

# NORTH AMERICAN AEROSPACE MUSEUM FLIGHT PLAN

MONTHLY NEWSLETTER

*Early Spaceflight:  
Mercury & Gemini*



Ed White EVA-Gemini IV

# America's Journey to the Moon

**BILL KOLB***FLIGHTPLAN EDITOR, MONDAY DOCENT*

This issue of FlightPlan picks up the story of America's journey to the Moon with John Glenn's historic orbital flight aboard Friendship 7. The earlier Mercury achievements, Alan Shepard's and Gus Grissom's pioneering suborbital flights, were covered in the June 2026 edition. Here we continue the narrative through the orbital Mercury missions and the full Gemini program that followed.

Mercury and Gemini were never ends in themselves. They were the deliberate, step-by-step programs that turned President Kennedy's 1961 challenge into an achievable goal. Mercury proved that a human could survive launch, orbit, and the searing heat of reentry. Gemini then mastered the advanced skills Apollo would require: orbital maneuvering, rendezvous, docking, long-duration flight, and productive work outside the spacecraft. Together these two programs built the technical foundation, the experienced crews, and the operational culture that made the lunar landings possible.

In the pages that follow, you will find the spacecraft and rockets that carried the first astronauts, the missions that tested new capabilities under real conditions, and the men who flew them. From the single-seat Mercury capsule to the more capable two-man Gemini, from the Atlas and Titan II boosters to the hard-won lessons of early spacewalks, each article examines a necessary piece of the path that led to the Sea of Tranquility.

## A Note on Format and Delivery

Beginning with this issue, FlightPlan introduces several changes made in coordination with the rollout of the Museum's new name, North American Aerospace Museum. Each edition will feature new cover art that changes to match the issue's theme. The length of each edition will be approximately 25 pages. Finally, the newsletter will no longer be distributed as a PDF by email; instead, it will be available via a web link. ➤

## GUIDELINES FOR SUBMITTING ARTICLES TO FLIGHTPLAN

1. The FlightPlan (FP) is published on the 1<sup>st</sup> of each month
2. Stories for the next issue can be filed up to the 10<sup>th</sup> of the prior month
3. Articles should be associated with an artifact at the Museum
4. Sources for specific information in the article should be provided
5. Stories should be approximately 500 words long
6. If appropriate, include one or two photos for publication with the article
7. Include name, day, and title at the bottom of each article submitted
8. Email articles to: [flightplan@evergreenmuseum.org](mailto:flightplan@evergreenmuseum.org)
9. Feedback is encouraged; submit to [flightplan@evergreenmuseum.org](mailto:flightplan@evergreenmuseum.org)

## SCOT LANEY

MUSEUM CEO

After Sputnik's launch, American schools placed new emphasis on identifying students with exceptional ability in mathematics and science. Howard Laney (my dad) was recognized through that effort as a highly skilled mathematician, a distinction that helped set him on a path toward technical work in the aerospace field, including his contribution to the Mercury heat shield design. Dad grew up as a farm kid in Northwest Ohio, far from the laboratories and launchpads that would define the Space Age. Although he would spend his working career as a polymer chemist and corporate executive, math was never too far away.

At age nineteen, he was invited to Chicago for a series of in-depth math tests designed to further assess the specific skills of the 400 or so invitees. Dad had never been to Chicago, so he was excited about the opportunity. Each day, more of the original group were told not to return for additional testing the following day. After four days, only Dad and three others were left in the room.

That group was then tasked with designing a type of reentry protection for what would become the Mercury capsule.

Because no one had more than a theoretical understanding of the forces and temperatures involved in reentering Earth's atmosphere, the Mercury heat protection program involved competing approaches early on: a **beryllium heat-sink shield** and an **ablative heat shield**. Originally, the space capsule was designed to accommodate either approach, while later Mercury orbital heat shields used fiberglass bonded with modified phenolic resin for ablation. Dad worked on the beryllium-copper heat-sink design at a classified facility operated by the Brush Beryllium Corporation, a company still in business today as Meterion Brush LLC. McDonnell Aircraft ran the program.

Beryllium copper had some major drawbacks. It was difficult to obtain (the USSR controlled much of the supply), difficult to smelt into the proper alloy, and heavy. Above all else, beryllium is exceedingly carcinogenic. The smelting issue was addressed by switching to a vacuum-pressed pure beryllium heat shield (more of a heatsink than a shield). However, this, too, proved unwieldy.

The shield had to separate from the capsule after reentry and return under a separate parachute. While theoretically possible, in practice it was a suboptimal design. NASA ordered six heatsinks, and they were flown on MR-1A (uncrewed, the follow-up to the scrubbed MR-1), MR-2 (flown by Ham the Chimpanzee), MR-3 (Freedom 7,

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# Howard Laney and the Mercury Heat Protection Program

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flown by Alan Shepard), and MR-4 (Liberty Bell 7, flown by Gus Grissom). Results were not great. The shield proved difficult to control after separation and, in one case, impacted the capsule while both were under parachute arrest.

The failed Big Joe shot on 9 September 1959 convinced NASA to abandon the beryllium sinks in favor of the ablative material. Both shields utilized the design that Dad and his team had worked out—all by slide rule and a few good guesses. Although the Big Joe booster failed early, the premature separation forced the capsule into a brutal reentry path where heat exceeded 10,000F yet the ablative shield performed flawlessly and just as designed.

The beryllium project was canceled, and one of the two surviving examples is in the Smithsonian archives. I am meeting with the Smithsonian in September and will request that the artifact be loaned to us for display here.

Dad retained his security clearance from the heatshield project for his entire life. From time to time, he would be recalled to work on one project or another, but always under some level of secrecy. He worked on the F-117 RAM project and the SDI Star Wars initiative during the Reagan administration.

As an additional note to the carcinogenic properties of beryllium, of the 600 or so people that worked on the design and fabrication of the heatsink, about 450 of them ultimately died of an unusual type of cancer, including Dad in August of 2011. The CDC still runs a program related to these deaths and has regularly sent letters to Dad and the others warning of the unnerving trend they are following. The last of these arrived in the mail about a month after Dad died. ➤



# NASA PROJECT MERCURY

## HEAT SHIELD

### LOCAL CONNECTION!

On October 4, 1957 the Soviet Union launched Sputnik, the world's first artificial satellite.

The launch caused a major panic in the United States as well as many other countries.

Fearing that the U.S. had fallen behind the Soviet Union in critical areas, the federal government started a massive testing program of all high school and college students to assess the U.S.

educational system for competencies in math and science. From that testing a handful of prodigies in those areas were identified. One of them was Howard Laney, a farm boy from Northwest Ohio.

Howard and two others were approached by the U.S. Space Administration, later renamed NASA, to design a heat shield or heat sink for a new type of aircraft, a "Space Capsule."

Working in utter secrecy with slide rules and some very complex and theoretical math, Howard and the team developed the geometry for what became the Project Mercury ablative heat shield. Also tested was a Beryllium Copper heat sink—a material later discarded due to being rare and difficult to acquire.

Howard then switched to the field of chemistry, becoming a polymer chemist in the early 1960's. Moving his family from Ohio to Beaverton, Oregon. in 1966, Howard went on to a long career at Portland, Oregon-based Griffith Rubber Mills where he served as President for more than twenty-five years before retiring in 1995.





# Stepping Stones to the Moon

## Mercury, Gemini & the Path to Apollo



**BILL KOLB**

MONDAY DOCENT

### Summary

*President Kennedy's 1961 Moon challenge required building capability step by step. Project Mercury (1961–1963) proved humans could survive launch, orbit, and reentry. Project Gemini (1965–1966) then mastered the advanced skills Apollo needed: orbital maneuvering, rendezvous, docking, spacewalking, and long-duration flight. Together these programs created the technical foundation, experienced crews, and operational culture that enabled the successful lunar landing in 1969.*

On May 25, 1961, President John F. Kennedy stood before a joint session of Congress and issued a challenge that would define a generation. “I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the Moon and returning him safely to the Earth,” he declared. At that moment the United States had flown exactly one American in space, Alan Shepard’s fifteen-minute suborbital hop just twenty days earlier. The Soviet Union already held the lead in the new frontier. Kennedy’s words transformed a tentative space effort into a national commitment of extraordinary scale and urgency.

To meet that deadline, NASA could not leap directly from Shepard’s short flight to a lunar landing. The path had to be built deliberately, capability by capability. Two programs, Project Mercury and Project Gemini, became the essential stepping stones to a moon landing.

Mercury answered the most fundamental questions. Could a human survive the violence of launch? Could a spacecraft protect its pilot through the searing heat of reentry? Could a man function usefully in the 68” x 132” = \$250

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# Stepping Stones to the Moon

## Mercury, Gemini & the Path to Apollo

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weightlessness of orbit and return safely to Earth? Between 1961 and 1963, six astronauts flew the single-seat Mercury capsule. Two suborbital flights and four orbital missions proved that the answers were yes. Mercury established the basic architecture of American manned spaceflight: the blunt-body capsule, the ablative heat shield, parachute recovery, and the concept of a pilot as an active participant rather than a passive passenger. It gave the nation its first orbital experience and, just as important, its first generation of spaceflight veterans.

Yet Mercury's achievements, while historic, were limited. The capsule could not change its orbit. It could not rendezvous with another vehicle. It offered no practical way for an astronaut to leave the spacecraft and work outside. Missions lasted only a day and a half at most. Landing on the Moon and returning would require far more sophisticated skills.

Project Gemini was created to supply them. From 1965 to 1966, ten crewed Gemini missions systematically closed the gaps between Mercury and Apollo. Astronauts learned to change orbits, to rendezvous with another spacecraft, and to dock. They practiced extravehicular activity until an astronaut could work productively outside the vehicle. They remained in space for as long as fourteen days, the duration of a round-trip lunar mission. They handled emergencies, refined procedures, and demonstrated that two men could live and work together in the confined volume of a spacecraft for weeks at a time. Every major technique Apollo would need was first proven in Earth orbit by Gemini crews.

Together, Mercury and Gemini formed a coherent progression. Mercury proved that manned spaceflight was possible. Gemini proved that the complex operations required for a lunar mission were achievable. Only then could Apollo attempt the final, far more ambitious steps: leaving Earth orbit, landing on another world, and returning home.

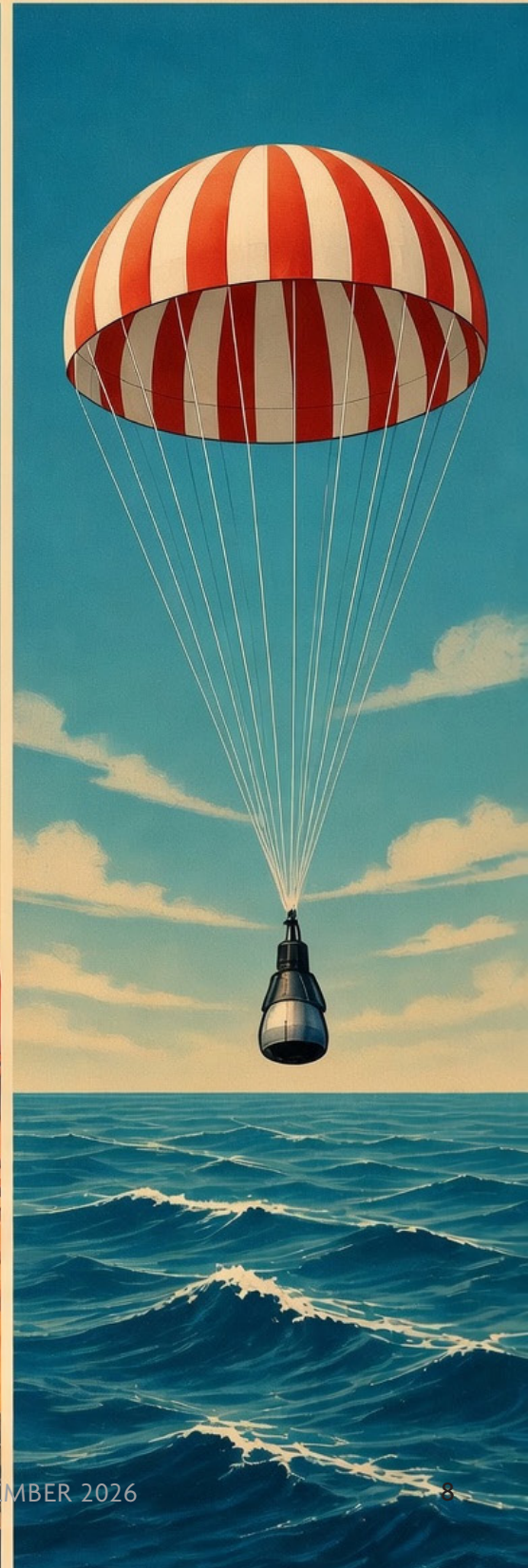
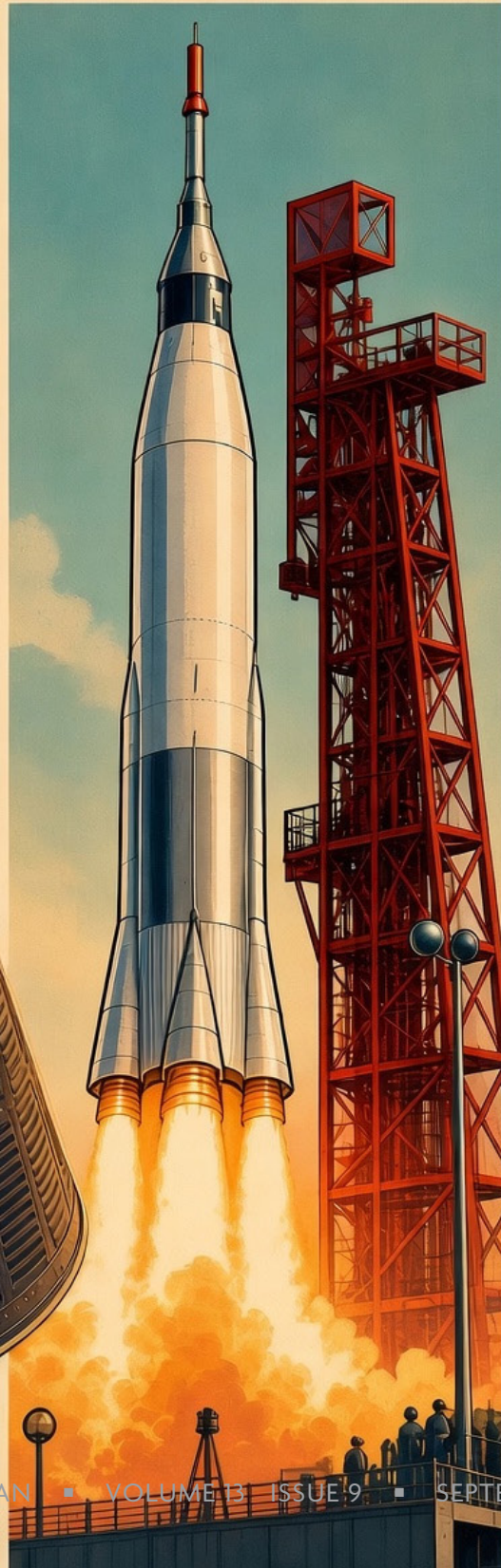
The programs also shaped the people and the institutions that would carry the nation to the Moon. Many of the astronauts who walked on the lunar surface first flew on Gemini. Flight controllers, engineers, and managers refined the real-time decision-making and systems discipline that later saved Apollo 13. The industrial base, the tracking networks, and the operational culture that supported the lunar landings were forged in the intense, rapid-fire schedule of Mercury and Gemini.

Kennedy's decade-long deadline was met on July 20, 1969, when Neil Armstrong and Buzz Aldrin stepped onto the Sea of Tranquility. That achievement rested on the foundation laid by the two earlier programs. Mercury and Gemini were never ends in themselves. They were the necessary intermediate chapters in a larger American story, the deliberate, step-by-step mastery of space that turned a bold presidential challenge into one of the defining accomplishments of the twentieth century.

In the pages that follow, we examine those chapters more closely: the spacecraft and rockets that carried the first astronauts, the missions that tested new capabilities, and the men who flew them. Understanding Mercury and Gemini remains essential to understanding how the United States reached the Moon. ➤

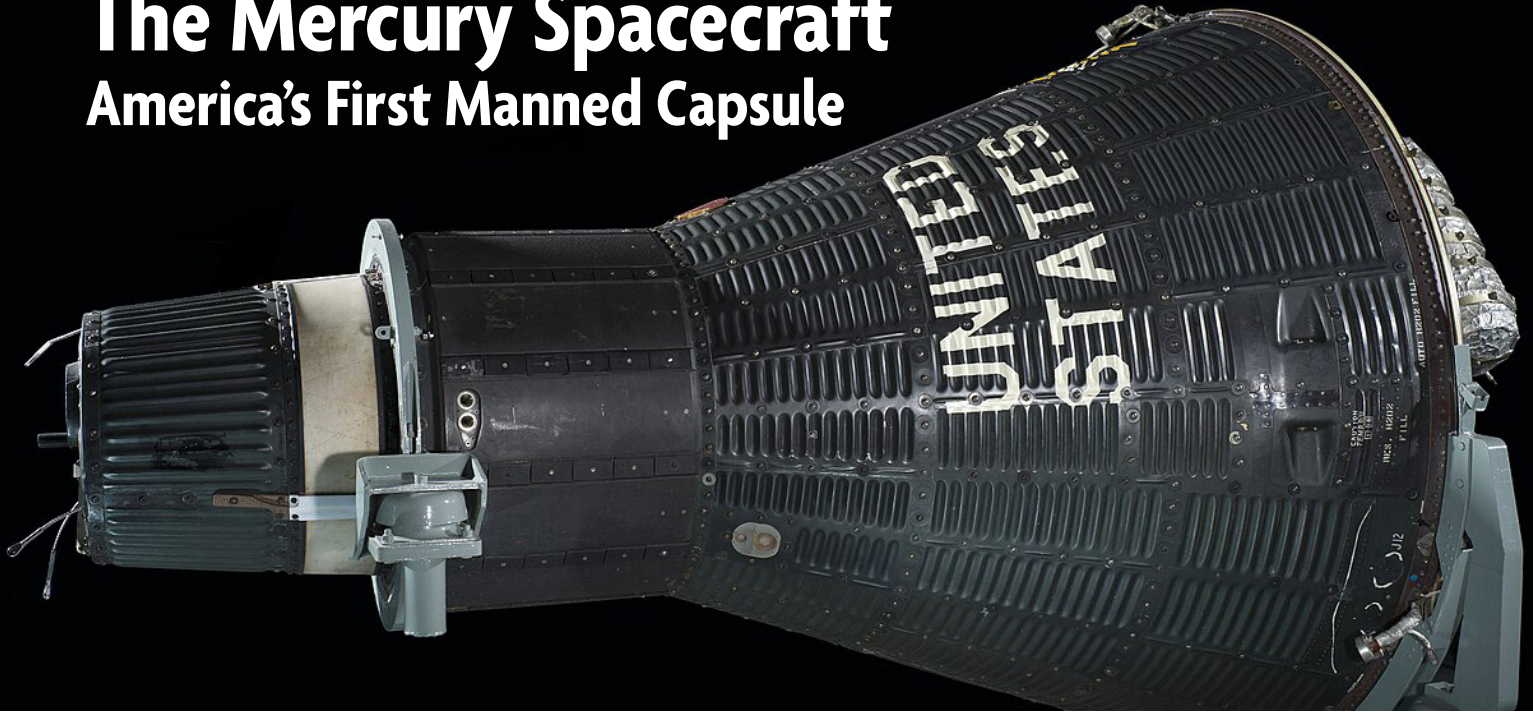
# PROJECT MERCURY

## *FLIGHT PLAN*



# The Mercury Spacecraft

## America's First Manned Capsule



**BILL KOLB**

MONDAY DOCENT

### Summary

*The Mercury spacecraft, built by McDonnell for NASA, was America's first manned capsule. Its blunt-body design, ablative heat shield, and compact pressurized cabin protected a single astronaut through launch, orbit, and reentry. Limited attitude thrusters and solid retrorockets enabled control and deorbit. Six successful flights (1961–1963) established the basic architecture of American manned spaceflight.*

The Mercury spacecraft was the United States' first vehicle designed to carry a human into space and return him safely to Earth. Built by McDonnell Aircraft Corporation, the single-seat capsule stood approximately 9 feet 6 inches tall (without the escape tower) and 6 feet 2 inches in diameter at the heat shield. Fully fueled and with its launch escape system attached, the vehicle measured about 26 feet in height. Launch mass for orbital missions was roughly 3,000 pounds. The design emphasized simplicity, reliability, and survival of the intense heating of reentry from orbital velocity.

### Overall Configuration

Unlike later modular designs, Mercury was a tightly integrated vehicle. Its major elements included the ablative heat shield at the base, the pressurized cabin in the center, the recovery section above the cabin, and the launch escape tower mounted on top for ascent aborts.

### Heat Shield and Thermal Protection

The defining feature of the Mercury capsule was its blunt heat shield. Early designs considered a beryllium heat-sink approach, but flight testing led NASA to adopt an ablative shield made of fiberglass honeycomb filled with phenolic resin. During reentry the shield charred and ablated, carrying heat away from the spacecraft. Peak temperatures on the shield surface exceeded 3,000 degrees Fahrenheit. The conical afterbody was covered with overlapping shingles of René 41 nickel alloy; beryllium was used in high-heat areas near the top of the capsule.

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# The Mercury Spacecraft

## America's First Manned Capsule

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### Cabin and Crew Accommodations

The pressurized cabin was extremely small. Astronauts often said they “wore” the spacecraft rather than rode in it. A contoured couch, custom-fitted to each pilot, supported the astronaut during the high accelerations of launch and reentry. The cabin atmosphere was pure oxygen at about 5 pounds per square inch. A small window provided limited outside visibility, and a periscope offered additional views during certain phases of flight. Controls and instruments were arranged so the pilot could reach nearly everything while remaining strapped in.

### Attitude Control and Retrofire

Mercury had limited maneuvering capability compared with later spacecraft. A reaction-control system of hydrogen-peroxide thrusters allowed the pilot to control pitch, yaw, and roll. Three solid-fuel retrorockets, mounted in a package on the heat-shield side of the capsule, fired to slow the spacecraft out of orbit. After retrofire the package was jettisoned so the heat shield was fully exposed for reentry.

### Power and Life Support

Electrical power came from batteries. Life-support systems maintained cabin pressure, temperature, and oxygen supply for flights lasting up to a day and a half (the longest Mercury mission, MA-9, lasted more than 34 hours). Food and water were limited; waste management was rudimentary.

### Legacy

The Mercury capsule proved the basic concept of manned spaceflight for the United States. Its blunt-body shape, ablative heat shield, and recovery systems influenced every subsequent American capsule. The six successful manned flights gave NASA the confidence and experience needed to move on to the more capable Gemini spacecraft.

### About Our Artifact

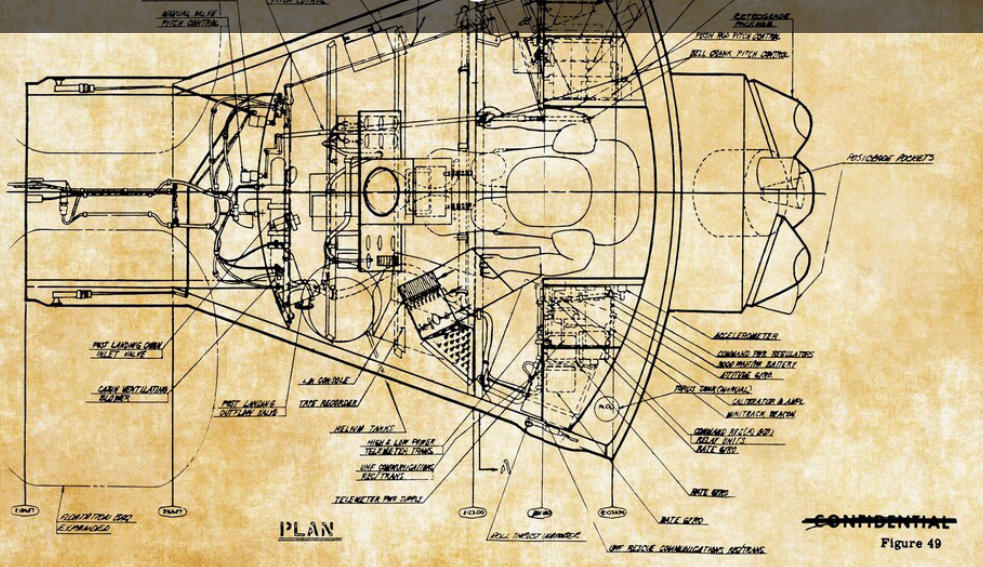
The Mercury capsule on display at the Museum is Mercury spacecraft serial number 10. It is a genuine, flight-rated production capsule built by McDonnell Aircraft for NASA's Project Mercury. Unlike the six capsules that carried astronauts, Mercury #10 never flew in space. It was completed as a flight article but remained a ground-test and spare vehicle.

The capsule is essentially complete except for the launch-escape tower. Visitors can see the classic Mercury shape: the blunt ablative heat shield, the conical afterbody with its distinctive shingles, the small cabin window, the side hatch, and the recovery section at the top. Because it is an original production vehicle rather than a replica, it offers a particularly authentic look at the spacecraft that first put Americans into space.

It is on long-term loan from the National Air and Space Museum (Smithsonian). ➤

# Designing the Mercury Space Capsule

## The Engineers versus the Astronauts



### BUD VARTY

WEDNESDAY DOCENT

The final configuration of the Mercury spacecraft, in which the USA's first astronauts flew, was not easily accomplished. A basic disagreement existed between the engineers who were designing the craft and the astronauts who would fly it.

The main issue between the two camps was control. The engineers felt that the capsule should be highly automated, with limited (if any) pilot input. The astronauts said that full automation would make them nothing more than passengers and would waste their experience and training.

The basis of the conflict was a combination of cultural and safety concerns. The engineers trusted systems while the pilots trusted skills. The engineers believed that having manual (versus automated) controls increased risk; the astronauts believed that lack of manual control increased risk.

The points in favor of automation were that it reduces error, that the speeds at which they would fly would make pilot control obsolete, and that safety comes from good engineering. The astronauts argued that machines fail, that pilots would have to intervene, and that human judgment was essential in unpredictable situations. The specific issues included a window, manual attitude controls, and the pilot's override capability.

The seven Mercury astronauts' insistence on meaningful pilot control was vindicated during the program's final flight. During Gordon Cooper's 34-hour Faith 7 mission (Mercury-Atlas 9), multiple automatic systems failed. The attitude-control system degraded, electrical power to critical functions was lost, and the cabin environmental controls ceased operating normally. Cooper oriented the spacecraft using the stars and Earth's horizon, timed the retrofire with his wristwatch, and flew the reentry manually. He landed just four miles from the recovery ship, the most accurate splashdown of the Mercury program.

The episode confirmed what the astronauts had argued from the beginning: in the unpredictable environment of spaceflight, a skilled pilot capable of intervening remained essential. That philosophy of the pilot as an active participant, rather than a passenger, carried forward into Gemini and Apollo. ➤

# The Atlas Rocket

## From Cold War Deterrent to America's First Orbital Workhorse

BILL KOLB

MONDAY DOCENT

### Summary

*Originally an Air Force intercontinental ballistic missile, the Atlas became NASA's first orbital booster for Project Mercury. Its distinctive stage-and-a-half design ignited two Rocketdyne LR89 boosters and a sustainer together at liftoff; the boosters were later jettisoned. Burning RP-1 and liquid oxygen, the Atlas carried John Glenn and three other astronauts into orbit, transforming a Cold War weapon into America's pioneering manned space launcher.*

### Origins as an Intercontinental Ballistic Missile

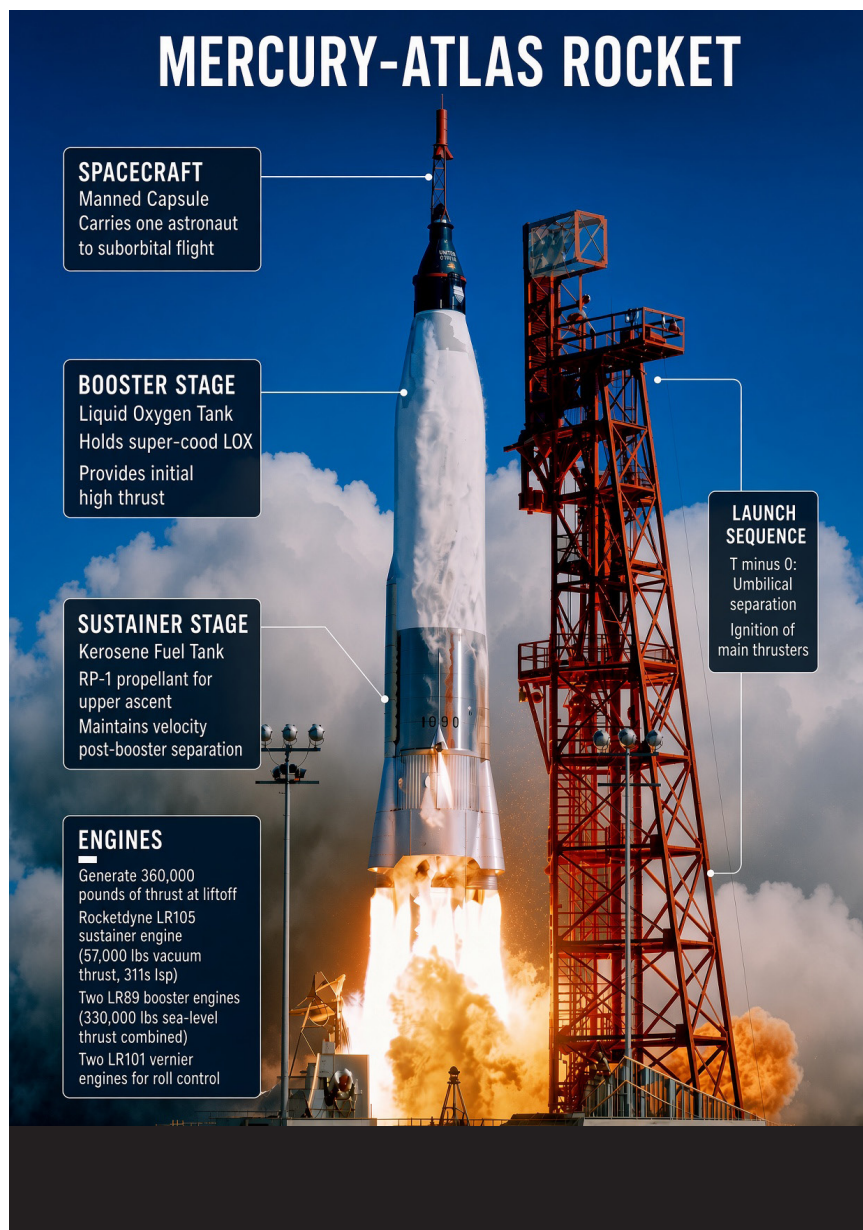
The Atlas rocket began life in the tense early years of the Cold War as the United States' first operational intercontinental ballistic missile. Designed by Convair for the Air Force, it was intended to deliver a nuclear warhead across continents in under an hour. Its thin stainless-steel tanks, pressurized like a balloon to maintain structural integrity, and its radical propulsion arrangement made it both lightweight and powerful. By the late 1950s the Atlas had become the backbone of America's land-based nuclear deterrent.

### Transition to Manned Spaceflight

That same power and reliability soon drew the attention of the new civilian space agency. When NASA needed a booster to place a manned capsule into Earth orbit, the Atlas was the only American vehicle ready for the task. Modified Atlas D missiles, designated Atlas LV-3B for Project Mercury, launched the first four American astronauts into orbit.

### The Stage-and-a-Half Design

What made the Atlas distinctive was its "stage-and-a-half" design. Unlike conventional multi-stage rockets that ignite engines in sequence, the Atlas ignited all of its main engines on the ground. Two powerful booster engines, a central sustainer engine, and a pair of small vernier engines for fine attitude control fired together at liftoff. After roughly two to two-and-a-half minutes—once enough propellant had been consumed to lighten the vehicle—the outer booster engines and their supporting structure were jettisoned. The central sustainer continued burning,



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# The Atlas Rocket

## From Cold War Deterrent to America's First Orbital Workhorse

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accelerating the remaining vehicle toward its final velocity. This arrangement avoided the still-risky practice of starting a large liquid-propellant engine in flight and provided the Atlas with an elegant solution to the era's thrust and mass problems.

### The Rocketdyne LR89 Booster Engine

At the heart of the booster section stood the Rocketdyne LR89 engine. Burning refined kerosene (RP-1) and liquid oxygen, the LR89 was a gas-generator-cycle engine producing roughly 165,000 to more than 200,000 pounds of thrust, depending on the variant. Fuel circulated through the walls of the thrust chamber before injection, providing regenerative cooling that kept the metal from melting under the extreme heat of combustion. Two LR89s supplied the bulk of the initial thrust needed to lift the heavy Atlas off the pad. Their turbopumps, plumbing, and gimbal mounts allowed the engines to swivel for steering during the critical early phase of flight. Later versions of the engine grew more powerful and reliable, supporting not only the Mercury flights but also a long series of satellite and planetary missions that followed.

### Legacy

The Atlas's combination of strategic origins, innovative staging, and proven engines made it one of the most important launch vehicles of the early space age. What began as a weapon of last resort became the vehicle that carried America's first astronauts into orbit and helped establish the United States as a spacefaring nation. Its legacy lives on in the engineering principles that still guide modern launch vehicles and in the tangible hardware preserved in museums, reminders of a time when the same remarkable rocket crossed the line between national survival and exploration. ✈



# The Mercury Orbital Flights America's First Steps into Orbit

**BILL KOLB**

MONDAY DOCENT

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## Summary

*After two Mercury-Redstone suborbital flights, NASA used the Atlas to place four astronauts into orbit (1962–1963). John Glenn's Friendship 7 made the first American orbital flight. Scott Carpenter's Aurora 7 faced fuel and landing issues. Wally Schirra's Sigma 7 proved longer-duration capability. Gordon Cooper's Faith 7 completed a 22-orbit, 34-hour mission under manual control, closing the Mercury program.*

## Friendship 7 – John Glenn

On February 20, 1962, John Glenn became the first American to orbit the Earth. Friendship 7 completed three revolutions lasting 4 hours and 55 minutes. Glenn took manual control when the automatic attitude system failed. Near the end of the mission a signal suggested the heat shield might be loose; controllers ordered him to keep the retropack attached. Glowing fragments streamed past the window during reentry, but the shield held. Glenn splashed down safely near the Bahamas and was recovered by the destroyer USS Noa.

## Aurora 7 – Scott Carpenter

On May 24, 1962, Scott Carpenter flew the second orbital mission. His three-orbit flight lasted nearly five hours. He conducted extensive observations and became the first American to eat solid food in space. Excess fuel use and a

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# The Mercury Orbital Flights America's First Steps into Orbit

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delayed retrofire caused him to overshoot the landing zone by about 250 miles. He waited nearly three hours in his life raft before recovery. The primary objectives were met, but the errors drew critical reviews.

## **Sigma 7 – Wally Schirra**

On October 3, 1962, Wally Schirra flew a six-orbit engineering test lasting 9 hours and 13 minutes—the first American splashdown in the Pacific. He conserved fuel, performed precise maneuvers, and landed accurately northeast of Midway Island. Sigma 7 showed the Mercury systems could support longer flights.

## **Faith 7 – Gordon Cooper**

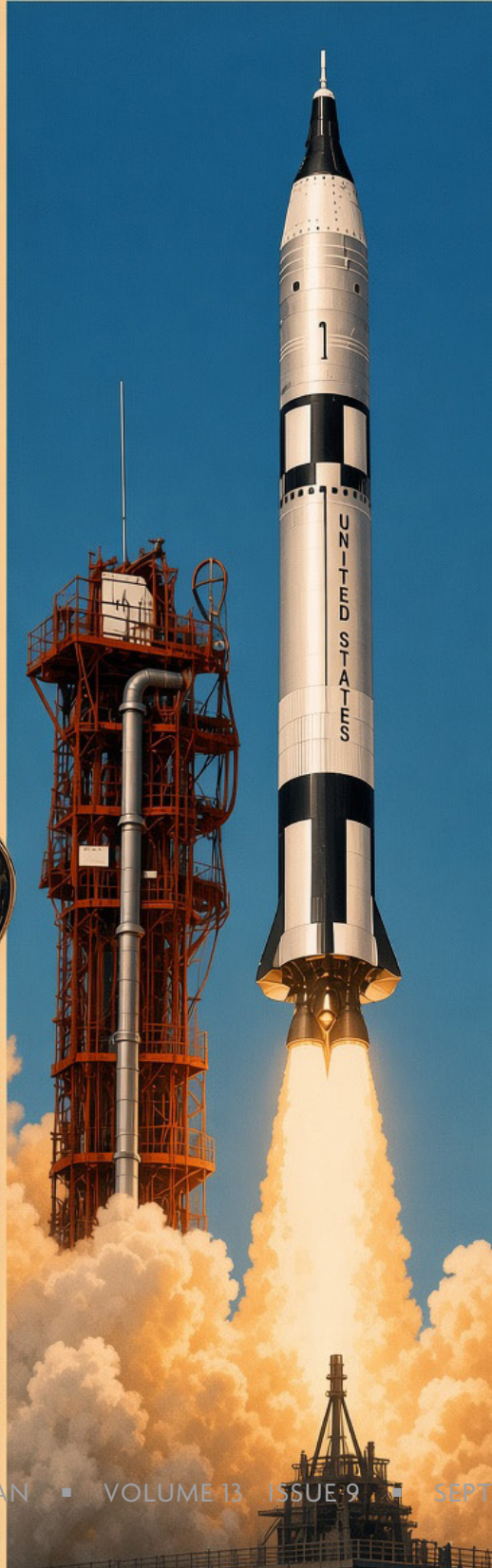
The final Mercury flight launched May 15, 1963. Cooper's 22-orbit mission lasted 34 hours and 20 minutes—longer than all previous American spaceflights combined. He became the first American to sleep in orbit. Late in the flight electrical problems disabled the automatic control system. Cooper took full manual control, timed retrofire with a wristwatch, and flew the reentry by hand, landing just four miles from the recovery ship.

## **Closing the Mercury Era**

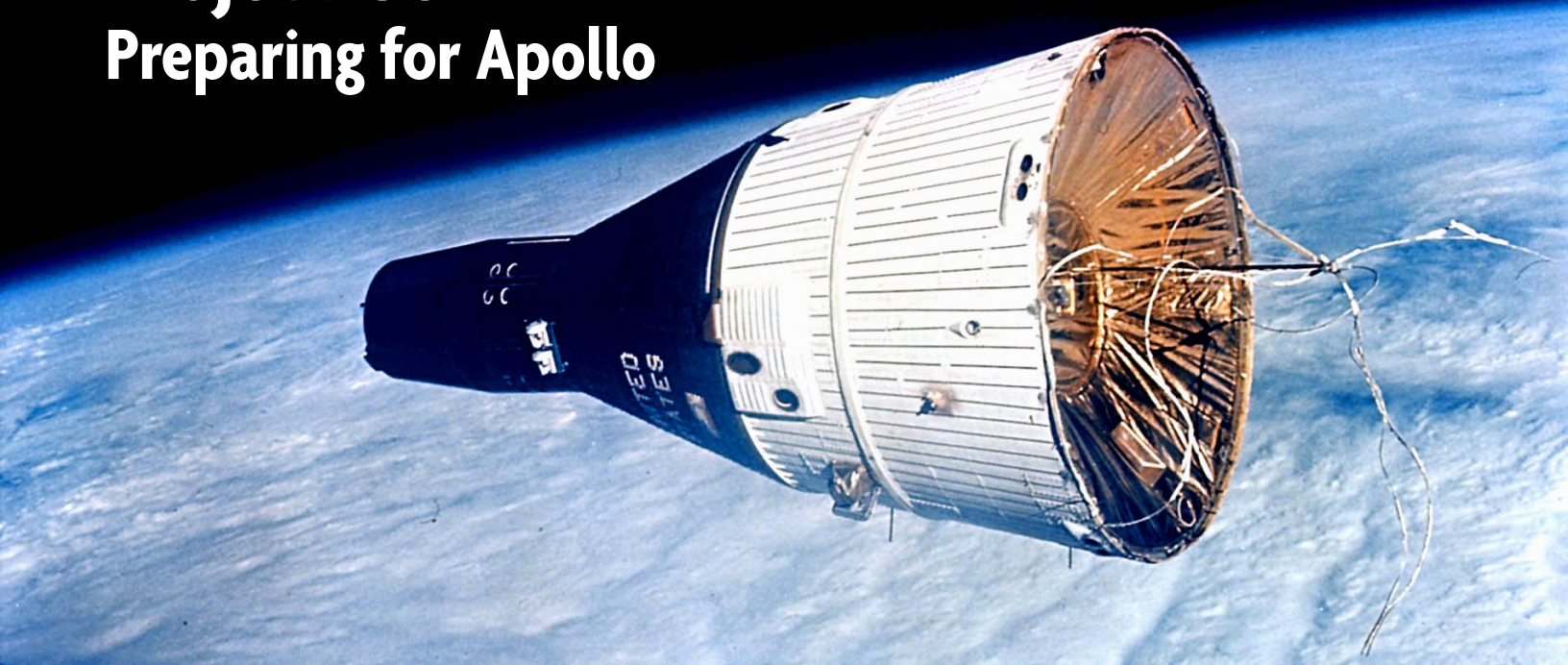
From Glenn's pioneering three orbits to Cooper's day-long voyage, the four orbital flights proved Americans could live and work in space. By the time Faith 7 returned, NASA had the experience and confidence needed to move toward rendezvous, extravehicular activity, and ultimately a landing on the Moon. ➤

# PROJECT GEMINI

## *FLIGHT PLAN*



# Project Gemini Preparing for Apollo



**BILL KOLB**

MONDAY DOCENT

## Summary

*Project Gemini bridged Mercury and Apollo by mastering the skills needed for a Moon landing. From 1964 to 1966, twelve flights using the two-man spacecraft and Titan II booster demonstrated orbital maneuvering, the first American spacewalk, long-duration endurance, rendezvous, docking, and productive extravehicular activity. By Gemini 12, Every critical technique had been proven in Earth orbit, giving NASA the experience and confidence required for Apollo.*

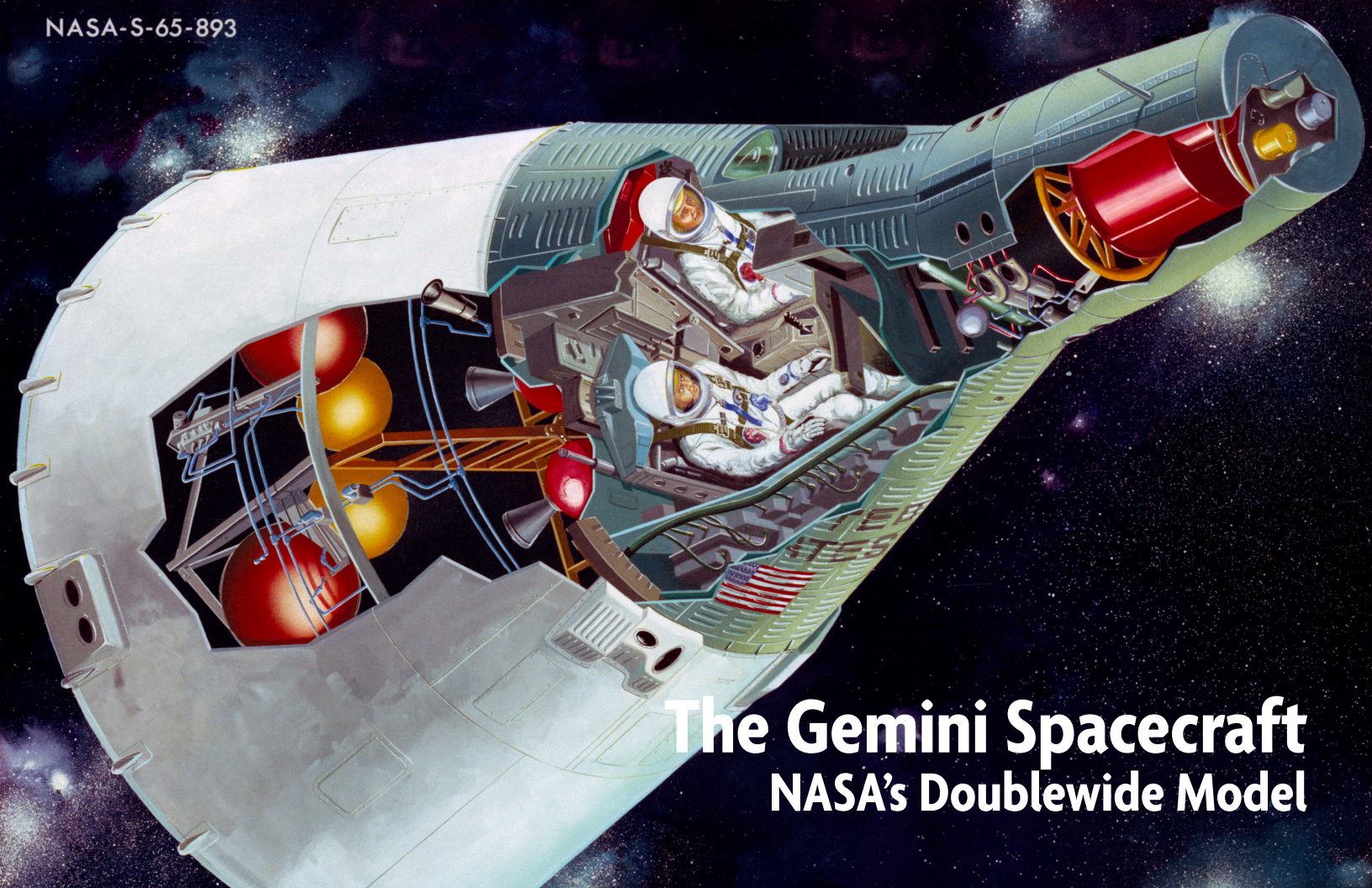
Project Gemini was the essential middle chapter between Mercury's first steps into space and Apollo's leap to the lunar surface. Its purpose was to master the skills a Moon landing would demand: rendezvous, docking, long-duration flight, and productive work outside the spacecraft, before attempting the far more complex Apollo missions.

The two-man spacecraft, launched atop a modified Titan II, gave NASA a more capable vehicle and a more powerful booster. Between 1964 and 1966, twelve Gemini flights (two uncrewed and ten crewed) systematically built those capabilities.

Early missions demonstrated basic orbital flight, the first American spacewalk, and endurance of up to fourteen days. Mid-program flights achieved the first rendezvous of two manned spacecraft and the first docking with an unmanned target, while also proving crews could handle a serious in-flight emergency. The final missions refined extravehicular activity until astronauts could work effectively outside the spacecraft and closed the program with a string of successful rendezvous and docking exercises.

By the time Gemini 12 returned in November 1966, every major technique needed for a lunar mission had been practiced in Earth orbit. NASA now had the operational experience, trained crews, proven hardware concepts, and confidence to begin the Apollo flights that would fulfill President Kennedy's goal of landing a man on the Moon before the decade ended. Gemini had turned the possibility of lunar flight into a practical, rehearsed reality.

The following articles examine several key components of the Gemini program: the Gemini spacecraft, the Titan II rocket, and the individual missions. ➤



# The Gemini Spacecraft

## NASA's Doublewide Model

**BILL KOLB**

MONDAY DOCENT

### Summary

*The Gemini spacecraft, built by McDonnell, served as NASA's two-man intermediate vehicle between Mercury and Apollo. Its modular design featured a reentry module and an adapter section with thrusters for orbital maneuvering, rendezvous, and docking. Supporting missions up to fourteen days and extravehicular activity, Gemini proved the critical techniques required for lunar flight during its 1965–1966 crewed program.*

The Gemini spacecraft was the critical intermediate step between the single-seat Mercury capsule and the three-person Apollo command module. Built by McDonnell Aircraft Corporation, it was designed to carry two astronauts for missions lasting up to two weeks, to change orbits, to rendezvous and dock with another vehicle, and to support extravehicular activity.

### Overall Configuration

The complete Gemini spacecraft stood roughly 18 feet 10 inches tall and measured 10 feet across at its widest point. Launch mass typically ranged from about 7,000 to 8,400 pounds, depending on the mission. Unlike the tightly integrated Mercury capsule, Gemini was modular. It consisted of two major sections: the reentry module, which returned the crew to Earth, and the adapter module, which remained attached only during orbital flight and was jettisoned before reentry.

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# The Gemini Spacecraft

## NASA's Doublewide Model

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The adapter module itself was divided into two parts. The equipment section at the base contained the orbital attitude and maneuvering system (OAMS) thrusters, fuel and oxidizer tanks, fuel cells (introduced on Gemini 5), oxygen, coolant, and other consumables needed for long-duration flight. Above it sat the retrograde section, which housed the solid-fuel retrorockets that slowed the spacecraft for reentry. A fiberglass blast shield separated the two sections of the adapter.

### The Reentry Module

The reentry module was a truncated cone approximately 11 feet tall. Its base measured about 7 feet 5 inches in diameter and carried the ablative heat shield. The pressurized cabin occupied the central portion and was sized for two astronauts seated side by side in ejection seats (later missions retained the seats even after parachute recovery became the primary means of recovery). The cabin was notoriously cramped—often compared to the front seat of a small automobile. Astronauts remained seated for the entire mission except during hatch-open operations.

Above the cabin sat the reentry control system (RCS) section with its thrusters, followed by the rendezvous and recovery section at the nose. This forward section held the drogue and main parachutes, the rendezvous radar antenna, and recovery aids. Two large side hatches allowed independent crew access and egress; each hatch contained a window. A third circular hatch was later cut into some heat shields for special recovery or experiment needs.

### Materials and Thermal Protection

The reentry module structure used titanium for the pressure vessel and nickel-alloy (primarily René 41) shingles on the conical exterior. Beryllium shingles protected the forward sections. The heat shield consisted of a fiberglass honeycomb filled with a silicone elastomer ablative material. During reentry, the shield charred and ablated, dissipating heat and protecting the cabin from temperatures exceeding 3,000 degrees Fahrenheit.

### Propulsion and Maneuvering

Gemini's greatest advance over Mercury was its ability to change its orbit. Sixteen OAMS thrusters of various thrust levels, mounted on the adapter, allowed the crew to translate and rotate the spacecraft. This capability made rendezvous and docking possible. Once the adapter was jettisoned, the smaller RCS thrusters on the reentry module provided attitude control during reentry. The combination of systems gave Gemini the first true "flying" spacecraft flown by American astronauts.

### Life Support and Power

Early Gemini missions relied on batteries; later flights introduced fuel cells that generated both electricity and drinking water as a byproduct. The environmental control system maintained a pure-oxygen cabin atmosphere at roughly 5 pounds per square inch. Food, water, and waste-management systems were designed for missions as long as fourteen days, as demonstrated on Gemini 7.

### About Our Artifact

Built by the Kansas Cosmosphere and Space Center for the HBO miniseries *From the Earth to the Moon*, our replica is displayed as a complete Gemini spacecraft, including the reentry module along with representations of the adapter sections (retro and equipment modules). It is positioned overhead so visitors can appreciate the two-person capsule's size, the distinctive side hatches used for extravehicular activity, and the overall configuration that differed so markedly from the single-seat Mercury. The astronaut on Extravehicular Activity (EVA) is Ed White, the first American to step out into the void of space. Astronaut White is also on the front cover of this newsletter. ➤

# The Titan II Rocket

## Gemini's Ride to Orbit

BILL KOLB

MONDAY DOCENT

### Summary

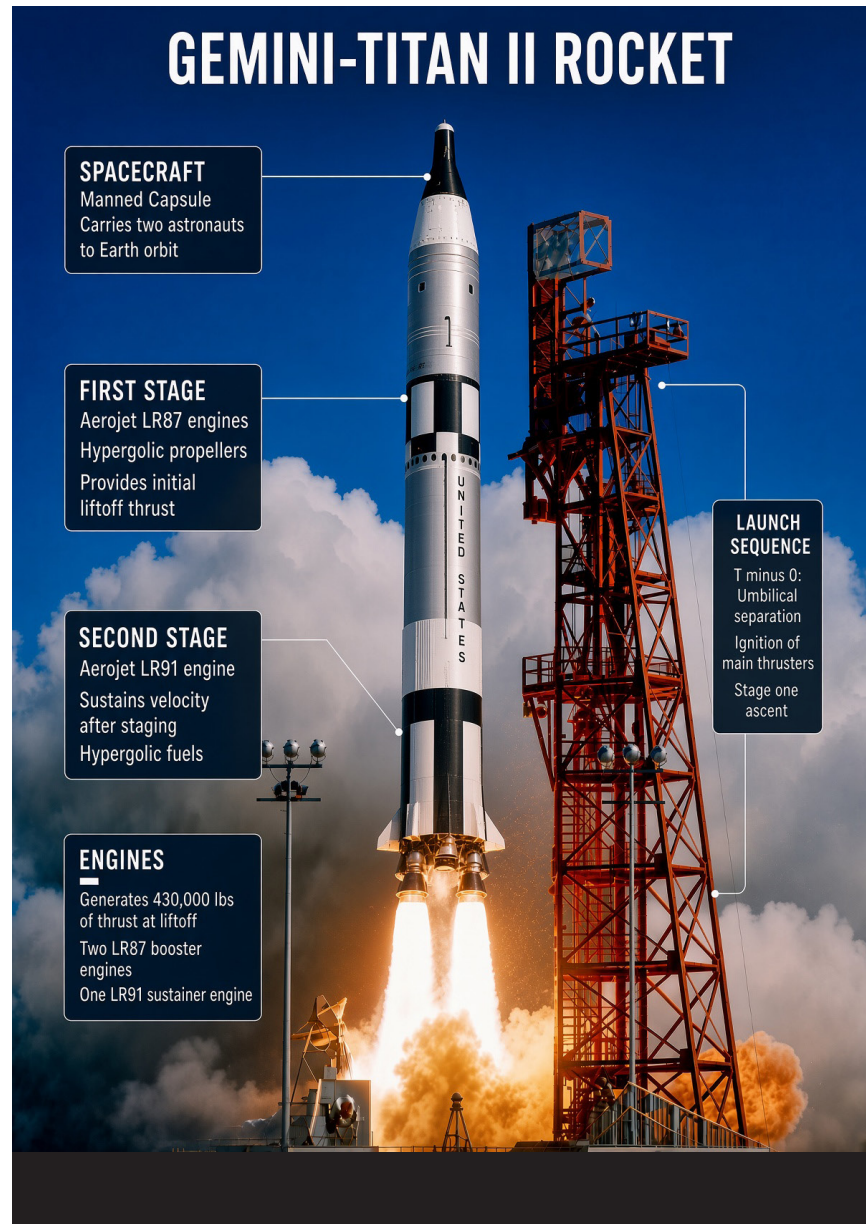
*The Titan II, originally a U.S. Air Force ICBM, became Gemini's reliable launch vehicle after human-rating modifications. Powered by storable hypergolic propellants and two Aerojet engines, it lifted the two-man spacecraft from Complex 19. Engineers solved pogo oscillations and added safety systems. All twelve Gemini launches succeeded, enabling the program's rapid progress toward Apollo techniques and establishing the Titan II as a highly successful early human-rated booster.*

The rocket that launched every Gemini mission began, like the Atlas before it, as a weapon. Developed by the Martin Company as an intercontinental ballistic missile for the U.S. Air Force, the Titan II was larger and more powerful than the Atlas. When NASA needed a booster capable of lifting the heavier two-man Gemini spacecraft, the Titan II was the clear choice. Modified and human-rated, it became the Gemini Launch Vehicle.

Unlike the Atlas, which used cryogenic liquid oxygen and kerosene, the Titan II burned storable hypergolic propellants: Aerozine 50 (a blend of hydrazine and unsymmetrical dimethylhydrazine) as fuel and nitrogen tetroxide as oxidizer. These propellants ignited spontaneously on contact, eliminating the need for complex ignition systems and allowing the missile to remain fueled for long periods in its silos. For Gemini, that same chemistry offered operational advantages and a measure of simplicity, though the propellants' toxicity required careful ground handling.

The Gemini Launch Vehicle was a two-stage rocket approximately 109 feet tall with the spacecraft attached and 10 feet in diameter. Liftoff thrust from the first-stage Aerojet LR87 engine (two chambers fed by a common turbopump system) was about 430,000 pounds. The second-stage LR91 engine produced roughly 100,000 pounds of thrust in vacuum. Total launch mass was between 330,000 and 340,000 pounds. The vehicle could place the roughly 8,000-pound Gemini spacecraft into low Earth orbit with margin.

Adapting an ICBM for manned flight required significant work. The most persistent problem was “pogo”—



(CONTINUED NEXT PAGE)

# The Titan II Rocket

## Gemini's Ride to Orbit

(CONTINUED FROM PREVIOUS PAGE)

longitudinal oscillations during first stage burn that could reach levels unacceptable for a crew. NASA insisted on limiting the vibration to no more than 10.25 g. Engineers added suppressors, standpipes, and other damping devices until the oscillations fell within safe limits. A Malfunction Detection System was installed to give the crew and ground controllers early warning of problems. Guidance, electrical, and hydraulic systems were improved for greater redundancy and reliability.

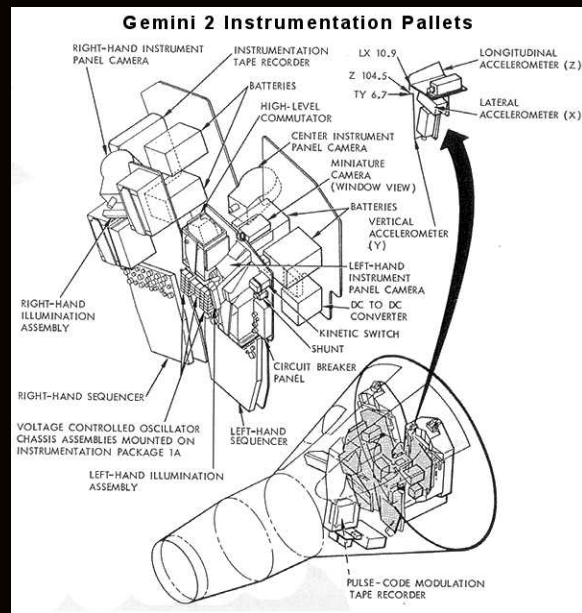
All twelve Gemini launches—two uncrewed qualification flights and ten crewed missions—lifted off from Launch Complex 19 at Cape Canaveral between April 1964 and November 1966. Every one of them succeeded. The Titan II delivered the spacecraft to orbit on schedule, enabling the rapid succession of missions that tested rendezvous, docking, extravehicular activity, and long-duration flight. Astronauts described the ride as firm and sometimes rough, with acceleration building to several g's, but the booster performed its job without a single failure that compromised a mission.

The Titan II's perfect record in the Gemini program stands in contrast to the more troubled early history of the Mercury-Atlas. Its combination of power, storable propellants, and eventual reliability allowed NASA to fly an aggressive schedule and master the techniques Apollo would require. By the time Gemini 12 landed in November 1966, the Titan II had proven itself one of the most successful human-rated launch vehicles of the early Space Age—an unlikely transformation of a Cold War missile into the rocket that helped put America on the path to the Moon.

### About Our Aircraft

The Titan II on display is the last variant of the Titan II family, the Space Launch Vehicle (SLV). On these missiles, the nuclear warhead was removed, and a new fairing was adapted that could carry a satellite into orbit, or, in one case, the Clementine, an unmanned space probe to the Moon. A total of 14 Titan IIs were converted to this role by Martin-Marietta, and all but the Museum's were used to launch satellites. Lacking a customer that required the Titan's lifting capacity, the missile was retired and turned over to the National Museum of the United States Air Force, which in turn loaned it to our Museum. ➤

# The Uncrewed Missions



**BILL KOLB**

MONDAY DOCENT

## The Gemini Program

Project Gemini (1965–1966) was NASA's essential bridge between Mercury and Apollo. In twenty months, ten crewed and two uncrewed missions systematically mastered the skills a lunar landing required: orbital maneuvering, rendezvous, docking, long-duration flight, and productive extravehicular activity. Launched on the Titan II, the two-man Gemini spacecraft proved far more capable than its single-seat Mercury predecessor. Early flights established basic orbital operations and the first American spacewalk; middle missions achieved the first rendezvous and docking while coping with a serious in-flight emergency; and the final flights solved the practical difficulties of working outside the spacecraft. By the time Gemini 12 returned, every critical technique Apollo would need had been demonstrated in Earth orbit.

### Gemini 1 — April 8, 1964 · Uncrewed · 3 orbits (63 total)

The first flight of the Gemini spacecraft and the first launch of the Titan II in its manned configuration. Primary goals were to prove the booster could place the capsule into orbit and to verify structural integrity during ascent and in space. No life-support systems or crew couches were installed; the vehicle carried 3,605 pounds of ballast instead. The mission also tested the new worldwide tracking network. After three orbits the systems were shut down. The spacecraft remained in orbit for 63 revolutions before reentering and breaking up as planned. All primary objectives were achieved.

### Gemini 2 — January 19, 1965 · Uncrewed · Suborbital

With launch and orbital insertion proven, Gemini 2 focused on reentry. Flown on a ballistic trajectory, it subjected the heat shield to full orbital-velocity heating—temperatures exceeded 3,000 °F. Telemetry confirmed the shield performed as designed. The parachutes deployed correctly, and the capsule splashed down roughly 2,100 miles downrange. Recovery forces found the spacecraft in excellent condition. Originally delayed by a hydraulic malfunction, the successful flight cleared the final major hurdle before crewed Gemini missions could begin. ➤



# Proving the Basics

## Gemini 3, 4 & 5

**BILL KOLB**

MONDAY DOCENT

### Summary

*The first three crewed Gemini missions transformed the program from an unproven vehicle into a working spacecraft. In just six months, NASA demonstrated that two astronauts could fly and maneuver in orbit, conducted the first American spacewalk, and showed that a crew could live and work in space for more than a week—the approximate duration of a lunar mission.*

### **Gemini 3 — March 23, 1965 · Gus Grissom & John Young · 3 orbits**

The first crewed Gemini flight, launched in the spacecraft nicknamed Molly Brown. Primary objectives were to prove that two astronauts could operate the new vehicle and to test its Orbital Attitude and Maneuvering System. Grissom and Young successfully changed their orbit—the first deliberate orbital maneuvers by an American spacecraft. Young also became the first person to eat solid food in space with a smuggled corned-beef sandwich. The three-orbit mission lasted 4 hours and 53 minutes and ended with a successful splashdown.

### **Gemini 4 — June 3, 1965 · James McDivitt & Edward White · 62 orbits**

A four-day mission centered on the first American spacewalk. On the second day Ed White floated outside for approximately 20 minutes using a handheld maneuvering unit while remaining tethered to the capsule. White was reluctant to return, later calling it “the saddest moment of my life.” The crew also conducted experiments and photography. Gemini 4 proved that an astronaut could survive and work outside the spacecraft.

### **Gemini 5 — August 21, 1965 · Gordon Cooper & Pete Conrad · 120 orbits**

An eight-day endurance flight designed to show that a crew and spacecraft could function for the length of a lunar mission. Gemini 5 was the first to use fuel cells for electrical power. Cooper and Conrad completed 120 orbits and remained in space 7 days, 22 hours, and 55 minutes, the longest American flight at that time, before returning safely. ➤



# Rendezvous, Docking & the First Crisis

## Gemini 7, 6A & 8

**BILL KOLB**

MONDAY DOCENT

### Summary

*With basic flight, spacewalking, and multi-day endurance established, the middle Gemini missions turned to the program's most demanding objectives: rendezvous, docking, and the ability to handle emergencies in orbit. These three flights delivered those capabilities—and one near-disaster that proved the value of cool-headed crew action.*

### **Gemini 7 — December 4, 1965 · Frank Borman & James Lovell · 206 orbits**

A fourteen-day endurance mission designed to show that a crew and spacecraft could function for the length of a lunar flight. Borman and Lovell lived in the cramped cabin for nearly two weeks while conducting medical experiments and systems checks. They also served as the passive target for the first rendezvous. The crew completed 206 orbits and returned safely after 13 days, 18 hours, and 35 minutes—the longest American spaceflight to that point.

### **Gemini 6A — December 15, 1965 · Wally Schirra & Thomas Stafford · 16 orbits**

Originally scheduled to dock with an Agena target, the mission was redesignated 6A after the Agena failed to reach orbit. Instead, NASA made Gemini 7 the target. Schirra and Stafford lifted off and, within hours, completed the first rendezvous of two manned spacecraft. The vehicles closed to within one foot of each other and station-kept for several orbits, proving that precise formation flying was possible. With the primary objective achieved, they returned after only one day in space.

### **Gemini 8 — March 16, 1966 · Neil Armstrong & David Scott · 6.5 orbits**

The first docking of a manned spacecraft with an unmanned target. Armstrong and Scott successfully joined with their Agena, but about 27 minutes later an OAMS thruster stuck on and the combined vehicles began to spin at an increasing rate. Armstrong undocked and used the reentry control system to stop the dangerous tumble. Mission rules required an immediate return once those thrusters had been fired; the crew splashed down safely after less than eleven hours. The flight proved both the feasibility of docking and the critical importance of rapid, correct decision-making when systems fail. ➤

A photograph of a Gemini spacecraft in orbit above Earth. The spacecraft is silver and white, with its nose pointed towards the left. The Earth's surface is visible below, showing blue oceans and white clouds. The background is a deep blue space.

# Refining EVA and Closing Out the Program

## Gemini 9A, 10, 11 & 12

**BILL KOLB**

MONDAY DOCENT

### Summary

*The final four crewed Gemini missions focused on perfecting the remaining skills Apollo would need, especially extravehicular activity, while continuing to practice rendezvous and docking under more demanding conditions. Early spacewalks had proven far more difficult than expected; these flights developed the training methods, restraints, and procedures that finally made useful work outside the spacecraft possible.*

### **Gemini 9A — June 3, 1966 · Thomas Stafford & Eugene Cernan · 45 orbits**

The original Agena target failed to reach orbit, so NASA substituted the Augmented Target Docking Adapter. When the crew arrived they found its protective shroud only partially open—Stafford called it an “angry alligator”—making docking impossible. They instead completed three separate rendezvous exercises. Cernan then began a lengthy EVA to test the Astronaut Maneuvering Unit. Lack of handholds, a stiff pressurized suit, and heavy exertion caused his visor to fog and freeze. Exhausted and nearly blinded, he struggled to return; Stafford had to help pull him inside. The spacewalk was terminated early but provided critical lessons.

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# Refining EVA and Closing Out the Program

## Gemini 9A, 10, 11 & 12

(CONTINUED FROM PREVIOUS PAGE)

### **Gemini 10 — July 18, 1966 · John Young & Michael Collins · 43 orbits**

Achieved docking with a new Agena and later rendezvoused with the passive Agena left from Gemini 8—the first dual-target mission. Collins performed two EVAs: one standing in the hatch and a second tethered excursion to retrieve a micrometeorite experiment package from the earlier Agena. The flight successfully combined docking, dual rendezvous, and productive extravehicular work in a single mission.

### **Gemini 11 — September 12, 1966 · Pete Conrad & Richard Gordon · 44 orbits**

Achieved a first-orbit rendezvous and docking, the fastest to date, then used the Agena's engine to boost the combined vehicles to a record apogee of about 850 miles. Gordon's primary EVA, which included attaching a tether between the two spacecraft, proved extremely tiring; he overheated and the spacewalk was cut short. A later standup EVA for photography went more smoothly. The mission showed that rapid rendezvous and high-altitude flight were feasible.

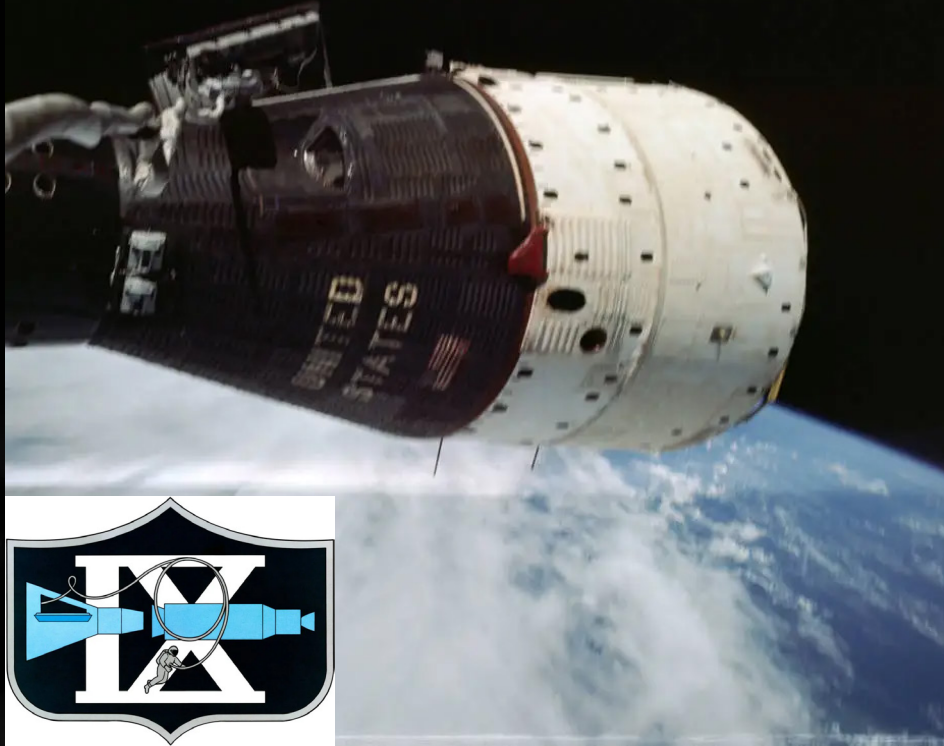
### **Gemini 12 — November 11, 1966 · James Lovell & Buzz Aldrin · 59 orbits**

The final Gemini flight solved the EVA problems that had plagued earlier missions. Aldrin trained extensively underwater in a neutral-buoyancy environment using improved restraints, handholds, and rest procedures. He then completed three successful extravehicular periods totaling more than five hours, demonstrating that an astronaut could work effectively outside the spacecraft. The crew also completed rendezvous and docking. By the end of Gemini 12, every major technique required for Apollo had been proven. ➤



# A Difficult Way To Walk

## Gene Cernan's Gemini 9A EVA



**ALAN DEUTMEYER**

MONDAY DOCENT

### Summary

*Gene Cernan's Gemini 9A spacewalk proved far more difficult than Ed White's earlier effort. Exhaustion, a fogged and frozen visor, a tangled umbilical, and a jagged spacecraft surface nearly trapped him outside while testing an astronaut maneuvering unit. After a struggle to reenter, lessons from this near-disaster—better restraints, handholds, and rest breaks—enabled Buzz Aldrin's successful 5.5-hour EVA on Gemini 12.*

"If we can't pressurize the spacecraft in a hurry and I have to stay in this position the rest of the flight, I'll die," Eugene Cernan said to Tom Stafford, Commander of Gemini 9A. Things were dire. America's second spacewalker was in trouble.

Most people are familiar with America's first spacewalker, astronaut Ed White. White had a relatively easy time outside Gemini 4. Despite how crowded it was in the small capsule, he was able to complete the clumsy business of donning a chest pack, his twenty-five-foot umbilical cord, and his maneuvering gun. Just getting his equipment ready was very tiring, but the "walk" itself was very brief (23 minutes) with no major problems. The maneuvering gun worked great. NASA was wildly enthusiastic about the mission outcomes - and overconfident.

The plan for the second spacewalk was much more ambitious. A two-hour walk: Cernan was to exit Gemini 9A, crawl to the rear of the spacecraft, and put on and test a new astronaut maneuvering unit (AMU) – a gas-powered backpack that would allow him to fly free in space, essentially.

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# A Difficult Way To Walk

## Gene Cernan's Gemini 9A EVA

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Nothing worked as planned. Every movement along the spacecraft - along with his umbilical cord- caused him to swing side to side, affecting the inertia of the spacecraft itself. Fighting this inertia was exhausting, causing Cernan to breathe heavily and his heartbeat to increase. His breath fogged his visor completely over while in the sun, but worse, it froze when he was out of the sun. While mostly blind and feeling his way to the adapter section of the spacecraft, he encountered a jagged edge where the booster had been attached before explosive bolts tore it away. Cernan gamely vaulted over and was able to get the AMU out for testing.

Nothing about the backpack maneuvering unit worked as advertised. It took all the strength Cernan had in one arm to hold himself in place while he tried to turn the various knobs. Radio communication between him and Stafford was also breaking up. "Is the visor starting to clear?" asked Stafford. "Only if I don't breathe," said Cernan. Stafford knew Cernan was in trouble and ordered him back into Gemini.

Getting in was no easy matter. Exhausted, Cernan had to work his way—visor frosted/fogged—back over the jagged metal that could slice his spacesuit. Cernan attempted to enter the hatch feet first, but his inflated spacesuit would not allow him to bend. Stafford had to pull Cernan's feet, but he could bend no further.

As he tried to close the hatch, the door banged into his helmeted head. Cernan bent further, pulled harder, and at last felt the latch mechanism engaging. As he confessed to Stafford about his pained position, the latch finally clicked, Stafford finally repressurized, and both men removed helmets and gloves; Cernan was close to tears of both pain and relief.

Problems with maneuvering, sweating, fog, and fatigue persisted with spacewalks during Gemini 10 and 11.

Buzz Aldrin studied and learned lessons from these spacewalks. James Lovell commanded Gemini 12 while Buzz Aldrin spacewalked for 5.5 hours. New protocols had been devised, making scheduled breaks a part of future spacewalks. Portable handholds and wrist tethers were used for better grip and stability. Foot restraints ("slippers") held him in place. The AMU was not tested further on any Gemini or Apollo flights, as it was not needed for walking on the Moon. Aldrin, once and for all, banished the gremlins of spacewalking with the last Gemini Mission. ✈

# The Delicate Dance of Orbital Mechanics

## How Mercury & Gemini Learned to Fall Around the Earth

**BILL KOLB**

MONDAY DOCENT

### Summary

*Orbital flight is continuous free fall: gravity provides the inward centripetal force, while high sideways speed (about 17,500 mph) matches Earth's curve, so the spacecraft never hits the ground. Cape Canaveral's eastward rotation and ocean safety made it ideal. Mercury rode fixed orbits; Gemini used thrusters to change altitude and relative speed, mastering the gravity–centrifugal balance essential for rendezvous and later Apollo missions.*

To stay in orbit, a spacecraft must do something that seems almost contradictory: it must fall continuously toward Earth without ever hitting the ground. That elegant balancing act is the heart of orbital mechanics, and it is the same principle you feel on a merry-go-round.

On a merry-go-round, you travel in a circle. Your body wants to move in a straight line (Newton's first law), but a real force—friction on the platform, the pole you hold, or the seat beneath you—constantly pulls you inward toward the center. That inward force is called centripetal force (“center-seeking”). It continuously changes the direction of your velocity, so you keep circling instead of flying off in a straight line. In the spinning world of the merry-go-round, you feel as though you are being thrown outward; that outward sensation is a fictitious centrifugal force that appears only because you are in a rotating frame. In the true, non-rotating view from the ground, only the inward centripetal force exists.

A spacecraft in orbit lives by the same rule. Gravity supplies the centripetal force, constantly pulling the vehicle toward Earth's center. At the same time, the spacecraft is racing sideways at roughly 17,500 mph (7.8 km/s). That high horizontal speed means the curve of its falling path matches the curve of the Earth itself. The spacecraft is in continuous free-fall, yet it never reaches the ground. In the spacecraft's own frame, the balance can be described as gravity pulling inward while centrifugal force pushes outward; when the two are equal, the altitude remains steady. That precise equilibrium is what we call being “in orbit.”

(CONTINUED NEXT PAGE)

# The Delicate Dance of Orbital Mechanics

## How Mercury & Gemini Learned to Fall Around the Earth

(CONTINUED FROM PREVIOUS PAGE)

If the spacecraft slows down, the outward effect weakens, gravity wins, and the orbit decays. If it speeds up, the outward effect grows, and the orbit rises. Higher orbits require less speed to maintain balance because gravity is weaker farther from Earth, but the time to complete one circuit increases.

These principles shaped everything about the early American space program.

### Why Florida's East Coast?

Cape Canaveral offered three decisive advantages. First, Earth rotates from west to east. At the Cape's latitude of about 28.5° N, the ground is already moving eastward at roughly 900 mph. Launching due east adds free velocity to the rocket, saving propellant and increasing payload capacity. Second, an eastward trajectory sends the vehicle out over the open Atlantic, so that any failure during the dangerous powered-flight phase drops debris into the ocean rather than onto land. Third, the Air Force already operated a missile test range there, complete with tracking stations, blockhouses, and recovery forces. NASA simply built on that foundation.

Most Mercury and Gemini launches therefore headed east or slightly southeast, producing orbits with inclinations of roughly 28–33°, close to the latitude of the Cape itself.

### Mercury: Riding the Balance

The Mercury capsule had almost no ability to change its orbit once the booster shut down. The Atlas or Redstone placed it on a trajectory that became a low Earth orbit (or a simple ballistic arc for the suborbital flights of Shepard and Grissom). The astronaut could control only the spacecraft's attitude. When it was time to come home, the retrorockets fired, the spacecraft slowed, the gravity–centrifugal balance tipped in favor of gravity, and the capsule fell back into the atmosphere.

### Gemini: Mastering the Balance

Gemini changed the game. Its Orbital Attitude and Maneuvering System let the crew make small, deliberate velocity changes. To catch a target vehicle ahead of them, they fired their thrusters to drop into a lower, faster orbit, exactly as a merry-go-round rider who steps closer to the center finds it easier to keep up. In the lower orbit, the spacecraft moved faster relative to the target, closed the gap, then raised its orbit again to match speed and position. This technique of using altitude to control relative speed became the foundation for every subsequent rendezvous, including the critical lunar-orbit rendezvous of Apollo.

### The Larger Story

Cape Canaveral gave the United States a practical place to begin. Mercury proved that an American astronaut and spacecraft could reach orbit and return. Gemini taught the more sophisticated art of adjusting the gravity–centrifugal balance so that two vehicles could meet and dock in space. The same physical principles that keep a child safely on a merry-go-round kept John Glenn circling the Earth and allowed Gemini crews to practice the maneuvers that would ultimately take astronauts to the Moon. ✈



# THE BALANCE THAT KEEPS SATELLITES IN LEO



**LOW EARTH ORBIT (LEO): ~100 – 1,200 miles altitude**

In Low Earth Orbit (LEO), a satellite stays in orbit when **CENTRIPETAL FORCE** (up) balances **GRAVITATIONAL FORCE** (down).



## CENTRIPETAL FORCE: THE “INWARD-PULLING” FORCE

Think of a spinning **merry-go-round**. When you spin fast, you feel pushed outward toward the edge. That outward feeling is caused by **centripetal force** pulling you **inward** toward the center to keep you moving in a circle.



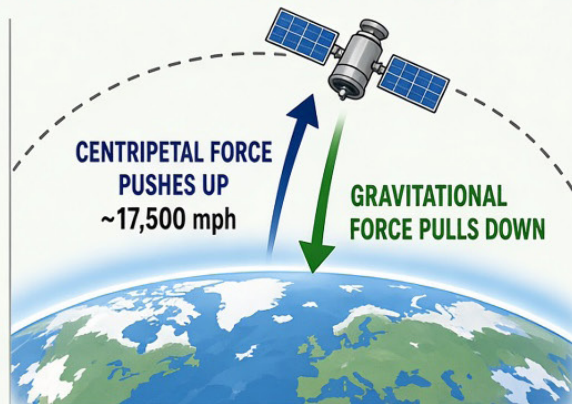
**CENTRIPETAL FORCE PUSHES UP**

(away from Earth's center) because of the satellite's speed and curved path.

## THE BALANCE IN LOW EARTH ORBIT (LEO)

**AT ~17,500 mph IN LEO:**

The satellite's speed creates centripetal force pushing **UP**.



Earth's gravity pulls the satellite **DOWN** toward the center of the Earth.

**= WHEN BALANCED:**

The satellite neither falls to Earth nor flies off into space. It stays in a **stable circular orbit**.



**~17,500 mph (25,750 km/h)** is the “sweet speed” for LEO. Faster = higher orbit or flyaway. Slower = falls back to Earth.

## WHY THE BALANCE MATTERS



### TOO SLOW

Gravity wins. Satellite falls back toward Earth.



### JUST RIGHT (~17,500 mph)

Forces balance. Stable LEO achieved.



### TOO FAST

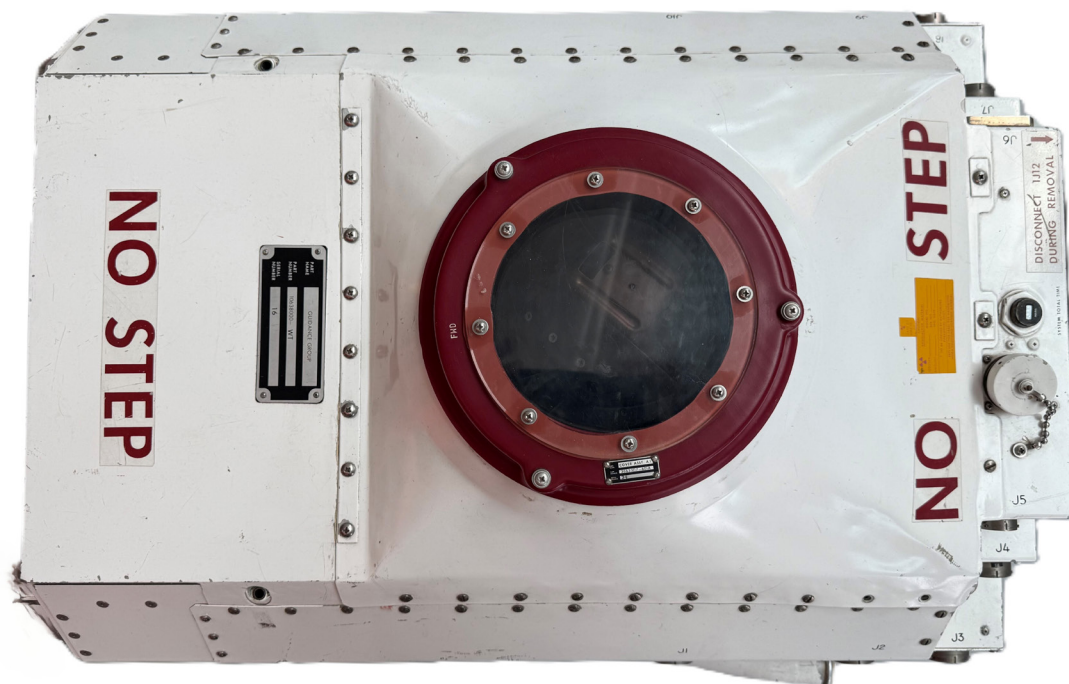
Centripetal force wins. Satellite climbs to a higher orbit or escapes.



**IN LEO, STABLE ORBIT IS A DELICATE BALANCE:**  
**CENTRIPETAL FORCE UP = GRAVITATIONAL FORCE DOWN**  
**AT ~17,500 mph, SATELLITES STAY IN ORBIT AROUND EARTH.**

## August Mystery Corner Answer

# The SR-71 Astro-Inertial Navigation System



**BILL KOLB**

*MONDAY DOCENT*

The SR-71 Blackbird's Astro-Inertial Navigation System (ANS) was a self-contained navigation suite that combined a high-quality inertial platform with an automatic star tracker. It allowed the aircraft to determine its position with high accuracy while flying at Mach 3+ and altitudes above 80,000 feet, long before GPS existed.

The inertial portion used gyroscopes and accelerometers mounted on a stabilized platform. The accelerometers measured the aircraft's accelerations; the system's computer integrated those signals to calculate velocity and position. Gyroscopes kept the platform aligned to a stable reference so the measurements remained accurate in three dimensions. Over time, however, small gyro drift and sensor errors accumulated.

To correct those errors, the ANS employed an automatic astro-tracker. Looking upward through a quartz window behind the Reconnaissance Systems Officer's cockpit, the tracker could lock onto stars in daylight as well as at night. The computer selected stars from an onboard catalog, directed the tracker to find them, and measured their precise angular positions. By comparing the observed star positions with those predicted from the inertial solution and exact time, the system calculated corrections and updated the inertial platform.

The result was continuous, autonomous navigation accurate to roughly 300 feet or better. (Many crews reported landing coordinates accurate to 30 feet or less.) Crews nicknamed the unit "R2-D2." It gave the SR-71 the ability to fly precise reconnaissance routes and return safely without relying on ground-based radio aids. ✈

# September Mystery Corner

**BILL KOLB**

*MONDAY DOCENT*

In this and future editions of the FlightPlan, Archives will provide a picture of an artifact/item for which they have no idea what it is, how it came about, or where it originated.

The following month, Archives will provide the answer or the best-guess submissions, if any. ➤

## THIS MONTH'S MYSTERY: What the heck is this?



This was found with some of the Goose's test gear. Answer to be revealed in the October edition.

Readers are encouraged to provide Archives with their best answer/guess by responding to Jean Herkamp at: [jean.herkamp@evergreenmuseum.org](mailto:jean.herkamp@evergreenmuseum.org).

# Band of Brothers



The McMinnville, Oregon Band of Brothers meets on the **first Thursday of each month**. Because of changes, we are not sure of the location at the Museum. The **meetings start at 11:30 am** and run about an hour, with coffee and cookies served. More details can be found at the group's **Facebook page**: <https://www.facebook.com/groups/838928846550343>

We are currently looking for speakers. If you would like to become one of the monthly speakers, please contact **Al Arguedas** at [aja@onlinemac.com](mailto:aja@onlinemac.com).

## MONTHLY THEMES

SEPTEMBER.....SPACE FLIGHT: EARLY MERCURY  
THROUGH GEMINI

OCTOBER.....AVIATION: WWII

NOVEMBER.....AVIATION: POST-WWII  
THROUGH KOREA

DECEMBER .....SPACE FLIGHT: APOLLO

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