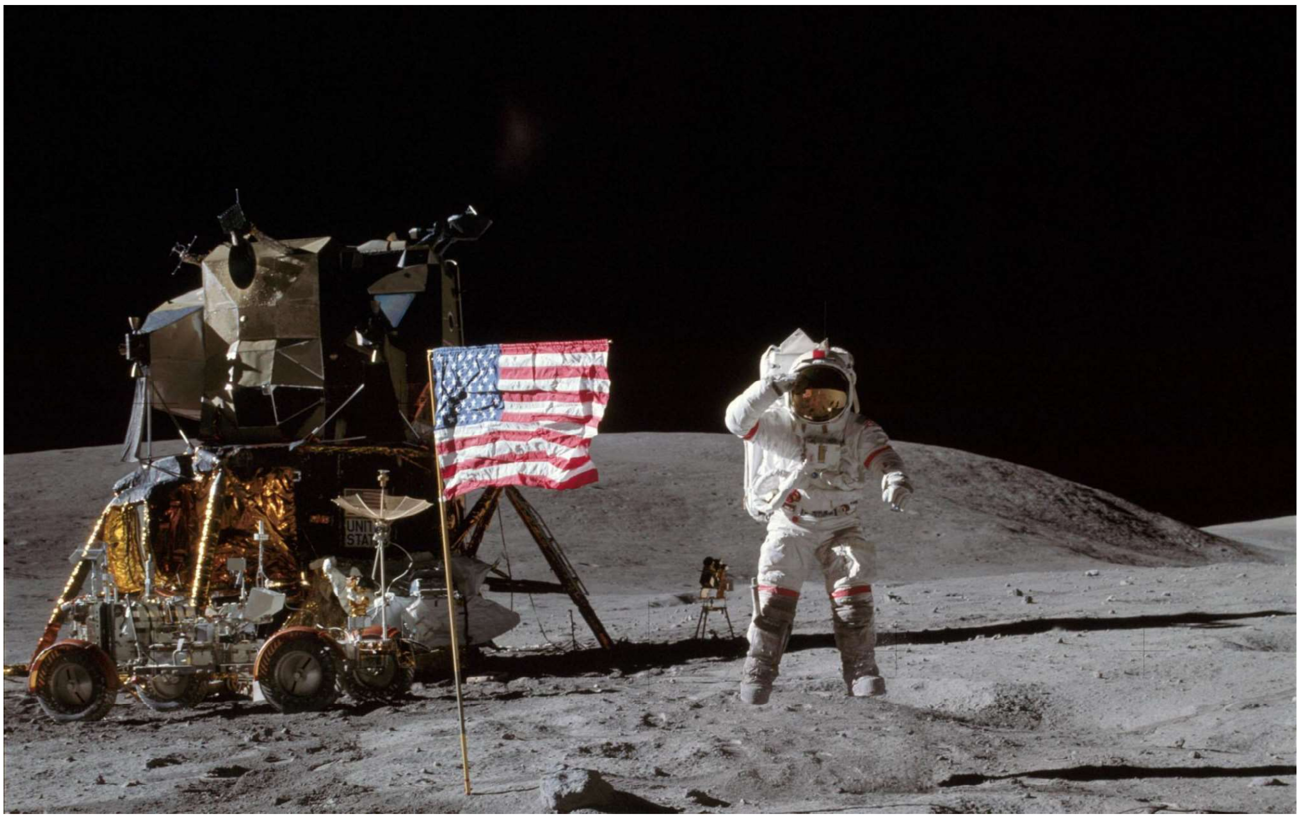
NASA's Golden Age: Mercury, Gemini, and Apollo

A Visual Celebration

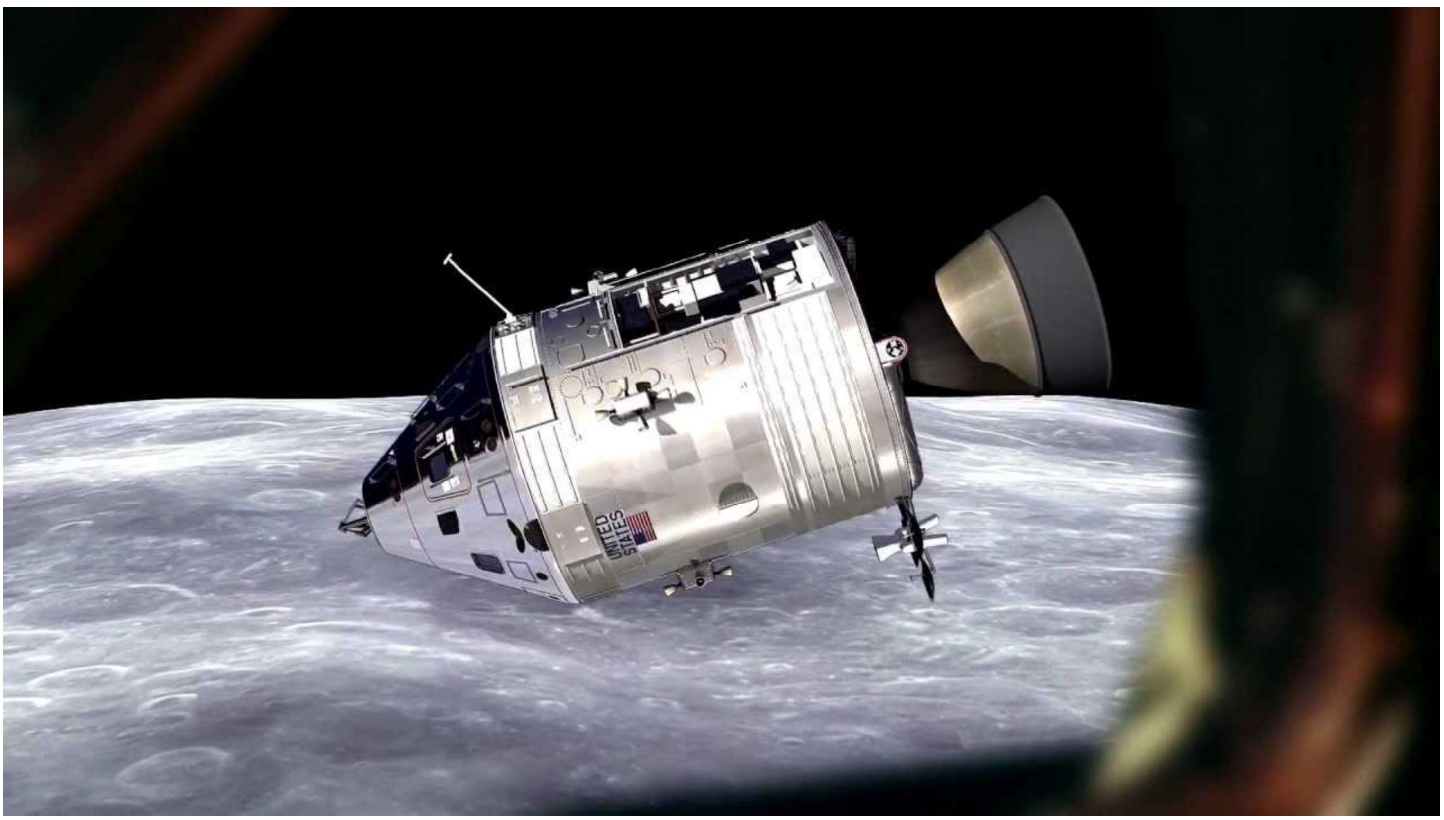
The Grandeur of Lunar Exploration

(Apollo 16 Astronaut John Young Exuberantly Salutes the American Flag;
Lunar Module *"Orion,"* and Lunar Roving Vehicle-2, are on the plain at Descartes.)



Launch of the Apollo 16 Saturn V Space Vehicle

The Apollo Command and Service Module in Orbit Around the Moon



“Earthrise”

(This dramatic photo, taken by the Apollo 8 crew during lunar orbit # 4 in December of 1968, had a profound emotional and psychological impact.)

Apollo 16 Photograph of Earth,
Depicting the Northern Portion of the Western Hemisphere

Apollo Program Overview

- **<u>Goals</u>:**
  - **<u>Stated</u>:** ***Land an American on the Moon and return him safely to the Earth before the end of the decade of the 1960s.***
  - **<u>Unstated</u>:** ***Beat the USSR to the Moon and thereby establish American pre-eminence in outer space technology; Project Apollo was a key component of the Cold War with the Soviet Union.***

- **<u>Mission Accomplished</u>:**
  - **In nine (9) flights from the Earth to the Moon from 1968 to 1972, 24 different American astronauts made that journey;**
  - **Twelve (12) different Americans landed and walked on the Moon;**
  - **Project Apollo accomplished six (6) successful lunar landings; flew one circumnavigation without a lunar lander; flew one dress rehearsal including a lunar lander (which did not land); and even the one mission which was aborted (Apollo 13) accomplished a lunar circumnavigation and was considered "a successful failure" (since the crew was returned alive). Three Apollo astronauts (Young, Cernan, and Lovell) traveled to the Moon twice.**
  - **As of 2018, no other nation on earth has yet circumnavigated the Moon with human beings, or landed astronauts on the Moon.**

- **<u>Launch Vehicle</u>: The Saturn V Moon Rocket was a 363-foot tall behemoth weighing almost 6.5 million pounds, developed specifically for manned lunar missions. It was launched successfully 12 times. (Only 1 of 13 total launches, the second of two unmanned test launches, experienced significant problems---but it still limped into low earth orbit).**

- **<u>There were two (2) distinct types of Apollo spacecraft sent to the Moon by the Saturn V rocket, as follows</u>:**
  - **The Command and Service Module, or "CSM"**
  - **The Lunar Lander, abbreviated "LM" and often pronounced "LEM" (from its original name, "Lunar Excursion Module")**

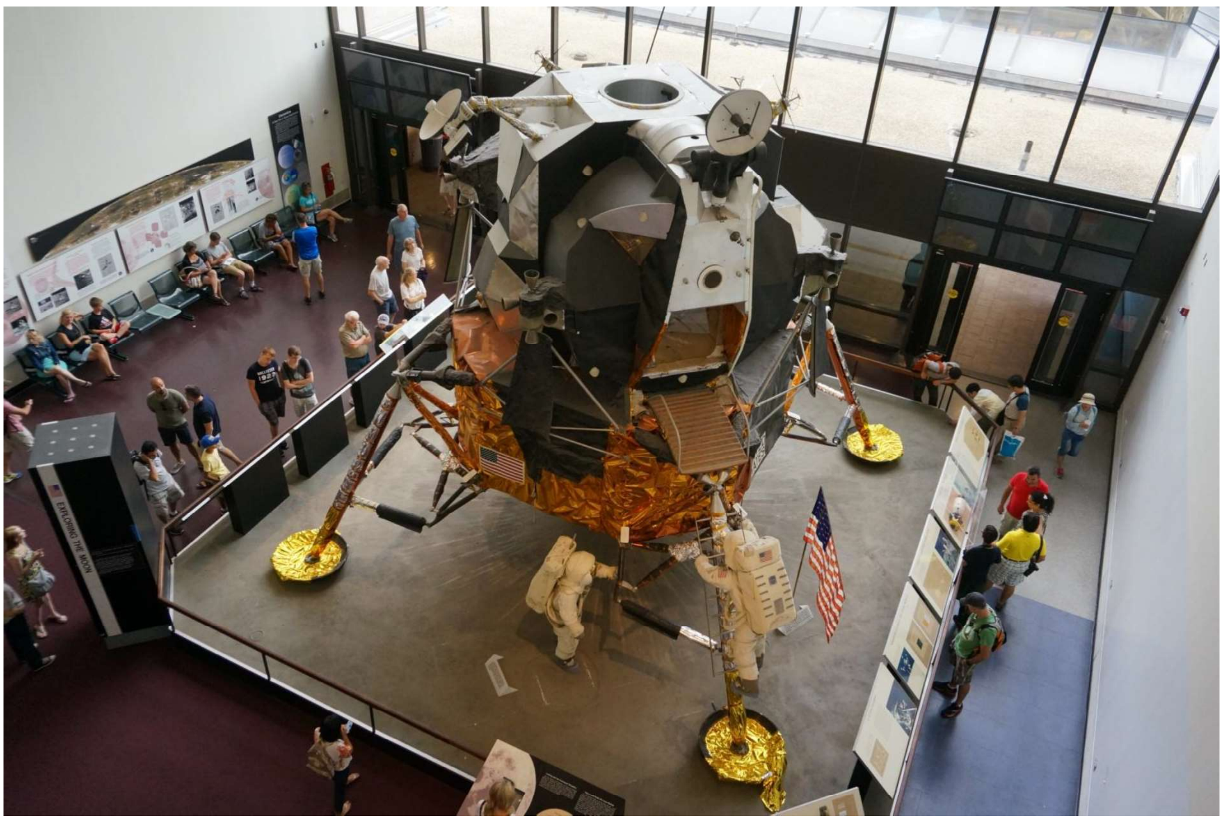
- After the completion of 6 lunar landings, **the Saturn V rocket launched America's first space station, "Skylab"** (a modified Saturn third stage), which was subsequently visited three times by manned missions using the Apollo CSM (which were all launched by the smaller Saturn IB rocket).

- In July of 1975, in support of geopolitical *détente* with the USSR, the **Apollo-Soyuz Test Project (ASTP)** saw an Apollo Command and Service Module rendezvous and dock with one of the Soviet Union's "Soyuz" spacecraft in low Earth orbit.

Apollo Command and Service Module [NASM]

The Apollo 11 Command Module *"Columbia"* After Return to Earth [NASM]

Lunar Module No. 2 [NASM, Washington, D.C.]



NASM Models of the Apollo-Saturn V Space Vehicle and the USSR's N-1

[There were 13 successful Saturn V launches (13 for 13) vs. *none* *(0 for 4)* for the N-1.]

Astronaut Dave Scott's Spacesuit from the Apollo 15 Mission

[From the "Space Race" Exhibit at NASM]

(The Hadley-Apennine destination of the Apollo 15 crew was the most geologically varied site visited by any of the Apollo missions.)

Close-Ups of Apollo 15 Commander Dave Scott's Lunar Spacesuit **[From the "Space Race" Exhibit at NASM]**

(Note the "dirt" on the suit---that's lunar soil, known as *regolith;* this is one kind of dirt you don't want to clean off.)

The Apollo 15 Crew and the Lunar Rover

(Astronaut Dave Scott is at left.)

Details of Apollo 15 Commander Dave Scott's Helmet and Gloves
[From the "Space Race" Exhibit at NASM]

(Former astronaut Dave Scott served as the <u>principal technical advisor</u> for the film *Apollo 13,* and for the HBO mini-series *From the Earth to the Moon.* These two films are not 100% perfect in all of their details, *<u>but in all major respects</u>*, they will nevertheless serve as a remarkably accurate historical record---detailing the hardware, operational procedures, and politics of the space program---for future audiences for hundreds of years to come, explaining how Americans traveled to the Moon from 1968-1972. They are much more than "mere entertainment.")

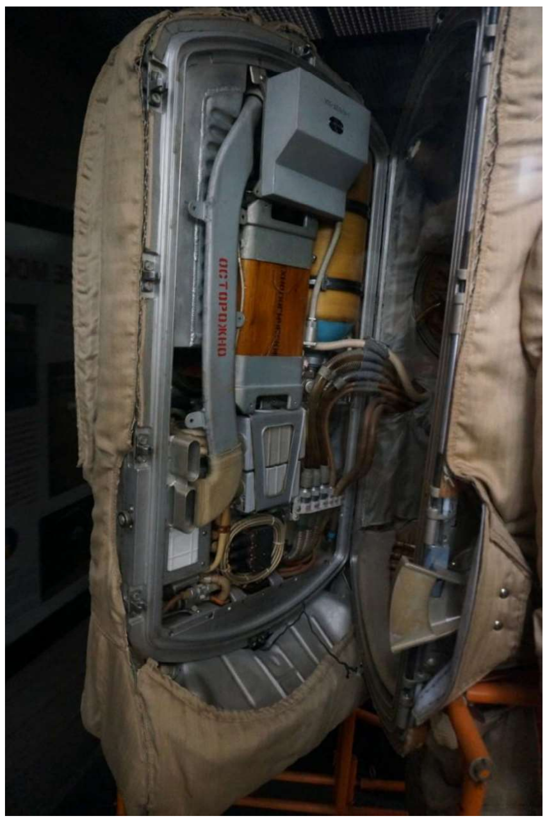
The Soviet Union's "Golden Falcon" Spacesuit Was Intended to be Worn by a Soviet Cosmonaut on the Moon, and Reveals the Serious Nature of the Competition During the 1960s [From the "Space Race" Exhibit at NASM]

(Note that the USSR's Moon Suit did not employ an external backpack for consumables, as NASA's lunar spacesuit did; the Cosmonaut stepped into the Golden Falcon suit from behind, and then the hinged back of the suit---containing his consumables---was closed.)

Detail of Rear Entrance to the "Golden Falcon" Moon Suit

[From the "Space Race" Exhibit at NASM]

(The Soviet Union's N-1 Moon Rocket was designed to launch a one-man landing vehicle to the Moon; the Russian Cosmonaut would have been required to enter his lunar lander via a space walk from the Soviet Command Module before descending to the lunar surface, *alone*.)



JFK's Moon Decision (1 of 3)

- The **"Moon Speech"** President John F. Kennedy delivered to Congress on May 25, 1961 challenged the nation to "land a man on the Moon and return him safely to the Earth" by the end of the decade. Congress and the American people enthusiastically accepted the challenge.
  - Kennedy laid down this challenge ***only 20 days after Alan Shepard's brief suborbital flight, when America had only 15 minutes and 22 seconds of manned spaceflight experience, and had not yet placed a man in Earth orbit.*** (The same goal had been set by the U.S. House of Representatives Committee on Science and Astronautics in July 1960; however, in the absence of a crisis atmosphere, it did not receive Presidential or public endorsement.)
  - JFK's challenge was made in the midst of a Cold War crisis:
    - America was behind the USSR in prestige space achievements; the USSR could boast of the first Earth satellite (Sputnik), the first animal placed in Earth orbit (the dog Laika), the first photos taken of the back side of the Moon, and the first human placed in orbit around the Earth (Yuri Gagarin);
    - Gagarin's single revolution around the Earth on April 12, 1961 was the latest shock received by the American public; U.S. experts feared a Soviet lunar landing by 1967.
    - The failed Cuban exile invasion at the Bay of Pigs from April 17th-19th, coming on the heels of Gagarin's flight, challenged America's leadership of the free world, and our resolve "to win," at the height of the Cold War with the Soviet Union.
  - JFK made a conscious decision to engage in an ***open, peaceful (i.e., non-military), highly visible technological competition*** with the USSR in outer space, rather than resolve our competition with the Soviet Union on the battlefield.
  - The Apollo Program was born as an integral strategy element in the Cold War, and was not sold merely as a scientific program of exploration. In 1999, Astronaut Frank Borman said:

    "Any idea that the Apollo program was a great voyage of exploration or scientific endeavor is nuts. People just aren't that excited about exploration. They were sure excited about beating the Russians."

JFK's Moon Decision (2 of 3)

- **It is ironic** that JFK is lionized today for his prescience and wisdom in picking a technological goal which allowed the United States to catch up with, surpass, and publicly defeat our Cold War adversary. Why ironic? Because the JFK of 1961 and 1962 wanted to ***win*** the Cold War through <u>competition</u> in space, and the JFK of late 1963 wanted to help ***end it*** through <u>cooperation</u> in space (details below):

  - **JFK's September 20, 1963 United Nations speech** proposed a joint lunar landing with the USSR in the interests of détente:

    > ***"Why, therefore, should man's first flight to the Moon be a matter of national competition?*** Why should the United States and the Soviet Union, in preparing for such expeditions, become involved in immense duplications of research, construction, and expenditure? Surely we should explore whether the scientists and astronauts of our two countries (indeed, of all the world) cannot work together in the conquest of space, ***sending some day in this decade to the Moon not the representatives of a single nation, but the representatives of all our countries."***

  - **President Kennedy followed this up with National Security Action Memo (NSAM) 271, on November 12, 1963**---which specifically referenced his U.N. speech on September 20th, and directed NASA administrator James Webb to develop a program of substantial cooperation with the USSR in outer space, ***"including cooperation in lunar landing programs."*** NSAM 271 directed Webb to provide an interim report on actions taken by December 15, 1963.

  - **JFK's assassination on November 22, 1963** abruptly terminated any chance of a joint lunar landing program with the USSR. Henceforth, the Apollo program was considered to be a debt that the nation owed to his memory; most in government also considered it a "national defense" program (hence, no cooperation).

JFK's Moon Decision (3 of 3)

- Historian David West Reynolds summarized JFK's role as follows in his 2002 book, ***Apollo: The Epic Journey to the Moon*:**

> *John F. Kennedy had pledged America to reaching the Moon "before this decade is out," skillfully finessing the nation's short-term prestige losses in space by redefining the ultimate contest as one that America had a chance of winning.* ***In spite of our embarrassing failures and almost pitiful space capabilities in 1961, Kennedy had made his bold move and expressed unflinching confidence in the face of demonstrated Soviet superiority. Now it was up to the nation to deliver on his promise.*** *The power of such a grandiose declaration might have waned if not for a sniper's bullet in Dallas, Texas.* ***In 1963, John Kennedy's assassination turned the political pledge into a deadline graven on a national headstone and lit by an eternal flame. There could be no compromise now, no reconsideration that would dishonor Kennedy's memory and belie his visionary faith in America's ability.*** *The looming deadline would drive all our efforts as we struggled to make manifest the instruments and abilities that would accomplish the Moon odyssey. [Emphasis added]*

Project Mercury Overview

- ***Goal**: Determine whether man can live and function in the space environment; and demonstrate the ability to place an astronaut in earth orbit.*

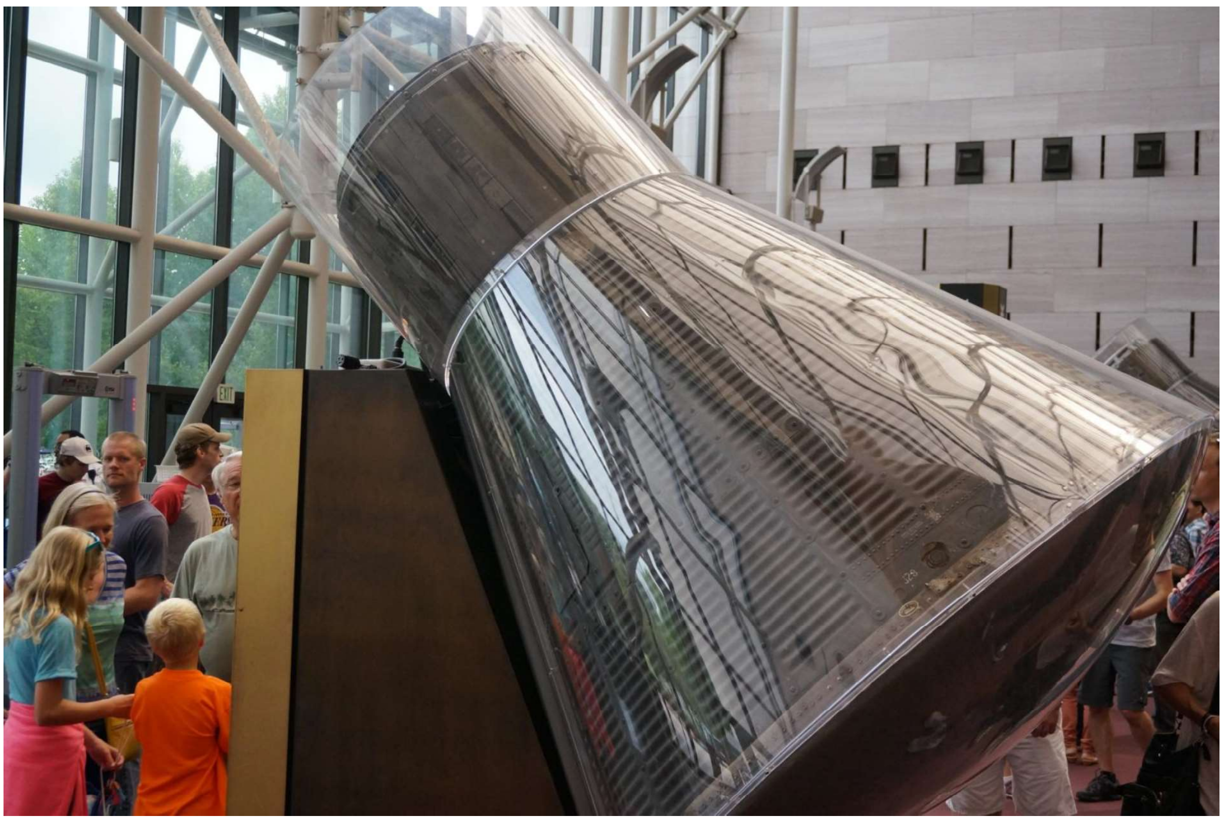
- ***Timeframe**: Born in December 1958, manned flights took place from 1961-63.*

- ***Spacecraft**: One man capsule, launched atop modified missiles originally designed to deliver nuclear weapons (Redstone and Atlas):*
  - **Redstone:** *Short-range (200 miles) "battlefield missile" with a thrust of 78,000 lbs;*
  - **Atlas:** *ICBM (9,000 mile range) with a first stage thrust of 360,000 lbs.*

- **Flights**:
  - *16 Unmanned Flights*
  - *4 Animal Flights (Sam, Miss Sam, Ham, and Enos)*
  - *6 Manned Flights*
    - *2 Suborbital (1961), using the Redstone launch vehicle*
    - *4 Orbital (1962-1963), using the Atlas launch vehicle*

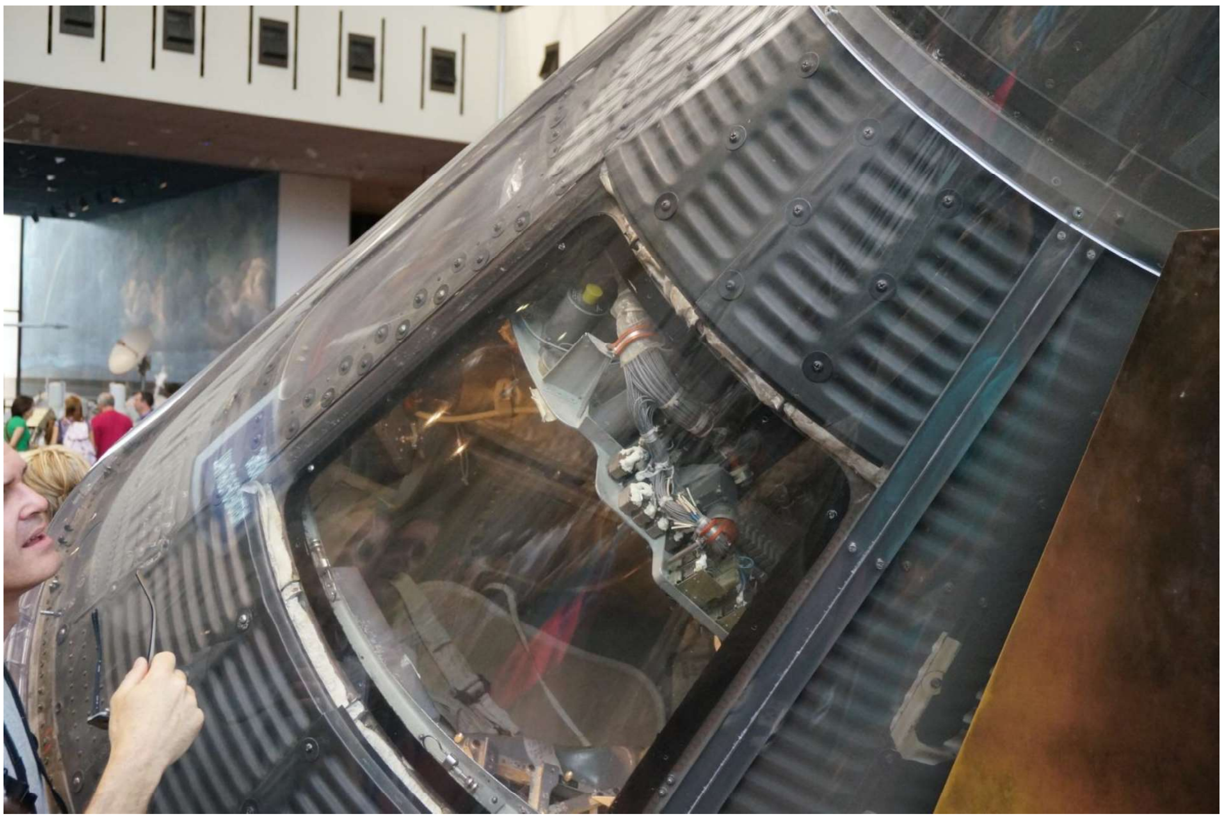
- **Astronauts/Flight Dates**:
  - **Alan Shepard (suborbital: May 5, 1961)**
  - **"Gus" Grissom (suborbital: July 21, 1961)**
  - **John Glenn (3 orbits: February 20, 1962)**
  - **Scott Carpenter (3 orbits: May 24, 1962)**
  - **"Wally" Schirra (6 orbits: October 3, 1962)**
  - **"Gordo" Cooper (22 orbits: May 15-16, 1963)**

John Glenn's Mercury Spacecraft [NASM, Washington, D.C.]



A View Inside the Hatch of the *Friendship 7* Spacecraft [NASM]

(Note exposed wiring bundles and "monkey shit" on wiring connections)



Close-Up of Friendship 7 Wiring Behind Control Panel [NASM]

An American Hero: John H. Glenn of Ohio [NASM]
First American to Orbit the Earth---February 20, 1962

John Glenn's Spacesuit at the National Air and Space Museum [NASM]

The aluminized outer skin was for style points alone ("Buck Rogers") and was not necessary.

When you see the name badge, you know you are looking at the "real thing."

Mercury Spacecraft Engineering Factoids (1 of 3)

- **Dimensions of Spacecraft:**
  - Length/height of complete spacecraft (with escape tower and retropack): 26 feet
  - **Length/height (in orbit, without escape tower): 11.17 feet**
  - Length/height (prior to landing bag deployment, w/o antenna fairing or retropack): 7.58 feet
  - Length/height (at landing, with landing bag deployed): 11.58 feet
  - **Maximum Diameter (at ablative shield): 6.2 feet**
- **Weights of MA-6 (John Glenn's) Spacecraft:**
  - At launch: 4,265 lbs
  - **At insertion into orbit: 2,987 lbs**
  - At retrograde: 2,970 lbs
  - Water landing weight: 2,493 lbs
  - Recovery weight: 2,422 lbs
- **Three basic sections to Mercury Spacecraft Afterbody:**
  - Conical Section (human occupant, electronics, ECS, ablative shield);
  - Cylindrical Section (main and reserve parachutes);
  - Antenna Fairing (VHF/UHF communications antennae and drogue parachute).
- **"Landing Bag"**
  - A fiberglass impact skirt impregnated with silicon rubber;
  - Suspended from conical section of afterbody by stainless steel straps; holes drilled in landing bag.
  - Four (4) feet long; deployed after main chute deployed, to attenuate landing accelerations from 45g to 15g;
- **Parachutes:**
  - Drogue parachute deployed at about 21,000 feet to stabilize and slow spacecraft;
  - Main and reserve parachutes were identical **63-feet diameter, "ringsail" parachutes;** main chute deployed at 10,000 feet; remained reefed at only 12% of full extension, for 4 seconds, before fully opening**; goal was to hit the water at a speed of 30 feet/sec.**
  - After water impact, main chute disconnected and reserve chute was automatically ejected.

Mercury Spacecraft Engineering Factoids (2 of 3)

- **Escape Rocket:**
  - Solid fuel; 52,000 lbs of thrust, for 1.39 seconds
  - Capable of lifting spacecraft 2,500 feet off launch pad (at 20gs of acceleration)
  - Tower jettison rocket (also solid fuel) produced about 800 lbs of thrust (used to dispose of escape rocket and tower after successful launch), fired for 1.5 seconds
- **Retrograde and Posigrade Rockets:**
  - Posigrade: 3 small solid fuel rockets fired in salvo, simultaneously, for 1.35 seconds, to separate spacecraft from booster after boost phase; 370 lbs thrust each
  - Retrograde ("Retro Rockets"): 3 solid fuel "retro" rockets fired sequentially for about 13.2 seconds each, with a 5 second delay between successive firings; 992 lbs of thrust each
- **Electrical System:**
  - Rechargeable silver-zinc batteries
  - Three (3) solid state inverters provided 115v, 400 cycle, single-phase A/C (one for ACS, one for ECS, one backup inverter)
- **Environmental Control System (ECS):**
  - Provided a single-gas (pure oxygen) environment at 5.1 psi; cabin pressure vessel designed to hold 5.5 psi of pressure; three (3) spherical titanium oxygen tanks at 7,500 psi (each the size of a grapefruit).
  - Two subsystems (pressure suit and cabin);
  - Actual temps (degrees F) maintained during MA-6 flight:
    - SUIT: 65 deg during launch; 65 to 75 degrees during orbit; 85 degrees during recovery (in the water after landing)
    - CABIN: 85 deg during launch; 90-105 deg in orbit; 103 deg during recovery (in the water after landing)
- **Attitude Control System (ACS)---[crucial for proper retrofire]:**
  - 2 independent systems: Automated Stabilization and Control System (ASCS) and Fly-By-Wire; and Manual Proportional (MP) System, and Rate Stabilization and Control System (RSCS)
  - Used a 90% hydrogen peroxide-and-catalyst system to provide thrust to 18 different attitude thrusters
  - Pitch and Yaw thrusters ranged from 1 to 24 pounds of thrust; Roll thrusters ranged from 1 to 6 pounds of thrust

Mercury Spacecraft Engineering Factoids (3 of 3)

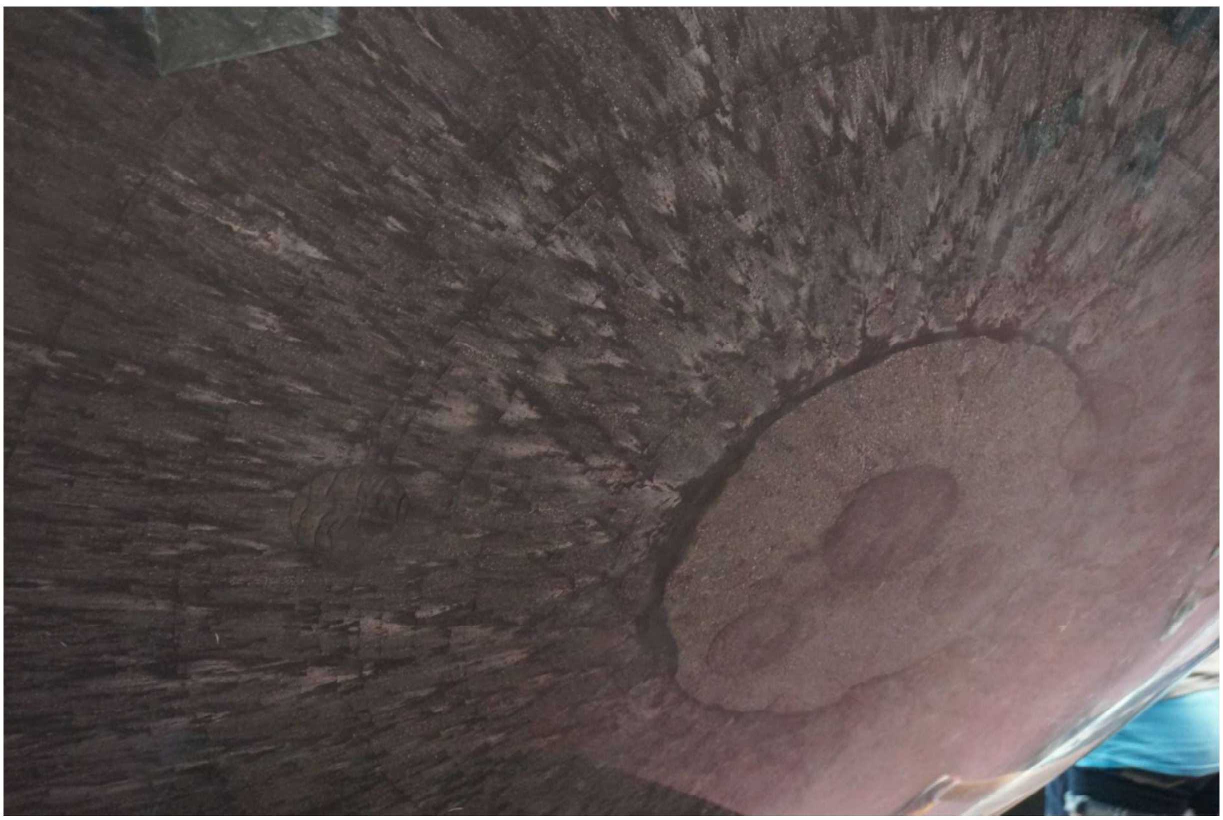
- Structural Details of Mercury Spacecraft Construction (built by McDonnell Aircraft):
  - Longitudinal members ("hat stringers") made of a **titanium alloy** (containing aluminum and tin);
  - Horizontal members ("framing rings") made of a **titanium alloy** (containing aluminum and vanadium);
  - Double pressure vessel made of **pure titanium;**
  - **There were 20,500 inches of seam welding on each Mercury spacecraft.**
  - Exterior shingles on conical section made from a heat-resistant **nickel alloy named Rene 41** (heat treated to develop a black oxide layer having high thermal emissivity); when mounted, oversized holes allowed free expansion during the heat of re-entry.
  - Cylindrical section: on ***suborbital flights*** covered by **aluminum shingles;** on ***orbital flights,*** covered by **beryllium shingles** because of greater heat experienced during re-entry from orbit.
  - Antenna Fairing: made of **Rene 41** (a heat-resistant nickel alloy); base surrounded by **Vycor glass** painted white**.**
  - Astronaut's cabin window (exterior) made of **Vycor glass;** triple-pane interior window (2 layers of regular glass, 1 of **Vycor**).
  - Heat Shield: on ***suborbital flights,*** a **beryllium heat sink** was used; on ***orbital flights,*** an **ablation shield** made of **laminated fiberglass and phenolic resin** was used. The ablative heat shield was lighter in weight than the beryllium heat sink, and could withstand greater heating; the ablative heat shield shed heat as it slowly burned away and dissolved during re-entry. A layer of *compressible aluminum honeycomb*---between the bottom of the outer titanium pressure hull and the heat shield---helped to cushion the shock of the water landing.

- Re-entry heating:
  - The "blunt body" shape of the Mercury spacecraft created a "dead air" zone behind the heat shield itself which protected the **Rene 41 exterior shingles** from most of the heat of re-entry; **only 5 to 10%** of the deadly heat in the air cap over the heat shield **(which reached 9,500 degrees F)** was transferred to the **Rene 41 shingles** on the exterior of the spacecraft, because of the slope of the spacecraft's sides.
  - The **surface ablation shield,** underneath the air cap, reached temperatures of **3,000 degrees F;**
  - The afterbody **Rene 41 exterior shingles** reached temperatures **ranging from 600 degrees to 1,000 degrees F.**

MA-6 (Friendship 7) Heat Shield (1 of 2) [NASM]

Close-Up of MA-6 Heat Shield (2 of 2) [NASM]

(Note where retro-pack was positioned during re-entry; it was kept on to ensure heat shield did not come off.)



Gemini Program Overview

- **Announced in January 1962; manned flights flown in 1965 and 1966.**

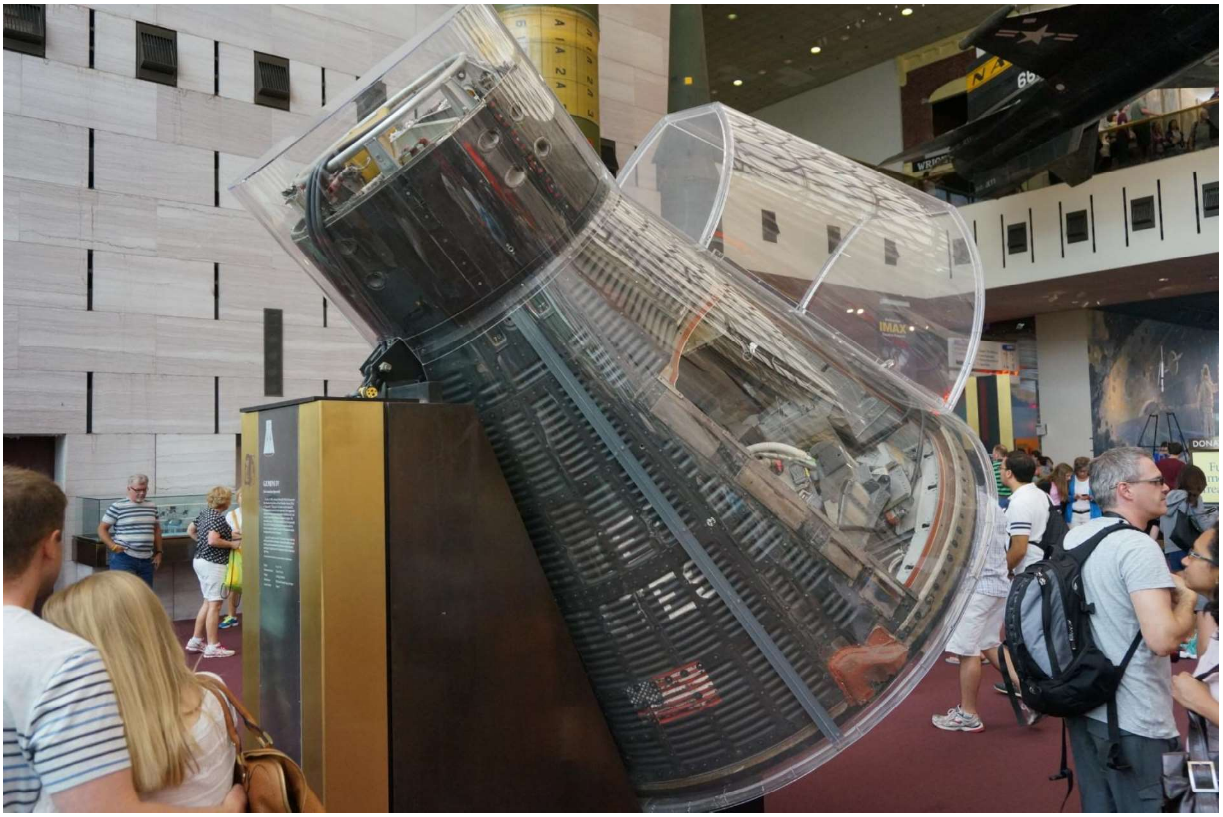
- **Gemini's 2-Man Spacecraft was an improved, slightly larger Mercury Spacecraft, launched atop a modified Titan II ICBM (first stage thrust: 430,000 lbs).**

- **Gemini served as a crucial intermediate step between the Mercury and Apollo programs.**

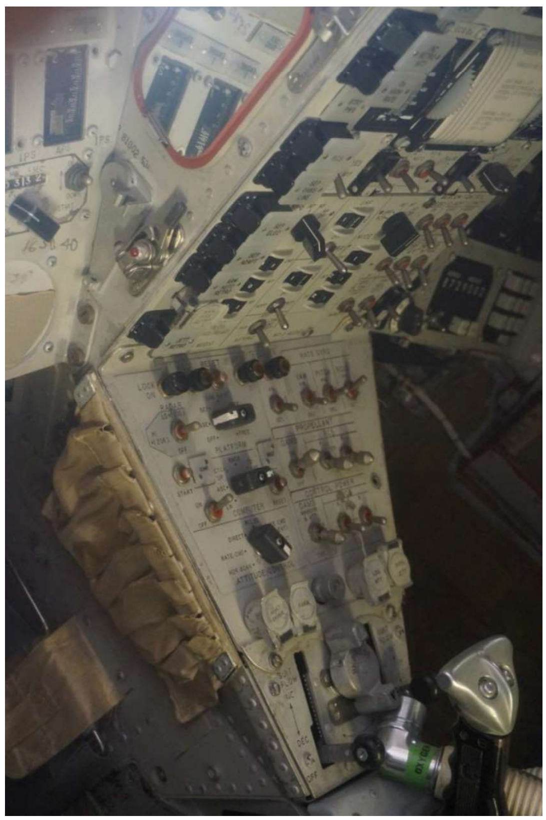
- **Flights:**
  - **2 unmanned flights (Gemini I and II); one in 1964 and one in 1965**
  - **10 manned flights (Gemini III through XII); five in 1965 and five in 1966**

- **Goals:**
  - **Demonstrate that man can accomplish "long duration flights" equivalent to the projected lunar missions, and evaluate the effects of weightlessness on crew health and efficiency;**
  - **Perfect accurate re-entry at preselected landing points;**
  - **Perform EVAs (Extra-Vehicular Activities) in space;**
  - **Demonstrate, and become proficient at, rendezvous and docking in space;**
  - **Transition from the use of batteries to fuel cells which produce electricity and drinking water (from gaseous hydrogen and oxygen).**
  - **Change orbit after launch (done using both OMS and Agena target vehicle)**

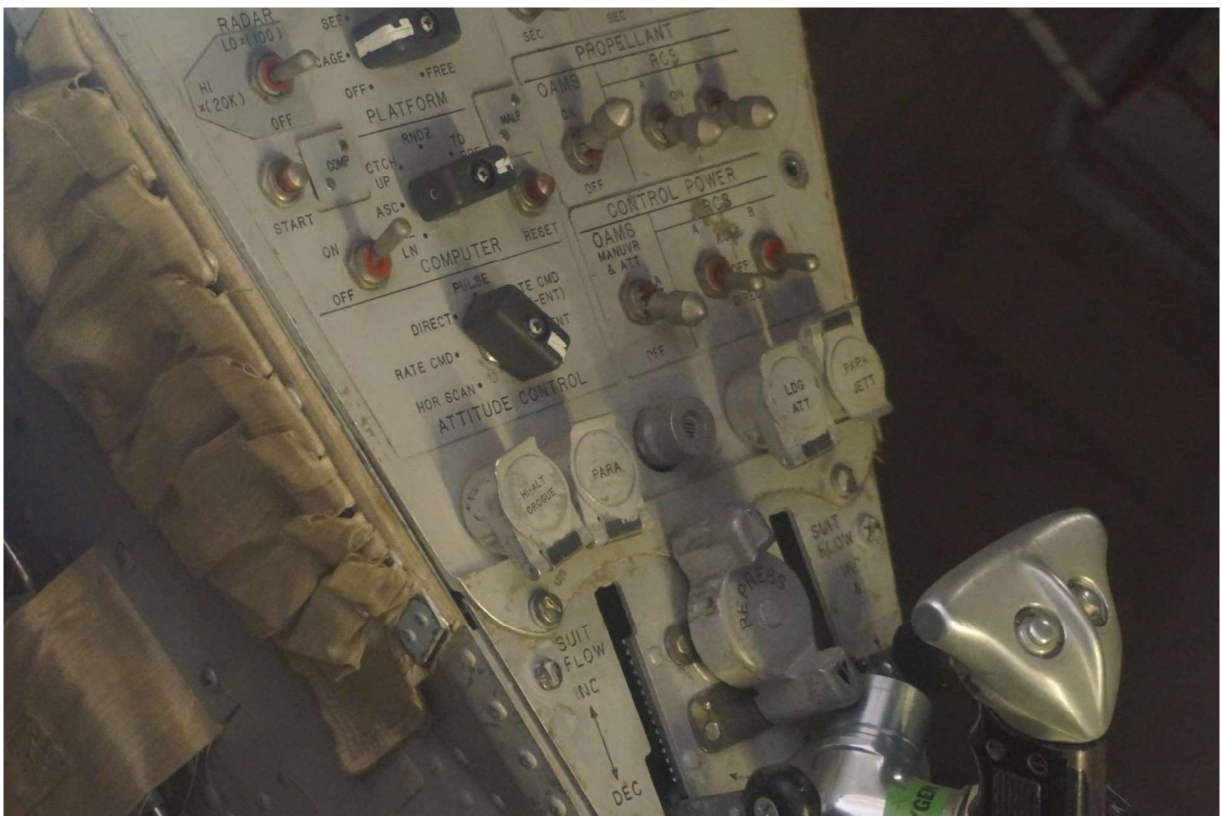
Gemini 4 Spacecraft [NASM, Washington, D.C.]



Gemini 4 Central Control Panel (1 of 3) [NASM]



Close-Up of Gemini 4 Central Control Panel (2 of 3) [NASM]



Another View of Gemini 4 Control Panels (3 of 3)
[NASM]

Project Gemini Mission Highlights

FLT #	Astronauts	Dates	Orbits	Objectives/Highlights
III	Grissom/Young	Mar 23, 1965	3	"Shakedown"
IV	McDivitt/White	June 3-7, 1965	62	4-day flight; first American EVA (White---22 minutes)
V	Cooper/Conrad	Aug 21-29, 1965	120	8-day mission; first use of fuel cells
VII	Borman/Lovell	Dec 4-18, 1965	206	14-day "long duration" mission (max. lunar mission estimated at 10-11 days)
VI-A	Schirra/Stafford	Dec 15-16, 1965	16	First rendezvous in space (with Gemini VII; earlier flight was postponed when Agena target vehicle blew up)
VIII	Armstrong/Scott	Mar 16-17, 1966	7	First combined rendezvous and docking (with Agena target vehicle); terminated early due to thruster problem on Gemini spacecraft
IX-A	Stafford/Cernan	June 3-6, 1966	45	Rendezvous with target adaptor vehicle (could not dock because shroud did not jettison); EVA (Cernan)
X	Young/Collins	July 18-21, 1966	43	Rendezvous and docking (with Agena target vehicle); changed orbit using Agena engine; EVA (Collins)
XI	Conrad/Gordon	Sep 12-15, 1966	44	Rendezvous and docking (with Agena target vehicle); changed orbit using Agena engine; EVA (Gordon)
XII	Lovell/Aldrin	Nov 11-15, 1966	59	Rendezvous and docking (with Agena target vehicle); EVA (Aldrin); problems experienced 3 previous EVAs resolved

Another View of Gemini 4 Spacecraft at NASM

(Note: length of these two sections: 8.17 feet)

Gemini Spacecraft Engineering Factoids (1 of 3)

- **Deficiencies of the Mercury Spacecraft:**
  - Could not change orbital plane (altitude); could only change attitude;
  - Was only designed to stay in space about one day;
  - Could not be "flown" during re-entry (and therefore could not perform precise landings unless re-entry burn was perfect).
- **The Mercury Mark II Program** was first conceived in March 1961, and was approved on December 22, 1961. It was officially named the "Gemini" program and announced in January of 1962 (before John Glenn's orbital flight in MA-6).
  - As support for the "direct ascent" mode for a lunar landing waned throughout 1961, NASA came to realize that it would have to become proficient at **rendezvous** to support either the "EOR" or "LOR" modes for going to the moon. The primary goal of the Gemini program was to become proficient at **rendezvous in space.**
  - The improved Gemini spacecraft would support **"long duration"** missions equivalent to the projected Apollo lunar trips; it was essential that Gemini verify that humans could survive in space **the length of a long lunar mission.**
  - Gemini was designed to be heavier on one side than the other; the displaced center of gravity would allow the astronauts to **pilot the spacecraft during re-entry by rolling the spacecraft,** and would facilitate **more precise re-entry targeting**.
- **Gemini was a modular spacecraft with two major sections;** each of these two major sections had subsections:
  - Adapter Module (unmanned, and constituted a "service module" for maneuvering fuel, consumables, and power)
    - Equipment Section (provided electrical power through either batteries or fuel cells; human consumables [oxygen and water]; and maneuvering fuel)
    - Retrograde Section (contained 4 solid fuel retro rockets)
  - Re-Entry Module (the habitable section for the two human occupants)
    - Rendezvous and Recovery Section (housed rendezvous radar and parachutes for the landing and recovery system; located forward of the Re-Entry Control Section)
    - Re-Entry Control Section (forward of spacecraft itself; housed the Reaction Control System for re-entry)
    - Spacecraft proper (housed two human occupants and their control systems)
- **Gemini Spacecraft Dimensions (built by McDonnell Aircraft):**
  - **Length overall of Adapter Module and Re-Entry Module (combined): 18.8′**
  - **Diameter of large end of Adaptor Module: 10′ (equal to diameter of the Titan II launch vehicle)**
  - **Diameter of base of spacecraft (heat shield): 7.5′ (equal to diameter of Retrograde Section)**
  - **Length of Re-Entry Module (Spacecraft + Re-Entry Control Section + Rendezvous/Recovery Section): 11.3′**
    - **Length of Spacecraft (pressure hull): 5.88′**
    - **Length of Re-Entry Control Section: 2.29′**
    - **Length of Rendezvous and Recovery Section: 3.15′**
  - **Length of Adapter Module (Equipment Section + Retrograde Section): 7.5′**
    - **Length of Equipment Section: 4.71′**
    - **Length of Retrograde Section: 2.79′**

Gemini Spacecraft Engineering Factoids (2 of 3)

- **Re-Entry Module Construction (Spacecraft):**
  - Double pressure vessel made of titanium; constructed on a titanium frame
  - Most of the outer skin consisted of Rene 41 shingles, an alloy produced chiefly from nickel, chromium, cobalt, and molybdenum (same as on the Mercury Spacecraft)
  - Temperatures on outer skin were as follows:
    - 300 degrees C during launch, due to atmospheric friction
    - 500 degrees C during re-entry
    - 100 degrees C on-orbit, due to sun's radiation
  - Two triple-paned windows; each was 8" wide and 6" thick
- **Adapter Module Construction:** was principally made of magnesium (did not have to withstand re-entry heat)
- **Heat Shield Construction** (built in two layers):
  - **Inner layer** consisted of a sandwich .75 inches thick, made of fiberglass honeycomb---and faced with fiberglass sheeting.
  - **Outer layer** was also made of fiberglass honeycomb; each cell was filled with a silicone-rubber compound. Thickness of the outer layer varied from .85" to 1.00."
  - **The outer rim of the heat shield** was finished with a ring of glass fiber and resin material that served both as an ablator, and as a weight-bearing structure.
- **Retrograde Section Details:**
  - Four (4) solid fuel rockets consisting of four 12" diameter titanium alloy spheres;
  - Burn time 5.5 seconds each; fired in sequence, for a constant thrust of 2,472 pounds for a total of about 22 seconds.
- **Parachutes:**
  - Drogue chute deployed at 40,000 feet in altitude; dimensions: 9.84 ' in diameter; reefed for 16 seconds;
  - Pilot (and thereafter main chute) deployed at 10,600 feet; pilot chute 18.37' in diameter; reefed for 2.5 seconds;
  - Main chute pulled out by pilot chute; dimensions: 58.07' in diameter; reefed for 10 seconds;
  - Main chute changed from single point suspension to 2-point suspension after deployment, providing a 55 degree tilt to spacecraft as it hit the ocean, lessening its impact from what a blunt-end landing would have been; impact speed less than 32.8 feet/sec
- **Thruster Systems:**
  - All hypergolic (fuel: monomethylhydrazine; oxidizer: nitrogen tetroxide);
  - 16 total Re-Entry Control System (RCS) thrusters [25 lb. thrust each] in the Re-Entry Control Section;
  - 16 total thrusters in the Adapter Module's "Orbital Attitude and Maneuver System" (OAMS): 8 of them were 25 lb. attitude thrusters; 8 were translation (i.e., propulsion) thrusters [6 were 100 lbs. thrust each; 2 were 85 lbs. thrust each].

Gemini Spacecraft Engineering Factoids (3 of 3)

- The **Inertial Guidance System** consisted of the Inertial Measuring Unit (IMU) and the spacecraft computer.
  - The **Inertial Measuring Unit** (IMU) was a stabilized platform with 3 gyroscopes (measuring attitude and velocity) mounted within 4 nested gimbals. Because the IMU was mounted on 4 gimbals, "gimbal lock" was not possible.
  - The **Spacecraft Computer,** built by IBM, was an important stage in the evolution of microcomputing. Its volume was about 31 liters, and its mass was about 25 kilograms (or just over 55 lbs). Its limited storage capacity (only 12K words, of 13 bits each) was overcome by recording all of its programs on magnetic tape, on the "Auxiliary Tape Memory Unit" in the spacecraft. Its features included:
    - 1,200 division sums/sec.
    - 2,400 multiplication sums/sec.
    - 7,150 addition or subtraction sums/sec.

- The **Titan II Launch Vehicle** was a two-stage rocket that used **hypergolic propellants** in each stage that ignited on contact (fuel: "Aerozene 50," or a mixture of hydrazine and unsymmetrical dimethylhydrazine; oxidizer: nitrogen tetroxide); maximum g-loading was between 6 and 7 gravities during launch. [The Gemini astronauts also experienced between 6 and 7 gravities during re-entry.]

- **The Atlas-Agena Launch Vehicle launched the Gemini-Agena Target Vehicle (GATV),** the Gemini Program's rendezvous and docking target. The Agena rocket was originally developed as both an upper stage for delivering payloads to orbit, and also as a photo-reconnaissance platform (for Corona and Gambit launches). The Agena rocket also boosted NASA's Ranger and Lunar Orbiter spacecraft on their missions to the moon, as well as early Mariner probes to Venus and Mars. The modified Agena vehicle used in conjunction with Gemini missions was fitted with a docking collar which accepted the nose of the Gemini spacecraft (the Rendezvous and Recovery Section); Gemini astronauts could start, stop, and re-start the Agena engine once docked. **Agena rocket (GATV) statistics follow:**
  - 26′ long;
  - 5′ in diameter;
  - Hypergolic propellants (fuel: unsymmetrical dimethylhydrazine; oxidizer: inhibited red fuming nitric acid);
  - Gimbaled engine, providing 15,960 lbs. of thrust for a total of 4 minutes.
- The **Augmented Target Docking Adaptor (ATDA)** was built---for docking purposes only; it had no propulsion motor---after the catastrophic loss of the Agena rocket launched prior to the Gemini VI mission; only one ATDA was built, and it was used on the Gemini IX mission after another Agena failure. Its shroud failed to open, so astronauts Stafford and Cernan could not practice docking with the "angry alligator" adaptor during their flight; however, they did use it for rendezvous practice. Its dimensions were: 11.8′ long, and 4.9′ in diameter.

How __Should__ We Go To The Moon? (or, Selecting the "Mode")

- **__There was no consensus within NASA__** on how to get to the Moon when JFK made his address to Congress in May of 1961.
- **There were, at that time, three generally understood options** for how to accomplish the goal of a manned lunar landing; **the three "modes" were:**
  - **__Direct Ascent__:** One enormous rocket would be used to travel directly from the Earth to the Moon, without stopping in Earth orbit or lunar orbit first; the same manned spacecraft that traveled to the Moon would land on the Moon and return the astronauts to the earth. The gargantuan rocket required for this was tentatively labeled "NOVA," and would have generated 12,000,000 pounds of thrust when launched. Building a rocket that powerful and that large was questionable; so was the ability to launch it.
    - This approach was initially favored by the Space Task Group (STG) at Langley, Virginia (originally a part of the old NACA) throughout 1959, 1960, and much of 1961. It was the classic concept of both science fiction authors, and proponents of space travel, during the 1930s, 1940s, and 1950s.
  - **__Earth Orbit Rendezvous__ (EOR):** Multiple launches would be required to assemble the moonship in Earth orbit (two Saturn V-type launch vehicles, or as many as three to five smaller Saturn vehicles), and also to transport its fuel and oxidizer to Earth orbit for transfer to the moonship. This one spacecraft would then leave Earth orbit, land on the Moon, and return to the Earth intact (without shedding any weight). Advantages: the questionable NOVA would not need to be built, and all dangerous rendezvous operations could be conducted in Earth orbit (close to home).
    - Wernher von Braun and the Marshall Space Flight Center (MSFC) at Huntsville, which he presided over, favored EOR over direct ascent. They already had a rough design in mind for a "C-5" rocket which would develop 7.5 million pounds of thrust. They preferred the use of two C-5s to the challenge of building the oversized (and potentially very dangerous) NOVA.
  - **__Lunar Orbit Rendezvous__ (LOR):** Only one Saturn V-sized rocket would be required for the Moon mission, and the savings in launch weight could be more than 50% compared to an earth orbit rendezvous mission. The modular spacecraft concept would allow the astronauts to shed weight by: (1) leaving a command ship in lunar orbit while a lightweight excursion vehicle went down to the lunar surface; (2) leaving the landing, or descent stage of the excursion vehicle on the surface when departing from the Moon; and (3) similarly discarding the ascent stage of the excursion vehicle after the lunar astronauts had returned to the mother ship in lunar orbit. The disadvantage was the requirement to perform space rendezvous and docking maneuvers in lunar orbit, far from earth (and any potential rescue). **In 1959, 1960, and throughout much of 1961, this was an unpopular concept and the consensus within NASA was that this was the least likely scenario to be adopted.**
- **__Proponents of Lunar Orbit Rendezvous__ (LOR):**
  - Yuri Kondratyuk, in 1916 (Russian theoretician)
  - H. E. Ross, in 1948 (British scientist, and member of the Interplanetary Society)
  - **Tom Dolan** of Vought Astronautics, who developed the concept independently in 1959 and 1960, was the first American to propose LOR once travel to the moon became a feasible possibility with current technology.
  - Clinton E. Brown; William H. Michael, Jr.; and John D. Bird---all engineers at the Langley Research Center---toyed with early concepts of LOR in 1960, but were scooped by Tom Dolan, who had put much more work into the concept.
  - __John C. Houbolt__ was a structural engineer at the Langley Research Center who was not a part of the Space Task Group; although Houbolt was not the originator of the LOR concept, his advocacy was crucial, and probably decisive, in getting LOR adopted by NASA management. His total commitment and crusading zeal from late 1959 through the spring of 1962 gradually won over an initially hostile Space Task Group, and won the support of key management staff within NASA HQ.

Houbolt's Crusade---The "Mode" Is Selected

- **John C. Houbolt had become Langley's expert on space rendezvous by September 1959.**
- Between September of 1959, and April of 1962, Houbolt---on 28 documented occasions---either gave formal presentations on Lunar Orbit Rendezvous, or wrote official correspondence, championing the concept. Early on, he encountered much resistance (from within STG and at HQ) and kept refining and improving the LOR concept.
- **Houbolt sent a (second) crucial letter to NASA Associate Administrator Robert Seamans on November 15, 1961** insisting that LOR was ***the only way*** to get to the Moon by decade's end. (He violated protocols and bypassed many levels of management in doing so---but it paid off.) His letter caused HQ to seriously reconsider LOR.
- In December of 1961 the Space Task Group at Langley, which was morphing into the nascent Manned Spaceflight Center (MSC), began moving to Houston, Texas; most of the staff relocated in February and March of 1962. Construction of the MSC facilities occurred in 1964 and 1965. By early 1962, MSC had shifted its preference from Direct Ascent to LOR, and MSC was now championing (instead of opposing) Houbolt's idea.
- MSC (championing LOR) was opposed by MSFC (the Marshall Space Flight Center), which championed EOR.
- Although Houbolt was not employed by MSC and remained at Langley, he assisted and briefed both MSC and MSFC staff while they debated LOR vs. EOR throughout the first half of 1962. It was the job of newly hired NASA HQ engineer Joe Shea (Deputy Director, Office of Manned Spaceflight) to resolve the "mode" dispute so that NASA could then build the appropriate spacecraft and facilities to get to the Moon by the decade's end.
- **In a key meeting between MSC and MSFC on June 7, 1962 Wernher von Braun shocked his own staff when he abandoned EOR and declared that while both modes were technically feasible, LOR "offers the highest confidence factor of successful accomplishment within this decade;" his bold move resolved the issue.**
- **On July 11, 1962 NASA made the official announcement that LOR was the mode selected for the Apollo Moon program. This mode was subsequently opposed (unsuccessfully) by Jerome Wiesner, JFK's science advisor.**
- **On November 7, 1962 NASA awarded the construction contract for the Lunar Excursion Module (LEM) to the Grumman Aircraft Engineering Corporation of Bethpage, Long Island; since the LEM was a two-stage vehicle which only made sense within the LOR concept, this cemented the mode decision. LOR had triumphed.**
- **Eighteen (18) months after the nation had decided to go to the Moon, NASA had finally decided how to do it!**
- On January 10, 1962 NASA announced that the final configuration of the **launch vehicle for the combined Apollo spacecraft** (i.e., the Command and Service Module, and the Lunar Excursion Module) **would be the "big rocket" called the C-5** which had recently been on the drawing boards at MSFC in Huntsville; **it was soon redesignated the Saturn V.** The propulsion configuration of the engines in each stage had been finalized in December 1961, and only the dimensions of the third stage on the C-5 (its diameter) were to change. The NOVA rocket was effectively now a dead concept, even though some NOVA design studies continued into early 1962. Once this launch vehicle decision was made, design and construction of the launch and checkout facilities in Florida could proceed.

Essential Apollo Spacecraft Data

- **Command Module (Built by North American Aviation)**
  - Height: 10′ 7″ (to base of probe and drogue assy.); maximum width at base: 12′ 10″; height of Apollo 7 and 8 CM (no probe): 11.4′
  - Fully loaded weight (as designed): 11,000 lbs.; as built: approx. 13,000 lbs.
  - Usable volume: approx. 218 cubic feet (equivalent to the family station wagon or a minivan)
  - Parachutes:
    - Two (2) 16.5′ diameter drogue chutes deployed at 24,000 feet, at a speed of about 320 mph;
    - Three (3) 83.5′ diameter, one-half acre area nylon rip-stop main chutes (preceded by three 3 small pilot chutes), deployed at 10,000 feet, at a speed of approx. 160 mph. (Impact speed of Command Module 21 mph, or 31 feet/sec. w/all 3 chutes.)
- **Service Module (Built by North American Aviation)**
  - Steerable high-gain antenna (featuring 4 antennae);
  - Three oxygen/hydrogen fuel cells; fed by 2 oxygen tanks and 2 hydrogen tanks (produced electricity and drinking water).
  - SPS Engine:
    - Gimbaled, but constant thrust (not throttleable);
    - 20,500 lbs. of constant thrust (as designed); actual thrust 22,000 lbs.
    - Burned 547 lbs. of propellant/sec.;
    - Hypergolic propellants (ignited upon contact) pressurized by helium:
      - Fuel: "Aerozene 50" (a 50-50 mixture of hydrazine and unsymmetrical dimethylhydrazine)
      - Oxidizer: nitrogen tetroxide
  - Length: 24′ 7″ overall:
    - SPS Engine: 9′ 9″ long, widest diameter 7′ 10.5″;
    - Main Body of SM: 22′ 11′′ (six internal longitudinal compartments or "Bays");
    - Fairing between Main Body and Command Module: 1′ 11″
- **Combined Weight of <u>Command and Service Module</u>**
  - Fully loaded with fuel and consumables: 63,400 lbs. (Apollo 13 CSM)
- **Lunar Module (Built by Grumman Aircraft Engineering Corporation)**
  - Approx. 23′ tall, with legs extended for landing; dry weight about 10,800 lbs.
  - Descent stage approx. 11′ tall; Ascent stage approx. 9′ 6″ tall;
  - Octagonal base of descent stage 14′ 1″ wide; fully spread legspan 31′ wide diagonally, footpad to footpad.
  - Descent engine (gimbaled, throttled) produced a maximum of 10, 500 lbs. of thrust;
  - Ascent engine (fixed, not throttled) produced 3,500 lbs. of constant thrust;
  - Hypergolic propellants (ignited upon contact) pressurized by helium:
    - Fuel: "Aerozene 50" (a 50-50 mixture of hydrazine and unsymmetrical dimethylhydrazine)
    - Oxidizer: nitrogen tetroxide
  - Actual launch weight of early Lunar Modules (Apollo 11-14): between 32,000-33,000 pounds;
  - Actual launch weight of later Lunar Modules (Apollo 15-17): about 36,000 pounds.

The Apollo Guidance, Navigation, and Control System (1 of 2)

- There were **3 main components** to the Apollo **inertial guidance system:**
  - The **Inertial Measurement Unit (IMU)**---same IMU installed in CM and LM;
  - The **Optical Star-Sighting Device** (sextant/scanning telescope)---similar devices installed in CM and LM;
  - The **Apollo Guidance Computer (AGC)**---same computer installed in CM and LM, but with different programs.
- The first Apollo program contract awarded by NASA was the inertial guidance system contract, on August 9, 1961---to the Massachusetts Institute of Technology (M.I.T.).
  - The head of M.I.T.'s research laboratory, **Charles Stark Draper**, had invented the IMUs used in trial aircraft, some submarines, and the Polaris submarine-launched MRBM.
- **Inertial Measurement Unit (IMU):**
  - The **IMU** was spherical, and was a little bit larger than a soccer ball, and slightly smaller than a basketball.
  - Design: **3 nested gimbals supported a stabilized inertial platform in the center;** ***the "platform" was designed to maintain its inertial orientation, while the spacecraft rotated around it.***
  - The **stabilized platform contained 3 orthogonally-mounted (90 degrees apart) gyroscopes, and three accelerometers measuring acceleration in three planes.** The "platform" was designed to remain in a stable orientation for at least a few hours, before it began to drift (due to bearing friction).
  - The **Flight Direction Attitude Indicator (FDAI),** or "Eight-Ball," converted inertial measurements to optical equivalents familiar to aircraft pilots (i.e., astronauts)---similar to the artificial horizon indicator in an aircraft cockpit. The "8-ball" imitated the way the spacecraft was rotating around the stable platform of the IMU, and allowed the astronaut to understand this in terms of roll, pitch, and yaw.
  - **Weakness of a 3-gimbal system (vice a four-gimbal system):** although it saved weight not having a fourth gimbal in the Apollo IMU, it created software complexities and wasted thruster fuel, since the spacecraft could not safely be maneuvered in certain positions. The dreaded **"gimbal lock"** could occur when any 2 of the 3 axes in the stable platform became lined up in the same plane. When "gimbal lock" occurred, the astronauts had to "reset the platform" from scratch, using the sextant and optical telescope---which was a time-consuming process. **The red markings on the "8-ball"** provided a visual warning of which attitude orientations the astronauts should avoid. The inertial guidance system in both the Gemini spacecraft, and the Saturn V rocket, both employed an IMU with four (4) gimbals. Weight was considered so crucial in the Apollo spacecraft that the fourth gimbal was abandoned early on, to reduce the mass of the LM's inertial guidance system. **In retrospect, this was probably not a good trade-off.**
- **Optical Star-Sighting Device: The sextant was a 28 power device, and the optical "telescope" had only a one-power magnification;** the Command Module **navigation station** where they were located was located in the lower equipment bay, opposite the feet of the astronaut in the CM center couch. This **navigation station** housed the sextant and telescope; the IMU; the guidance computer for the CM; and the computer's display and keyboard (DSKY), which was essential for entering star-sight data into the guidance computer, and adjusting the "platform."

The Apollo Guidance, Navigation and Control System (2 of 2)

- The **Apollo Guidance Computer (AGC)** hardware was identical in both the CM and LM; the unique programs for the Command Module were called *Colossus*, and the specialized Lunar Module programs were called *Luminary*.
  - Its **volume** was only **1 cubic foot.** Its dimensions were 21.5" long; 13" wide; and 6" high; it weighed about 70 lbs. (or 32 kilograms). [Equivalent computers in the M.I.T. lab took up the space of 4 large refrigerators.]
  - Its **memory capacity** was quite limited by today's standards: **38,000 words, or 38K** (36,864 words of ROM, or 36K; and 2,048 words, or 2K, of erasable memory). Each AGC "word" consisted of 15 bits, plus one more parity bit to detect errors. [A modern "smart phone" may contain as many as 2 billion words of memory; an MP3 player ten years ago could store 50,000 times more information than the Apollo computer.] This 36K ROM = **72 kilobytes** in today's terms.
  - **Core Rope Memory** was used to record the **40 + programs** in the Apollo Guidance Computer; this was a now-archaic, hand-verified, hand-woven, machine wired ***binary memory system*** that was constructed by weaving copper wires through or around small, circular magnetic cores. The work was performed by meticulous women-weavers in the factory; it sometimes took months, and a minimum of 6 weeks, to program (or "weave") the memory rope in an Apollo guidance computer. All 36,864 words of ROM was on Core Rope; erasable memory was not on Core Rope.
  - Early-generation **integrated circuits** (silicon chips) were used to perform the calculations in the guidance computer; the Apollo program purchased about 60% of all chips in the American market in the 1960s (and 50% world market).
  - **Three types of information** could be entered into the guidance computer by the astronauts: **program numbers; verbs; and nouns.** They were all entered as decimal system numbers on the DSKY, in English (Imperial, or non-metric) units, *and were then converted to machine language, and metric units, in the computer.* All computer calculations were done in metric units, and were then converted and displayed for the astronauts in decimal numbers and in English (Imperial) measurement units (i.e., feet, lbs., nautical miles, etc.). [See the miniseries *From the Earth to the Moon* for good examples of AGC data entry and commands, using the DSKY.]
  - M.I.T. software engineer **Hal Laning** designed a system called **"interruptible executive design"** that prioritized the computer's tasks, performing the most important tasks first and abandoning the lesser ones if the computer ran out of time between computing cycles. This **"executive overflow"** feature saved the Apollo 11 landing by preventing an abort when the computer was overloaded by tasks it did not have time to perform. (As many as seven different tasks were normally being performed by the computer simultaneously; in a normal "time-sharing" system, the overloaded "Eagle" computer would have frozen, and an automatic abort would have occurred.)
  - Serious friction occurred between NASA and M.I.T. during 1966 and 1967 about the slow development of the software; eventually NASA decided that the "ground" (Mission Control) would provide ***primary navigation*** (through PADs---preliminary advisory data), since ***through the use of doppler,*** the ground could determine accurate position of the spacecraft within 33 feet, and accurate velocity within 1.5 feet/sec. The MCC's mainframe computers provided the PADs for the astronauts prior to each burn. M.I.T.'s onboard system would provide ***secondary, or backup navigation.***
  - But in practical terms, the M.I.T. guidance computer performed yeoman service that was indispensible: **it served as a digital autopilot---it was an imbedded controller, tightly integrated into spacecraft systems. The guidance computer could control gimbaled SPS engine burns, the spacecraft thrusters that controlled attitude in the CM or LM, the LM's throttleable descent engine and fixed thrust ascent engine, could calculate the size and shape of orbits, and aim cameras and other instruments.** It became "the" crucial guidance system for engine burns that occurred behind the Moon, or at any other time when there might be no communications with Mission Control.
  - The Lunar Module's guidance computer had two separate guidance systems: **PGNS (Primary Guidance and Navigation System)** and **AGS (Abort Guidance System).** The simpler AGS would guide the ascent stage of the LM to a rendezvous with the Command Module in the event of a PGNS "crash," or an abort for any other reason.
- ***SUMMARY: The astronauts actually flew the spacecraft themselves, using the Apollo Guidance, Navigation and Control System as an interface with the spacecraft's propulsion and attitude control systems.***

Apollo Command and Service Module (CSM) [NASM]

(Attached to Apollo/Soyuz docking module in this display in Washington, D.C.; note the white radiator panels on the external skin of the Service Module.)

Close-Up, Apollo CSM (1 of 5) [NASM]
(Note umbilical section connecting CM with SM; and sextant and optical telescope ports.)

Close-Up, Apollo CSM (2 of 5) [NASM]
(Note Kapton <u>aluminized film</u> on CM, and <u>radiators</u> on SM.)

Close-Up of Apollo CSM (3 of 5) [NASM]

(Note "quad" thrusters on SM body; each small rocket engine produced 100 lbs. of thrust for attitude control of CSM.)