missions, meaning in this case that they flew with an S-I first stage and dummy upper stages,

**SA-5** was the first launch of the Block II-capable Saturn 1 rocket as part of the early Apollo program. On 16 November 1963, President Kennedy visited Cape Canaveral and met with Dr. von Braun. SA-5 was being planned as the first live test of the stage 2 rocket. After viewing the size of the Saturn 1 on the launch pad, Kennedy identified this launch, which was to occur in January, 1964, as the one which would place "U. S. lift capability ahead of the Soviet Union." The U. S. had continued to lag behind the Soviets in the "Space Race" since Sputnik 1 six years earlier. Ironically, President Kennedy never had the opportunity to see the actual launch of SA-5.

The next five launches of the Saturn 1 were also unmanned test flights and were known as Block 1 missions. The two in 1964 were the first to carry a Command Service Module (CSM) boilerplate, which was a mass simulation of a non-functional spacecraft in physical size and weight. They were used to test the characteristics of the Saturn launch vehicles with the larger payloads, as well as to determine the procedures for mating the spacecraft to the launch vehicle. Other features of the boilerplate CSMs provided engineers with methods for emergency access and egress, processes for transporting to the launch site, and various maintenance support activities.

Those launch vehicles included an uprated S-I stage. Early Saturn 1 missions flew without aerodynamic fins, but Block-II missions, starting with SA-5, included eight fins to provide stability. The second stage, called an S-IV, was built by Douglas Aircraft Company, and was powered by six Pratt and Whitney RL-10 engines. The engines were gimbaled and used liquid hydrogen and liquid oxygen as propellants. The Block-II missions included a boilerplate Apollo spacecraft and Launch Escape System (LES) tower. After first stage separation and second-stage ignition, the launch escape system was jettisoned. When the second stage attained orbit, the 10,000-pound Apollo boilerplate CSM was jettisoned into a separate orbit. These tests verified the aerodynamics of the Saturn rockets in the launch phase.

The last three missions of the Saturn 1 occurred in 1965, successfully launching the three Pegasus satellites. Among the largest payloads in orbit at that time, the Pegasus satellites were designed to detect micrometeoroid hits and to study the frequency of micrometeorite impacts on spacecraft. The MSFC was responsible for the design, production and operation of the three Pegasus satellites which were launched by Saturn I rocket test flights. At launch, the Pegasus experiment was folded inside the boilerplate Command Service Module. Then it was released and a motor driven device extended the wing-like panels on the Pegasus to a span of 96 feet. The Pegasus wings remained attached to the Saturn I's second stage as planned. The sensors were mounted on protective shields and successfully measured the frequency, size, direction and penetration of scores of micrometeoroid impacts. All three Pegasus missions provided more than just data on micrometeoroid penetration. Scientists also were able to gather data regarding gyroscopic motion and orbital characteristics of rigid bodies in space, lifetimes of electronic components in the space environment, and thermal control systems and the degrading effects of space on thermal control coatings. For physicists the Pegasus missions provided additional knowledge about the radiation environments of space known as the Van Allen Radiation Belt phenomena (to be discussed later)..

## Saturn 1B

The Saturn I design later evolved into the Saturn IB rocket design of the latter Apollo era. Although similar in actual size, the Saturn 1B was an uprated version of the Saturn 1. It generated slightly more thrust (1.6 M lbs. v 1.5 M lbs.) and replaced the S-1V second stage of the Saturn 1 with the much more powerful S-IVB, which had more than 225% of the thrust capacity of the S-1V. This new combination could now place a 62,000-pound payload into low Earth orbit. While the Apollo program was awaiting the development of Saturn V, the S-1B was able to launch a partially fueled Command Service Module (CSM) and eventually a fully fueled Lunar Excursion Module (LEM) into a Low Earth orbit (LEO) for early flight tests before the larger Saturn V was ready for lunar flights.

The Saturn I-B was a two-stage rocket and both stages were expended in launching their payload. The eight H-1 engines in its Chrysler-built S-IB first stage burned liquid oxygen (LOX) and RP-1. The **S-IVB** stage served double-duty as the second stage on the Saturn 1-B, and later as the Saturn V moon rocket's third stage. The S-IVB (sometimes referenced as S-4B) was built by the Douglas Aircraft Company at its main manufacturing facility in Long Beach, California. It had a single J-2 engine, which was a liquid-fuel cryogenic rocket engine. Since the propellants for the J-2 were liquid hydrogen (LH2) and liquid oxygen (LOX), the corresponding fuel tanks were smaller and lighter, saving a considerable amount of weight.

**Figure 2.** An Early Saturn IB

Built in the U.S. by the Rocketdyne Division of North American Aviation in Canoga Park, California, each J-2 engine produced about a quarter of a million pounds of thrust in a vacuum. I still remember visiting my aunt and uncle in Canoga Park in the sixties and hearing those engines being tested; the roar was deafening and the entire area vibrated.

Unlike most liquid-fueled rocket engines in service at the time, the J-2 was designed to be restarted once after shutdown when flown on the Saturn V S-IVB third stage. The first burn, lasting about two minutes, would place the Apollo spacecraft into a Low Earth "parking orbit", which was simply a temporary, stable orbit that permitted the crew and ground personnel to check out every aspect of the spacecraft and position it for translunar injection (TLI). After the crew had verified that the spacecraft was operating nominally, the J-2 would then be re-ignited, a six minute thirty second burn which would accelerate the modules on a course to the Moon.

The Instrument Unit ring above the second stage contained the Saturn IB's computer, built by IBM. This electronic brain controlled the rocket's flight path and in-flight events, such as first-stage separation and second-stage ignition. The part above that ring, which was labeled the "Apollo spacecraft," was in fact composed of several major systems. These included the Command Module, Service Module (which would be jettisoned before re-entry), and the Lunar Excursion Module (LEM). The long, skinny Launch Escape System (LES) tower at the very top contained a solid-propellant rocket motor designed to pull the three-man CSM to which it was attached to safety in the event the Saturn IB malfunctioned.

Of the nine Saturn 1B launches, the first three missions were planned to be unmanned. Saturn 1B's first mission, designated at that time as AS-201, occurred on 26 February 1966. It was an unmanned suborbital test of the Block I CSM (Command Service Module). The second launch (AS-203) occurred on 05 July 1966, but had no spacecraft in order to lighten the load, since the S-IVB on the Saturn IB needed all of its propellant to achieve Low Earth Orbit. NASA engineers and scientists studied the behavior of unburned LH2 in orbit to support the ability of the S-1VB rocket to restart in a weightless atmosphere. Mission AS-202 occurred on 25 August 1966 and was also an unmanned suborbital flight to test a heavier Block 1 CSM. The next mission (AS-204) was to be the first manned orbital test of the Block 1 CSM, which was planned for 21 February 1967. Because of the tragedy that was described earlier, this mission never occurred.

Nevertheless, Saturn IB rockets did manage to carry CSM spacecraft bearing U. S. astronauts into LEO once as part of the Apollo program. Mission AS-204 was continued after a nearly year-long delay in the program. On **22 January 1968** S-1B would launch an unmanned orbital test of the Lunar Excursion Module (LEM). This was followed later that year on 11 October 1968 with the first piloted Saturn IB, formally mission SA-205, but now known as **Apollo 7**. Apollo 7 was the last mission of the Saturn 1B in the Apollo program. In 1973, the year after the Apollo lunar program ended, three Apollo CSM/Saturn IBs ferried crews to the Skylab Space Station. In 1975, one last Apollo/Saturn IB launched the Apollo portion of the joint U. S.-Soviet Union Apollo-Soyuz Test Project. The remaining Saturn IB's in NASA's inventory were scrapped after the ASTP mission, as no use could be found for them and all heavy lift needs of the US space program could be serviced by the cheaper and more versatile Titan III family of rockets.

## Saturn V

On 10 January 1962 NASA announced plans to build the **C-5**, a three-stage rocket consisting of the S-IC first stage, the S-II second stage, and the S-IVB third stage. The C-5 would be designed for a 90,000-pound (45 ton) payload capacity, capable of carrying American astronauts to the Moon. This was to be the largest production model of the Saturn family of rockets, and was already in the process of being designed at the Marshall Space Flight Center in Huntsville under the direction of Dr. Von Braun. Von Braun and his team had been working on greatly improving rocket thrust in Huntsville since 1950 and had created a less complex operating system, designing better mechanical systems. During these revisions the decision to reject the single engine of the V-2's design had come about, and the team moved to a multiple-engine design. **Arthur Rudolph**, an integral part of the V-2 rocket team coordinated by von Braun, was the assistant director under von Braun at the Marshall Space Flight Center. Although von Braun and his team had been transferred to NASA in 1960, Rudolph stayed with the Army Ballistics Missile Agency (ABMA) to continue critical work on the Pershing project through 1960. He was credited with the design and success of the Pershing missile, before rejoining von Braun to develop the C-5.

## Arthur Rudolph

**Arthur Rudolph** had worked with Dr. von Braun in Peenemunde, Germany during World War II under the Nazi regime, as they struggled mightily to complete Hitler's V-2 rocket program, which Hitler saw as his only hope for possible military success. After the Brits bombed Peenemunde, which was a city on an island in the Baltic Sea, the V-2 program was moved in 1943 to Mittelwerk in inland Germany. There the Germans were able to manufacture several V-2 rockets just before the end of 1944. However, the rockets were largely ineffective from a military standpoint, although they did manage to kill nearly ten thousand Allied civilians before the Nazis surrendered in early May of 1945; the V-2 rocket had very little military impact on World War II.

The saga of how the U. S. Army covertly brought von Braun's entire V-2 rocket team to the United States was known as Operation Paperclip. Their team was eventually stationed in 1950 at the Redstone Arsenal in Huntsville, Alabama, which became a major part of the MSFC under NASA. Rudolph finally moved to NASA in 1961, once again working for von Braun. He became the assistant director of systems engineering, serving as liaison between vehicle development at the MSFC and the Manned Spacecraft Center in Houston. He later became the project director of the entire Saturn V rocket program in August 1963, responsible for developing the requirements for the rocket system and for the Apollo program mission plan. He was then assigned as the special assistant to the director of MSFC in May 1968 and subsequently retired from NASA on 01 January 1969.

During his tenure Rudolph was awarded the NASA Exceptional Service Medal and the NASA Distinguished Service Medal. His individual achievements for putting an American on the Moon and returning him safely to Earth were simply remarkable. His efforts earned him other awards, including the U. S. Army's highest civilian award. Having been granted U. S. citizenship after his retirement from NASA in 1969, he was many years later charged with "war crimes" by the OSI (Office of Special Investigations) in 1983. He was stripped of his citizenship and was purportedly fearful for the welfare of his wife and daughter. Rudolph under duress signed an agreement with the OSI stating that he would leave the United States and renounce his United States citizenship. He was "railroaded" back to West Germany by the U. S. State Department in 1984, where he was found not guilty of causing the deaths of many of the slave laborers who died while working on the German V-2 program. He died before he could be exonerated.

## Saturn V Design

The Saturn V's size and payload capacity dwarfed all other previous rockets which had successfully flown at that time. With the Apollo spacecraft on top, Saturn V had an overall height of 363 feet and was more than 33 feet in diameter, including fins. Fully fueled, the Saturn V weighed nearly 6.5 million pounds, and had a thrust capability of 7.5 million lbf. Its Low Earth Orbit capacity was originally estimated at 261,000 pounds, and it was designed to send at least 90,000 pounds to the Moon, including the third stage, necessary fuel, the CSM and the LEM. The stages were designed by the Marshall Space Flight Center (MSFC) in Huntsville, and numerous outside contractors were chosen for the construction. By 1962, NASA had finalized its plans to proceed with von Braun's Saturn designs, and the Apollo space program gained speed. The C-5 was confirmed as NASA's choice for the Apollo Program in early 1963, and was renamed the **Saturn V** and used by NASA between 1967 and 1973. It would be a three-stage, heavy-lift launch vehicle, human-rated and liquid-fueled but expendable. Von Braun headed the Saturn team at the MSFC in designing and developing a vehicle capable of launching a manned spacecraft on a trajectory to the Moon. In addition to Saturn V being used for human exploration of the Moon, it was later used to launch Skylab, the first American space station.

A total of fifteen flight-capable vehicles were built, and it was the launch vehicle from the Kennedy Space Center in Florida for thirteen missions, never losing a manned crew or a payload. As of this day the Saturn V remains the tallest, heaviest, and most powerful rocket ever brought to operational status, and holds records for the heaviest payload launched and largest payload capacity ever placed into Low Earth Orbit (LEO). The weight of the lunar expedition system, which included the third stage and propellant necessary for translunar navigation as well as the Command Service Module and the Lunar Module, exceeded 160,000 tons. With the configuration of Saturn V finalized, NASA turned its attention to procedural missions for the translunar flights. Despite much controversy, the lunar orbit rendezvous combined with a lunar module had been chosen over an Earth orbital rendezvous or direct landing. Issues such as type of fuel injections, the needed amount of fuel for such a trip, and rocket manufacturing processes were ironed out, and the designs for the Saturn V were accelerated.

## First Stage: S-1C Using the F-1 Rocket Engine

The Saturn V consisted of three stages: S-IC first stage, S-II second stage and the S-IVB third stage, plus the instrument unit. All three stages would use liquid oxygen (LOX) as the oxidizer. The first stage would use RP-1 for fuel, while the second and third stages would use liquid hydrogen **(LH2),** primarily for overall weight reduction**.** The S-IC was built by the Boeing Company at the Michoud Assembly Facility outside New Orleans on a lease arrangement from the Chrysler Corporation. The majority of its mass at launch was propellant – RP-1 as the fuel and LOX as the oxidizer. The S-1C was 138 feet tall and 33 feet in diameter, and it provided over 7,600,000 pounds-force of thrust. The S-IC stage had a dry weight of about 145 tons; fully fueled at launch it had a total weight of over 2,500 tons. The Saturn V's final design had several key design features. Engineers determined that the best engines to be used in the S-1C first stage were the powerful new F-1 gas-generator rocket engines that were then being developed by Rocketdyne. Five F-1 engines were used in the S-1C first stage of each Saturn V. The center engine was held in a fixed position, while the four outer engines could be hydraulically gimballed to steer the rocket. During the flight, the center engine was turned off about 26 seconds earlier than the outboard engines

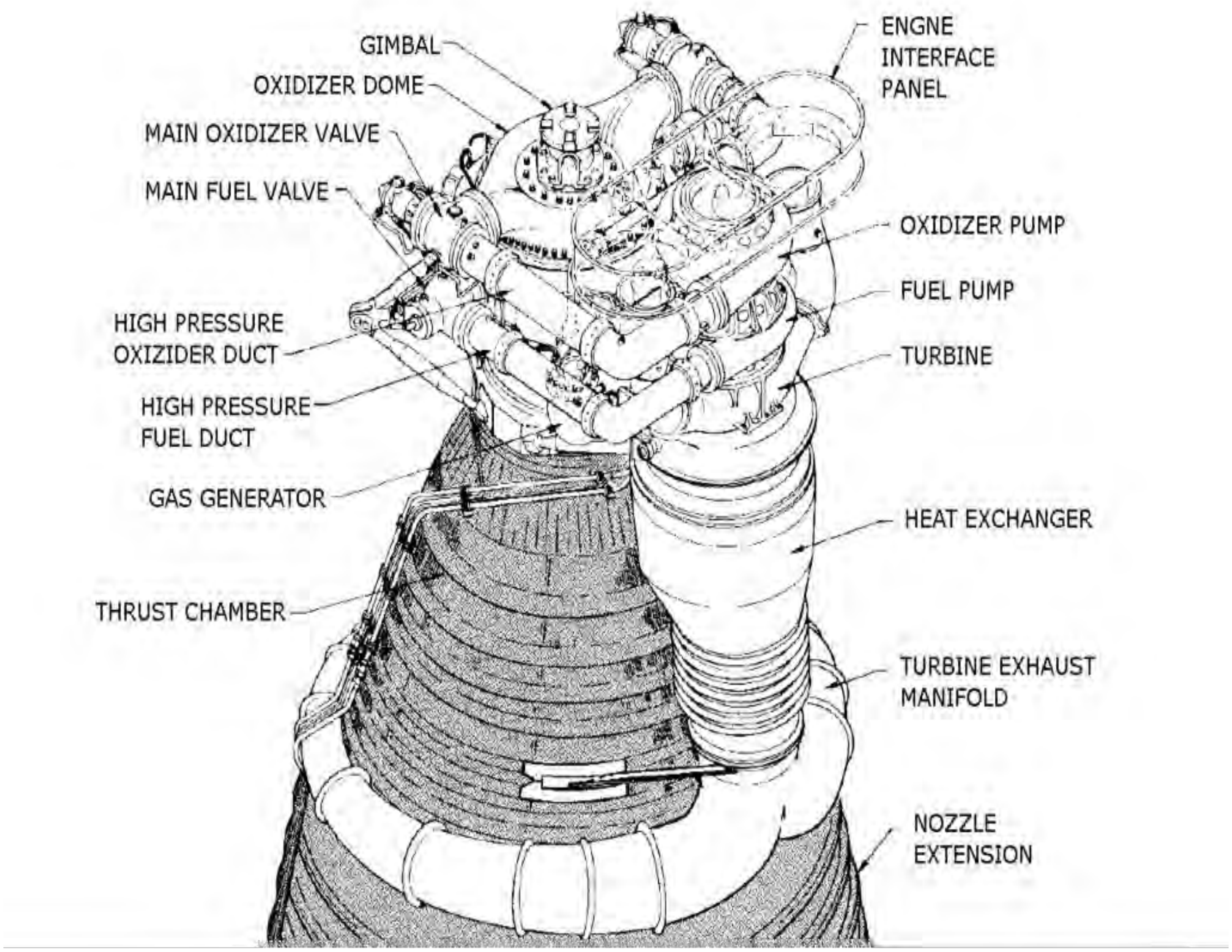


**Figure 3.** F-1 rocket engine components

to limit acceleration. At the time of launch, the S-IC fired its engines for 168 seconds (ignition occurred about 9 seconds before liftoff) and at engine cutoff, the vehicle was already at an altitude of about 42 miles, was downrange about 60 miles, and was travelling at a velocity of about 7,500 feet per second (5,000+ mph). The F-1 engine is the most powerful **single-nozzle** liquid-fueled rocket ever flown. Other rockets were designed to have greater thrust, but they had at least four nozzles. A turbopump was used to inject fuel and oxygen into the combustion chamber. The combined flow rate of the five F-1's in the Saturn V was more than 3,333 gallons per second. The quality of the turbopump was outstanding: in addition to its high delivery requirements, it was designed to withstand temperatures ranging from the input gas at 1,500 °F to the liquid oxygen at −300 °F.

The heart of the engine was the thrust chamber, which mixed and burned the fuel and oxidizer to produce thrust. A domed chamber at the top of the engine served as a manifold supplying liquid oxygen to the injectors, which directed fuel and oxidizer into the thrust chamber in a way designed to promote mixing and combustion. Fuel was supplied to the injectors from a separate manifold; some of the fuel first traveled in 178 tubes down the length of the thrust chamber, which formed approximately the upper half of the exhaust nozzle, and then in reverse order to cool the nozzle. A gas generator drove a turbine, which in turn drove separate fuel and oxygen pumps, each feeding the thrust chamber assembly. The turbine was driven at 5,550 RPM, and was capable of producing more than 55,000 horsepower. The fuel pump delivered in excess of 15,000 gallons of RP-1 per minute, while the oxidizer pump delivered nearly 25,000 gallons of liquid oxygen per minute during their two and a half minutes of operation.

## Second Stage: S-II Using Five J-2 Rocket Engines

The S-II was built by North American Aviation at Seal Beach, California. The S-II was 81.6 feet tall with a diameter of 33 feet, thus making it compatible with and identical to the S-IC. The S-II had a dry weight of about 40 tons and fully fueled, weighed approximately 530 tons. When loaded, significantly more than 90 percent of the mass of the stage was propellant; The second stage accelerated the Saturn V through the upper atmosphere with 1,100,000 pounds-force of thrust. As with most of the larger stages of the NASA program, the S-II was transported from its manufacturing plant to Cape Kennedy by sea. This particular stage of the Saturn proved to be the most difficult of the Saturn V stages to develop. The second stage was almost always behind schedule and over budget, requiring constant attention by NASA engineers as well as substantial increases in funding constantly.

Like the S-I, the S-II had five J-2 engines in a similar arrangement to the S-IC, using the outer engines for control. The J-2 rocket engines, which were built by Rocketdyne, a division of North American Aviation, were liquid-fuel rockets that NASA and the MSFC planned to use on the Saturn 1-B. The J-2 burned liquid hydrogen (LH2) for its fuel and liquid oxygen (LOX) for its oxidizer. Each engine produced nearly one quarter of a million (232,250) pounds of thrust in vacuum. Although Rocketdyne had won approval to develop the J-2 in June 1960, the J-2 underwent several minor upgrades over its operational history to improve the engine's performance before its first flight on 26 February 1966.

The J-2 had a mass of approximately two tons (3,942 pounds). Five J-2 engines were used on the Saturn V's S-II second stage, and one J-2 was used on the S-IVB upper stage on both the Saturn IB and Saturn V. Unlike most other liquid-fueled rocket engines, the J-2 was designed to be restarted after shutdown, a necessity with the Saturn V S-IVB third stage. The first burn, which was to last about two minutes, would place the Apollo spacecraft into its stable Low Earth parking orbit. After the crew verified that the spacecraft was operating nominally, the J-2 would be re-ignited for its translunar journey. That 6.5-minute TLI burn would accelerate the vehicle on a course toward the Moon.

## Third Stage: S-IVB Using a Single J-2 Rocket Engine

The S-1VB-500 third stage of the Saturn V was based on the S-IVB-200 second stage of the Saturn 1B, even using the same computer that controlled the Saturn V and shared the characteristics with those of the Saturn IB. The S-IVB evolved from the upper stage of the Saturn I rocket, and was the first stage of the Saturn V to be designed. Even though the S-IV had used a cluster of six engines, nevertheless it used the same fuels as the S-IVB — LH2 and LOX. It was also originally meant to be the fourth stage of a rocket planned in the future called the C-4, but the concept was later discarded.

The Marshall Space Flight Center made the final decision to use the C-5 rocket, now known as Saturn V, which would have three stages. Its third stage would be an uprated S-IV called the S-IVB, which instead of using a cluster of engines would have a single J-2 engine. At the same time the MSFC decided to create the C-IB rocket for the Saturn IB that would also use the S-IVB as its second stage and could be used for launching any Apollo test spacecraft into Low Earth Orbit. Eleven companies submitted proposals for being the lead contractor on this third stage by the deadline established by Keith Glennan, who was still the NASA administrator in 1960. Douglas, an aircraft company based in Santa Monica, California with manufacturing facilities in Long Beach, was awarded the contract for the S-IVB because of the many similarities between it and the S-IV. Convair had come a close second in the bidding, but Glennan did not want to monopolize the liquid hydrogen-fueled rocket market, as Convair was already building stages of the Centaur rocket for the Atlas and Titan programs.

The upper stages also used small solid-fueled ullage motors (rockets) that helped to separate the stages during the launch, and to ensure that the liquid propellants were in a proper position to be drawn into the pumps. The F-1 rocket engines in tandem with the new liquid hydrogen propulsion system proposed for the J-2 rocket engines made the Saturn C-5 configuration optimal. The Saturn I and IB reflected these changes, but were not large enough to send a manned spacecraft to the Moon. These designs, however, provided a basis for which NASA could determine its best method towards landing a man on the Moon.

The firing of the ullage motors is used during stage separation of rocket and/or stabilization of a rocket when there are brief reductions in acceleration which could allow the liquid propellant to float upward and away from the engine intakes. Ullage motors would also be commonly employed on deep-space missions where a liquid rocket would be needed to start a burn after traveling in micro-gravity. The second stage (S-II) of the Saturn V used four ullage motors located on the aft interstage skirt. In the S-IVB third stage, there was an Auxiliary Propulsion

System that also had ullage functions. Ullage rockets were also used as a secondary function on the Lunar Excursion Module (LEM).

Even though the MSFC, and to a lesser extent NASA, were dealing with Boeing, North American Aviation, Douglas Aircraft and IBM at the same time and on a daily basis, their engineers had decided early on to attempt to use as much technology from the Saturn I program as possible. The C-5 (Saturn V) would undergo component testing even before the first model was constructed. The S-IVB third stage would be used as the second stage for the C-IB, which would serve both to demonstrate proof of concept and feasibility for the C-5, but would also provide flight data critical to development of the C-5. Von Braun and his associates at the MSFC carefully performed rigorous testing for each part of the project for which they were responsible. While this approach assured thoroughness, George Mueller, Director of NASA's Manned Space Flight, disagreed with this concept. He prevailed, and rather than undergoing testing for each major component, the C-5 would later be tested in an "all-up" fashion, meaning that the first test flight of the rocket would include complete versions of all three stages. By testing all components at once, numbers of missions would be reduced and fewer test flights would be required before a manned launch would occur.

# 2. Command/Service Module

Once the decision was made to adopt the lunar orbit rendezvous, this meant that two astronauts would remain in lunar orbit and control the CSM, while a lunar module (LM) with the other astronaut would descend to the Moon's surface. Many other aspects of the mission were significantly based on this fundamental design decision. Realizing that space rendezvous would be an integral part of any Moon landing, NASA inaugurated Project Gemini, a bridge project between the Mercury and Apollo programs, which would focus on spacecraft rendezvous and docking techniques. They also chose the second group of American astronauts in 1962, known as the New Nine, primarily to command and fly in the Gemini program.

The **Apollo spacecraft** was composed of several parts designed to accomplish the Apollo program's goal of landing American astronauts on the Moon by the end of the 1960s and returning them safely to Earth. The partially expendable (single-use) spacecraft consisted of a combined Command and Service Module (CSM) and a Lunar Module (LM). Two additional components complemented the spacecraft stack for space vehicle assembly. The first was the Spacecraft Lunar Module Adapter (SLA) designed to shield the LM from the aerodynamic stress of launch and to connect the CSM to the third stage (S-IVB) of the Saturn. It also included the Launch Escape System (LES), originally developed at the Langley Research Center for the Mercury Project, to carry the crew in the Command Module safely away from the launch vehicle in the event of a launch emergency. The LES was jettisoned during launch upon reaching the point where it was no longer needed, and the SLA remained attached to the launch vehicle's upper stage.

The change to lunar orbit rendezvous, plus several technical obstacles encountered in some subsystems (such as environmental controls internal to the CSM), soon made North American aware that substantial redesign would be required. Per an agreement with Faget, North American's project team determined that the most time-saving and efficient way to keep the program on track was to proceed with the development of the CSM in two versions. Thus, Block I and Block II came into being.

1. **Block I** would continue the preliminary design, to be used for early low Earth orbit test flights only.
2. **Block II** would be the lunar-capable version, including a docking hatch and incorporating weight reduction and lessons learned in Block I.

Detailed design of the docking capability depended on design of the LM, which wasn't contracted to Grumman Aircraft until November 1962, nearly one full year after North American had been awarded the contract for the CSM. The original plan was to have North American build capsules ready for flight by 1965. However, with the major concept being changed to a Lunar Module, the logical plan was to discontinue design changes on the Block I capsule, and to continue the design changes on the Block II capsule, which would not be needed until sometime in 1967.

## Command/Service Module

The CSM consisted of two segments: the cone-shaped **Command Module**, which was a cabin that housed the crew and carried equipment needed for reentry and splashdown; and the cylindrical **Service Module,** which provided electrical power and storage for various consumables required during a mission, and also included the S-IVB which would propel the CSM to and from the Moon.

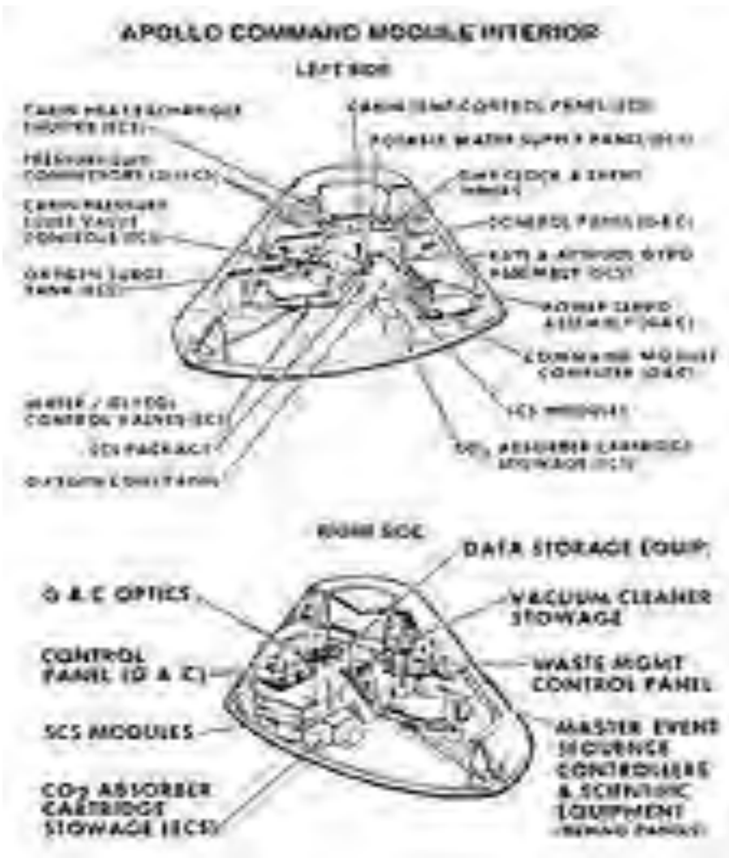


**Figure 4.** Command module interior arrangement

An umbilical connection transferred the electrical power and consumables such as oxygen and water between the two modules, and provided the astronauts with the necessary communication capabilities. Just before re-entry of the Command Module on the return to Earth, the Service Module would be separated from the Command Module, the umbilical connection would be severed, and the Service Module would be cast off and allowed to burn up in the atmosphere. The Block I (original CSM) had no provisions for docking with another spacecraft, specifically the Lunar Module. This plus other required design changes led to the decision to design two versions of the CSM. Block I was to be used for unmanned missions and a single manned Earth orbit flight, which was then referenced as AS204, but later was known as Apollo 1.

The teardrop-shaped Command Module was initially designed to land on the Moon atop a landing rocket stage, from which all three astronauts would depart and then reenter for a return on a direct ascent mission which would not use a separate Lunar Module. The more advanced Block II was designed for use with the Lunar Module, in that it had two hatches – one on the side for entry and egress of the crew at the beginning and end of the flight, and one in the nose with a docking collar for use in moving to and from the Lunar Module. The CM was necessarily small, with a height of 10 ft. 7 in. and a diameter slightly less than 13 ft.

Even that limited space was divided into three compartments: forward, crew, and aft. The forward compartment was the relatively small area at the apex of the module which contained two Reaction Control Engines, the docking tunnel, and the components of the Earth Landing System. The crew compartment occupied most of the center section of the structure, including the inner pressure vessel which housed the crew accommodations, equipment bays, controls and displays, and many spacecraft systems. The aft compartment was another relatively small area around the periphery of the module near the base that contained refresh water tanks, ten reaction control engines and their respective propellant tanks, and the extended wiring and plumbing from the umbilical lines.

After the cabin fire in the Block I module killed the entire crew and destroyed the Command Module during a launch rehearsal test for Apollo 1, corrections of the problems which caused the fire were applied to the Block II spacecraft. Further work on the Block I was abandoned, and Block II would be used for all manned missions. The Block II used a one-piece, quick-release, outward opening hatch instead of the three-piece plug hatch used on Block I, in which the inner piece had to be unbolted and placed inside the cabin in order to enter or exit the spacecraft (a design flaw that doomed the Apollo 1 crew). The Block II hatch could be opened quickly in case of an emergency. Both hatch versions were covered with an extra, removable section of the Boost Protective Cover which surrounded the CM to protect it in case of a launch abort.

## Service Module

Block I command modules lacked forward docking tunnels, and had no hatches which would allow EVA's. All this fell to the service module, the cylindrical spacecraft mated to the command module that fed the electrical, propulsion, and environmental systems for the bulk of the mission to the Moon. It was 12 feet 10 inches in diameter and 24 feet 11 inches long, and was divided into six sections around a central area. The central part of the cylinder held the main Service Propulsion System engine and its associated plumbing while the six other sections held hydrogen-oxygen fuel cells, and cryogenic liquid hydrogen and liquid oxygen for the S-IVB rocket.

The Service Module was an unpressurized cylindrical structure, and its interior was a simple structure. It consisted of a central tunnel section 44 inches in diameter, surrounded by six pie-shaped sectors. The sectors were topped by a forward bulkhead and fairing, separated by six radial beams, covered on the outside by four honeycomb panels, and supported by an aft bulkhead and engine heat shield. The sectors were not all equal 60° angles, but varied according to required size.

The Service Module was connected to the Command Module using three tension ties and six compression pads. The tension ties were stainless steel straps bolted to the Command Module's aft heat shield. It remained attached to the Command Module throughout the mission, until being jettisoned just prior to the Command Module's re-entry into the Earth's atmosphere. At jettison, the umbillical connections were cut using a pyrotechnic-activated guillotine assembly. Following jettison, the Service Module aft translation thrusters automatically fired continuously to distance it from the Command Module, until either its Re-entry Control System fuel or the fuel cell power was depleted. The roll thrusters were also fired for five seconds to make sure it followed a different trajectory from the Command Module and would incur faster break-up on re-entry.

## 3. Lunar Module (LM)

The design and construction of the Lunar Module was arguably the most serious, if not the most complicated, technical challenge of the Apollo program. Begun more than a year later than most of the other parts of the Apollo Project, the LM was consistently behind schedule and over budget. The design which NASA used was based on the Lunar Orbit Rendezvous, in which two docked modules were sent to the Moon and went into lunar orbit. While the LM separated and landed, the CSM remained in lunar orbit, usually at an apogee of between sixty-eight and seventy miles above the lunar surface. After the lunar landing and debarking, the LM would ascend, the two craft would rendezvous and dock in lunar orbit, and the CSM would return the crew to Earth. The Command Module would be the only part of the space vehicle that returned with the crew to the Earth's surface.

Most of the problems with the LM consisted of designing and developing a propulsion system for the descent stage of the LM in tandem with a propulsion system for the ascent, all of this in a no-atmosphere, near-weightless environment. Guidance and maneuverability in those conditions, with one or two astronauts standing at the LM controls, was also critical or the astronauts could have been stranded on the lunar surface. To add to the problems with Grumman's design, the LM had to be fairly lightweight, but sturdy and mostly shock-proof.

**Dr. Thomas Kelly**, a mechanical engineering graduate from Cornell University, is generally credited with the great success of the LM. A native of Brooklyn, Kelly became Project Director and supervised the more than 7,000 employees who were involved in the design and construction contract that Grumman Aircraft received in November of 1962. The Lunar Module (LM) was the first manned spacecraft to operate exclusively in the airless vacuum of space. It was also the first, and to date only, crewed vehicle to land anywhere beyond Earth. After completing its mission, the LM would be discarded. It was capable of operation only in outer space; structurally and aerodynamically it was incapable of flight through the Earth's atmosphere. It was eventually designed for lunar orbit rendezvous by Grumman to carry a crew of two from lunar orbit to the surface of the Moon and back. Its ascent stage and descent stage would be ferried to lunar orbit by the Command Service Module.

At launch, the LM weighed about 33,500 pounds and would sit directly beneath the CSM with its legs folded, inside the CSM-LM Adaptor, which was designed and built by North American

Aviation as part of their CSM contract. The Adaptor was in turn attached to the S-IVB, which was the third stage of the Saturn V rocket. It would remain there through Earth parking orbit and through the Trans Lunar Injection (TLI) rocket burn, which would propel the entire spacecraft toward the Moon.

Soon after TLI, the Adaptor would open and the CSM initially would separate from the LM and turn around. It would then come back to dock with the Lunar Module, and then would extract the LM from the S-IVB. During the flight to the Moon, the docking hatches would be opened and the LM Pilot could enter the LM to temporarily power up – it was battery-powered - and test its systems (except for propulsion). Throughout the flight to the Moon, an astronaut could perform the role of an engineering officer, responsible for monitoring the systems of both spacecraft modules.

Once the spacecraft was placed into a Moon parking orbit, the two modules would undock, and the CSM would raise and optimize its circularized orbit for the remainder of the mission at the Moon. The LM would engage the descent stage and gradually land on the lunar surface. When ready to leave the Moon, the LM would separate the descent stage and fire the ascent engine to climb back into orbit, using the descent stage as a launch platform. After a few course correction burns, the LM would rendezvous with the CSM and dock for transfer of the crew and any souvenirs and/or rock samples. Having completed its transfer, the LM would be separated from the CSM and sent into solar orbit or to crash into the Moon.

The Apollo Lunar Module (LM) was a two-stage vehicle designed by Grumman to ferry two astronauts from lunar orbit to the lunar surface and back. It was 23 feet high (with landing gear extended), 31 feet wide, and 31 feet deep. The upper ascent stage consisted of a pressurized crew compartment, equipment areas, and an ascent rocket engine. The lower descent stage had the landing gear and contained the descent rocket engine and lunar surface experiments. LM 2 had been built for a second unmanned Earth-orbit test flight. However, because the test flight of LM 1, performed as part of the Apollo 5 mission, was so successful, a second unmanned LM test mission was deemed unnecessary. LM-2 would be used for ground testing prior to the first successful Moon-landing mission.

## Descent Stage

The Descent stage's primary job was to support a powered landing and lunar extravehicular activity. Octagon-shaped, it was supported by four folding landing gear legs, and contained a propulsion system that was developed by Thompson-Ramo-Woolridge (TRW). The engine used Aerozine 50 for fuel and used Nitrous Dioxide as its oxidizer. A Doppler radar system antenna was mounted by the engine on the bottom surface, which would send altitude and rate of descent data to the guidance system and pilot display during the lunar landing. A front landing leg had an attached platform (informally known as the "porch") in front of the ascent stage's EVA hatch and a ladder, which the astronauts would use to ascend and descend between the cabin to the surface. The footpad of each landing gear contained a 67-inch-long surface contact sensor probe, which would signal the LM commander to switch off the descent engine.

Equipment for the lunar exploration was carried in the stowage assembly, a drawer mounted on a hinged panel dropping out of the left-hand forward compartment. Besides the astronauts' surface excavation tools and sample collection boxes, the drawer also contained a television camera with a tripod, so that the commander could open the drawer by pulling on a lanyard while descending the ladder. The camera would be automatically activated to send the first pictures of the astronauts on the surface of the Moon back to Earth. Unlike what has been depicted in a recent Hollywood drama, a United States flag would be carried in a container mounted on the ladder of each landing mission for the astronauts to easily access and erect on the lunar surface at the beginning of each lunar landing.

## Ascent Stage

The Ascent stage contained the crew cabin with instrument panels and flight controls. It also contained its own propulsion system engine for return to lunar orbit and rendezvous with the Apollo CSM. The LM Pilot could operate a control system for attitude and translation adjustment, which would enable the rendezvous with the CSM to occur. The control system consisted of sixteen hypergolic thrusters similar to those used on the Service Module, mounted in four quads, with their own propellant supply. A forward EVA hatch provided access to and from the lunar surface, while an overhead hatch and docking port provided access to and from the Command Module.  Life support systems included an environmental control, VHF communications system with the Command Module, portable antennas mounted on the astronauts' spacesuits, an optical telescope for visually determining the spacecraft orientation, and rendezvous radar with its own antenna. Electrical storage batteries, cooling water, and breathing oxygen were stored in amounts sufficient for a lunar surface stay of 48 hours initially, but would be extended to 75 hours for the later missions. Note: All of these items would become extremely valuable later.

The original lunar landing concept through 1966 was for only one astronaut (Commander) to leave the LM while the other (Pilot) remained inside in order "to maintain communications". However, communications would improve so rapidly and were eventually deemed to be reasonably reliable - even from the Moon - so that both crew members (some of whom pushed back on the single-astronaut concept) could walk on the lunar surface, leaving the spacecraft to be only remotely attended by Mission Control.

**Configuration**

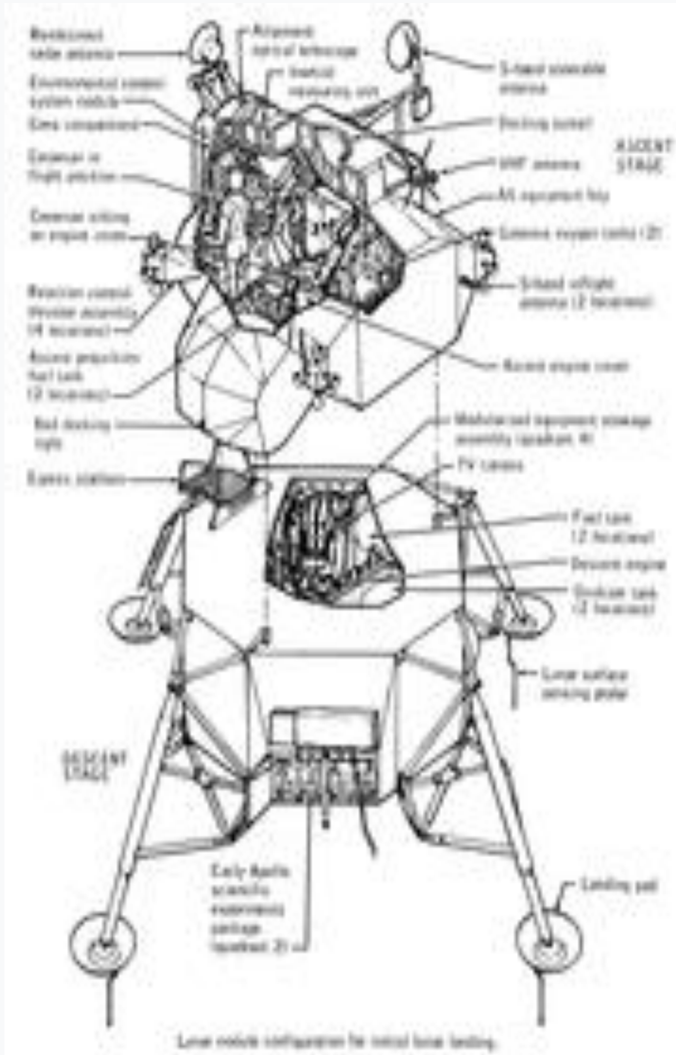

**Figure 5.** Apollo LM diagram

When ready to leave the Moon, the LM would separate the descent stage and fire the ascent engine to climb back into orbit, using the descent stage as a launch platform. After a few course correction burns, the LM would rendezvous with the CSM and dock for transfer of the crew and rock samples that had been collected. With the rendezvous and docking having been completed, the ascent stage would also be separated. The ascent stage would be left in lunar orbit to eventually crash into the lunar surface. All subsequent ascent stages would be intentionally steered into the Moon to obtain readings from seismometers placed on the surface. The mostly depleted Lunar Module carried back to Earth's orbit would weigh only about 10,000 pounds.

# III. NASA's Objectives

The main objective of the U. S. space program in 1960 was to exceed the capabilities of the Soviet Union in the "Space Race" into outer space. A secondary objective of NASA was to develop a spacecraft large enough to allow three American astronauts to fly comfortably for lengthy periods, and for them to perform EVA's and many other experiments. Preliminary specifications had been laid out for a spacecraft with a **mission module** cabin separate from the **command module,** which would be both a piloting and re-entry cabin as well as a **propulsion and equipment module.** In August 1960, a feasibility study competition was announced by NASA, and three study contracts were awarded to General Dynamics/Convair, General Electric, and Glenn L. Martin Company. NASA performed its own in-house spacecraft design studies under the direction of Maxime Faget, principal designer of the Mercury spacecraft, to serve as a gauge to judge and monitor the three industry designs. The concept of landing a man on the Moon was only a vision held by some engineers at NASA, until Hugh Dryden mentioned it to President Kennedy, who then presented it to Congress in May of 1961.

At this time the Mercury Project was underway, but Project Gemini did not come into being until:

1. After President Kennedy's address to Congress, when the decision was made by NASA that summer to put a man on the Moon and return him safely to Earth.
2. The decision was made by NASA to discount a direct flight from the Earth to the Moon.
3. The two options to be considered for lunar landing were:

    a. Lunar Orbit Rendezvous (LOR)

    b. Earth Orbit Rendezvous (EOR)

However, Earth Orbit Rendezvous (EOR) and Lunar Orbit Rendezvous (LOR) were still being evaluated by NASA from an overall cost standpoint. When NASA awarded the initial Apollo module contract to North American Aviation on 28 November 1961, most in the NASA administration still were in favor of the lunar landing being achieved by direct ascent from EOR rather than by LOR. Therefore, North American (as directed by Faget) proceeded to design the module without any regard for a Lunar Module (LM), nor did it include any means of docking the Command Module to another spacecraft.

Nevertheless, not everyone in NASA was convicted to landing a large spacecraft onto the lunar surface. There were serious concerns regarding the mass and size of the descent/ascent engines that would be required, as well as the size of the launch vehicle that would be needed for the spacecraft to reach low Earth orbit. One of the most vocal of a minority of engineers who supported LOR was John Houbolt, an engineer at the Langley Research Center in Hampton, Virginia. Supported by his fellow engineers at Langley, he launched a vigorous campaign in 1961 and 1962 in favor of the LOR.

### John Cornelius Houbolt

John Houbolt was born in Altoona, Iowa in 1919, and his family later moved to Joliet, Illinois. He received both a BS and an MS in Civil Engineering from the University of Illinois at Urbana-Champaign. Houbolt began his career at NACA, receiving his doctorate in Technical Sciences from the prestigious ETH Zurich in Switzerland. He stayed on at NASA after it succeeded NACA until retirement in 1985. His idea of landing a much smaller spacecraft on the Moon, thus also realizing a huge cost savings, had the agreement of several key people in NASA. Chief among them were Wernher von Braun, director of the Marshall Space Flight Center, and Robert Gilruth, head of NASA's Space Task Group. They concluded that the LOR was the better and cheaper way to land an American astronaut on the Moon before the end of the decade as proposed by President Kennedy. This method was presented to James E. Webb, NASA Administrator, and he made the decision in July, 1962 to adopt the LOR for the Apollo program.

## A. Early Missions (Unmanned)

### Saturn 1

As late as the summer of 1962, NASA engineers were still planning for the lunar landing to be achieved by direct ascent, meaning that all necessary equipment for a lunar landing would be assembled in a low Earth orbit rendezvous. When fully prepared, the Command/Service Module would turn toward the Moon, determine an optimum lunar orbit and location, and descend to the lunar surface with all three astronauts on board. Therefore, design proceeded without a means of docking the Command Service Module to a Lunar Landing Module (LLM), also referenced as a Lunar Excursion Module (LEM), or simply as an LM. But the change to lunar orbit rendezvous (LOR), plus several technical obstacles encountered in some subsystems (such as environmental control), soon made NASA administrators aware that substantial redesign would be required.

As we saw in an earlier photograph, Saturn 1's first stage, equipped with a dummy second stage (S-II) had been launched from Cape Canaveral on 27 October 1961. This was the first of several tests of the Saturn rocket to become the Apollo program launch vehicle. This was followed by two more Saturn 1 test flights in April and November of 1962, and a fourth one in March, 1963. Each flight carried a dummy second stage which carried water and released it into the atmosphere to investigate its effects on changes in weather conditions and radio transmissions.

Flight SA-5 on 29 January 1964 became the first Saturn flight to fire a live second stage, and it also became the first orbital flight in the Apollo program, orbiting the Earth 58 times before finally plunging into the Pacific Ocean.

SA-6, also known as AS-101, was launched from Cape Kennedy on 24 May 1964, carrying a boilerplate spacecraft, also known as a mass simulator. As was discussed earlier, boilerplate spacecraft was a nonfunctional module that simulated the physical size and payload of an actual spacecraft, and was used to test various configurations and basic size, load, and handling characteristics of the Saturn launch vehicles. This method was far less expensive to build than multiple, full-scale, functional spacecrafts. In this way, boilerplate spacecraft allowed components and aspects of cutting-edge technology to be tested while the final project was being developed. These methods were used to develop procedures for mating a spacecraft to its launch vehicle, means of emergency access and egress, methods for maintenance support activities, and various transportation processes. Boilerplate spacecraft were most commonly used on the Apollo Project, but were also utilized to test Project Mercury spacecraft atop Atlas rockets.

On **18 September 1964** Saturn 1 launched from Launch Complex 37, carrying the first programmable, in-flight computer. Designated as AS-102, and also as SA-7, this was the last launch vehicle development flight of the Saturn 1 rocket. The last three flights of the Saturn 1 rocket, in February, May and July of 1965, were each used to launch the large Pegasus satellite. These flights were known by the MSFC as SA-7 through SA-9, and were designated by NASA as AS-103 through AS-105. The Saturn V was not quite ready for prime time, but the uprated S1B was being prepared to carry the heavier burdens.

## Saturn 1B

On **26 February 1966** the Saturn 1B, which was the uprated version of the Saturn 1, made its first test flight, carrying a Block 1 Command Service Module. The flight, designated as 1B AS-201, was a suborbital flight that provided NASA and the MSFC with mostly positive results. The spacecraft was made up of both a Block 1 Command Module and a Block 1 Service Module. During the suborbital flight of slightly more than half an hour, in which the spacecraft reached an apogee of approximately 307 miles, the service propulsion system and the reaction control systems of both modules were successful. The launch included a Block I Launch Escape System (LES), and the first flight of the Spacecraft-LM Adapter (SLA) which connected the Lunar Module to the launch vehicle. The flight also demonstrated the capability of the Command Module's heat shield to withstand re-entry from a low Earth orbit, and it was recovered intact by the carrier USS Boxer in the Atlantic Ocean almost 5,300 miles downrange.

The Saturn 1B featured an upgrade of the first stage engines to increase thrust from 1,500,000 lbf of thrust to 1,600,000 lbf, and also replaced the second stage with the S-1VB that used a newly designed J-2 engine. The J-2 was a liquid hydrogen (LH2) burning engine, and this propellant would also be used on the second stage (SII) of the Saturn V. The S-IVB would be used as the third stage of the Saturn V. Because it was to be the engine to place the CSM and LM into lunar orbit, the S-IVB would be equipped with an in-space restartable J-2 engine, and a new model of the guidance and control system known as the Instrument Unit. This unit contained a digital computer, analog flight control computer, emergency detection system, inertial guidance platform, control accelerometers and control rate gyros, which would also be used on the Saturn V. The one serious mishap during this flight was that the LH2 propellant suffered a pressure loss, which caused the Service Module engine (J-2) to stop prematurely.

The next two missions were out of sequence and occurred with a Saturn 1B, but they proved to be successful and provided NASA administrators and engineers with a great deal of encouragement and excitement. On **05 July 1966** flight 1B AS-203 launched from Cape Kennedy with the intention of testing the stage 3 S-IVB for its restart capabilities. No Apollo spacecraft was on board, and the stage 3 made more than four orbits before being accidently destroyed due to a test that caused a rupture to the fuel tank.

Then on **25 August 1966** flight 1B AS-202 launched from a similar location (Launch Complex 34) and was the second unmanned, suborbital test flight of a production Block I CSM launched by the Saturn 1B launch vehicle. AS-202 was the third test flight of the Saturn IB, because a delay in the readiness of the Apollo spacecraft 011 (CSM-011) had pushed its launch past the July 1966 launch of AS-203. It was the first flight which included the spacecraft Guidance and Navigation Control System and the newest version of fuel cells. The success of this flight enabled the Apollo program to judge the Block I spacecraft and Saturn IB as being ready to carry men into orbit on the next mission**,** which would have been 1B AS-204**.**

This launch was designed to test the rocket more rigorously than had been done on AS-201 by launching the rocket higher and having the flight lasting twice as long. It was also a test of the Command Service Module (CSM-011) by having the engine fire at least four times during the flight. The heat shield was also planned to undergo a strenuous test. The CSM-011 was basically a Block 1 production model with the capability of carrying a crew, although it lacked the crew couches and some displays that would be included on later missions for the astronauts. The CSM was separated from the rocket stage at an altitude of 483 miles. The CSM was preprogrammed to make four burns of its Service Propulsion System (SPS). The first occurred a couple of seconds after separation from the S-1VB second stage. Three more burns to test the rapid restart capabilities of the J2 rocket eventually lifted the spacecraft to an apogee of 714 miles.

The Command Module entered the atmosphere at a speed of 19,440 miles per hour. The spacecraft performed a modified skip re-entry, employing aerodynamic lift in the high upper atmosphere, a skip-like concept intended to lower the heating loads on the vehicle by extending the re-entry time. In first descending to 42 miles, then lifting back up to 50 miles during this process, it had shed nearly 3,000 miles per hour of speed. It then continued to descend, and the main parachutes deployed at 4 ½ miles. However, it splashed down more than 237 miles from the target landing site, and the carrier USS Hornet took 8 ½ hours to reach the capsule. This "boost-glide" had roughly doubled the range over the normal ballistic trajectory, and this concept was never used on any manned flights.

## Saturn V – Apollo 4

Following the fatal fire of 27 January 1967, NASA's Associate Administrator for Manned Space Flight, Dr. George E. Mueller, announced that the mission originally scheduled for Grissom, White and Chaffee would be known as Apollo 1. That flight, of course, never flew, but three other Saturn 1B unmanned test flights had been launched between February and August of 1966. Mueller then declared that the first Saturn V launch, scheduled for November 1967, would be known as Apollo 4. No missions or flights were ever designated Apollo 2 or 3. The extensive reworking of the Apollo command modules after an exhaustive investigation of the fire resulted in postponement of crewed launches. Manned Apollo flights were suspended for 20 months while the Command Module's hazards were addressed until NASA officials cleared them for flight. Saturn IB schedules were suspended for nearly a year. The 1B launch vehicle that finally bore the designation AS-204 carried only a Block I lunar module (LM) as the payload, instead of a CSM. The missions of AS-201 and AS-202 with Apollo spacecraft aboard had been unofficially known as Apollo 1 and Apollo 2 missions. AS-203 carried only the aerodynamic nose cone. The eventual launch of AS-204 became known as the Apollo 5 mission.

The first flight of a Saturn V rocket occurred on **09 November 1967** and was launched from Launch Complex 39A at Cape Kennedy. Designated as V AS-501, but renamed Apollo 4, it was the first flight launched in the Apollo program following the fatal fire on 27 January 1967 and was unmanned. Apollo 4 was an "all-up" test, meaning all rocket stages and spacecraft were intended to be fully functional on the initial flight, a first for NASA. For the first time the S-IC first stage and the S-II second stage flew. This flight also demonstrated the in-flight capability of the S-IVB third stage to restart. The mission used a Block I Command Service Module (CSM) for the last time, although it had been modified to test several key Block II revisions, including its heat shield at a simulated lunar-return velocity and angle.

Originally planned for late 1966, the flight was delayed to November 9, 1967, initially due to development problems of the S-II stage encountered by North American Aviation, the manufacturer of the stage. Delay was also caused, to a lesser extent, by a large number of wiring defects found by NASA in the Apollo spacecraft, also built by North American. Schedule delays resulted in NASA dispatching teams of engineers and program managers to North American in order to expedite their manufacturing process. Of course, the short moratorium placed on the entire Apollo program had significant effect, since this mission would be the first

Apollo flight following the stand-down imposed after the Apollo 1 fire which had killed the first Apollo crew. Subsequent inspection of the wiring in the Command and Service Modules had placed North American in financial jeopardy, which was resolved in major fashion when they were purchased by the Rockwell Corporation.

This flight was also the first to use NASA's official Apollo numbering scheme established in April 1967, following the fatal fire. The flight was designated Apollo 4 because there had been three previous unmanned Apollo/Saturn flights in 1966, using the Saturn 1B launch vehicle. The payload was a Block 1 design Command Service Module, meant for systems testing, with several significant Block II modifications made strictly for certification, since NASA had made the decision that no Block I spacecraft would fly with a crew. The modifications included a new heat shield outer covering for the Command Module, a new CM-to-SM umbilical connector, and the modified crew compartment hatches.

Much like the maiden flight of Saturn 1 six years earlier, the fear of a low altitude launch failure, and especially a pad explosion, was high. Saturn V, the largest rocket ever built, was assembled at Launch Complex 39A, more than three miles from the nearest other LC. Several NASA studies had been conducted to assess this scenario by studying previous such accidents, but in all such cases, they involved launch vehicles less than half the size and fuel load of the Saturn V. Such an event would have become a catastrophe beyond all proportions. Fortunately for all concerned, the largest rocket ever built lifted from LC-39A flawlessly and performed perfectly through all stages of the flight.

The total payload was just under 42 tons, and included a dummy Lunar Module known as a **Lunar Module Test Article,** which was carried as ballast to simulate the loadings of the LM on the launch vehicle. The mission lasted almost nine hours, completed three low Earth orbits, and splashed down in the Pacific Ocean, achieving all mission goals. NASA deemed the mission a complete success, because it proved the Saturn V worked. This was an important step towards achieving the Apollo program's objective of landing astronauts on the Moon and bringing them back safely before the end of the decade.

The launch had placed the S-IVB and CSM into a nearly circular 110-mile orbit, a nominal parking orbit that would be used on the actual lunar missions. After two orbits, the S-IVB's very first in-space re-ignition put the spacecraft into an elliptical orbit with an apogee of 10,750 miles and a perigee deliberately aimed 53 miles (-53) below the Earth's surface; this was to ensure both a high-speed atmospheric reentry of the Command Module and destruction after reentry of the S-IVB. Shortly after this burn, the CSM separated from the S-IVB and fired its Service Module engine to adjust the apogee to 11,300 miles and a perigee of −46 miles, simulating a return from the Moon. The descent of the Command Module landed it approximately ten miles from the target landing site northwest of Midway Island in the North Pacific Ocean. Its descent was visible from the deck of the carrier USS Bennington, the prime recovery ship.

## Saturn 1B – Apollo 5

The next flight in the Apollo program designated as 1B AS-204, or Apollo 5, was launched out of LC 37B at Cape Kennedy on **22 January 1968.** The primary objective of this flight was to test the capabilities of the Lunar Module in a no-atmosphere space environment. In particular its descent and ascent engine systems were tested, and its ability to separate the ascent and descent stages had to be proven. The mission also performed a simulation of a lunar landing abort, in which the ascent stage engine would be fired while still attached to the descent stage. This had been a major concern of the Grumman engineers, and probably contributed heavily to the late delivery of the first LM to NASA. This first unmanned launch with an LM was originally planned for April 1967, requiring delivery at the Cape around September 1966. But delays kept occurring, even though the Lunar Module was for all intents and purposes fully designed. There was trouble fabricating the custom-made parts, and Grumman was also having difficulties with the engines. The descent engine, which would eventually become the first rocket engine capable of being throttled in space, was just not burning smoothly. In addition, the ascent engine was having fabrication and welding difficulties which caused even further delays and cost overruns.

The launch vehicle for Apollo 5 was the Saturn IB SA-204, the same one originally intended for the Apollo 1 flight. It had been undamaged in the fire at Launch Complex 34, so NASA had time to reassemble it at LC 37B for the Apollo 5 mission. The Saturn IB, although a smaller rocket than the Saturn V, was still capable of launching an Apollo spacecraft into Earth orbit. The windows of this LM, because of Grumman's concern that they would crack and shatter during the flight, were replaced before the flight with solid aluminum plates. To hasten delivery, NASA had decided to accept the LM without the Lunar Module's legs. Without a crew there was also no need for a launch escape system (LES). Thus, the height of the assembled rocket package to be launched was only about 181 ft high, as compared to the usual height with a CSM and an ESP of approximately 224 ft.

The Saturn IB performed perfectly, inserting the second stage (there was no third stage) and LM into an elliptical 101-mile by 139-mile orbit. The nose cone was jettisoned and, after a 44-minute coast, the LM was separated from its adapter. Shortly before launch, NASA engineers had suspected a fuel leak somewhere in the system, so they made the decision to delay arming the engine until the time of ignition. After two orbits, the first planned 39 second descent engine burn was started, but was almost immediately aborted by the Apollo Guidance Computer. This would have increased the time required for the propellant tanks to pressurize and for thrust to re-build to a satisfactory firing level. However, the AGC was not programmed to measure this short thrust, and this particular maneuver had to be aborted. Nevertheless, the ground controllers moved to an alternate plan to fire the descent engine manually two more times, and they also performed another ascent engine burn.

After a little more than 11 hours, the test was over and control of the two stages was terminated. The stages were left in a low enough orbit that atmospheric drag would soon cause their orbits to decay and re-enter the atmosphere. The ascent stage re-entered two days after launch and burned up in the atmosphere. The descent stage re-entered three weeks after launch, and fell into the Pacific Ocean several hundred miles southwest of Guam. Despite the trouble during the descent engine burn, NASA deemed the demonstration of the LM systems a success, and a second unmanned flight test using a second LM was canceled. The third LM (LM-3) was cleared for the first manned LM flight, which would occur on Apollo 9 and will be described in Part II.

## Saturn V – Apollo 6

NASA had originally planned to fly at least two manned Block 1 flights, possibly one each for the Saturn 1B and the Saturn V. However, lagging production times and schedule pressures had reduced this number down to just one Block 1 mission by late 1966. By this time two unmanned Block 1 CSM's and one unmanned LM had been carried into space by Saturn 1B launch vehicles for low Earth orbit Apollo missions. Despite all the numerous delays, NASA had decided to launch another unmanned Saturn V on **04 April 1968.** Because of the sheer size and firepower of the Saturn V, the flight known as AS-502 and Apollo 6 was launched from Launch Complex 39A at Cape Kennedy, and carried a full complement of three stages as well as a Block I CSM and a Block I LM.

The primary objective of the flight test was to demonstrate the trans-lunar injection (TLI) capability of the Saturn V with a simulated payload equal to about 80% of that on a full lunar mission. The spacecraft would have to perform a TLI in order to begin a lunar transfer from a low Earth circular parking orbit. The large TLI burn by the third stage rocket would increase the spacecraft's velocity, changing its orbit from a circular LEO to a highly eccentric orbit. As the spacecraft reached the lunar transfer arc, its trajectory would approximate an elliptical orbit around the Earth, and its apogee would simulate the radius of the lunar orbit. The TLI burn would be precisely sized and timed to target the Moon as it revolved around the Earth. Finally, the calculation would have to take into consideration the effect on the spacecraft as it entered the Moon's gravitational sphere of influence.

A secondary objective of Apollo 6 was to repeat the demonstration of the Command Module's heat shield capabilities during re-entry. The flight plan called for a total flight time of about 10 hours, with a TLI followed by a direct return abort using the CSM main engine. A Block I spacecraft was used for this flight, similar to the unmanned Saturn V test flight on Apollo 4. After the tragedy of Apollo 1, manned Block 1 flights were no longer being considered.

Although this was the second flight of Saturn V, a phenomenon known as pogo oscillation damaged some of the J-2 engines in the second stage by rupturing internal fuel lines, which resulted in two of the engines shutting down prematurely. The third stage failed to restart due to the same pogo oscillations. The vehicle's onboard guidance system, however, was able to compensate by burning both the second and third stages longer, although the resulting parking orbit was more elliptical than planned. Since the damaged third stage engine had failed to restart for trans-lunar injection, flight controllers elected to repeat the flight profile of the Apollo 4 test, and were able to achieve a high orbit and high-speed return using the Service Module engine. Despite these engine failures, NASA had enough confidence to use the Saturn V for the upcoming manned launches. Their attitude was that, since Apollo 4 had already demonstrated an S-IVB restart and the heat shield had tested well at full lunar re-entry velocity, a potential third unmanned flight was cancelled. NASA administrators believed that they had the launch vehicle and spacecraft modules (CSM-Block 2 and LM) to continue the mission, and that their development of orbital operations would enable them to move on to more complex missions.

## IV. Apollo 7 Ready - First Manned Apollo Mission

**Apollo 7** was launched on **11 October 1968** from Launch Complex 34 at Cape Kennedy, the only manned Apollo flight ever launched from that location. It was the first mission in the Apollo program by the United States to carry a crew into space. It was also the first U.S. spaceflight to carry U. S. astronauts since the flight of Gemini 12 carried James Lovell and Buzz Aldrin into space on 11 November 1966. The Apollo 1 had been intended to be the first manned flight of the Apollo program, having been scheduled by NASA to launch in February 1967. However, the fatal fire plus a myriad of schedule delays caused manned Apollo flights to be suspended for 20 months. NASA used that time period wisely to make improvements to the Block II spacecraft and the lunar module, and to further solidify the Saturn V as their premium launch vehicle. Apollo 7 was now prepared to fulfill Apollo 1's original mission of testing the Command Service Module in a low Earth orbit for a lengthy duration.

Their mission was an 11-day Earth-orbital test flight to check out the redesigned Block II Command Service Module with a crew on board. The launch vehicle was a **Saturn 1B**, possibly because NASA still was proofing the capabilities of the Saturn V after the Apollo 6 flight. This was the first time a 1B vehicle would put a crew into space. Apollo 7 was the first three-person American space mission, and it was the first to include a live TV broadcast from an American spacecraft. Despite tension between the crew and ground control (Capsule Communicators) regarding the food, waste removal, and television broadcasts, the mission was a complete technical success and actually gave NASA the confidence to send Apollo 8 into a lunar orbit a short time later.

### Backup Crew Given Critical Assignment

The Apollo 7 astronauts had been the backup crew to the Apollo 1 crew, and they had been given official titles which would become consistent with the same titles as those that would be used for the lunar landing missions. The Commander of the Apollo 7 flight was **Wally Schirra**, a former naval aviator and one of the original seven U. S. astronauts selected by NASA. Schirra flew in both the Mercury and Gemini programs, and became the first and only U. S. astronaut to fly in all three NASA space programs.

The senior pilot/navigator was **Donn Eisele**, a member of the third group of astronauts selected by NASA in 1963. Eisele was a highly regarded USAF colonel who was originally selected for Apollo 1, but had to be replaced due to shoulder problems, which were later repaired. His title was Command Module Pilot, and this was his only flight in the Apollo program, although he later served as backup Command Module Pilot for Apollo 10.

The Lunar Module Pilot was **Walter Cunningham**, a Marine reservist and one of three civilians in the U. S. space program. Selected by NASA in the third group of astronauts, he performed well despite the fact that there was no LM on board this flight, which was also his final Apollo flight.

Apollo 7 was placed in a slightly elliptical, very constant low Earth orbit with an apogee of 177 miles and a perigee of 141 miles. It was in flight for almost eleven full days, and very importantly flew nearly four-and-a-half million miles. This flight of the first "all up" Block II spacecraft was successfully concluded on 22 October 1968, with splashdown occurring in the Atlantic Ocean, less than one-half mile from its predicted target, and only 8 miles from the carrier USS Essex.

# V. Apollo 8 – Flight to/Orbiting the Moon

Originally Apollo 8 was planned as a second manned Command Service Module/Lunar Module test flight in early 1969, performing an elliptical medium Earth orbit. The mission profile was changed dramatically in August 1968 to a much more ambitious Command Service Module-only lunar orbital flight to be flown in December, 1968. Because the Block II Lunar Module was not yet ready to make its first flight, the Apollo 8 crew would now be scheduled to fly two to three months sooner than originally planned, leaving them a shorter time for training and preparation. This acceleration in their schedule placed more demands than usual on their time and their discipline for preparation.

## Overcoming Numerous Engineering Obstacles

The unreadiness of the Lunar Module was not the only significant obstacle facing NASA. The Saturn V rocket, which was to be used for the Apollo 8 flight and was designated SA-503 (the 3rd model of the Saturn V rocket in the Saturn-Apollo (SA) program, was now somewhat suspect. Apollo 6 had suffered several major problems during its April 1968 flight, including severe pogo oscillation during its first stage, as well as 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.

Teams of engineers from the Marshall Space Flight Center, the contractors (Boeing, North American Rockwell and Douglas), and NASA representatives analyzed 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. This "task force" 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 these vibrations was installed and successfully demonstrated at the MSFC in August of 1968.

Of equal importance was the failure of three engines during the same flight. The Task Force was able to quickly determine that a leaking hydrogen fuel line had 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 an electrical wiring error. As a result, engine three failed almost immediately after engine two's shutdown. Further investigation revealed a similar problem for the third-stage engine - a faulty igniter line. The team had the igniter lines modified, while a Saturn Stage 2 (S-II) was retrofitted with modified fuel lines to demonstrate their resistance to leaks and ruptures in vacuum conditions. These tests convinced NASA administrators that the problems were solved, and they gave their approval for a manned mission using SA-503. Nevertheless, testing continued right up to just three days before the launch. Final testing of modifications to address the problems of pogo oscillation, ruptured fuel lines, and bad igniter lines took place on December 18,

When Apollo 8's Lunar Module arrived at the Kennedy Space Center in June 1968, significant defects were discovered. This required Grumman, the lead contractor for the LM, to predict that the first mission-ready LM would not be ready until at least February 1969. The impact of this situation was significant and would mean delaying subsequent missions, thus endangering the program's goal of a lunar landing before the end of 1969. Apollo 8, originally planned as a low Earth orbit flight, was now affecting the entire Apollo program. George Low, the Manager of the Apollo Spacecraft Program Office, proposed a solution in August to keep the program on track despite the LM delay. Since the Block 2 Command Service Module would be ready three months before the Lunar Module, a CSM-only mission could be flown in December 1968. This CSM could be sent all the way to the Moon, with the possibility of entering a lunar orbit. The new mission would also allow NASA to test lunar landing procedures that would otherwise have to wait for later scheduled missions.

Since almost every senior manager at NASA agreed with this new mission, having confidence in the hardware and personnel, NASA Administrator James Webb approved the change in plans, which was a significant morale boost to the entire program. With the rest of his agency in support of this new mission, the mission was officially changed from a low Earth orbit mission to a circumlunar mission, but without any fanfare or publicity at Webb's direction. No public announcement was made about the change in mission until 12 November 1968, less than 40 days before launch. NASA had decided in September to swap the Apollo 8 and Apollo 9 prime and backup crews in the flight schedule so that the crew trained for the low-orbit test could fly it as Apollo 9, when the LM would be ready, thus giving the Apollo 8 crew three months of intensive training to get ready. The Apollo 8 flight crew now consisted of Commander **Frank Borman**, Command Module Pilot **James Lovell**, and Lunar Module Pilot **William Anders.**

## Frank Borman

**Frank Borman** was born in 1928 in Gary, Indiana, but his family moved to the drier, warmer climate of Tucson, Arizona because of his early sinus problems. He received a BS degree from the U. S. Military Academy in 1950. He entered the newly formed U. S. Air Force and became a fighter pilot before receiving his MS in Aeronautical Engineering from Cal Tech. Later, Borman became a test pilot, and was selected by NASA in the second group of U. S. astronauts in 1962. He was backup Command Pilot for Gemini 4 and was chosen as the Command Pilot for Gemini 7, which flew in December 1965. That was a fourteen-day long flight which set an endurance record, and also was the target vehicle in the first space rendezvous with Gemini 6A. His Pilot for that flight was James Lovell.

Borman had been selected in late 1966 to command the third manned Apollo mission, which was to occur sometime in 1967 and would include the Lunar Module in an elliptical medium Earth orbit. However, the deadly fire in January 1967 which took the lives of the entire Apollo 1 crew delayed the Apollo program for several months. Borman had been chosen as the only astronaut to serve on the review board. In April 1967, while serving on the board, Borman testified before a U.S. Congressional committee investigating the Apollo 1 fire, and helped convince them that the Apollo program would be safe to fly again.

NASA was still in a quandary near the end of 1968 because the Lunar Module was not ready. They reassigned Borman from an Apollo 9 low Earth orbit and LM test flight to a lunar mission, using the Command Service Module only for Apollo 8. Jim McDivitt was placed in command of Apollo 9, which was expected to fly sometime in March, 1969.

## James Lovell

Lovell was Borman's Gemini 7 crewmate. Born in 1928 in Cleveland, Ohio, Lovell and his widowed mother relocated to Milwaukee, Wisconsin. He graduated from the U. S. Naval Academy in the spring of 1952 with a B.S. degree. He then went to flight training at Naval Air Station Pensacola and was designated a Naval Aviator. From there he attended the U. S. Naval Test Pilot School at Patuxent River, Maryland, and was on the list for the first group of U. S. astronauts being considered by NASA. However, he was rejected due to a temporary blood disorder, but was accepted in the second group of astronauts.

Lovell was selected for his first space flight mission as Pilot of Gemini 7 with Command Pilot Frank Borman in December 1965. The flight evaluated the effects on the crew and spacecraft from fourteen days in orbit, which set an endurance record. It made 206 orbits and was also noteworthy for performing the first space rendezvous (with Gemini 6A). Lovell was selected for his second flight and first command of Gemini 12 in November 1966 with Pilot Buzz Aldrin. That flight had three EVA's (extravehicular activities), flew 59 orbits, and achieved the fifth space rendezvous. The docking capabilities of Gemini 12 and Lovell's ability to work outside the spacecraft paved the way for the Apollo missions to reach the goal of getting a man on the Moon by the end of the decade.

Lovell was on the backup crew for Apollo 9, along with Neil Armstrong (Commander) and Buzz Aldrin (Lunar Module Pilot). However, he was chosen in the summer of 1968 as Command Module pilot for Apollo 8 by Deke Slayton, replacing Michael Collins when Collins required surgery to remove a bone spur on his spine. Apollo 9 was then being planned as a high-apogee Earth orbital test of the Lunar Module. The flight of Apollo 8 reunited Lovell with his Gemini 7 commander Frank Borman. Among numerous other duties for which he was responsible as CM Pilot, Lovell served as the navigator and operated the spacecraft's built-in sextant to determine its position by measuring star positions. This information would then be used to calculate required mid-course corrections during the trans-lunar flight.

### William Anders

Borman's Lunar Module Pilot (and spacecraft systems engineer) was William Anders, whose father was a U. S. Naval Lieutenant and who was born in British Hong Kong in 1933. His family fled to the Philippines from the Japanese invasion in China, and then escaped to Southern California after the Japanese invaded the Philippines. Following high school, Anders received an appointment to the U. S. Naval Academy, receiving a BS degree in Electrical Engineering. Upon graduation, he was commissioned a Second Lieutenant in the U. S. Air Force. He continued his studies, receiving an MS degree in Nuclear Engineering from the Air Force Institute of Technology at the Wright-Patterson Air Force Base in Dayton, Ohio.

Anders served as a fighter pilot in all-weather interceptor squadrons of the Air Defense Command in California and Iceland, participating in early intercepts of Soviet heavy bombers which were then challenging America's air defense borders. In 1963, Anders was selected by NASA in the third group of astronauts, and was the backup pilot for the Gemini 11 mission, although he never flew in the Gemini program. Anders had been selected as Lunar Module Pilot under the command of Frank Borman.

## Apollo 8 Flight

**Apollo 8**, the second manned spaceflight mission in the United States Apollo program, was launched on **21 December 1968**, from Kennedy Space Center.

**Figure 6.** Apollo 8 launch

Although this was the first manned flight of the Saturn V, the Saturn V rocket used by Apollo 8 was designated SA-503, or the 3rd model of the Saturn V rocket to be used in the Saturn-Apollo (SA) program.

Apollo 8 was the third flight of the Saturn V complete system, and the Saturn V performed flawlessly. The S-1C first stage and S-II second stage jettisoned as scheduled and fell into the Atlantic Ocean. The S-IVB third stage injected the craft into Earth orbit, but remained attached in order to later perform the trans-lunar injection (TLI) burn that would put the spacecraft on a trajectory to the Moon.

Once the spacecraft reached a relatively circular low Earth orbit of about 115 miles, both the crew and Houston Flight Control spent the next 2 hours and 38 minutes checking that the spacecraft was in proper working order and ready for TLI. The proper operation of the S-IVB third stage of the rocket was of paramount importance since it had failed to re-ignite in the last unmanned test. During the flight, three fellow astronauts served on the ground as Capsule Communicators (CapCom) on a rotating schedule. They were the only people who regularly communicated with the crew. Astronaut Michael Collins radioed, "Apollo 8. You are Go for TLI." This communication signified that Mission Control had given official permission for Apollo 8 to go to the Moon. Over the next 12 minutes before the TLI burn, the Apollo 8 crew continued to monitor the spacecraft and the S-IVB. The spacecraft had increased its apogee by about seven miles. The S-IVB engine ignited on time and performed the TLI burn of five minutes and eighteen seconds perfectly.

## Leaving the Earth's Gravitational Field

The spacecraft accelerated to the injection velocity of 24,200 miles per hour from an orbital velocity of 17,430 miles per hour. This speed was slightly less than the Earth's escape velocity, but did put Apollo 8 into an elongated elliptical Earth orbit to a point where the Moon's gravity could capture it. The standard lunar orbit for Apollo missions had been calculated to be a nominal 68.75-mile circular orbit above the Moon's surface. However, initial lunar orbit insertion was an ellipse of 68.75 miles by 195 miles. The lunar orbital period had been calculated to be 126 minutes, but would be 128.7 minutes due to heavier than anticipated lunar mass. The accuracy of this TLI by the NASA engineers was truly remarkable, considering the speed that the Earth travels on an axis around the sun (64,500 mph) combined with the speed that the Moon rotates around the Earth (2,200 mph).

While the crew rotated the spacecraft, they had their first views of the entire Earth. After the crew had jettisoned the S-IVB third stage, Borman became concerned that the S-IVB was staying too close to the Command/Service Module and suggested to Mission Control that the crew perform a separation maneuver. The crew used the Reaction Control System, which were twelve attitude control thrusters on the Service Module, to add speed to the spacecraft while still keeping the S-IVB rocket in sight. Five hours after launch, Mission Control sent a command to the S-IVB booster to vent its remaining fuel through its engine bell to change the booster's trajectory. This allowed the S-IVB to pass the Moon and enter into a solar orbit, posed no further hazard to Apollo 8, and became a derelict object that would continue to orbit the sun for several years.

The Apollo 8 crew then passed through the Van Allen radiation belt, a ring of charged particles, most of which originate from the solar wind. They are captured by and held around a planet by that planet's magnetic field, which extended up to 15,000 miles from Earth. Passing through the belts quickly at the spacecraft's high speed caused only a small radiation dosage. According to the badges that were worn by the astronauts on their flight from Earth and on their return to Earth, they received no more than what would occur with a chest x-ray, as was predicted by NASA scientists.

Lovell's principal function as Command Module Pilot was to navigate the spacecraft, although Mission Control in Houston was able to perform all the actual navigation calculations. Nevertheless, a crew member had to serve as navigator so that the crew could safely return to Earth in the event of loss of communication with Mission Control. Lovell was supposed to navigate by star sightings using a sextant that had been built into the spacecraft, measuring the angle between a star and the Earth's horizon. This task had become difficult because a large cloud of debris around the spacecraft, formed by the venting S-IVB, had made distinguishing the stars somewhat difficult.

Seven hours into the mission, the crew placed the spacecraft into Passive Thermal Control (PTC), in which the spacecraft rotated once every hour around its long axis to ensure even heat distribution across the surface of the spacecraft. In direct sunlight, the spacecraft could be heated to over 392 °F while the parts in shadow would be −148 °F. These extreme temperatures could have caused the heat shield to crack and/or propellant lines to burst. Because it was impossible to get a perfect roll, the crew had to make minor adjustments every half hour as the roll pattern of the spacecraft got larger and larger. The first mid-course correction came 11 hours into the flight with a short (2½ second) burn of the Service Propulsion System (SPS) engine. This first correction burn added about 20.4 ft/s velocity in the direction of travel (prograde). This change was slightly less than the planned 24.8 ft/s, so the crew had to use the small RCS thrusters to make up the shortfall. Two later planned mid-course corrections were canceled because the Apollo 8 trajectory was found to be perfect.

## Entering the Lunar Sphere of Influence

At 55 hours and 40 minutes into the flight, the crew of Apollo 8 entered the gravitational sphere of influence of the Moon. The effect of the Moon's gravitational force on Apollo 8 became stronger than that of the Earth. At the time, Apollo 8 was still nearly 39,000 miles from the Moon, but more than 195,000 miles from Earth, and was traveling at a speed of more than 27,000 miles/hour. They were still 13 hours away from entering lunar orbit and expected to perform their last mid-course correction with their second engine burn. At exactly 61 hours after launch, and still about 24,200 miles from the Moon, the crew made the second major mid-course correction before Lunar Orbit Insertion, which was a retrograde burn (against direction of travel) and slowed the spacecraft down by 2.0 ft/s. This effectively lowered the closest distance that the spacecraft would pass the Moon to 71.7 miles from the lunar surface.

At 64 hours into the flight, the crew began to prepare for the first Lunar Orbit Insertion. This maneuver had to be performed perfectly, and due to the direction from which they were coming, had to be determined when the spacecraft was on the far side of the Moon. Mission Control had been polled, and the crew was told at 68 hours that they were "Go". With ten minutes to go before the LOI, the crew began one last check of the spacecraft systems and made sure that every switch was in the correct position. At that time, they finally got their first glimpses of the Moon, as they had been flying over the unlit side. As they travelled behind the Moon, completely out of contact with Mission Control, the crew was able to establish the epicenter of the Moon for their lunar orbits. Apollo 8 had achieved a maximum distance from Earth of nearly 234,500 miles.

## Lunar Orbit

The Service Propulsion System burned for slightly over 4 minutes, placing the Apollo 8 spacecraft in orbit around the Moon. The timing of the burn was extremely critical: if the burn had not lasted exactly the correct amount of time, the spacecraft could have ended up in a highly elliptical lunar orbit or even been catapaulted into space; if it had lasted too long, the spacecraft could have struck the Moon's surface. The engineers at Mission Control breathed a collective sigh of relief after Apollo 8 appeared from behind the dark side of the Moon exactly at the calculated moment, and the signal was received from the spacecraft, indicating it was in an elliptical orbit around the Moon of 194 miles by 69.5 miles. The crew then established the parameters of the spacecraft at a more circular 73.6 miles by 67.8 miles.

After making sure the spacecraft was working perfectly, the crew finally had a chance to look at the Moon, which they would orbit ten times over the next 20 hours. Lovell gave the first description of what the lunar surface looked like, saying that it was like plaster of Paris, a kind of grayish beach sand. He described the craters as being rounded off, as though they had been hit by numerous meteorites or other projectiles. Anders made over 700 photographs, some for the ages. Frank Borman broadcast this message back to Earth on Christmas day, 1968:

"And, from the crew of Apollo 8, we close with good night, good luck, a Merry Christmas, and God bless all of you—all of you on the good Earth."

## Return to Planet Earth

The crew began their return to Earth later on Christmas Day, 1968 with a rocket burn made on the Moon's far side, again out of radio contact with Mission Control. The trans-Earth injection (TEI) burn was just as intense as the lunar orbit insertion, which were the two most critical moments of this first lunar mission. When contact was re-established after Apollo 8 was emerging from the tenth orbit, Lovell was the first to announce the good news, "Please be informed, there is a Santa Claus." The craft had entered lunar orbit on Christmas Eve and had made those ten orbits, most of them circular at an altitude of approximately 69 miles in twenty hours.

On Christmas afternoon after the successful TEI, the somewhat relaxed crew made their fifth television broadcast. This time they gave a tour of the spacecraft, showing how an astronaut lived in space. When they finished broadcasting they found a small present from astronaut coordinator Deke Slayton in the food locker: a real turkey dinner with stuffing, in the same kind of pack that the troops in Vietnam had received. The next day at about 124 hours into the mission, the sixth and final TV transmission in a four-minute broadcast showed the mission's best video images of the Earth from the astronauts' viewpoint.

The cruise back to Earth was mostly a time for the crew to relax and monitor the spacecraft. As long as the trajectory specialists had calculated everything correctly, the spacecraft would re-enter two-and-half days after TEI and perform the planned re-entry which the crew and Mission Control had prepared for Apollo 8. The computer would control the re-entry, but the crew had to orient and position the spacecraft in the correct attitude, with the blunt end forward. If the computer had a glitch, Commander Borman would be required to take over the spacecraft controls.

The Service Module had powered this Apollo 8 mission, but it was now disposable. It was cast off as the Command Module entered the low Earth orbit position at the end of the trans-lunar flight and left to burn in the atmosphere. The Service Module was never intended to return to Earth; only the Command Module was aerodynamically designed to safely fall through the atmosphere. Just before re-entry, the crew put the Command Module on its internal batteries, then separated the CM from the SM. A guillotine mechanism with two stainless steel blades driven by redundant cord charges cut the wires and tubes in the umbilical, and small charges severed the tension ties. The umbilical firing pulled away and stayed attached to the Service Module, leaving the Command Module unhampered for its return to Earth. All the service modules were left to eventually burn up in the atmosphere.

Once the Command Module was separated from the Service Module, the astronauts were committed to re-entry. Six minutes before they hit the top of the atmosphere, the crew saw the Moon rising above the Earth's horizon, just as had been predicted on the computer by the trajectory specialists. The spacecraft started slowing down as the computer controlled the descent by changing the attitude of the spacecraft. Apollo 8's drogue parachute opened at 30,000 feet and stabilized the spacecraft, and the three main parachutes opened at 10,000 feet. The spacecraft splashed down safely in the North Pacific Ocean south of Hawaii on 27 December. When it hit the water, the parachutes dragged the spacecraft over and left it upside down. After about six minutes the Command Module was righted into its normal apex-up splashdown orientation by three inflatable flotation balloons to place it in an upright position. As the Apollo 8 had landed before sunrise, the crew and Apollo 8 spacecraft were unable to be brought aboard the USS Yorktown until about 1 ½ hours after splashdown.

Apollo 8's mission had taken 68 hours (4.0 hours short of three days) to travel the distance to the Moon and back, and their successful mission paved the way for the rest of the Apollo program. The success of Apollo 8 avoided jeopardizing the goal of making the first manned lunar landing by the end of 1969 by not waiting for the delayed LM, and also provided invaluable experience in navigation to the Moon. Aside from the many firsts Of the Apollo 8 flight, the flight was also notable for the reading of the first ten verses from the Book of Genesis by all three crew members, as well as for the live black and white television broadcasts which were beamed to millions back on Earth.

Note: The crew members were named Time Magazine's "Men of the Year" for 1968 upon their return.

# Summary

This first part of the Apollo program's mission to place an American astronaut on the Moon and return him safely to Earth is both lengthy and detailed. The account, however, describes the many challenges faced by those in the NASA organization as well as the numerous engineering contractors and construction personnel who were involved. Possibly having performed the greatest achievement in the history of mankind, the men and women of the Apollo program were more than worthy of the honors and accolades bestowed on them. There were many firsts in the program, most of them associated with Apollo 8:

1. Apollo 8 was the first manned spacecraft and crew to leave low Earth orbit and Earth's gravitation field.
2. The Apollo 8 crew became the first humans to pass through the Van Allen radiation belt.
3. Apollo 8 was the first manned spacecraft to reach the Earth's Moon.
4. Apollo 8 was the first manned spacecraft to orbit the Moon and return safely to Earth.
5. The Apollo 8 crew became the first humans to see Earth as a whole planet;
6. Apollo 8 was the first manned spacecraft to enter the Moon's gravity well.
7. The Apollo 8 crew became the first humans to see the far side of the Moon.

The Saturn V would remain the launch vehicle of choice by NASA, the Lunar Module would become very reliable with its lunar landings and dockings, and the Command Service Module would continue to be improved and adjusted. The many achievements of the Apollo program could never be captured in one publication or one documentary. In Part 2 of this series, we will focus more on the timing and the activities of the astronauts as they first prepared to land, then actually landed, on the Moon and returned safely to Earth. Part 2 will also describe in great detail the first landing on the lunar surface by the crew of Apollo 11 as well as the near fatal mission and miraculous recovery of Apollo 13.