
America's Greatest Projects and Their Engineers - VI

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AGP-VI: America's Greatest Projects

American Engineers in Space – Phase 2 – Project Gemini

Overview

This course chronicles the events and achievements of American engineers and scientists who followed the Mercury Project, but who were very aware that there was a major hurdle between placing a man in space and placing a man on the moon and assuring his safe return. The members of this project had the responsibility for placing the first pair of American astronauts into outer space in preparation for a lunar landing. It summarizes the concepts and planning by the officials of NASA (National Aeronautics and Space Administration) and other involved engineers and contractors. This course describes the engineering and design efforts necessary to provide the equipment and the technology to enable our second group of astronauts to orbit above the earth's surface for lengthy periods of time, to walk in space, and to rendezvous with other spacecrafts. This is the sixth in a series of Twentieth Century projects in which engineers overcame major technological challenges and were on the forefront of engineering innovation. The course details the contributions of the many engineers, manufacturers, and contractors, and their remarkable foresight.

Project Gemini - Outline

A. The Close Space Race Between the U. S. and the Soviets

- 1. Mercury Project Still Leaves USA Behind Soviet Union**
- 2. Challenges to Reach Moon by End of Decade**

B. America's Engineering Response

- 1. Planning and Design for Lengthy Space Travel**
- 2. Docking, Space Walking, Lunar Landing Programs**

C. Project Gemini

- 1. Astronaut Selections**
- 2. Preparing for the Long Flight to the Moon**

F. Summary

A. The Close Space Race Between the U. S. and the Soviets

1. Mercury Project Still Leaves USA Behind Soviet Union

The National Aeronautics and Space Administration (NASA) was formed under the Eisenhower Administration in the summer of 1958 following the successful launch of Sputniks 1 & 2 by the Soviet Union. Its formation was an effort by the United States to coordinate the space programs that were fragmented among the various Department of Defense (DOD) segments of the U. S. military. All three of the major military organizations were in the process of generating and conducting their own satellite launches and space programs. But the formation of NASA was not as basic and simplistic as it may seem today. NASA was viewed as an unnecessary albatross by the majority of military officials, especially those who had their own agendas. NASA needed a leader who commanded authority and respect, had great administrative and leadership skills, and understood the nuances of working with the U. S. Congress to meet the financial requirements of such a historic undertaking. Dr. T. Keith Glennan was appointed by President Dwight D. Eisenhower to be the very first NASA administrator in August, 1958, shortly after the Soviet Union had launched Sputniks I and II.

Dr. T. Keith Glennan

Dr. Glennan, an electrical engineering graduate from Yale University, had served in an administrative capacity for the United States Navy during World War II. After the war Dr. Glennan went into corporate America, although he continued to serve on various national committees, and was highly regarded in Washington, DC circles. In 1952 he became president of Case Institute of Technology in Cleveland, Ohio, and was instrumental in expanding their enrollment and their prestige to a national level. He was selected as the first NASA Administrator in August of 1958, and he coordinated the necessary protocol to bring the many-faceted U. S. Space Program under one authority.

Within a short time after NASA's formal organization, Glennan incorporated other organizations involved in U. S. space exploration projects from other federal agencies into NASA to ensure that a viable scientific program of space exploration could be reasonably conducted over the long-term. He brought in part of the Naval Research Laboratory to NASA and created for its use the Goddard Space Flight Center in Greenbelt, Maryland, which currently employs nearly ten thousand personnel, most of whom are civil servants and contractors. He also incorporated several disparate satellite programs, two lunar probes, and the research effort to develop a 4.4 million ton thrust, single-chamber rocket engine through the U. S. Air Force and the DOD. In December 1958 Glennan also acquired control of the Jet Propulsion Laboratory (JPL), a contractor facility operated by the California Institute of Technology. In 1960, Glennan obtained the transfer to NASA of the Army Ballistic Missile Agency, located at Huntsville, Alabama, and renamed it the Marshall Space Flight Center.

By mid-1960, Glennan had secured for NASA primacy in the U.S. federal government for the execution of all space activities except reconnaissance satellites, ballistic missiles, and a few other

space-related projects, most of which were still in the study stage, that the DOD controlled. Glennan presided over an organization that had absorbed the earlier National Advisory Committee for Aeronautics (NACA) intact, including its 8,000 employees and an annual budget of over \$100 million. At the same time three major research laboratories (Langley Aeronautical, Ames Aeronautical, and Lewis Flight Propulsion), as well as two small test facilities, were consigned to NASA and made up the core of the new administration. During his brief two and a half years as the NASA administrator, Dr. Glennan managed to craft very nearly the organization as we know it today, to screen and select the base astronaut core, to pull even with the Soviet Union in the Space Race, and to choose the key engineering personnel who would move the program forward to a successful conclusion.

Project Mercury was officially approved on October 7, 1958 and publicly announced on December 17 of that year. Originally called Project Astronaut, President Dwight David Eisenhower felt that gave too much attention to the pilot, and not enough to the vast numbers of personnel who would be developing the necessary technology. Instead, the name Mercury was chosen from Greek mythology, which had already lent names to rockets like the Greek Atlas and the Roman Jupiter for ICBM's (Intercontinental Ballistic Missiles).

Hugh L. Dryden

The acquisition of NACA brought with it Hugh L. Dryden, the last Director of NACA, as Glennan's Deputy Administrator. Dryden, a native of Pocomoke City, Maryland, excelled in mathematics as a student, graduated high school at the age of 14, and was awarded the Peabody Prize for excellence in mathematics. He earned a scholarship and was admitted to Johns Hopkins University, graduating with honors after only three years. His study of aerodynamic principles enabled him to receive his doctorate in physics and mathematics in 1919 at the age of 21, also from John Hopkins.

Dryden joined the National Bureau of Standards, and was appointed the director of the Aerodynamics Division, a newly created section. He performed studies of airfoils near the speed of sound. He also performed pioneering aerodynamics research on the problems of airflow and turbulence. Dryden was appointed the bureau's Chief of the Mechanics and Sound Division, and in 1939 he became a member of NACA. His work contributed to the design of the wings for the P-51 Mustang as well as other aircraft designed during World War II.

During World War II, Dryden served in an advisory capacity to the U. S. Army Air Force, leading the development of a radar-homing guided bomb program that was successfully employed in combat in April, 1945, and credited with sinking a Japanese Destroyer. After the war, Dryden became the Director of Aeronautical Research for NACA in 1946. While at the NACA he supervised the development of supersonic aircraft, established programs various jet aircraft, and studied the problem of atmospheric reentry. Dryden held the position of Director of NACA, NASA's actual predecessor, from 1947 until October 1958. In addition, he served on numerous government advisory committees, including the Scientific Advisory Committee to the President. From 1941 until 1956 he was also the editor of the first airplane publication of its type, the Journal of the Institute of the Aeronautical Sciences.

Walter C. Williams

Williams was a graduate of Louisiana State University with a Bachelor of Science degree in Aeronautical Engineering. After graduation he joined the staff at Langley Research Center in DC, and at the end of World War II he joined NACA (The National Advisory for Aeronautics) as a Project Engineer. During this period at NACA he authored numerous technical papers on aircraft flight research, and he was considered one of the highest-ranking experts on "High-Speed Airplane Stability and Control Characteristics."

Following the formation of NASA, which absorbed NACA into its organization in October 1958, Williams left the High-Speed Flight Station and was assigned responsibility for overall launch operations in Project Mercury at Cape Canaveral. He directed the Worldwide Tracking Network and recovery operations for manned space flight missions. As Operations Director in Mercury Control Center at Cape Canaveral, Florida, Williams utilized the combined know-how of approximately 20 scientists and engineers on the site. Each of these men was responsible for a specific facet of space flight and reported directly to Williams during flight operations, which enabled him to assess the flight and make necessary decisions. As Flight Operations Director, Williams was responsible for America's earliest manned space flights, including suborbital and orbital flights. He held the position of Chief Engineer at NASA Headquarters until 1982.

Objectives of the Mercury Program

Working with Glennan and Dryden, at the creation of the agency on October 1, 1958, was a group of engineers responsible for Project Mercury who were officially named NASA's Space Task Group. The Group was initially stationed at the Langley Research Center in Hampton, Virginia, but became so large that they were eventually moved into a much larger complex on land donated by the Humble Oil Refining Company in Clear Lake, Texas, in September of 1963. The complex was later named the Johnson Space Flight Center in honor of former president Lyndon B. Johnson by an act of Congress in 1973. The STG had three main goals for the Mercury program:

- A. Orbit a manned spacecraft around Earth,
- B. Investigate the astronaut's ability to function in space,
- C. Recover both the astronaut and the spacecraft safely.

Existing technology and off-the-shelf equipment were to be used wherever practical, system design was simplified, and an existing launch vehicle named Atlas was being prepared for employment. The actual spacecraft requirements included:

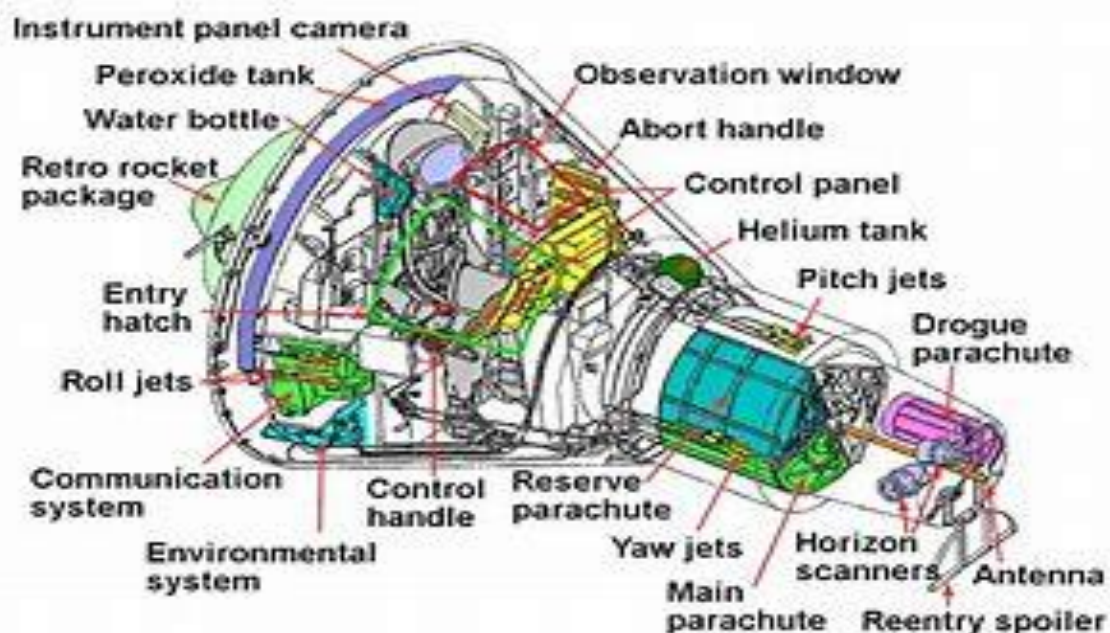
1. a launch escape system to separate the spacecraft and its occupant from the launch vehicle in case of impending failure;
2. attitude control for orientation of the spacecraft in orbit;
3. a retrorocket system to slow the spacecraft down and to bring it out of orbit;
4. a drag braking, high temperature-resistant blunt body for atmospheric reentry;
5. an extensive communications network for the spacecraft to land on water.

Since the U.S. space program, in general, and Project Mercury, in particular, was considered to be a civilian project, President Eisenhower initially refused to give the project top national priority

to avoid giving the program an overly military flavor, however, the highest priority rating was granted in May 1959, a little more than a year and a half after Sputniks 1 and 2 were launched.

The Mercury spacecraft's principal designer was Maxime Faget, a native of British Honduras, who received his mechanical engineering degree from the City College of San Francisco. After serving three years in the U. S. Navy, he began his career for NACA at the Langley Research Center. Following the incorporation of NACA into NASA in 1958, Faget became one of the principal engineers that made up the Space Task Group. His experience in the design of high-speed jet aircraft cockpits placed him in a prime position to design the Mercury spacecraft. The module was initially just 10.8 feet long and 6.0 feet wide; however, with the launch escape system added, the overall length grew to just under 26 feet. With only about 100 cubic feet of habitable volume, the capsule was just large enough for a single crew member. Inside the module there were 120 controls, including 55 electrical switches, 30 fuses and 35 mechanical levers. The outer skin of the spacecraft was made of Rene 41, a nearly 50 percent nickel alloy produced by General Electric, that was able to withstand very high temperatures.

The spacecraft had a convex base, which carried a **heat shield** consisting of an aluminum honeycomb covered with multiple layers of Fiberglas. Strapped to it was a **retropack** consisting of three rockets deployed to brake the spacecraft during reentry. Between these were three minor rockets for separating the spacecraft from the launch vehicle at orbital insertion. The straps that held the package could be severed when it was no longer needed. Next to the heat shield was the **pressurized crew compartment**. Inside, an astronaut was strapped to a form-fitting seat with instruments in front of him and with his back to the heat shield. Underneath the seat was the environmental control system which included oxygen and heat, a CO₂ scrubber, and (on orbital flights) the collection of urine. The **recovery compartment** at the narrow end of the spacecraft contained three parachutes: a drogue to stabilize free fall and two main chutes, a primary and reserve.



On top of the recovery compartment was the **antenna section** containing one antenna for communication and a scanner for guiding spacecraft orientation.

The Mercury spacecraft did not have an on-board computer, instead relying on all computation for reentry to be calculated by computers on the ground, with their results (retrofire times and firing attitude) then transmitted to the spacecraft by radio while in flight. A **launch escape system** was mounted to the narrow end of the spacecraft that contained three small solid-fueled rockets which could be fired briefly in a launch failure to separate the capsule safely from its booster, and then deploy the capsule's parachute for a landing nearby at sea.

Mercury Project Status – 1961

For the next two plus years, between the fourth quarter of 1958 and the first quarter of 1961, NASA dedicated itself to moving forward as the premier space technology center in the world. Meanwhile the U. S. Congress had budgeted more than one hundred million dollars to fund NASA and its affiliated agencies. Calm regarding the space program seemed to have prevailed nationally under the Eisenhower administration in Washington following the surprise launchings of Sputniks 1 and 2 in 1957. The United States had managed to launch its own satellites, thanks in large part to the Redstone Arsenal Team, and its leader Wehrner Von Braun (see **America's Greatest Projects-IV-Mercury Project**). Until the first quarter of 1961, the status of the Mercury Project had been extremely conservative and reserved. Between October of 1958 and April of 1961 NASA had conducted twenty unmanned developmental flights (three using chimpanzees). Of those twenty flights, only slightly more than half of them were rated as very successful by NASA administrators. Review of the first twenty unmanned flights gives unmistakable proof that the extreme caution and conservatism of the NASA engineers allowed the Soviet Union to gain an edge over the United States in the **Space Race**. Although manned spaceflight was an immediate goal of the U. S. space program, there didn't seem to be a NASA policy of urgency. The attitude among the engineers and scientists associated with NASA was that they would not sacrifice their principles for the sake of expediency. During the fourth quarter of 1960 a very preliminary plan to place an American on the moon was first conceived by NASA engineers. Code-named the Apollo Program by the NASA administration, the cost was so prohibitive for the times that it was placed on the back burners.

James E. Webb

However, the seeming lack of leadership in the U. S. space program became a political issue during the presidential campaign of 1960. On 20 January 1961 John F. Kennedy, who had been successful in being elected to succeed Dwight D. Eisenhower as President of the United States, had the prerogative to change NASA Administrators. Fully aware of this situation, Dr. Glennan tendered his resignation and Hugh Dryden was named the interim NASA Administrator. Less than one month later President Kennedy named **James Edwin Webb** as the new Administrator to succeed Dr. Glennan. Webb was essentially a career politician who had been involved with the Roosevelt administration, primarily in a supportive role to Congressional leaders. Prior to World War II, he was hired by the Sperry Rand Corporation, and was instrumental in their development as the leading supplier of radar equipment to the U. S. military.

After enlisting in the United States Navy in 1944, he was placed in command of a task force in August of 1945 with the responsibility for preparing a radar plan that would allow the U. S. Armed Forces to ultimately invade Japan. However, the atomic bombs on Hiroshima and Nagasaki, and Japan's ultimate surrender on 15 August 1945, fortunately circumvented the need for an American invasion. A lawyer by training, Webb had been an undersecretary in the U. S. State Department, and he was somewhat surprisingly appointed to head the U. S. Bureau of Budget by President Truman in 1949. He developed numerous Congressional contacts while serving in the Truman Administration, but returned to private practice following General Eisenhower's election as president in 1952.

Webb's peaceful coexistence with President Kennedy came to an abrupt end less than two months later on 12 April 1961, when the Soviet Union shocked the United States by putting the first man into space. The United States was simply unaware of the pending successful launch of Vostok 1 with Cosmonaut Yuri Gagarin on board. Gagarin, a twenty-seven years old cosmonaut, became the first man to reach outer space, and did it in grand style by traveling a complete orbit around the Earth. Gagarin was hailed by the Soviets as a hero, was feted by the world's press, and his launch date became a national holiday in the Soviet Union. There was a considerable amount of anxiety and concern by the more than 2 million NASA-related personnel, including about a dozen prime contractors and over seventy-five major sub-contractors who were associated with Project Mercury, a name that had been taken, ironically enough, from the Roman god of speed.

There was also great anxiety among the members of the U. S. Government, including President Kennedy, following the Soviet's successful flight of Vostok 1, since Project Mercury had already cost about \$400 million in 1965 US dollars, with seemingly very little to show for it. During the period leading up to the first U. S. manned space flight by Astronaut Alan Shepard on **05 May 1961**, Dryden made a comment in a meeting attended by President Kennedy. He stated that the quickest way to forge well ahead of Soviet technology and put some distance between them and the United States in the Space Race was to announce to the world that the U. S. planned to put a man on the moon. A few weeks after Dryden's comment, President Kennedy shocked the world (as well as most of NASA) by declaring that the U. S. planned to place a man on the moon and bring him safely back to Earth by the end of the decade.

The mission of Project Mercury from the very beginning had been to have the United States put a man into an orbit of the Earth and return him safely, ideally before the USSR did. After a slow start riddled with humiliating mistakes, the Mercury Project gained a measure of popularity, and its missions were followed by millions on radio and TV around the world. The project ran for five years, beginning informally at the inception of NASA in 1958, and ending after the sixth manned space flight in 1963.

There had been more than a six-month time period between the **Mercury Atlas-8 (MA-8)** flight and the **Mercury Atlas-9 (MA-9)**, which proved to be the final manned space flight of Project Mercury. This was due to several reasons:

1. The Soviets had already launched Vostok 3, which accomplished sixty-four orbits.

2. Many in NASA believed that **MA-8** was as good as they could do in Project Mercury, and they were anxious to move on and develop the two-man missions of Project Gemini.
3. When NASA did decide on an **MA-9** flight, they had to renegotiate with McDonnell for several capsule modifications to accommodate the longer flight.

Chosen for the MA-9 assignment was **U. S. Air Force Colonel L. Gordon Cooper, Jr.**, U. S. Air Force pilot, test pilot, and the youngest of the original seven astronauts chosen for Project Mercury. Cooper attended the U. S. Air Force Institute of Technology in Dayton for two years, and he received his Bachelor of Science degree in Aeronautical Engineering in 1956. As the pilot for MA-9, the last of the Mercury Project flights, Cooper logged over thirty-four hours in space, and he flew a total of twenty-two orbits.

Project Mercury is Complete

Following Cooper's flight in Faith 7 on **15 May 1963**, a 22-orbit, 34-hour flight, Alan Shepard and others pushed for a six-day Mercury Atlas-10 (MA-10) endurance mission. After the MA-9 mission's electrical mishaps, there was an ongoing debate about whether to fly one more Mercury flight (MA-10). This would have been a three-day, 48-orbit mission to be flown by Shepard in October 1963. This would have given America the manned space endurance record for the first time, and also would have covered the biological objectives of the upcoming Gemini's first two missions. The Mercury capsule had already been modified by McDonnell Corporation for long-duration flight, and Shepard had the name 'Freedom 7 II' painted on the side. But the risk of the flight, coupled with the work that was already underway on Gemini, persuaded NASA managers in the end not to undertake another Mercury Project mission. NASA officials decided that the Mercury Project had fulfilled its goal and most of its objectives, so the time had come to move on to Project Gemini, and MA-10 never flew.

2. Challenges to Reach Moon by End of Decade

Although the strength and superiority of United States space technology suffered in the early stages of the Space Race, the framework had been established by NASA to move forward successfully. The mission of placing an American on the moon had first been conceived late in the Eisenhower administration, and the name Project Apollo had been designated for it in 1960. The original concept was to have a single spacecraft carry three astronauts to a moon landing, and then to have that spacecraft lift off from the moon and return to Earth. NASA's administration and their engineers, many of whom were from Canada as well as Germany, realized as early as the spring of 1961 that a well-defined intermediate program would be necessary to bridge **Project Mercury** with the **Moon Landing Project**. Most believed that a program was required to develop certain spaceflight capabilities before any moon landing could be seriously considered.

Some of the necessary technologies of a subsequent lunar landing had been achieved during the Mercury Project, but several more concerns had to be addressed, including:

1. Long-term weightlessness

2. Connecting one spacecraft to a second spacecraft
3. Life in outer space without fresh air or water

These issues may seem commonplace today, in hindsight, but they were serious and very challenging problems when they were encountered in 1961. Project Gemini's primary goal was the development of space travel techniques to support the Apollo mission to land astronauts on the Moon, and to return them safely to Earth. Only after these new techniques were proven by Project Gemini could the Apollo Project pursue its prime mission without doing these fundamental exploratory operations. The most immediate major objectives of Project Gemini were:

1. Design a spacecraft to support two astronauts and their necessary supplies.
2. Furnish a launch vehicle that would lift and send into orbit the much-increased weight.

One of the most important engineers who played a significant role in determining the processes to meet these challenges was **Robert R. Gilruth**.

Robert R. Gilruth

Gilruth, who was born in Nashwauk, Minnesota in 1913, received both his Bachelor's and Master's degrees in aerospace engineering from the University of Minnesota in the mid-1930's. Following graduation, he joined NACA (National Advisory Committee for Aeronautics), and pioneered flight research in both newly conventional aircraft as well as pilotless missiles and rockets. His research led to the NACA Report R755, Requirements for Satisfactory Flying Qualities of an Airplane, published in 1941 for the United States Army Air Force. In this report, he defined a set of requirements for the handling characteristics of an aircraft, which was the first set of guidelines for American pilots and aircraft designers.

As the assistant director of the Pilotless Aircraft Research Division of NACA, he and his team pushed their superiors to pursue a program to launch satellites into space as a part of the International Geophysical Year (IGY), when the French first proposed the IGY in 1955, but he was rebuffed by administrators. The dynamic quickly changed after the Soviets succeeded in launching Sputnik I. Less than one year later, Gilruth and his team were an important part of the transition of NACA into NASA. When NASA was created, Gilruth became head of the Space Task Group, charged with putting a man in space ostensibly before the Soviet Union, and was named the lead Engineer for Project Mercury. He was a principal advocate for planning and designing a means for NASA to learn more about operating in space before attempting a lunar landing.

When the Apollo (Lunar Landing) Program was first conceived, Gilruth was made head of the new NASA Manned Spacecraft Center (MSC) which ran it. He and his STG quickly outgrew their offices and moved from Langley to the new, much larger facility outside Houston, Texas, which we now know as the Johnson Space Center. As director of the MSC, he oversaw a total of 25 manned space flights, from Mercury-Redstone 3 through Apollo 15. As the director of NASA's Space Task Group, he had the responsibility, for instance, of informing the seven original astronauts in January of 1961 that Alan B. Shepard had been chosen for the first American manned mission into space.

President Kennedy gave his famous speech on 25 May 1961, just a few short weeks after Shepard had only managed to reach outer space, announcing that America would put a man on the Moon before the end of the decade. Gilruth, who had been integral to the creation of the Gemini Program, was extremely perplexed with Kennedy's proclamation and unsure that such a goal could be accomplished. He was a strong proponent of an intermediate program which would require extensive planning, and he advocated it as a necessary means for NASA to learn more about operating in space before attempting a lunar landing.

B. America's Engineering Response

1. Planning and Design for Lengthy Space Travel.

Spacecraft

The design of a capsule that would support two astronauts, the necessary controls – including computers, as well as the critical supplies for a journey that would last at least eight days was a major undertaking of the project. Because of his experience in developing two-pilot aircraft for Avro Canada and Avro Arrow during World War II, Canadian Jim Chamberlain was put in charge of this very important phase of Project Gemini. Many components in the capsule itself were reachable through their own small access doors. Unlike Mercury, Gemini used completely solid-state electronics, and its modular design made the many new systems easier to repair.

Gemini's emergency Launch Escape System (LES) did not use an escape tower powered by a solid-fuel rocket, but instead used two aircraft-style ejection seats, probably due in large part to Jim Chamberlin's earlier experiences. The tower was heavy and complicated, and NASA engineers reasoned that they could do away with it since the Titan II's propellant system would burn immediately on contact. A Titan II booster explosion would have a smaller blast effect and flame than on the cryogenically fueled Atlas and Saturn. NASA engineers concluded that ejection seats were sufficient to separate the astronauts from a malfunctioning launch vehicle. At higher altitudes, where the ejection seats could not be used, the astronauts would return inside the spacecraft, which would presumably separate from the launch vehicle.

James A. Chamberlin

James A. Chamberlin proved to be invaluable to the U. S. Space Program. Known to his colleagues as Jim, Chamberlin was born in Kamloops, British Columbia in 1915. Having maintained a keen interest in model aircraft during high school, he received his mechanical engineering degree at the University of Toronto in 1936 and his master's at the Imperial College of London, England in 1939, developing a strong affinity for aerospace.

Chamberlin began his engineering career with the British aircraft company (and later ejection seat manufacturers) Martin-Baker in 1940, choosing to remain in the UK during the German Blitzkrieg of London. Chamberlin returned to Canada later in 1940, and he worked on the design and production of the British Avro Anson, a twin-engine, two-pilot reconnaissance plane at Federal Aircraft Ltd. in Montreal through 1941, and later as chief engineer and research engineer

in Nova Scotia and Montreal, working on various aircraft and serving as an aircraft engineer until the end of World War II. At the end of the war, Chamberlin went back to work for Avro Canada, and he and his Avro Team developed the Avro Arrow, a delta-winged interceptor aircraft for the Royal Canadian Air Force. Although it could fly at Mach 2 speed and reach 50,000 feet in altitude, Avro's attempt to sell the aircraft to the United States and Great Britain did not materialize, the leaving only the Canadian Government as a potential market.

Following the Canadian government's cancellation of the Avro Arrow project in 1959, Chamberlin led a team of 25 engineers from Avro who joined NASA's Space Task Group. This group eventually grew to 32 former Avro engineers, collectively known as the "Avro Group", who joined NASA and become emblematic of what many Canadians viewed as a "brain drain" to the United States in the early 1960's.

Chamberlin, who had been named head of engineering for the Mercury Project, became chief designer and NASA's first Project Manager for the Project Gemini spacecraft. Chamberlin played an instrumental role in creating and implementing the first three generations of American crewed spacecraft. Specifically, Chamberlin became the head of engineering at the Space Task Group (STG), and he had already been assigned to start working on a bridge program between Mercury and Apollo in February 1961. He presented two initial versions of the Gemini capsule at a NASA retreat at Wallops Island in March 1961, and he helped prepare scale models of Mercury Mark II. The McDonnell Aircraft Corporation, which was also the prime contractor for the Mercury capsule, was contracted to build the two-pilot spacecraft on 22 December 1961, two months before John Glenn had made his first orbit around the Earth. He was one of the key people that proposed that the Lunar Orbit Rendezvous (LOR) was the best option for landing a crew on the Moon. A concept that had first been proposed several decades earlier by a Russian engineer, American engineers stacked the Command and Service Module (CSM) with the Lunar Landing Module (LLM), the method which was eventually used on Apollo lunar landing missions. Chamberlin was often described by co-workers and space historians as "probably one of the most brilliant men ever to work for NASA."

Others Who Were Involved in Gemini Spacecraft Design

Astronaut Virgil "Gus" Grissom was another individual who was very involved in the design of the Gemini capsule, so much so that many of the other Mercury astronauts dubbed the Gemini spacecraft the "Gus-mobile". Grissom was born and raised in Michell, Indiana, and received his Bachelor of Science in Mechanical Engineering from Purdue University after World War II. A U.S. Air force Test Pilot, Grissom was one of the original seven original Mercury astronauts. He was the second American to fly in space, and the first member of the Astronaut Corps to fly in space twice. Grissom was the pilot of the second American suborbital flight in the Liberty Bell 7. He would fly in one flight for Project Gemini, and Grissom was scheduled to fly in the Apollo Program as well. However, he was killed along with fellow astronauts Ed White and Roger Chafee during a pre-launch test for Apollo 1's first manned spaceflight mission at Cape Canaveral, Florida in January, 1967.

McDonnell Aircraft's Chief Engineer was Gunter Wendt, who supervised launch preparations for both the Mercury and Gemini programs, and would later go on to do the same when the Apollo

program launched crews. His team was responsible for completion of the complex pad close-out procedures just prior to spacecraft launch, and he was the last person the astronauts would see prior to closing the hatch. The astronauts appreciated his taking absolute authority over, and responsibility for, the condition of the spacecraft and developed a good-humored rapport with him.

The first Gemini spacecraft was delivered from McDonnell in 1963. It was about eighteen and a half feet long and ten feet wide, and its launch weight varied from 7,100 to 8,350 pounds, depending on the particular flight requirements. The Gemini crew capsule (referred to as the **Reentry Module**) was essentially an enlarged version of the Mercury capsule. Unlike Mercury, however, the retrorockets, electrical power, propulsion systems, oxygen, and water were located in a detachable Adapter Module behind the Reentry Module. A major design improvement in Gemini was to locate all internal spacecraft systems in modular components, which could be independently tested and replaced when necessary, without removing or disturbing other already tested components.



A cutaway illustration of the Gemini spacecraft

Launch Vehicle

The Atlas ICBM had been the launch vehicle of choice for the Mercury Project, even though it was late in development, and the Redstone rocket had to be used for the first two manned spaceflights (MR-3 and MR-4). Atlas was informally classified as a "stage-and-a-half" rocket; both the central sustainer engine and the set of two booster engines were started at launch, each drawing from a single set of propellant tanks. At staging, the booster engines would be shut off and a series of mechanical and hydraulic mechanisms would close the plumbing lines to them.

The booster section would then be released by a series of hydraulic clamps (aside from the early test model Atlas B which used explosive bolts) and slide off the missile. From there on, the sustainer engine and verniers would operate by themselves.

Booster staging took place at roughly two minutes into launch, although the exact timing could vary considerably depending on the model of Atlas as well as the particular mission being flown. The boosters were more powerful than the sustainer engine and did most of the lifting for the first two minutes of flight. The stage-and-a-half design mainly came about because of the most functional Atlas design had been finalized in the mid-1950s, at a time when engineers had not yet figured out how to air-start a rocket engine. Having all engines running at liftoff would avoid this problem (the contemporary Soviet R-7 missile used a similar design for the same reason).

Note: A "stage" of a liquid propellant rocket is normally thought of as tanks **and** engine(s) together. The jettisoned engine, therefore, was considered to constitute a "half stage".

However, technology advanced quickly, and not long after design work on Atlas was completed by the Convair engineers, the Glenn L. Martin Aircraft Company of Baltimore, Maryland proposed a solution to the air-starting problem. They were contracted by the U. S. Air Force to develop a conventional two-stage design ICBM as an Atlas backup. They began with the design of the Titan I, but after their merger with the Marietta Corporation in 1961, they shifted most of their design and production of the Titan rockets to the Titan II ICBM and their civilian derivatives for NASA.

The Titan I had used an LR-87 engine that had been developed in the late 1950's by Aerojet Corporation, based in Rancho Cordova, California, that had been founded by a group of Caltech engineers and professors. The **LR87** was a liquid-propellant rocket which was used on the first stages of early ICBM's and launch vehicles. Composed of twin motors with separate combustion chambers and turbopump machinery, they were considered single units, first flying in 1959. The reasonably high density of liquid propellant allowed the volume of the propellant tanks to be relatively low, and lightweight centrifugal turbopumps could be used to pump the propellant from the tanks into the combustion chamber. This meant that the propellants could be kept under low pressure, permitting the use of low-mass propellant tanks, which resulted in a high mass ratio for the rocket.

However, the Titan II used a modified version of the LR-87 engine, renamed the **LR-87-5** that relied on a **hypergolic propellant combination**, in which case the components spontaneously ignite when they come into contact with each other. The components of the hypergolic propellant combination used in the Titan II rocket engine were nitrogen tetroxide for the oxidizer and Aerozine 50 for the fuel. Nitrogen tetroxide is a popular oxidizer that was first used in large quantities on the Titan rockets, and it is still used today by both the U. S. and Russia. It was first introduced by the Germans during World War II, and it became the oxidizer of choice because of its chemical properties of being storable in liquid form at room temperatures.

Aerozine 50 is a 50%/50% mixture of hydrazine, an inorganic compound, and UDMH, another inorganic compound with a pungent ammonia-type smell, for its fuel for the Titan II rockets. This new hypergolic combination was originally developed by Aerojet in the late 1950's to replace the liquid oxygen and RP-1 (refined petroleum – think jet fuel or high-grade kerosene) combination that was used in the Titan I. Aerozine 50, also a storable, high-energy, hypergolic fuel for the Titan

II rocket engines, is more stable than hydrazine alone, and has a higher density and boiling point than UDMH. It continues in wide use today as a rocket fuel, typically with nitrogen tetroxide as the oxidizer. Even though the LR-87-5 was a fixed-thrust engine, which could not be throttled or restarted in flight, it delivered approximately 1,900 kilonewtons (430,000 pounds) of thrust. For the Titan II, the conversion of the engines to a hypergolic propellant combination allowed Titan II missiles to be kept fully fueled and ready to launch on short notice.

The first Titan II guidance system was designed by engineers at the Charles Stark Draper Laboratories at Massachusetts Institute of Technology in Cambridge, MA. The laboratory had become well-known for developing guidance, navigation, and control technologies and systems; fault-tolerant computing; advanced algorithms and multichip module technology, software solutions; and modeling and simulation. The actual microelectromechanical systems were manufactured by the AC Spark Plug Division of General Motors Corporation, and the missile guidance computer (MGC) was an IBM.

Overall, twelve Titan II launch vehicles would be utilized to launch two U.S. unmanned Gemini test launches and ten manned capsules with two-man crews. All Gemini flights were launched from Launch Complex 19 (LC-19) at Cape Kennedy Air Force Station in Florida. Gemini was the first program to use the newly built Mission Control Center outside Houston, Texas for manned flight-control. All of the launches would prove to be successful, and Titans became part of the U. S. Air Force's intercontinental ballistic missile fleet until 1987, lifting other American military payloads as well as civilian agency intelligence-gathering satellites. Titans have also been used to send highly successful interplanetary scientific probes throughout our Solar System.

Endurance of Humans and Equipment

The general criterion among NASA Administrators and the STG was that the duration of a lunar landing and safe return would be at least eight days. Consequently, eleven of the twelve missions to be performed in Project Gemini had a duration of at least eight days, long enough for a trip to the Moon and a safe return to Earth. The Gemini Program planned to feature endurance missions that went as long as two weeks, which would be ample time for astronauts to get to and from the moon. During these lengthy flights, NASA intended to perform physiological studies of the human body in lunar mission duration flights.

The Soviet Union had moved well ahead of the U. S. in the **Space Race** with the flight of Vostok 3. That was a spaceflight of the Soviet space program that was intended to determine the ability of the human body to function in conditions of weightlessness, and to test the endurance of the Vostok spacecraft over longer flights. Cosmonaut Andriyan Nikolayev orbited the Earth 64 times over nearly four days in space, between 11 and 15 August 1962. This was a feat which would not be matched by the United States until the early phases of Project Gemini in 1965.

In actuality, Vostok 3 and Vostok 4 were launched just one day apart on trajectories that brought the two spacecrafts within approximately 4.0 miles of one another. The cosmonauts aboard the two capsules also communicated with each other via radio, the first ship-to-ship communications in space. These missions marked the first time that more than one manned spacecraft was in

orbit at the same time, giving the mission controllers in the Soviet Union the opportunity to learn to manage multiple spacecrafts, and moving the Soviets much further ahead of the United States.

2. Docking, Space Walking, Lunar Landing Programs

Rendezvous and Docking, Space-"Walks" and Other Maneuvers

The rudimentary planning of the NASA Administrators in the early stages of the Apollo Program was that the astronauts would land on the Moon, leave the spacecrafts, and collect samples of the Moon's surface. Thus, the members of the STG invented the term Extra Vehicular Activity (EVA) in the early stages of Project Gemini. To support this, and other Apollo objectives which might include future scientific experiments, Project Gemini developed the capability for astronauts to work outside their two-man Earth orbiting spacecraft. However, the Soviet Union remained fiercely competitive in maintaining the early lead it had gained in manned spaceflight. The Soviets ordered the conversion of its single-pilot Vostok capsule to be quickly redesigned into a two- or three-cosmonaut spacecraft renamed Voskhod in order to compete with Gemini. The Soviets were actually able to launch two of their two-man Voskhod capsules before the U.S. was able to launch its first manned Gemini.

However, the Voskhod's flight system required cooling by cabin air to prevent overheating, so that an airlock was required for the spacewalking cosmonaut to exit and re-enter the cabin while it remained pressurized. Conversely, the Gemini avionics did not require air cooling, allowing a spacewalking astronaut to exit and re-enter the depressurized cabin through an open hatch. Because of this factor, the duration of the EVA for the United States was shorter and simpler than that of the Soviets, primarily because the Soviet EVA began when the outer airlock hatch was open and the cosmonaut was in a vacuum.

The first EVA was performed on March 18, 1965, by Soviet cosmonaut Alexi Leonov, who spent 12 minutes outside the Voskhod 2 spacecraft. Carrying a white metal backpack containing 45 minutes of breathing pressurization oxygen, Leonov had no means to control his motion other than pulling on his 50 ft. tether. After the flight, he claimed this was easy, but his space suit had ballooned from its internal pressure against the vacuum of space, stiffening so much that he could not activate the shutter on his chest-mounted camera.

At the end of his space-walk, the suit stiffening caused a more serious problem: Leonov had to re-enter the capsule through the inflatable cloth airlock, which was about four feet in diameter and barely eight feet long. He improperly entered the airlock head-first and got stuck sideways. He could not get back into the spacecraft without reducing the pressure in his suit, thus risking "the bends". This added another twelve minutes to his time in vacuum, causing him to become seriously overheated from the exertion. Misrepresenting to the press how much difficulty Leonov had, the Soviets did not attempt another EVA until almost four years later. Despite the oversimplification by the Soviets, NASA continued to try to perfect the process of working outside the spacecraft, developing many innovations regarding EVA, and pioneered numerous orbital spacecraft maneuvers to achieve rendezvous and docking in outer space.

C. Project Gemini

1. Astronaut Selections

The astronaut corps that supported Project Gemini included the **Mercury Seven**, **New Nine**, and the **1963 Astronaut Class**. During the program, three astronauts died in air crashes during training, including the prime crew for Gemini 9. This mission was flown by the backup crew, the only time that has happened in NASA's history to date.

Mercury Seven

The **Mercury Seven** were the group of seven Mercury Project astronauts announced by NASA on 09 April 1959. They were also referred to as the **Original Seven** or **Astronaut Group 1**. They piloted the manned spaceflights of the Mercury program from May 1961 to May 1963. All seven original American astronauts were graduate engineers and test pilots whose backgrounds are well-defined in **America's Greatest Projects & Their Engineers – Vol IV.** They were, in order of travel to outer space:

1. **Alan Shepard**, the first American in outer space, who became the fifth American to walk on the moon.
2. **Gus Grissom**, the second American in space, who also was a pilot in the Gemini Program, but died in a pre-launch flight in the Apollo Program in 1967
3. **John Glenn**, who was the first American to orbit the Earth (3 orbits), became a senator from Ohio, and was the oldest person to participate in the Space Shuttle Program.
4. **Scott Carpenter**, the second American to orbit the Earth (also 3 orbits), who was criticized (possibly unjustifiably) after his flight, and never flew for NASA again
5. **Wally Schirra**, who performed a six-orbit flight, and also flew in both the Gemini and Apollo Programs, becoming the first person to go into outer space three times
6. **L. Gordon Cooper**, who flew the sixth Mercury mission, and later was able to command a Gemini mission.
7. **Deke Slayton**, who was initially grounded due to an atrial fibrillation condition, became Director of Flight Crew Operations, and later flew in the Apollo-Soyuz Program.

Of the original Mercury Seven astronauts, three of them (Grissom, Schirra, and Cooper) also flew on Gemini missions, and Shepard and Schirra were able to command Apollo missions as well.

New Nine

Astronaut Group 2, also known as **NASA's New Nine**, was the second group of astronauts selected and announced on September 17, 1962. The group was required to augment the original

Mercury Seven with the announcement of the Gemini Program as well as the Apollo Program, which had been announced, but was far from being resolved. While the Original 7 had been selected to accomplish the risky but more fundamental task of orbital flight, the new challenges of rendezvous and preparation for lunar landing would lead to the selection of candidates with advanced engineering degrees as well as test pilot experience. In addition, Group 2 became the first group with accepted civilian test pilots, although each man selected had a considerable amount of previous military experience. Of the nine new astronauts, all except **Elliot See** flew at least one Gemini mission.

See was born in 1927 in Dallas, Texas. After high school graduation, he received an appointment to the U. S. Merchant Marine Academy, from which he graduated with a Bachelor of Science degree in 1949. He later obtained a Master of Science degree in Engineering from UCLA in 1962. See was also a naval aviator and test pilot when he was chosen by NASA in the second group of astronauts. He was chosen as the prime command pilot for what would have been his first space flight on Gemini 9. He was killed with his crewmate Charles Bassett on 26 February 1966 in a NASA trainer jet crash at the McDonnell Aircraft plant, where they had been scheduled to take two weeks of space rendezvous simulator training.

The eight astronauts of the **New Nine** who did fly in the Gemini program included the following:

1. **Neil Armstrong** (1930–2012), Ohio native, BS in Aeronautical Engineering from Purdue, naval aviator, test pilot for NACA (became NASA)
2. **Frank Borman**, born 1928 in Gary, Indiana, raised in Tucson, Arizona, BS from U. S. Military Academy, MS in Aeronautical Engineering from Caltech, fighter pilot, test pilot
3. **Charles "Pete" Conrad** (1930–1999), Philadelphia native, BS in Aeronautical Engineering from Princeton, naval aviator, test pilot
4. **Jim Lovell**, born 1928 in Cleveland, raised in Milwaukee, BS from U. S. Naval Academy, Naval aviator, test pilot, flew two Gemini missions
5. **James McDivitt**, born 1929 in Chicago, raised in Kalamazoo, MI, BS in Aeronautical Engineering from Michigan, U.S. Air Force combat pilot, test pilot
6. **Thomas P. Stafford**, born in 1930. raised in Weatherford, OK, BS from U. S. Naval Academy, was U.S. Air Force test pilot, test pilot flight instructor, flew two Gemini missions
7. **Ed White** (1930–1967), born and raised in San Antonio, BS from U. S. Military Academy, MS in Aeronautical Engineering from Michigan, U.S. Air Force test pilot, died in a pre-launch pad test fire in the Apollo Program in 1967 along with Gus Grissom and Roger Chaffee

8. **John Young** (1930–2018), born in San Francisco, raised in Orlando, BS in Aeronautical Engineering from Georgia Tech, U.S. Navy, naval aviator, test pilot flew two Gemini missions

1963 Astronaut Class

Astronaut Group 3 was the third group of astronauts selected by NASA. Fourteen astronauts made up Group 3, and their selection was announced in October 1963. Group 3 was the first to waive the requirement of having a test pilot background, although military jet fighter aircraft experience was substituted. Four of the Group 3 astronauts died in training accidents before they could fly in space:

1. **Theodore C. Freeman** (1930–1964), born in Haverford, PA, received his BS from the U. S. Naval Academy, joined the U. S. Air Force, and received his MS in Aeronautical Engineering from Michigan. A flight test engineer and flight test instructor, he was killed on 31 October 1964 when his T-38 flamed out and his ejection seat parachute did not deploy in time.
2. **Charles A. Bassett II** (1931–1966), born in Dayton, Ohio, received his BS in Electrical Engineering from Texas Tech. He joined the U. S. Air Force and was both an experimental test pilot and engineering test pilot. He was selected as Pilot for Gemini 9, but died in the same T-38 plane crash that killed Elliot See less than four months before the mission.
3. **Clifton C. Williams** (1932–1967), born and raised in Mobile, AL, received a BS in Mechanical Engineering from Auburn. He was a naval aviator and test pilot in the U. S. Marine Corps. Crash was caused by a mechanical failure in a NASA T-38 jet trainer. He activated the ejection seat, but it did not save him. He was a backup pilot for Gemini 10.
4. **Roger B. Chaffee** (1935–1967), born and raised in Grand Rapids, MI, received his BS in Aeronautical Engineering from Purdue, U.S. Naval photo reconnaissance and test pilot training for NASA, slated to be pilot on the Prime Crew for first manned [Apollo mission](#), but was killed in a cabin fire during launch rehearsal, along with Ed White and Gus Grissom.

Of the three men in Group 3 who were killed while flying in Jet plane training accidents, only Charles Bassett had been scheduled to pilot a Gemini mission, while Clifton Williams was training on the Lunar Landing Module and was listed as a backup on the Gemini Program. Of those in the **1963 Astronaut Class**, the waiving of the requirement of having a test pilot background applied only to Aldrin and Cernan; all the others were test pilots.

While all of the surviving ten astronauts from the **1963 Class** went on to fly in at least one mission in the Apollo Program, only five of the surviving astronauts in Group 3 flew Gemini missions. They were:

1. **Edwin E. (Buzz) Aldrin, Jr.**, born 1930 and raised in Montclair, NJ, received a BS in Mechanical Engineering from the U. S. Military Academy, served as a jet fighter pilot in

the U. S. Air Force in Korea, received his Sc. D. degree in astronautics from MIT, flew one Gemini mission

2. **Eugene A. Cernan** (1934–2017), born in Chicago, raised in Bellwood and Maywood IL, received a BS in Electrical Engineering from Purdue, was a naval aviator, and received an MS in Aeronautical Engineering from the U.S. Navy Postgraduate School, flew one Gemini mission
3. **Michael Collins**, born 1930 in Rome, Italy, the son of a U.S. Army General, and grew up mostly in Washington, DC. Received a BS degree from the U. S. Military Academy, joined the U. S. Air Force, trained as a fighter pilot, and became part of the Air Force test pilot school, flew one Gemini mission.
4. **Richard F. Gordon Jr.** (1929–2017), was born in Seattle, raised in Poulsbo, WA, received his BS in chemistry from U. of Washington. Gordon joined the U. S. Navy and received his wings as a naval aviator. Served as a flight test pilot, was both a flight safety officer and jet fighter training officer, flew one Gemini mission.
5. **David R. Scott**, born 1932 in San Antonio, son of a U. S. Air Force career officer, attended Michigan U. for one year before receiving appointment to U. S. Military Academy, where he received his BS degree and joined the U.S. Air Force. After jet pilot training and fighter squadron duties, he received an MS in Aeronautics/Astronautics from MIT, flew one Gemini mission.

2. Preparing for the Long Flight to the Moon

Between the last Mercury flights by astronaut Gordon Cooper on 15 May 1963, much preparation was required before the United States could even consider **sending** a man to the Moon, let alone **landing** him on the Moon and **returning him safely** to Earth. The result was a second intermediate program named **Project Gemini**, which actually was initiated in 1961 shortly after President Kennedy's 25 May announcement to the world that America should plan a lunar landing before the end of the decade. NASA officials came to a much-debated conclusion that a follow-on to the Mercury program was required to develop certain spaceflight capabilities in support of Apollo. Project Gemini became NASA's second human spaceflight program, which was conducted between 1961 and 1966.

The Gemini spacecraft, as you have seen, was designed to carry a two-astronaut crew. A total of ten Gemini crews flew low Earth orbit (LEO) missions during 1965 and 1966, placing the United States well ahead of the Soviet Union in the Cold War as well as in the so-called Space Race.

Gemini's primary goal was to develop space travel techniques which would support the Apollo mission to land astronauts on the Moon, and to return them safely back to Earth. In order to achieve this goal, Project Gemini's objectives were to perform missions long enough for a trip to the Moon and back, and to develop the critical technologies for orbital maneuvers necessary to achieve concise space rendezvous and spacecraft docking procedures. Another objective, which proved to be equally critical, was the necessity for perfecting working procedures outside the spacecraft, which were simply referenced as extra vehicular activities (EVA's). With these new

techniques proven by Gemini, Apollo was then able pursue its prime mission without doing these fundamental exploratory operations.

Jim Chamberlin, the head of engineering at the Space Task Group (STG), had already been assigned to start working on a bridge program between Mercury and Apollo in February 1961, even before Kennedy's announcement. He presented two initial versions of the Gemini spacecraft at a NASA retreat at Wallops Island in March 1961. Scale models of the basic spacecraft were presented in July 1961 by McDonnell Aircraft Corporation in St. Louis. Project Gemini was officially approved by NASA on 07 December 1961, and McDonnell was contracted to build the new spacecrafts on 22 December 1961. Although all Gemini flights were launched from the U. S. Air Force Launch Complex at Cape Kennedy in Florida, Project Gemini was the first program to use the newly built Mission Control Center at the Manned Spacecraft Complex in Houston for flight control.

Trial by Error and Experience

Now that the launch vehicle (Titan II) and the spacecraft (Gemini) were in production, all that was left to prove was the rest of the objectives for the Gemini Program that would be necessary for Apollo's eventual lunar landing, including the following:

1. Demonstration of spaceflight for extended periods, with at least eight days to a maximum of two weeks required for a Moon landing.
2. An effective rendezvous and precise docking procedure with another vehicle, with the ability to maneuver the combined spacecraft using the propulsion system of the target vehicle.
3. Demonstration of space-"walks" and other maneuvers outside the protection of the spacecraft, which would be used to evaluate the astronauts' ability to perform tasks in a weightless or low-gravity environment.
4. Improve and, if possible, perfect techniques of atmospheric reentry and touchdown at a pre-selected location on land.

When the NASA bridge project was publicly announced on 03 January 1962, it was formally re-christened *Project Gemini*. *Gemini* in Latin means "twins", which reflected that the spacecraft would hold two astronauts. Many members of the NASA team played key roles in the ultimate success of Project Gemini, including:

1. Astronaut Gus Grissom flew in both the Mercury and Gemini programs, was scheduled to fly in the Apollo program prior to his tragic death, and he was heavily involved in the design and development of the Gemini spacecraft.
2. Dr. George E. Mueller, Associate Administrator of NASA for Manned Space Flight, served as acting director of the Gemini program.
3. Guenter Wendt, a McDonnell engineer who supervised launch preparations for both the Mercury and Gemini programs and would go on to do the same when the Apollo program launched crews.
4. Deke Slayton, who had the final decision on the makeup and compatibility of each Gemini crew.

Agena Target Vehicle

The **Agena Target Vehicle (ATV)**, also known as **Gemini-Agena Target Vehicle (GATV)** was an unmanned spacecraft used in the Gemini program to develop and practice orbital space rendezvous and docking techniques, and to perform various orbital changes, in preparation for the requirements for the Apollo lunar missions. The spacecraft was actually an Agena-D upper stage rocket manufactured by Lockheed Aircraft, but was fitted with a docking device (target) manufactured by McDonnell Aircraft. The combined spacecraft was 26 feet long, with a cylindrical diameter of 5 feet. It was placed into a low Earth orbit by the Atlas-Agena launch vehicle. It carried approximately 14,000 pounds of propellant and gas at launch, and it had a gross mass at orbital insertion of slightly over 7,000 pounds. Various delays in the production of the Agena Target Vehicle caused the first of several rearrangements of the crew rotation by Deke Slayton, but the Task Group and the Astronaut Corps were up to the task.

Project Gemini Flights, Crews, and Results

In 1964 and 1965 two Gemini missions were flown without crews to test out systems and the heat shields. These were followed by ten flights with crews in 1965 and 1966. Fifteen Titan II's were ordered in 1962, so the serial numbers were "62-12XXX", but only "12XXX" was painted on the Titan II launch vehicles. The order for the last three of the 15 launch vehicles was canceled on July 30, 1964, and they were never built. The U. S. Air Force maintained Launch Complex 19, and they prepared and launched all of the Gemini-Titan II launch vehicles. Data knowledge and experience operating and maintaining the Titans was of great value to both the U. S. Air Force and NASA.

Launch Date: 08 April 1964

Launch Name: Gemini 1

Prime Commander: Unmanned

Pilot: None

Performance/Breakthrough:

Gemini 1 was the first unmanned test flight of the Gemini spacecraft in NASA's Gemini program. Its main objectives were to test the structural integrity of the new spacecraft and the upgraded Titan II launch vehicle. Gemini I was also the first test of the new tracking and communication systems for the Gemini program and provided training for the ground support crews for the upcoming manned missions.

The unmanned spacecraft stayed attached to the second stage of the Titan II rocket, and the mission was scheduled by the planners to last for only three orbits while test data were being taken. However, one problem was that the spacecraft stayed in orbit for nearly 64 orbits and almost four days. The launch vehicle had provided a bit too much speed and had placed the spacecraft into an orbit with a higher apogee of 200 miles instead of the planned 189 miles. This higher orbit contributed to the spacecraft staying in orbit for slightly longer (by only about 12 hours) than was planned. The spacecraft had specifically been designed for an unmanned mission, and it was not intended to be recovered. Crew life support systems had been replaced

with ballast to approximate the weight of a crewed spacecraft. Four large holes, in fact, were drilled in the capsule's heat shield to ensure the spacecraft would be destroyed during reentry. Instruments to measure pressure, vibration, temperature, stress, and acceleration took up much of the spacecraft during what was intended to be a relatively short flight. Four hours and 50 minutes later, after three orbits, the mission was completed.

The Titan II launch vehicle performed reasonably well; the first stage was jettisoned after two and a half minutes with the rocket 40 miles high and 57 miles downrange. At that moment there was an unexpected three second loss of signal from the craft. This brief communications blackout was later determined to be caused by charged ions from the separation and startup of the second stage, similar to the blackout during a spacecraft reentry. The spacecraft achieved orbit five and a half minutes after launch. When the spacecraft orbit decayed due to atmospheric drag, Gemini 1 reentered the Earth's atmosphere over the south Atlantic approximately halfway between South America and Africa.

Launch Date: 19 January 1965

Launch Name: Gemini 2

Prime Commander: Unmanned

Pilot: None

Performance/Breakthrough:

Gemini 2 had been scheduled for launch on 09 December 1964. On that date, the countdown reached zero and the first stage engines were ignited. The launch vehicle's Malfunction Detection System detected technical problems due to a loss of hydraulic pressure and shut down the engines about one second after ignition. The Titan II/Gemini 2 launch vehicle had twice been dismantled to protect it from two hurricanes (Dora and Cleo) in 1964, and it was erected for the final time on 12 September 1964.

The objectives of the Gemini 2 flight included:

1. Operation of the spacecraft by an onboard computer
2. Precise firing of the retrorockets
3. Operation of the fuel cells
4. Precise landing location

Shortly after launch the Mission Control Center in Houston suffered a power outage, and control of the mission was quickly transferred to a tracking ship. The outage was later traced to an overload of the electrical system from the network television equipment being used to cover the launch. Gemini 2 flew a ballistic suborbital arc over the Atlantic Ocean, reaching a maximum altitude of 107 miles. The flight lasted slightly more than 18 minutes, and the spacecraft landed approximately 2,149 miles downrange from the launch pad. When the Gemini 2 spacecraft was brought aboard the carrier USS Lake Champlain, it was in excellent condition.

Most goals were achieved: its heat shield and retrorockets had functioned as expected. Actually, the fuel cells had failed before liftoff and were turned off, resulting in the spacecraft cooling system temperature being too high. The landing was about 16 miles short of the planned impact

point, and a little over 50 miles from the recovery aircraft carrier. Many ground tests were carried out on both the Gemini 2 and the Titan II to prepare for the Gemini 3 manned flight. Procedures for flight crew and spacecraft ingress and egress were practiced during simulated launch. The prime flight crew for Gemini 3 donned pressure suits and full biomedical instrumentation, assisted by their backup crew and the space suit bioinstrumentation and aeromedical personnel who would participate in the Gemini 3 launch operation.

Launch Date: 23 March 1965

Launch Name: Gemini 3

Prime Commander: Gus Grissom

Pilot: John Young

Performance/Breakthrough:

Gemini 3 was the first manned mission in the Gemini program, the first manned U. S. flight since Gordon Cooper's 22-orbit flight on 15 May 1963 in Faith 7, which was the last flight of the Mercury Project. Grissom, who was the second American in outer space as an astronaut in the Mercury Seven, was the Command Pilot, while John Young of the New Nine was the Pilot. The Gemini 3 flew three low Earth orbits in their spacecraft, which they had nicknamed ***Molly Brown***. This was the final manned flight controlled from the Cape Kennedy Air Force Station in Florida, before control was shifted to the Manned Spacecraft Center in Houston. The crews had been rearranged by Deke Slayton when Alan Shepard developed Ménière's disease, an inner ear problem. Grissom was then moved to command Gemini 3. Young, whom Slayton felt was a better personality match with Grissom, was switched for Tom Stafford.



Launch of the first manned Gemini flight

Although Gemini 3 was the first time that two astronauts flew aboard an American spacecraft, the Soviet Union had managed to stuff three men without spacesuits into a Voskhod 1 capsule for a 24-hour flight on 12 October 1964. This political stunt by the Soviets to upstage the two-man Gemini and three-man Apollo programs had no effect on the Project Task Group. The mission's primary goal was to test the new, maneuverable Gemini spacecraft. At the end of the first orbit, the crew fired thrusters to change the shape of their orbit and drop to a lower altitude from 101 miles by 140 miles, to 99 miles by 106 miles. This was the first orbital maneuver made by any manned spacecraft, and it was also the first manned reentry where the spacecraft was able to produce lift to change its touchdown point. Early in the flight, the crew noticed the craft gradually yawing left. This was first attributed to a stuck thruster, but the problem was later traced to a venting water boiler.

The crewmen made their second burn, changing the orbital inclination by 0.02 degrees, about 45 minutes later. The last burn, during the third orbit, lowered the perigee to 45 miles. This was made so that, in case the retrorockets had failed, the spacecraft would still have reentered the Earth's atmosphere. On descent, the capsule shifted from a vertical to horizontal attitude when its parachutes were deployed. The change was so sudden that Grissom cracked his acrylic faceplate on the control panel in front of him. Later Gemini and all Apollo as well as Space Shuttle spacesuits used the stronger, tougher polycarbonate plastic material.

NASA instructed the crew to not rely on the on-board computer if its data differed with pre-flight data. The craft landed 50 miles short of its intended splashdown point, because wind tunnel testing had incorrectly predicted the craft's ability to compensate for course deviation. When the crewmen discovered the error, they decided to stay in the capsule, not wanting to open the hatch before the arrival of the recovery ship. The crew spent an uncomfortable half-hour in a spacecraft not designed to be a boat. Due to unexpected smoke from the thrusters, the astronauts decided to deviate from the post landing checklist and to keep their helmets on with the face plates closed for some time after splashdown before the USS Intrepid was able to recover the spacecraft and its crew.

Launch Date: 03 June 1965

Launch Name: Gemini 4

Prime Commander: James McDivitt

Pilot: Ed White

Performance/Breakthrough:

Gemini 4 was the next manned spaceflight in the Gemini program, occurring less than three months after the flight of Gemini 3, in a concerted effort by NASA and the Johnson administration to catch up to the Soviets in the "space race." New Nine astronauts James McDivitt and Ed White were the Commander and Pilot respectively. Gemini 4 was intended to become the first multi-day space flight by the United States, and the flight was designed to show the possibility that humans could remain in outer space for extended lengths of time. Their four-day, 66-orbit flight would approach but not break the five-day record set by a single Soviet cosmonaut in the Vostok 5 in June 1963; however, subsequent Gemini flights would be considerably longer, to justify the time and endurance required for a lunar landing and safe return to Earth.

The launch of Gemini 4 went relatively smoothly, notwithstanding a few early vibrations, and it entered into a 100-mile by 177-mile orbit. A third objective was an attempt by Gemini 4 to rendezvous with the spent Titan second stage. During the first orbit, McDivitt attempted this rendezvous, but this particular exercise was unsuccessful and was doomed from the start, for reasons that included:

- NASA engineers had not yet prepared an on-board computer for space rendezvous.
- Erratic movement by the second stage as it dumped its residual propellant.
- There were only two running lights on the stage, making visual sighting of the stage difficult.
- There was no radar on board Gemini 4 to give a precise range to the target, so the astronauts had to rely on their visual depth perception to estimate the range.

Rendezvous in orbit is not a straightforward maneuver. Should a spacecraft increase its speed to catch up with another, the result is that it goes into a higher and slower orbit and the distance thereby increases. The right procedure is to slow down and go to a lower orbit first, and then later to increase speed and go to the same orbit as the other. After expending almost half his thruster fuel, McDivitt finally gave up, in order to concentrate on the more important EVA objective. Following the attempted rendezvous, Gemini 4's orbit had become 94 miles by 146 miles. After twenty-two hours into the mission, Mission Control estimated the orbit would decay further, resulting in reentry by the 63rd orbit.

A second objective was the first American extra-vehicular activity, known simply as a "space-walk". The first EVA had already been performed by Soviet Alexei Leonov on Voskhod 2 in March 1965. NASA moved up the spacewalk from the original schedule, to demonstrate that the U. S. was gaining on the early lead taken by the Soviets in the Space Race. This proved to be the highlight of the mission, and Ed White became the first American to perform a space-walk. During his EVA, White floated freely outside the spacecraft, tethered to it, for approximately 20 minutes. This accomplishment would help the United States overcome the Soviet Union's early lead in the Space Race.

Reentry actually occurred on the 62nd revolution. An open-loop rolling reentry, as was used in the Mercury Project, had to be used because of the onboard computer failure during the 48th orbit. The astronauts began rolling the spacecraft at 75 miles altitude to increase its stability, gradually slowing the roll rate down, and stopping it when the drogue parachute and the main parachute were deployed. The landing was rough, but neither of the crew encountered any problems, despite their landing upright — as opposed to on their backs, as in Mercury — after four days in space. Gemini 4 landed 50 miles short of the intended landing target, but a helicopter was able to see them land, and they were quickly recovered and placed on board the USS Wasp.

Launch Date: 21 August 1965

Launch Name: Gemini 5

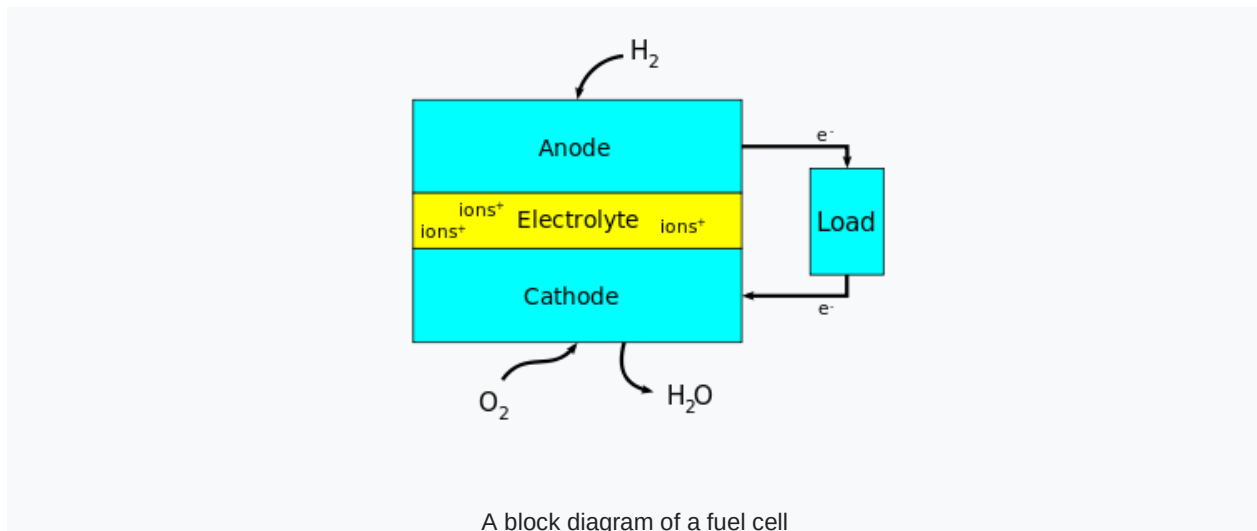
Prime Commander: Gordon Cooper

Pilot: Pete Conrad

Performance/Breakthrough:

Gemini 5 was the third manned Gemini flight, and it was also the first time an American manned space mission held the world record for duration. Slayton tapped Gordon Cooper, who had flown in Mercury 6 to command the long-duration Gemini 5. For reasons of compatibility, he moved Pete Conrad of the New Nine group of astronauts from backup commander of Gemini 4 to pilot of Gemini 5. The launch went perfectly except for about 13 seconds of severe oscillation (axial vibration of the rocket), which momentarily impaired the vision and speech of the crew. The cause of the strong vibrations was traced to improper gas levels in an oxidizer standpipe, and severe oscillations did not affect any subsequent Gemini flights. Once in outer space, Gemini 5 settled into an initial orbit of 102 miles by 218 miles.

The primary objective of Gemini 5 mission was to perform a long-duration flight, which would be made possible due to new fuel cells that generated enough electricity to power longer missions, which would naturally be critical to future Apollo lunar landing missions. Gemini 5 nearly doubled the U.S space-flight record of the Gemini 4 mission to almost eight full days, the length of time nominally required to fly to the Moon, land and return. Fuel cells replaced the chemical batteries used on previous manned spacecraft, a major innovation for future Apollo flights. Fuel cells had been around for over a century when NASA engineers began to develop them for a long-term power source. Fuel cells come in many varieties; however, they all work in the same general manner. They are made up of three adjacent segments: the anode, the electrolyte, and the cathode. Two chemical reactions occur at the interfaces of the three different segments. The net result of the two reactions is that fuel is consumed, water or carbon dioxide is created, and an electric current is created, which can be used to power electrical devices, normally referred to as the load. See diagram below.



The fuel in the anode is usually hydrogen, the catalyst is most often fine platinum powder, and the anode breaks down the fuel into electrons and ions. The electrolyte substance is made from a hydroxide or a carbonate with phosphoric acid, and it is designed to pass through positively charged ions and reject negatively charged electrons. The cathode is most often nickel, and it converts the ions back to a neutral substance such as water or carbon dioxide. A typical fuel cell produces a voltage from 0.6 V to 0.7 V at full rated load. Voltage decreases as current increases, due to activation, component loss, and depletion of the reactants. Fuel cell voltages can be increased by placing them in series, while higher current can be supplied by placing the cells in parallel.

Cooper and Conrad had planned to make a practice space rendezvous with a "pod" deployed from the Gemini 5 spacecraft, but problems with the fuel cell electrical supply forced a switch to a simpler "phantom rendezvous," whereby the Gemini craft maneuvered to a predetermined position in space. The phantom rendezvous came on the third day. It went perfectly, even though it was the first precision maneuver on a spaceflight. They were able to take high-resolution photographs, but problems with the fuel cells and maneuvering system forced the cancellation of several other experiments. The astronauts found themselves marking time in orbit

On Day 4, the crew was shivering in the cold air of their spacecraft when they were told that the fuel cells were producing waste water not suitable for drinking, as it was too acidic. In general, the fuel cells were successful at producing cool drinking water, but the astronauts reported that it had a high quantity of gas bubbles in it. The next day one of the group of thruster blocks malfunctioned, causing another experiment to be abandoned, but all of the medical experiments from Gemini 4 were performed.

Retrofire was initiated over the Hawaiian Islands, and the astronauts controlled the reentry, creating drag and lift by rotating the capsule. However, due to a computing error by a programmer, the crew landed 80 miles short of the planned landing point in the Atlantic Ocean, where it was recovered and the crew was taken aboard the USS Champlain.

Launch Date: 15 December 1965

Launch Name: Gemini 6A

Prime Commander: Wally Schirra

Pilot: Tom Stafford

Performance/Breakthrough:

Original Mission Scrubbed

The original Gemini 6 mission, scheduled for launch on 25 October 1965, had a planned mission to include four dockings with the Agena target vehicle. Its total duration was to be just under 47 hours and, after completing a total of 29 orbits, it was to land in the western Atlantic Ocean south of Bermuda. That morning Schirra, one of the Mercury 7 astronauts, and Stafford, who was part of the 2nd group of astronauts, boarded their Gemini 6 craft to prepare for launch. Fifteen minutes later, the unmanned Atlas-Agena target vehicle launched. The burn of the Atlas booster was successful, but when the Agena's secondary engines fired to separate it from the Atlas, a catastrophic failure apparently caused the vehicle to explode. Range Safety began tracking multiple pieces of debris falling into the Atlantic Ocean. After 50 minutes the Gemini launch was canceled.

The first attempt to launch the 6A mission (second attempt for Gemini spacecraft No. 6) was on 12 December 1965. All went well right up to ignition; the engines ignited, but after about 1.5 seconds of operation, they abruptly shut down. Mission rules dictated that Wally Schirra, as the commander, had to immediately pull the D-ring above the center console and activate the ejection seats, carrying the astronauts away from the disaster that would be the result of a fully fueled Titan II falling back onto the launch pad. However, Schirra did not feel any movement and

knew that the booster had not lifted, so he decided to not abort. His quick thinking probably saved the mission as well as the lives of the two astronauts. The reliability of the Gemini ejector seats was questionable, as the seats had to launch the astronauts at least 800 feet away from the rocket. In addition, the cabin interior had been soaking in pure oxygen for hours. The astronauts could have not only been badly injured from the high g-force ejections, but they also could have been critically burned during the ejection attempt.

The Gemini 6A finally launched more than a week and a half after the launch of Gemini 7. The plan called for a rendezvous to take place on the fourth orbit of Gemini 6 with another spacecraft, its sister Gemini 7. Although the Soviet Union had twice previously launched simultaneous pairs of Vostok single crew spacecraft, these did establish radio contact, but came no closer than several miles of each other. The rendezvous between Gemini 6A and 7 was scheduled for five hours and forty minutes into the mission. Due to their lower orbit they were able to gain on Gemini 7 and were only 730 miles behind. Subsequent burns put them on the same orbital inclination as Gemini 7. They now only trailed by 300 miles.

The radar on Gemini 6A first made contact with Gemini 7 at three hours and fifteen minutes when they were 270 miles away. As they slowly gained, Schirra put Gemini 6A's computer in charge of the rendezvous, another first. At just over five hours, he saw a bright star that he thought was Sirius, but this was in fact Gemini 7. After several more burns, the two spacecrafts were only 130 feet apart. The burns had only used 112 lbs. of fuel on Gemini 6A, leaving plenty of fuel for some fly-arounds. During the next 270 minutes, the crews moved as close as one foot, talking over the radio. At one stage the spacecrafts were so synchronized that neither crew had to make any burns for 20 minutes. The mission achieved the first manned rendezvous. They probably could have docked had they been so equipped.

Schirra's mastery of the controls allowed him to do fly-around inspections of Gemini 7, assuring him of a place in the Apollo program. However, as the sleep periods approached, Gemini 6A made a separation burn and slowly drifted out to about 10 miles to ensure that there would not be any accidental collisions in the night.

Gemini 6A reentered the Earth's atmosphere the next day after little more than 25 hours in space, landing within 11 miles of the planned site northeast of Turks and Caicos in the Atlantic Ocean, the first truly accurate reentry for the Gemini program. This was also the first recovery to be televised live, through a transportable satellite earth station (developed by ITT) on the deck of the recovery aircraft carrier USS Wasp.

Launch Date: 04 December 1965

Launch Name: Gemini 7

Prime Commander: Frank Borman

Pilot: Jim Lovell

Performance/Breakthrough:

As we have already seen, Gemini 7 was originally and obviously intended to fly after Gemini 6, but the original Gemini 6 mission was cancelled after the failure during launch of the Agena Target Vehicle, with which it was meant to rendezvous, followed by a 3-day delay due to a failure

of the Titan II launch vehicle. The objective of a rendezvous was so important that the Gemini Task Group decided to fly the alternate Gemini 6A mission concurrently with Gemini 7, using the latter as the rendezvous target.

The original mission of Gemini 7 changed little with these new plans. The crew of Frank Borman and Jim Lovell, both members of the New Nine group of astronauts, were expected to spend nearly 14 days in space, in which they would make a total of 206 orbits. This long duration flight would investigate the effects of fourteen days in space on the human body, and it would also double the length of time that anyone had been in space up to that time.

Launch went without any problems as all systems on the Titan II seemed to perform reasonably well. Borman did report feeling a very light shaking sensation, although Lovell felt nothing. After separating from the spent rocket stage, they turned the spacecraft around and proceeded to maneuver their spacecraft to follow the same orbit of the second stage rocket from which they had separated. This formation is termed "station keeping", and Borman maneuvered the Gemini 7 in this manner for about 15 minutes. However, the stage was moving erratically as it vented its own remaining fuel, so Borman stopped because he felt too much spacecraft fuel was being consumed.

Stowage of waste and a decent water supply were two of the most significant problems that NASA was required to solve on this 14-day mission of long-duration space flight. Both men worked and slept at the same time, but still managed to conduct twenty experiments. This was the highest number of any Gemini mission, including studies of nutrition in space and the evaluation of a lightweight spacesuit, which proved uncomfortable when worn for a long time in the Gemini spacecraft's hot, cramped quarters. For the first time during a flight, one of the crew was allowed to take off his suit. Borman and Lovell had planned to both take them off two days into the mission, when they were satisfied that the environmental system was working properly. The NASA managers did not like this idea, and they said that at least one crew member had to be wearing a suit at all times. Borman wore his suit and sweated profusely, but he agreed to let Lovell stay out of his suit, as Lovell was the larger of the two. Since a lot of effort was required to get in and out of a suit in little more space than the front seat of a car, NASA relented, and both Lovell and Borman were allowed to remove their spacesuits simultaneously.

The high point of the Gemini 7 mission came on the eleventh day with the rendezvous with Gemini 6A. After performing a myriad of experiments, reading books, and refusing to perform some seemingly mindless records, Borman and Lovell were ready for action. The radar systems on the two spacecrafts worked to near perfection with only a few burns. A third burn put Gemini 6A into a similar orbit as Gemini 7 at 169 miles by 171 miles. After several short burns the two spacecrafts were only 130 feet apart. During the next four and a half hours, the crews moved as close as 1 foot, talking over the radio. At one stage the spacecrafts were station-keeping so well with each other that neither crew had to make any burns for 20 minutes. As the sleep periods approached, Gemini 6A made a separation burn and slowly drifted out to 10 miles in order to prevent an accidental collision in the night.

Gemini 6A reentered the Earth's atmosphere and landed the next day, while Gemini continued on its mission for three more days. During that period several functions started to deteriorate, including the fuel cells and various thrusters. Nevertheless, the retrorockets fired perfectly, and

the landing was smooth and precise, being less than four miles from their recovery point. The crewmen were somewhat weakened by their time in space, but both were in good health and were up and about after a good night's sleep on the recovery ship USS Wasp.

Launch Date: 16 March 1966

Launch Name: Gemini 8

Prime Commander: Neil Armstrong

Pilot: David Scott

Performance/Breakthrough:

Gemini 8 was the sixth manned spaceflight in the Gemini program. The mission was planned to conduct the first docking of two spacecrafts in orbit, but it suffered the first critical system failure of a U.S. spacecraft in outer space, which threatened the lives of the astronauts and required immediate abort of the mission. The crew was returned to Earth safely, the only time this would happen until the near-fatal flight of Apollo 13. Slayton named Neil Armstrong who was from the New Nine group of astronauts and who later became the first man to walk on the Moon, as the Commander. However, Slayton felt that Elliot See wasn't up to the physical demands of rigorous EVA planned on Gemini 8, so he replaced him as Pilot with David Scott, the first of the 1963 Astronaut Class to fly in the Gemini program.

Unlike the Atlas-Agena launch for Gemini 6 five months prior, this time everything worked perfectly; the Agena put itself into a 168-mile circular orbit and oriented itself to the correct attitude for the docking. Gemini 8, which was planned to be a three-day mission, was launched a few hours later into a 100-mile by 169-mile orbit. The plan was to not only rendezvous, but also to dock, with the Agena Target Vehicle on Gemini 8's fourth orbit. This would be the first space docking in history, and four separate dockings and undockings were planned.

During the first docking, Pilot David Scott had planned to perform an ambitious, two-hour-and-10-minute EVA, which would have been the second spacewalk (Ed White did the first one in June 1965 on Gemini 4.) Tied to a 25-foot tether for one and a half revolutions around the Earth, Scott planned to retrieve a nuclear emulsion radiation experiment from the front of the Gemini's spacecraft adapter, then activate a micrometeoroid experiment on the Agena, followed by a move back to Gemini 8. After Gemini undocked from the Agena, Scott was to don and test an Extravehicular Support Pack (ESP) stored at the back of the spacecraft adapter. This was a backpack with a self-contained oxygen supply, extra Freon propellant for his Hand Held Maneuvering Unit, and a 75-foot extension to his tether. Scott planned to practice several maneuvers in formation with the Gemini and Agena vehicles, which would then be separated by a distance of about 60 feet. Unfortunately, Scott never got to perform this EVA, due to the aborting of the flight because of a critical in-flight emergency which occurred shortly after docking with the Agena.

Armstrong was able to spot the Agena and, after several bursts of the thrusters, moved towards the Agena at 3.15 inches per second. In a matter of minutes, the Agena's docking latches clicked and a green light indicated that the docking had been successfully completed, achieving the first space docking with an unmanned target vehicle. Agena turned 90° to the right, as programmed,

but the combined spacecraft began to yaw. Armstrong used the Gemini's computerized thrusters to stop the yaw momentarily, but it immediately started again. When Armstrong reported that the OAMS (Orbit Attitude and Maneuvering System) fuel had dropped to 30%, the astronauts and ground crew realized that the problem was on the Gemini. Once Armstrong was able to undock the Agena, and move safely away, the Gemini began to tumble, reaching a rate of nearly one revolution per second. Armstrong was able to stabilize the Gemini by shutting down the OAMS and using the Re-entry Control System (RCS) thrusters to stop the tumble. The Gemini crew tested each OAMS thruster individually and found that Number 8 had stuck in the on position. Almost 75% of the reentry maneuvering fuel had been used to stop the tumble; mission rules dictated that the flight be aborted once the Re-entry Control System was fired for any reason. Gemini 8 immediately prepared for an emergency landing.

Mission Control decided to let the spacecraft reenter one orbit later so that it could land in a place that could be reached by the secondary recovery forces. Originally planned to land in the Atlantic three days later, reentry took place over China, out of range of NASA tracking stations. Landing at a site that was 500 miles east of Okinawa, three pararescuers jumped from a C-54 and attached a flotation collar to the capsule. Three hours after splashdown, the USS Leonard F. Mason had both the men and the spacecraft on board. The astronauts were exhausted, but they had otherwise survived the flight and their time in the water in good condition.

No conclusive reason for the thruster malfunction was found. The most probable cause was determined to be an electrical short, most likely due to a static electricity discharge. Power still flowed to the thruster, even after it had been switched off. To prevent recurrence of this problem, the design was change so that each thruster would have its own isolated circuit.

Note: Four months later, the crew of Gemini 10 would rendezvous with the spent and inert Agena.

Launch Date: 03 June 1966

Launch Name: Gemini 9

Prime Commander: Thomas Stafford

Pilot: Eugene Cernan

Performance/Breakthrough:

Gemini 9A was the seventh manned spaceflight in NASA's Gemini space program. The original crew for Gemini 9, command pilot Elliot See and pilot Charles Bassett, were killed in a crash on 28 February 1966 while trying to land a T-38 jet trainer at the McDonnell Aircraft plant airport in St. Louis, Missouri to inspect their Gemini 9 spacecraft. Their deaths prompted Deke Slayton to name Thomas Stafford and Eugene Cernan as the prime crew. Stafford, who had flown as the Pilot in Gemini 6A, was named as the Commander. Cernan, from the 1963 Astronaut Class, was made the Pilot.

The mission was originally scheduled for 17 May 1966, but once again the Atlas-Agena target vehicle failed. This time, however, the failure occurred when the Atlas rocket did an about-face before firing the Agena target vehicle into outer space, and the attached Atlas-Agena assembly

plunged into the Atlantic Ocean south of Cape Kennedy. The mission, with the two astronauts on board, was scrubbed and rescheduled for 03 June 1966 and renamed Gemini 9A.

On 01 June 1966 the Atlas rocket carried an Augmented Target Docking Adaptor (ATDA). The ATDA had been designed for use as a contingency for the ATV, which had failed during the original Gemini 6 launch. Built by spacecraft manufacturer McDonnell Aircraft Corporation, the ATDA replaced the Agena rocket with the reentry control section of a Gemini. It was built using already tested equipment, and successfully launched into a 186-mile orbit, using the Atlas launch vehicle. After launch, telemetry indicated that the conical nose shroud had failed to open properly. It had been improperly installed, due to a "turf" war between McDonnell and Lockheed-Douglas. Douglas had built the shroud to be attached to the Agena second stage, but the U. S. Air Force made the decision at the last minute that Atlas could achieve the desired orbit without NASA's second stage. This dropped NASA out of the launch and meant that the ATDA and fairing would be installed directly on Atlas—not Agena—and by a McDonnell crew instead of the normal Lockheed crew. Despite the fact that a Douglas engineer stood ready to advise on the installation of the shroud, McDonnell management would not let him on site.

The first launch attempt of Gemini 9A was scheduled to occur shortly after the ATDA launch. But three minutes prior to launch, the ground computers lost contact with the Gemini computers for an unknown reason, and the launch was scrubbed again. The second launch attempt on **03 June 1966** went perfectly, with the spacecraft entering into orbit at a perigee of 100 miles. After a series of thruster burns, they were at a 172-mile orbit, and closing fast on the ATDA. They made radar contact at 150 miles, and visual contact at 58 miles. As they got closer, they found the ATDA to be in a slow rotation, with the conical nose shroud still attached, the two pieces hanging agape at the front like a giant, open jaw.

The first mission objective of Gemini 9A had been to dock with the ATDA, a mission which was now in jeopardy since the shroud had not been blown away from the conical nose. The Gemini 9A was unable to dock with it because the nose fairing failed to eject from the docking target due to the pre-launch preparation error. The crew then did some planned rendezvous practice that involved them moving away from the ATDA by firing their thrusters and then practicing approaching from below the target. Once they were station-keeping alongside the ATDA, they were given permission for their planned EVA, which was the second objective of the Gemini 9A flight.

This EVA, or "space-walk", was to be performed by Cernan using an Astronaut Maneuvering Unit (AMU), a U. S. Air Force 'rocket pack' which would allow the pilot to move to the rear of the spacecraft independent of the capsule's life support system. Cernan was to perform a two-hour EVA, during which he was to demonstrate free flight in a self-contained rocket pack. Use of the AMU was not achieved due to Cernan experiencing high cardiac stress, overheating, and fatigue during EVA. NASA decided to postpone the EVA until the third day, which suited the two astronauts. They were tired and Stafford did not want to waste fuel keeping himself near the ATDA during the EVA when there was little they could do with it. They then got some much-needed food and rest. On the second day of the mission, they again approached the ATDA, this time from above. Once they were station-keeping alongside, they were given permission for their EVA, but they were tired and Stafford did not want to waste fuel keeping himself near the ATDA

during the EVA when there was little they could do with it. It was decided to postpone the EVA until the third day.

On the third day, Cernan began the EVA, which proved to be troublesome from the start. After pumping up his pressure suit to three and a half pounds of pressure per square inch, "the suit took on a life of its own and became so stiff that it didn't want to bend at all." He struggled to move inside his stiff suit. As soon as he left the spacecraft, he began tumbling uncontrollably, which was not helped by his umbilical which moved wildly and gave Cernan difficulty holding on to the spacecraft.

This day of the EVA was also their last in space. On their 45th revolution of the Earth, the crewmen fired the retro-rockets that slowed them down so that they would reenter. This time the computer worked perfectly, as they landed less than one-half mile from the planned landing site and were close enough to see the prime recovery ship, the USS Wasp. The splashdown of Gemini 9A happened closer to the recovery ship than any other manned spacecraft.

After the mission NASA management decided to set up a Mission Review committee to make sure that the objectives planned for each mission were realistic and that they had a direct benefit for Apollo. Of the seven manned missions flown in the Gemini program to this date, nearly all had failed to meet their objectives, while some of the objectives would not have benefited the Apollo program at all.

Launch Date: 18 July 1966

Launch Name: Gemini 10

Prime Commander: John Young

Pilot: Michael Collins

Performance/Breakthrough:

The Atlas-Agena Target Vehicle (GATV) launched perfectly for the second time on **18 July 1966**, and it was followed one hour and forty minutes later by Gemini 10. Gemini 10 carried astronauts John Young, who had been the Pilot on Gemini 3, and Michael Collins of the 1963 Astronaut Class, who was making his first flight. Tracking camera footage showed that the first stage oxidizer tank dome ruptured after staging and released a cloud of nitrogen tetroxide. Film review of Titan II ICBM launches found at least seven other instances of post-staging tank rupture, most likely caused by flying debris, second stage engine exhaust, or structural bending. NASA finally decided that this phenomenon did not pose any safety risk to the astronauts and no corrective action had to be taken.

The primary objective of Gemini 10 was to conduct several rendezvous and docking tests with the Agena Target Vehicle. The mission plan also included a rendezvous with the spent Agena Target Vehicle from the Gemini 8 mission, two extravehicular activity (EVA) excursions, and the performance of several scientific, technological, and medical experiments that were to have been performed by Gemini 9A. Gemini 10 was designed to achieve the objectives planned for the last two missions: rendezvous, docking, and EVA. Although the battery power of the Agena from Gemini 8 had failed many months earlier, this would demonstrate the ability to rendezvous with

a passive object. This was also intended to be the first mission to fire the GATV-10's own rocket, allowing both the Gemini 10 and the GATV-10 to reach higher orbits.

The Agena Target Vehicle had been launched into a near circular orbit, while the Gemini 10 spacecraft was inserted into a 100-mile by 168-mile orbit. This placed the Gemini 10 about 1,000 miles behind the Gemini 10 Agena Target Vehicle 10 (GATV-10). Rendezvous with GATV-10 was not achieved until the 4th revolution. A large out-of-plane error in the initial orbit required the Gemini to use 60% of its fuel for the rendezvous, which was more than twice the planned amount. The first scheduled docking was achieved about one-half hour after rendezvous. However, as a result of the excessive use of fuel to achieve rendezvous, most of the mission plan was revised. To conserve fuel, Gemini 10 remained docked to GATV-10 for the next 39 hours and used the GATV propulsion system for maneuvers. The other planned docking practice runs were cancelled.

After docking with their Agena booster in low orbit, Gemini 10 next established that radiation at high altitude was not a problem. Young and Collins used the power of the Agena to climb temporarily to 475 miles. Collins began the first of two EVAs on Gemini 10. This was to be just a standup EVA, where Collins would stand in the open hatch and take some photographs of stars as part of a photography experiment. He used a 70 mm general purpose camera to image the southern Milky Way in ultraviolet. After orbital sunrise, Collins then photographed a color plate on the side of the spacecraft to see whether film would reproduce colors accurately in space. They reentered the spacecraft six minutes early when they both found their eyes were irritated, which was caused by a minor leak of lithium hydroxide in the astronauts' oxygen supply. After repressurizing the cabin, they ran the oxygen at high rates and flushed the environmental system.

Tired from the exercise of the EVA, Young and Collins slept in their second 'night' in space. Their sleep period lasted for eight hours and then they were ready for another busy day. The next 'morning' they started preparing for the second rendezvous and another EVA while checking spacecraft systems and watching the radiation dosage meter. They then made two burns with the Agena engine to put them into the same orbit as the Gemini 8 Agena. They slowed their speed to circularize their orbit to 236 miles.

After undocking from the first Agena, the crew was about 100 miles away from the dead, drifting Agena, which was left over from the aborted Gemini 8 flight. After a few more correction burns, they were station-keeping 10 feet away from the Gemini 8 Agena, thus executing the program's first double rendezvous. With no electricity on board the second Agena, the rendezvous was accomplished by sight only and without radar. They found the Agena to be very stable and in good condition.

At nearly 49 hours into the mission, the second EVA began. Collins first task was to "space-walk" over to the dormant Agena at the end of a 50-foot tether, making Collins the first astronaut to meet another spacecraft in orbit. He retrieved a cosmic dust-collecting panel from the side of the Agena, but he was not able to take any pictures. Unfortunately, while dealing with the complications of keeping his tether clear of the Gemini and Agena, his Hasselblad camera worked itself free and drifted away. He next traveled over to the Agena and tried to grab onto the docking cone, but he found this to be an impossible task as the cone was smooth and had no grip. Collins used a nitrogen-propelled Hand-Held Maneuvering Unit (HHMU) to move himself towards the Gemini and then back to the Agena. This time he was able to grab hold of some wire bundles and

retrieved the Micrometeorite Collector from the spent Agena, but he decided against replacing it as he could lose the one he had just retrieved.

His last task on this EVA was to test out the HHMU; however, it had stopped working, meaning that they had finished the second EVA after only 39 minutes. During this time, closing the hatch took the crew eight minutes, as they had some difficulty with the 50-foot umbilical. They finally decided an hour later to jettison it along with the chest-pack used by Collins when they opened the hatch for the third and final time.

The last day of the mission was shortened; retrofire came at just over 70 hours into the mission, and they landed after less than three days in flight. Their landing site was only three and a half miles away from the intended landing target, and they were quickly recovered by the USS Guadalcanal.

Launch Date: 12 September 1966

Launch Name: Gemini 11

Prime Commander: Pete Conrad

Pilot: Dick Gordon

Performance/Breakthrough:

The launch of Gemini 11 was postponed twice: on 09 September 1966 due to a small leak in the first stage oxidizer tank of the Titan II Launch Vehicle, and again the next day due to a suspected malfunction of the autopilot on the Agena capsule. Gemini 11 was finally launched on **12 September 1966**, approximately one hour and thirty-seven minutes after the successful launch of the Agena Target Vehicle. Gemini was inserted into a 100-mile by 175-mile low Earth orbit approximately six minutes later. Commander of Gemini 11 was Pete Conrad, who had been the Pilot of the Gemini 5 flight, while Dick Gordon, who was a member of the 1963 Astronaut Class, served as the Pilot.

The primary objective of the Gemini 11 flight was to dock with an Agena Target Vehicle on a **direct-ascent rendezvous**. By this stage in the project, NASA engineers had concluded that one large spacecraft, backing onto the Moon's surface with the nose up and then lifting off from the Moon's surface for the return to Earth, would be prohibitive. The direct-ascent rendezvous and docking would, in their estimation, simulate an Apollo Lunar Landing Module ascending from the Moon's surface and docking with a spacecraft (Command/Service Module) that was in lunar orbit before returning to Earth. Secondary objectives included docking practice, two EVAs, scientific experiments, maneuvers while being docked, a tethered vehicle test, and demonstrating automatic reentry.

Gemini 11 proceeded to perform the first-ever direct-ascent (first orbit) rendezvous with an Agena Target Vehicle, docking with the unmanned Agena Target Vehicle (GATV-11) one hour and thirty-four minutes after launch. The docking was completed after only five flight maneuvers, and there were no fuel problems. It then used the Agena rocket engine boosters to bring the two-spacecraft complex to a high apogee of 850 miles, thus achieving a world record apogee Earth orbit. It also created a small amount of artificial gravity by spinning the two spacecrafts connected by a tether.

Gordon then performed two extra-vehicular activities that lasted a total of two hours and 41 minutes. The first EVA on the first full day was a planned one hour and 47-minute space-walk by Gordon during which he attached a 100-foot tether stowed on Agena 11 to Gemini 11's nose to perform the artificial gravity experiment. He also retrieved the S9 nuclear emulsion package from Gemini 11's adapter section, and tested a foot restraint, an HHMU, and a torque-less power tool. Gordon tested oxygen flow from the suit life support system and became uncomfortably warm because the life support oxygen cooling system heat exchanger could not be used - it was designed for vacuum operation. Gordon continued to attempt other functions on his EVA, but the spacesuit was cumbersome, and he tired very easily. He moved back to the cockpit area to rest, and Conrad ordered him back inside the spacecraft. An hour later, the astronauts opened the hatch and jettisoned loose equipment.

The second EVA on 14 September 1966 (2h 08m) was in fact a photo shoot. Gordon opened the hatch just before orbital sunset, installed the S13 ultraviolet astronomical camera, and took pictures of Orion and Antares. A short tether held him in the cabin, permitting him to use both hands. During the daylight pass Gordon performed "general photography", which included snapping pictures of Houston and Florida. During their pass over the Atlantic they had no photographic targets, so both astronauts fell asleep, an indication of the relaxed pace of this particular flight. The spacecraft again moved into darkness, and Gordon snapped more pictures of astronomical targets.

After two orbits the Agena was fired again for 22.5 seconds to lower the Gemini-Agena back down to a 180-mile by 190-mile orbit. The joined pair spacecrafts were then brought into a rotation to build a small gravity in the spacecrafts. The rotation rate checked out at 55 degrees per minute, and the crew could test for a very tiny amount of artificial gravity, but they did not sense any physiological effect of gravity.

At the end of the Gemini 11 mission the first fully automatic controlled reentry was performed. Gemini 11 splashed down 2.8 miles from its recovery ship, the USS Guam. Gemini 11 set a manned Earth orbital altitude record of 850 miles, using the propulsion system of its Agena Target Vehicle, a record that still stands today. Along with the deaths of Grissom, White, and Chaffee in the fire of Apollo 1, the final arrangements for the makeup of the first seven Apollo crews were being determined, including who would be in position to be the first astronaut to walk on the Moon.

Launch Date: 11 November 1966

Launch Name: Gemini 12

Prime Commander: Jim Lovell

Pilot: Buzz Aldrin

Performance/Breakthrough:

The tenth manned flight of the Gemini Project, the twelfth and last flight of the program, was Gemini 12. Liftoff of Gemini 12 occurred on 11 November 1966, approximately one hour and 38 minutes after the successful mid-afternoon launch of the Atlas/Agena Target Vehicle. On board Gemini 12 were Jim Lovell, who had been the Pilot on Gemini 7, and Buzz Aldrin, a member of the 1963 Astronaut Class, who was making his first flight. All launch vehicle systems performed

nominally during powered flight, but at staging of Gemini 12 there was a recurrence of the first stage oxidizer tank rupture first seen on Gemini 10's launch. On Gemini 12, the fuel tank appeared to have also ruptured as a white cloud was seen emitting from the spent stage, but the launch of Gemini 12 went as planned.

Gemini 12 was designed to perform rendezvous and docking with the Agena target vehicle, to conduct three EVA operations, to conduct a tethered station-keeping exercise, to perform docked maneuvers using the Agena propulsion system to change orbit, and to demonstrate an automatic reentry. At the completion of the previous Gemini flight, the program still had not demonstrated that an astronaut could work easily and efficiently outside the spacecraft. In preparation for Gemini 12, new and improved restraints were added to the outside of the capsule, and a new technique—underwater training—was introduced, which would become a staple of future space-walk simulation. During orbital injection, the GATV engine had experienced a drop in turbopump speed lasting only a few seconds. Since the exact reason for the pump slowdown was unclear, the climb to a higher orbit, however, was canceled.

The flight featured three periods of EVA by Aldrin, lasting a total of 5 hours and 30 minutes. Gemini 12 also achieved the fifth rendezvous and fourth docking with a GATV. Aldrin became the first space traveler to prove that useful work could be done outside a spacecraft without life-threatening exhaustion. Aldrin's two-hour, 20-minute tethered space-walk, during which he photographed star fields, retrieved a micrometeorite collector and did other chores, at last demonstrated the feasibility of extravehicular activity. Two more stand-up EVAs also went smoothly, as did the by-now routine rendezvous and docking with an Agena, which had to be done "manually" using the onboard computer and charts, when a rendezvous radar failed. Most of the mission's experiments were carried out, even though not all were completed. Much of the success of Aldrin's space-walk was attributed to his underwater training.

As per the mission objective, the capsule was controlled on reentry by computer and splashed down three miles from its target. The crew were taken aboard the aircraft carrier USS WASP. Postflight medical examination disclosed that, although both astronauts were slightly exhausted and dehydrated due to problems with the spacecraft's water supply system and were forced to reduce their fluid intake on the last day of the mission, no unusual conditions were present in either Lovell or Aldrin.

F. Summary

Gemini 12 marked a successful conclusion of the Gemini program, achieving the last of its goals by successfully demonstrating that astronauts can effectively work outside of spacecraft. This was instrumental in paving the way for NASA's flagship program, the Apollo Project, to achieve its goal of landing a man on the Moon by the end of the 1960s. The two unmanned and ten manned flights were far from perfect, but they did achieve their critical objectives. They also gave each engineer and astronaut the training, experience, and the perspective to believe that a Lunar Landing was a distinct possibility.

In a NASA report to the U. S. Congress in 1969, they estimated that the cost for the Gemini Project from 1962 to close of the project in 1967 was nearly \$1.3 billion, including nearly \$800 million for spacecraft, just over \$400 million for launch vehicles, and the balance for support and personnel. In today's dollars, that cost would approach \$7.5 billion.