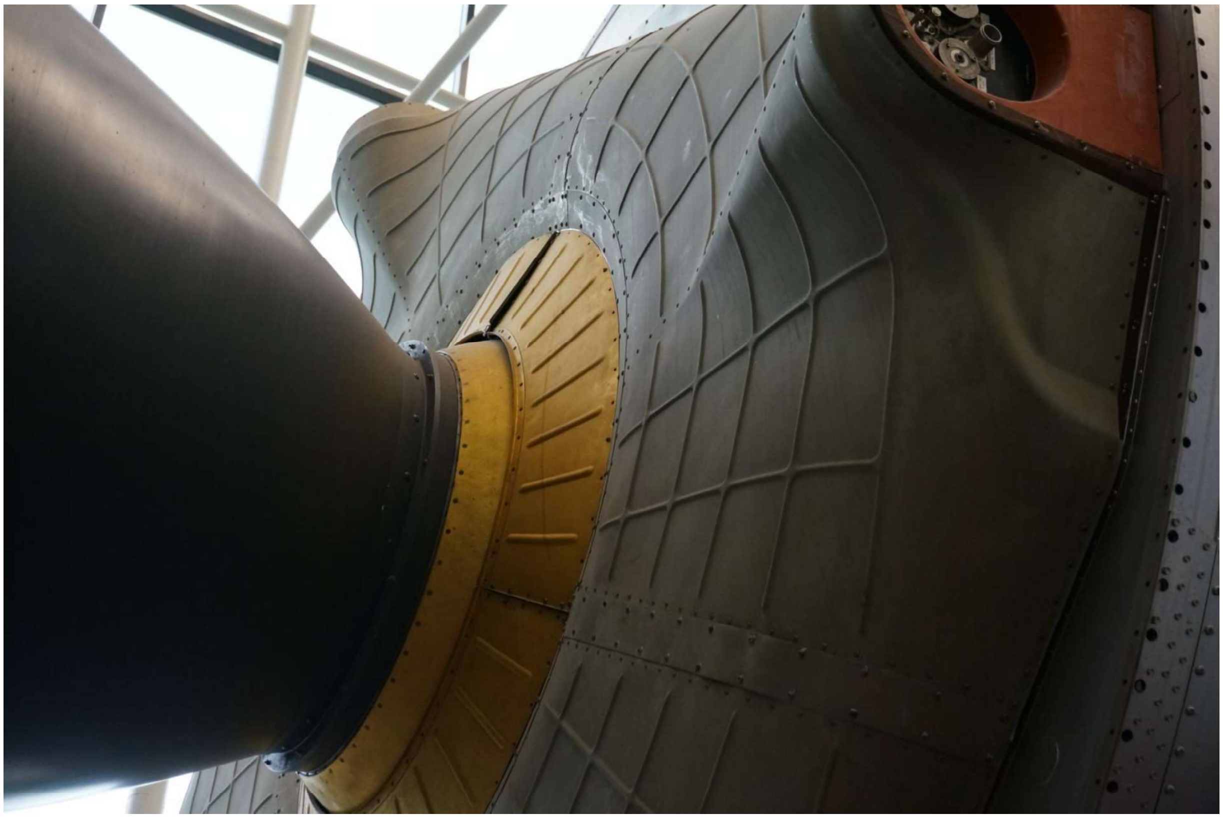
Close-Up of Apollo CSM (4 of 5) [NASM]

(The Service Propulsion System, or SPS engine generated 22,000 lbs. of thrust; it could be gimbaled, but not throttled.)

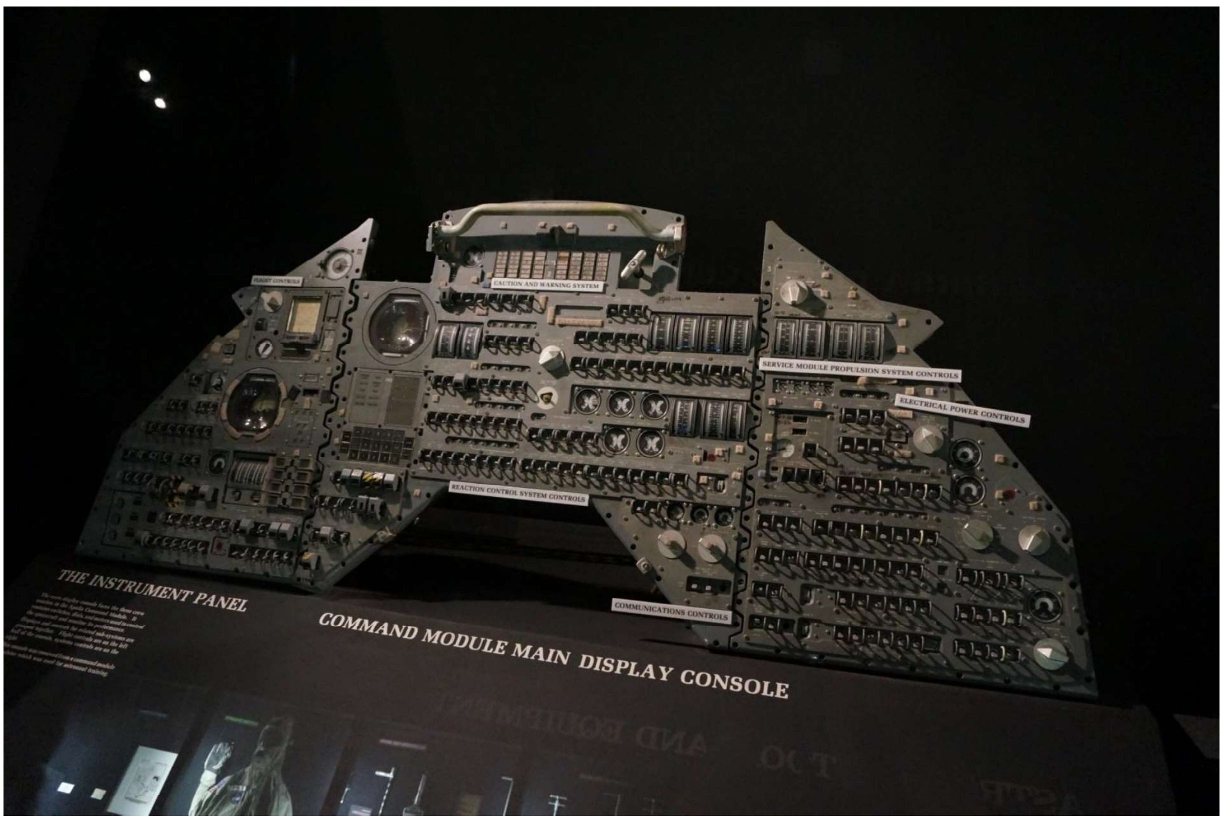
Close-Up of Apollo CSM (5 of 5)   [NASM]

(The SPS engine was oversized for its tasks, and extremely robust; it was originally intended to lift the entire command and service module off of the lunar surface! Although the "direct ascent" and "EOR" modes were abandoned in favor of "LOR" after the CSM contract was awarded, the SPS engine was not redesigned.)



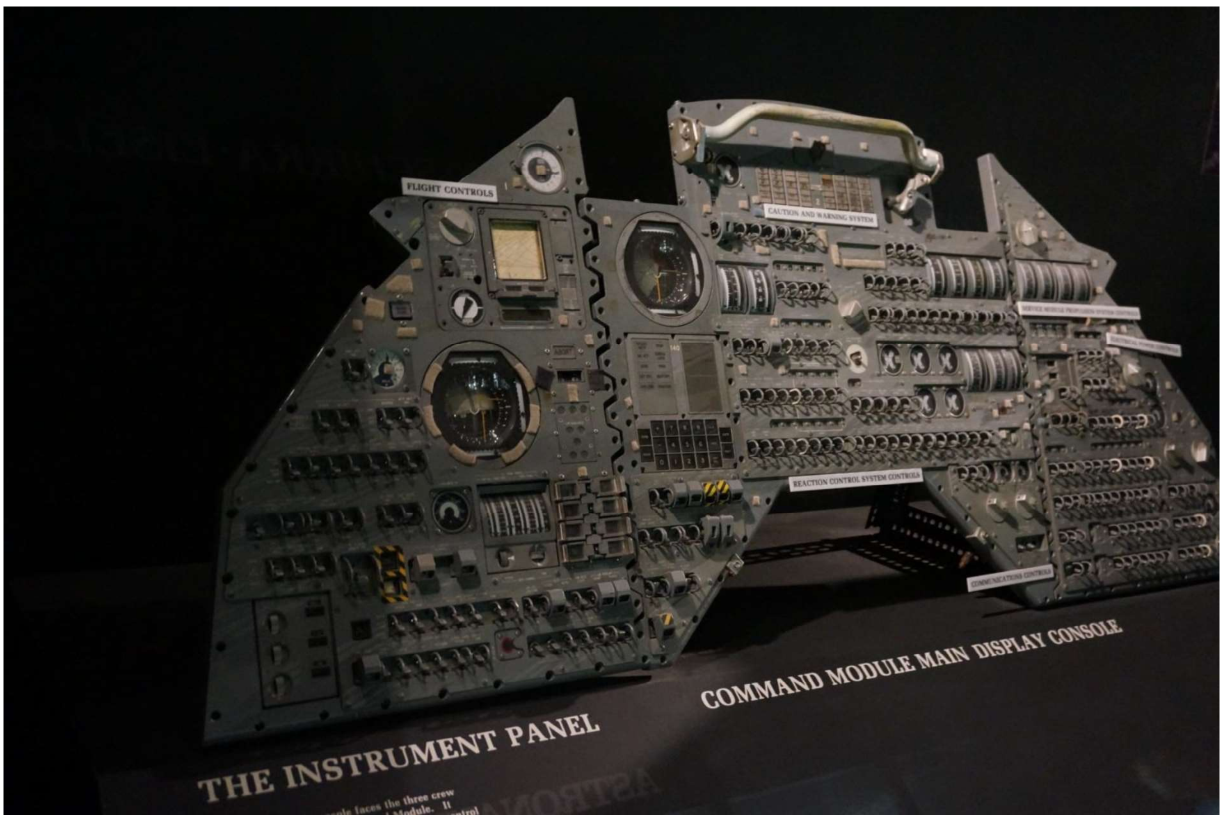
Apollo Command Module <u>Main Instrument Panel</u> (1 of 4) [NASM]

(Note protective guards over switches; the détente in the center of the panel allowed astronaut access to the <u>Lower Equipment Bay</u>, in-flight.)



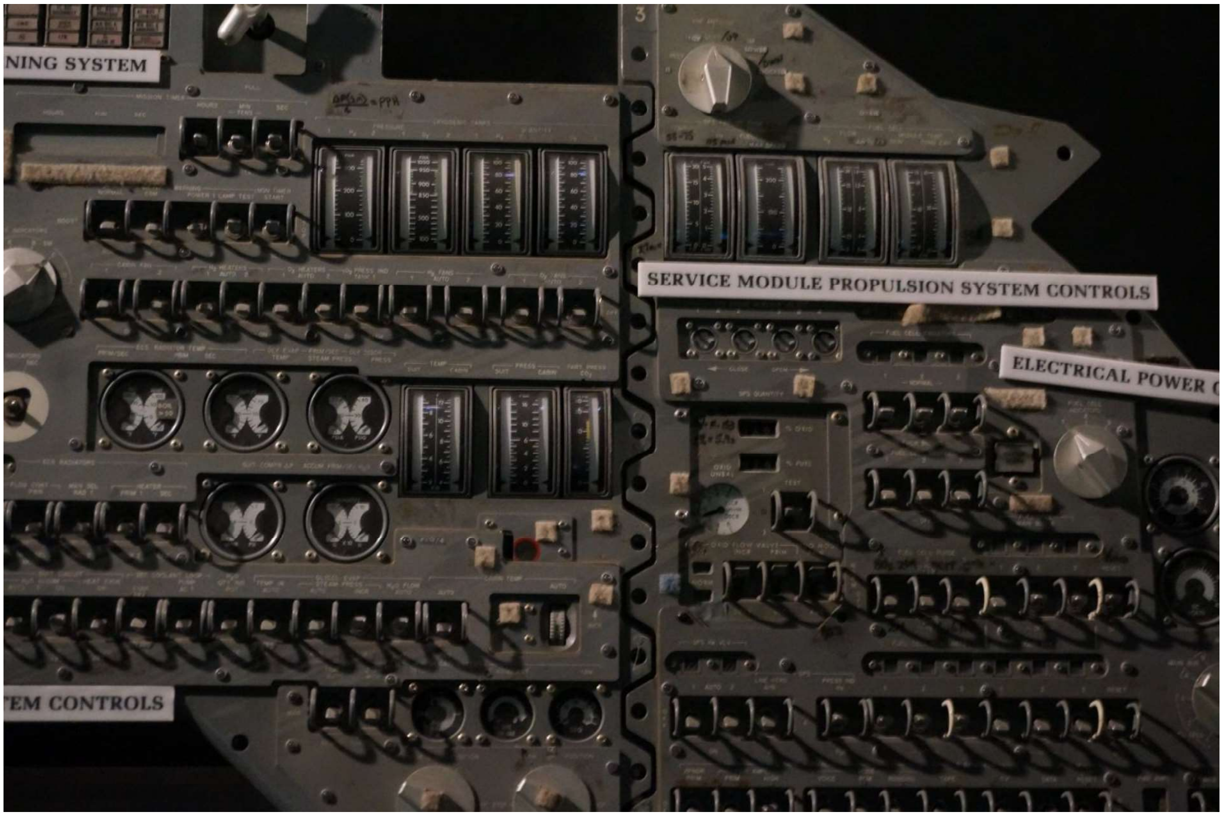
Apollo Command Module Main Instrument Panel (2 of 4) [NASM]

(Note the DSKY keyboard for the guidance computer, and the two Flight Direction Attitude Indicators (FDAIs), unofficially known as "eight balls.")



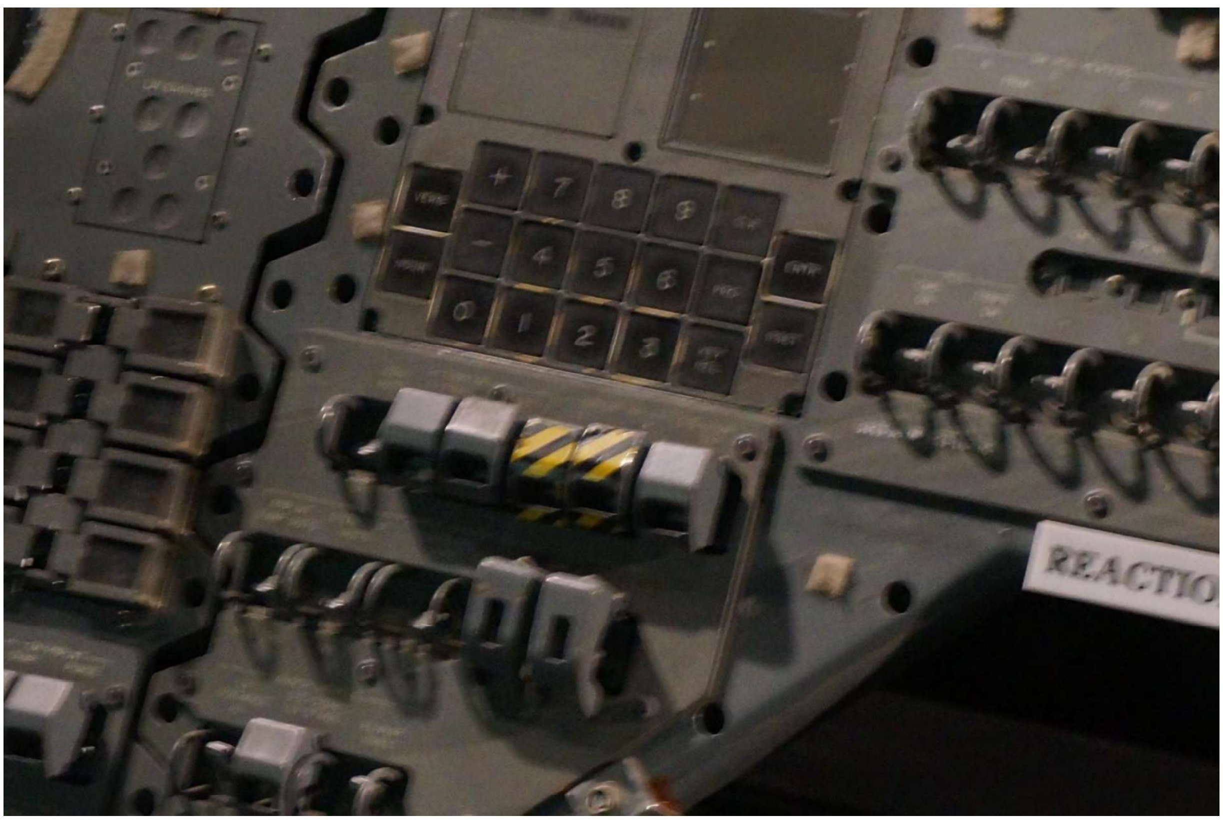
Apollo Command Module Main Instrument Panel (3 of 4) [NASM]

(In center of photo, note fan switches for "cryo stir" of the 2 hydrogen tanks and 2 oxygen tanks located in the Service Module.)



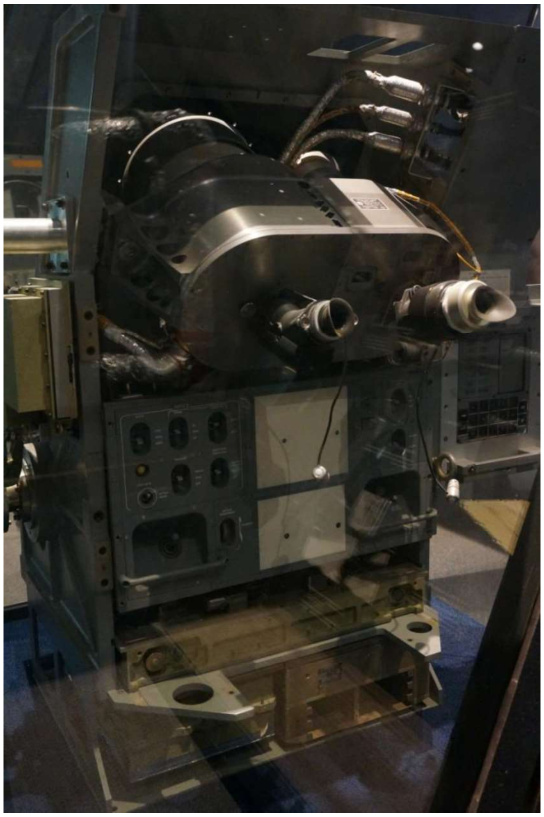
Apollo Command Module Main Instrument Panel (4 of 4) [NASM]

[Close-Up of "DSKY" Keyboard, Used for Communicating with the Command Module Guidance Computer (i.e., Flying the Spacecraft).]



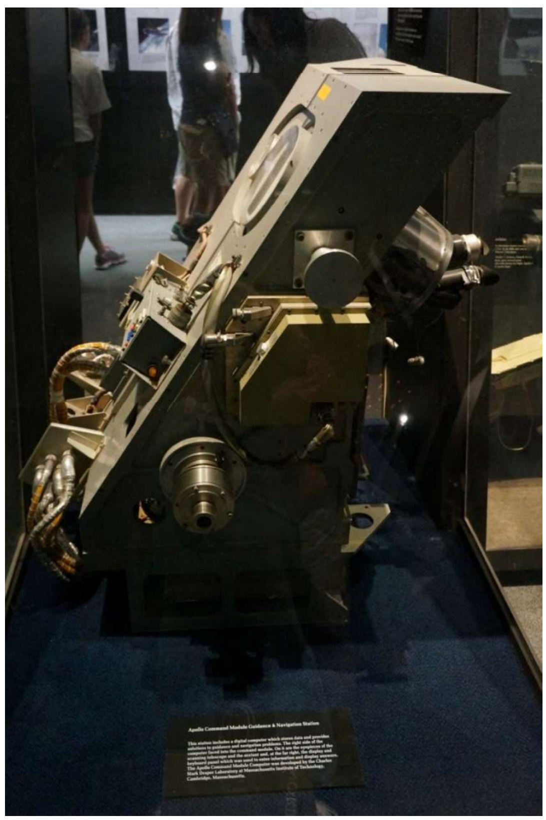
Apollo Command Module Navigation Station [NASM]

(Note eyepieces for Sextant on Left, Optical Telescope on Right; DSKY keyboard is mounted to the right of the optical telescope. Station is located across from the foot of the center astronaut couch, in the Lower Equipment Bay, on the opposite side of the cabin from the Crew Hatch. The Command Module Guidance Computer is the thin, horizontal cabinet at bottom. The spherical IMU was hidden behind the control panel.)



Apollo CM Sextant and Optical Telescope Subassembly [NASM]

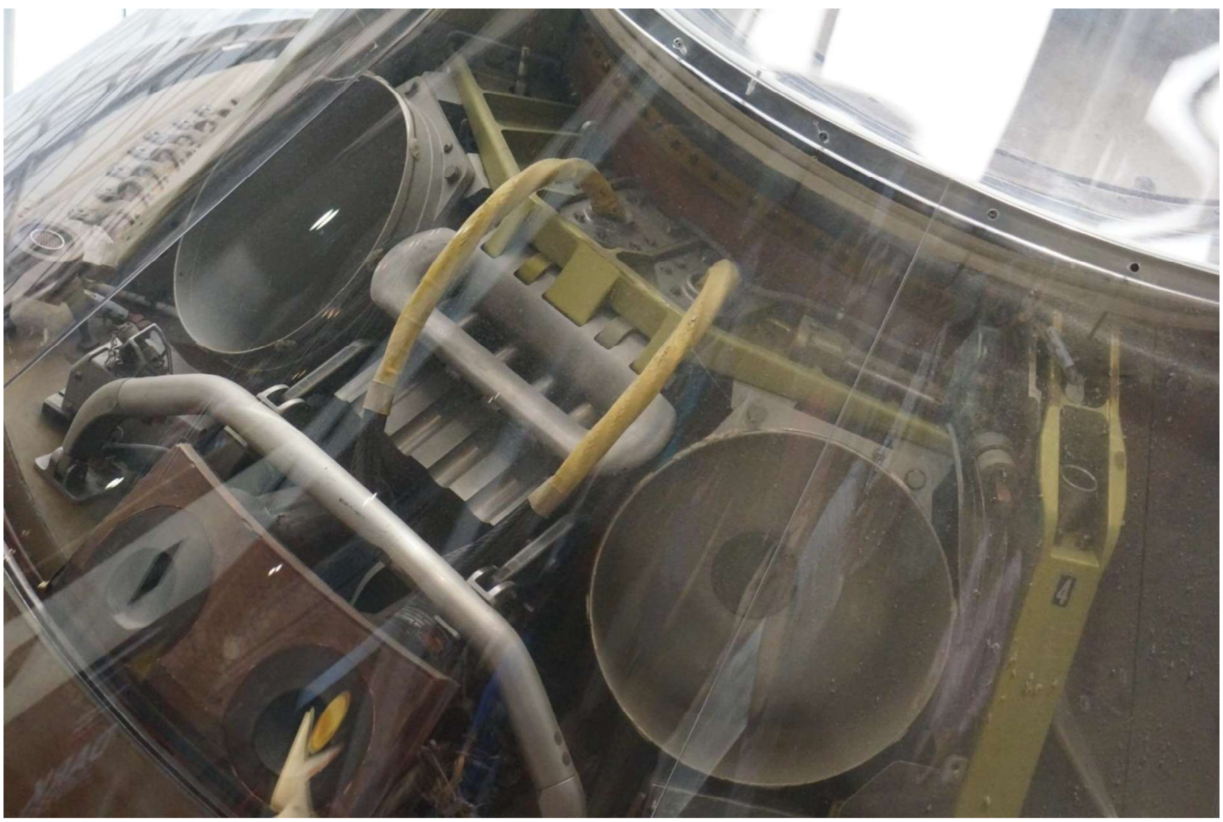
(Note: Left Side of Artifact Mates With External Surface of Spacecraft; the spherical IMU, about the size of a soccer ball, was in the center of the subassembly.)



Command Module's *Forward Compartment* (Upper Right) [NASM]

(Note <u>main parachute bays</u> and <u>docking/transfer tunnel</u>; the two large canisters are the <u>drogue chute mortars</u>.)

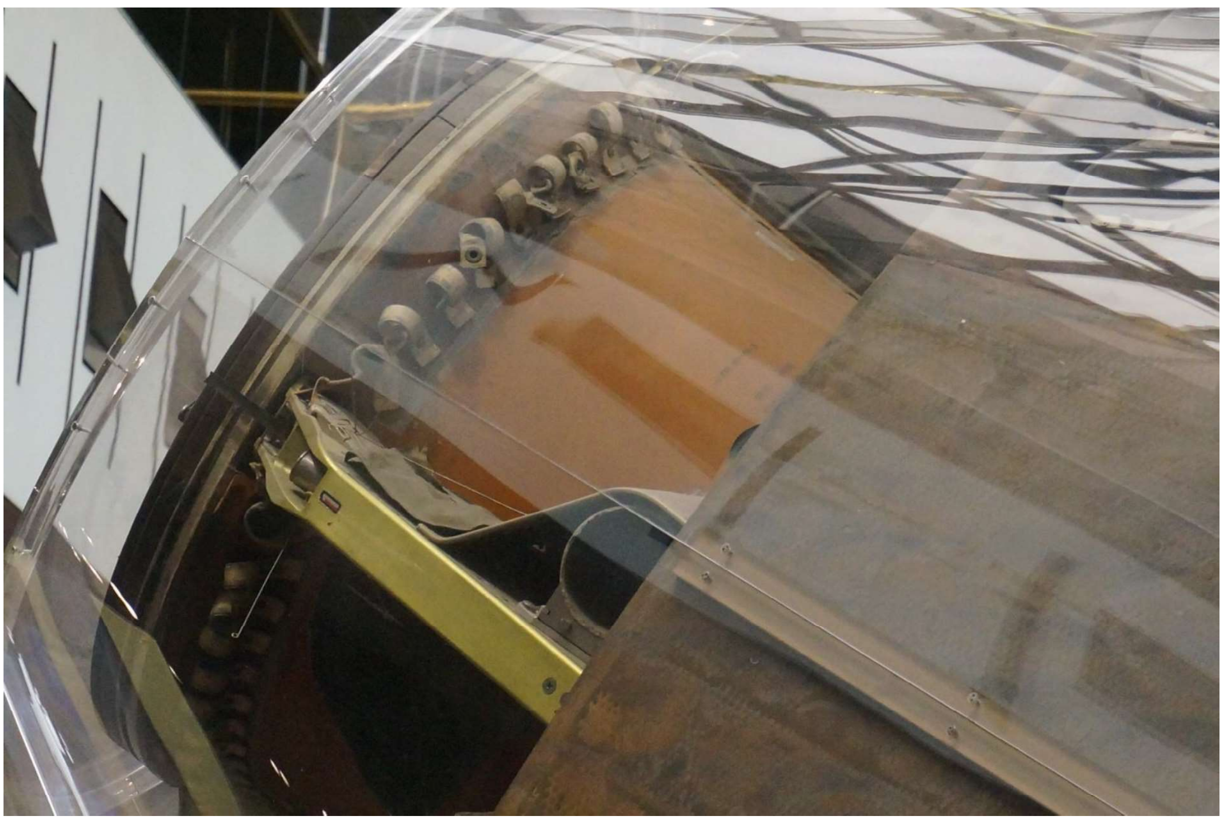
Close-Up of Apollo 11 CM Forward Compartment [NASM]
(Note the two drogue chute mortars and two re-entry attitude thrusters)



Close-Up of Apollo 11 CM Forward Compartment [NASM]

(Note docking/transfer tunnel, two of the three main parachute bays, and small mortar for deploying one of the three pilot chutes.)

Final Close-Up of Apollo 11 CSM Forward Compartment [NASM]
(Note docking/transfer tunnel, two of the three main parachute bays; and pilot chute mortar. ***The main chutes were compressed to the density of a block of maple wood before they were loaded into the parachute bays.)***

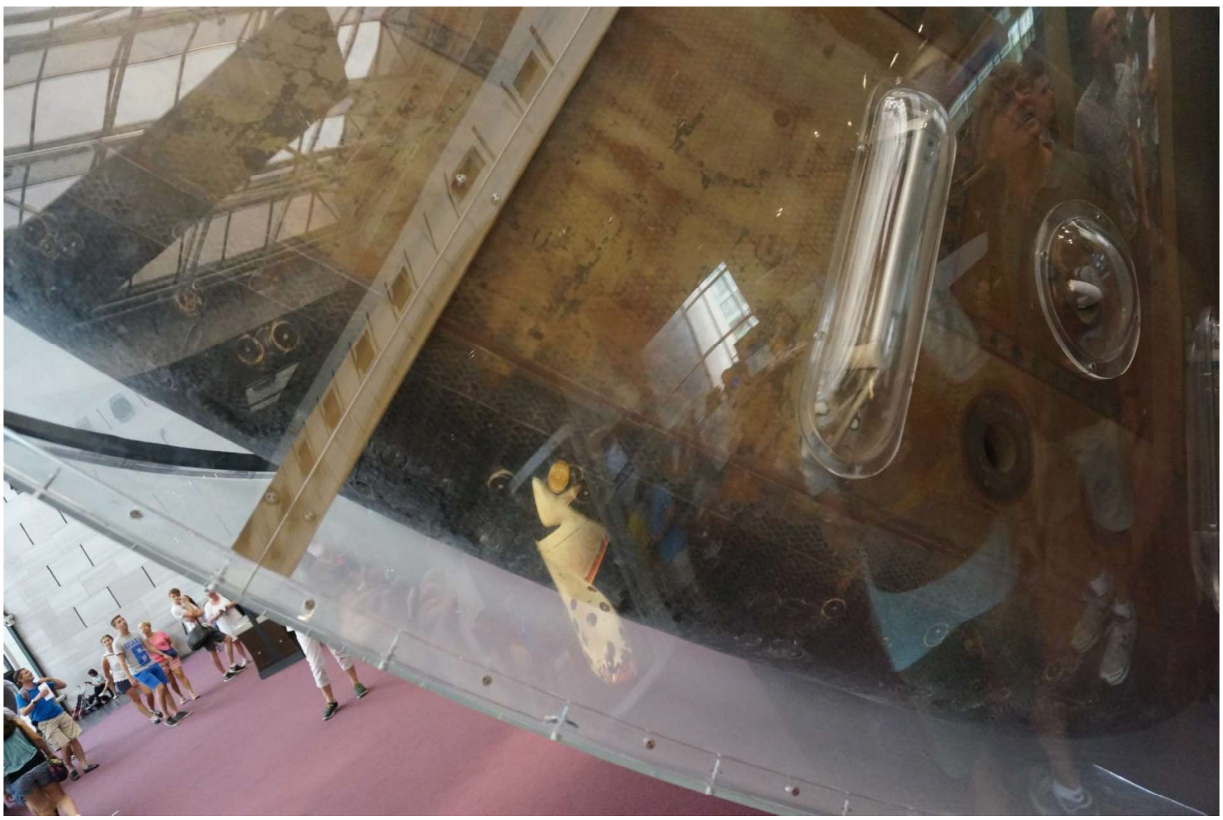


The Apollo CM Heat Shield Had to Withstand 5,000 degree F Heat During Re-entry from Cislunar Space [NASM]

(Note charring of ablative heat shield at the base of the spacecraft)

The Apollo CM Heat Shield Extended From the Blunt End of the Spacecraft *All the Way to the Top of the Crew Compartment* [NASM]

(The **380,000 one-cubic-inch** **steel honeycomb cells** in every command module heat shield were each filled by hand, with **epoxy resin.** The AVCO Corporation of Lowell, MA employed about 12 workers---predominantly women---to perform this crucial work.)



Close-Up of Blunt End of Apollo 11 CM Heat Shield [NASM]

(Note honeycomb structure of ablative heat shield; if x-rays revealed air bubbles inside any epoxy cells, they had to be drilled out and re-filled.)

An Engineering Marvel:

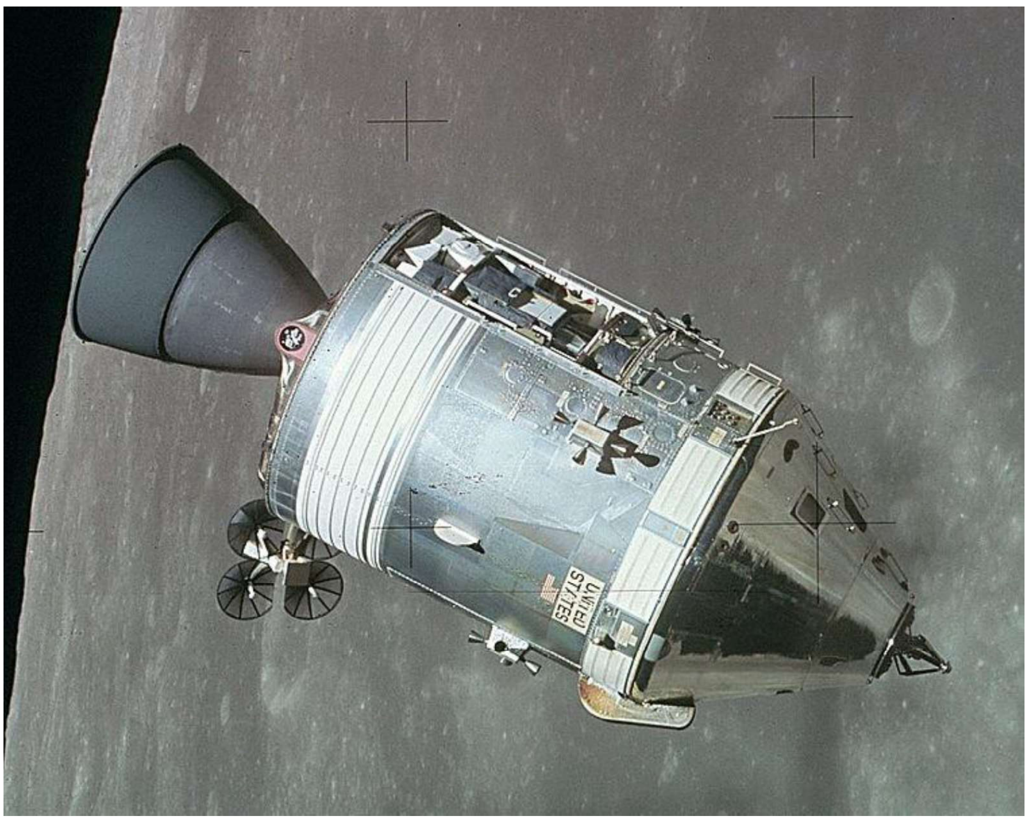
The Probe and Drogue Docking Assembly Used by the Command Module to Dock With the Lunar Lander (1 of 2)

- The male-female **Probe and Drogue Docking Assembly** was one of the engineering marvels of the Apollo spacecraft. **It had to be utilized on two occasions during each Apollo Lunar Landing Mission** to effect hard docking of the Command Module with the Lunar Module:
  - The first use of the Probe and Drogue Assembly for a hard dock was immediately after the TLI burn, right after departing Earth, so that the LM could be pulled out of the SLA atop the third stage of the Saturn V; this was called the Transposition, Docking and Extraction maneuver (TD&E). After the TLI burn the Command Module Pilot assumed the left-hand seat in the CM, and flew the Command Module during the TD&E maneuver.
    - Successful completion of the TD&E maneuver was essential to an Apollo Moon landing, for the spacecraft "stack" had to perform mid-course corrections, and the LOI-1 and LOI-2 burns around the Moon, as one unit.
    - **After the TD&E maneuver, the Command Module Pilot disassembled the Probe mechanism and stowed it in the Lower Equipment Bay in the Command Module,** so that the astronauts could use the transfer tunnel to enter the Lunar Module.
    - The CMP had to reinstall the Probe in the docking ring above the Command Module transfer tunnel prior to casting off the Lunar Module for the Moon landing; the Probe had to already be in place for the second hard dock between CM and LM when the Ascent Stage lifted off from the Moon.
  - After the Lunar Module's Ascent Stage lifted off from the lunar surface and rendezvoused with the Command and Service Module in lunar orbit, ***the Command Module Pilot once again was required to perform a hard dock with the Lunar Module (this time only with the Ascent Stage).*** If, for any reason, the second hard docking attempt had failed, the two Lunar Module astronauts could have transferred themselves, and their cargo of moon rocks, to the Command Module by an EVA, or spacewalk; a handrail was installed on the left front face of the LM Ascent Stage for this contingency (but it was never used).
- Design and Construction:
  - **The Probe,** mounted on a docking ring above the Command Module transfer tunnel, was essentially **a retractable rod with an articulated tip on the end; there were three capture latches on the end of the Probe.** Three support arms held the Probe onto the docking ring, and there were three shock absorber arms as well. **Inside the docking ring there were 12 hard dock capture latches.**
  - **The Drogue,** mounted atop the Lunar Module transfer tunnel in the LM docking ring, **was merely a concave cone, with a hole in the middle,** sized to just barely accommodate the tip of the Probe. The cone shape of the Drogue gently shepherded the tip of the Probe into the hole, as the docking event commenced.

The Probe and Drogue Docking Assembly (2 of 2)

- **Docking the Command Module With the Lunar Module Was a Three-Step Procedure:**
  - **"Soft Dock"** occurred when the three capture latches in the tip of the Probe were captured by the Drogue; There was no stability or rigidity between the two spacecraft at this point in the docking procedure.
  - Once the Probe was captured by the Drogue, a pressurized nitrogen bottle (1 of 4) then **ensured the retraction of the Probe's retractable rod,** bringing the docking rings of the CM and LM together.
  - **"Hard Dock"** was achieved after the two docking rings were mated, and **the twelve (12) capture latches in the Command Module's docking ring engaged successfully with the Lunar Module's docking ring,** and "captured" the Lunar Module.
- **After the TD&E Maneuver following the TLI burn,** the Command Module Pilot first had to ***disassemble the Probe assembly in the nose of the Command Module, and stow it in the Command Module's Lower Equipment Bay.*** Next, he had to pressurize the LM and its docking tunnel, using oxygen from the Command Module; he then inspected the twelve capture latches to ensure a good "hard dock." (This was a 40-minute procedure.) After the inspection was complete, the Command Module Pilot connected two electrical umbilical cables in the CM and the LM so that the appropriate signal could be sent to the SLA (Spacecraft-Lunar Module Adaptor) ordering it to set off pyrotechnic charges which released spring-loaded devices, freeing the Lunar Module from the four hard-point attachments in the lower section of the SLA. Once the LM was released from the SLA by the spring-loaded devices, the CM "quad" thrusters assisted with the withdrawal of the LM from the SLA.
- **Problems with the Probe and Drogue Assembly were experienced on three missions:**
  - **The Apollo 14 Command Module *"Kitty Hawk"*** failed several times, after TLI, to achieve a "soft dock" with Lunar Module ***"Antares."*** **After numerous attempts, a "soft dock" was eventually achieved.** The Probe was returned to Earth (instead of being cast off into space when the Ascent Stage was later discarded after its return from the Moon) and inspected, and no obvious cause was found for the earlier malfunctions.
  - **The Apollo 15 and 16 missions** experienced relatively minor problems in effecting docking with their Lunar Modules, also; no cause was ever determined.
  - **Failure to successfully dock the LM with the CSM following the TLI burn would have been a show-stopper, and would have terminated a lunar landing mission.** [To NASA's credit, this never happened.]
  - During the 3-month checkout, prior to launch, of the Lunar Module and Command Module in the Manned Spacecraft Operations Building at the Kennedy Space Center, NASA was prudent enough to perform a mating test of the Probe and Drogue Assembly being used for that mission. ***The test consisted of lifting the Lunar Module with a crane, and carefully lowering it---in an upside down position---onto the Command Module and its Probe. Only if a "soft dock" and "hard dock" were successfully achieved at the MSOB, were the two spacecraft certified for flight.***
- The bipolar, male-female docking mechanism served Apollo well, but today's spacecraft are fitted with a "unisex" docking mechanism so that spacecraft of different nations can dock with each other on unforeseen occasions.

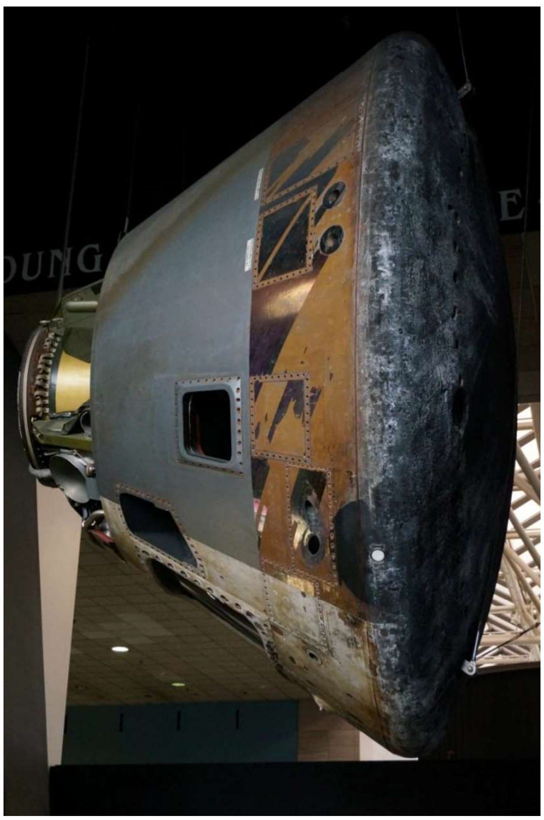
Note Docking Probe Assembly in the Nose of the Apollo Command Module



Another View of the Command Module <u>Docking Probe</u>

Command Module from Skylab Orbital Mission [NASM]

(Note the two small rendezvous windows on either side of the crew hatch, and the square window on each side of the crew compartment; a fifth, circular window---a porthole---was installed in the crew hatch.)

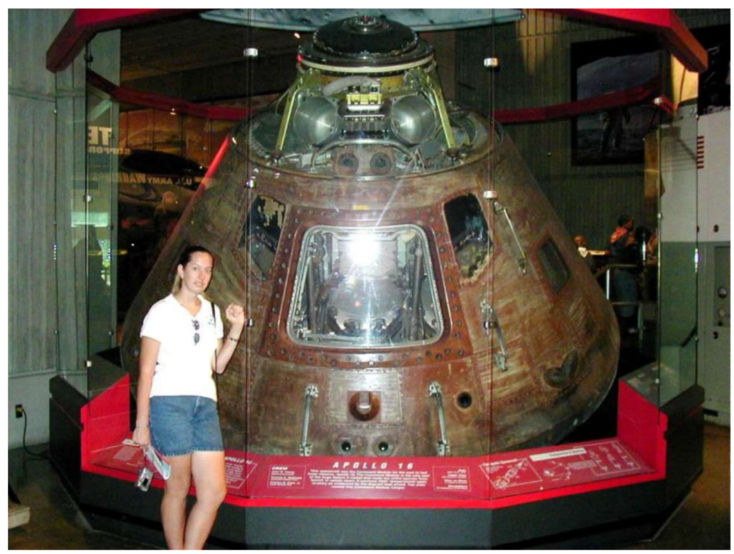


The Apollo 10 Command Module *"Charlie Brown"*
[London, England]

Other Post-Flight Apollo Command Modules On Display in the United States (1 of 2)

Apollo 12 Command Module *"Yankee Clipper"* [Hampton, Virginia]

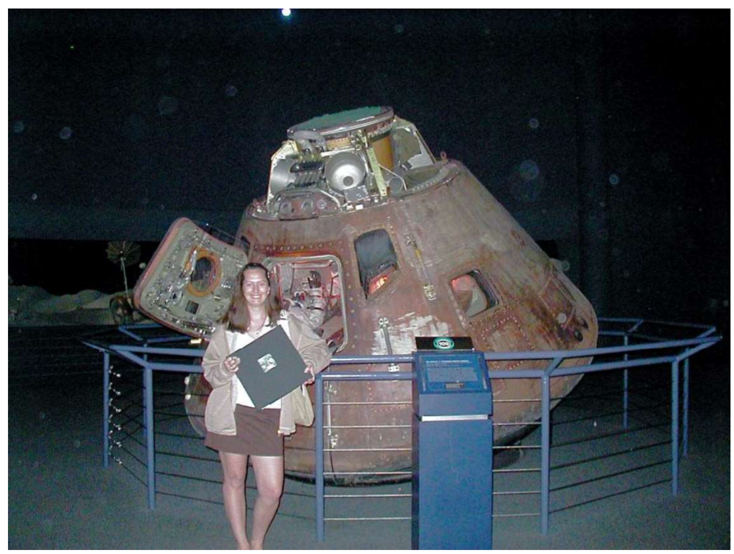
Apollo 16 Command Module *"Casper"* [Huntsville, Alabama]



Other Post-Flight Apollo Command Modules On Display in the United States (2 of 2)

Apollo 15 Command Module *"Endeavour"*
[Dayton, Ohio]

Apollo 17 Command Module *"America"*
[Houston, Texas]



The Apollo One Fire (1 of 2)

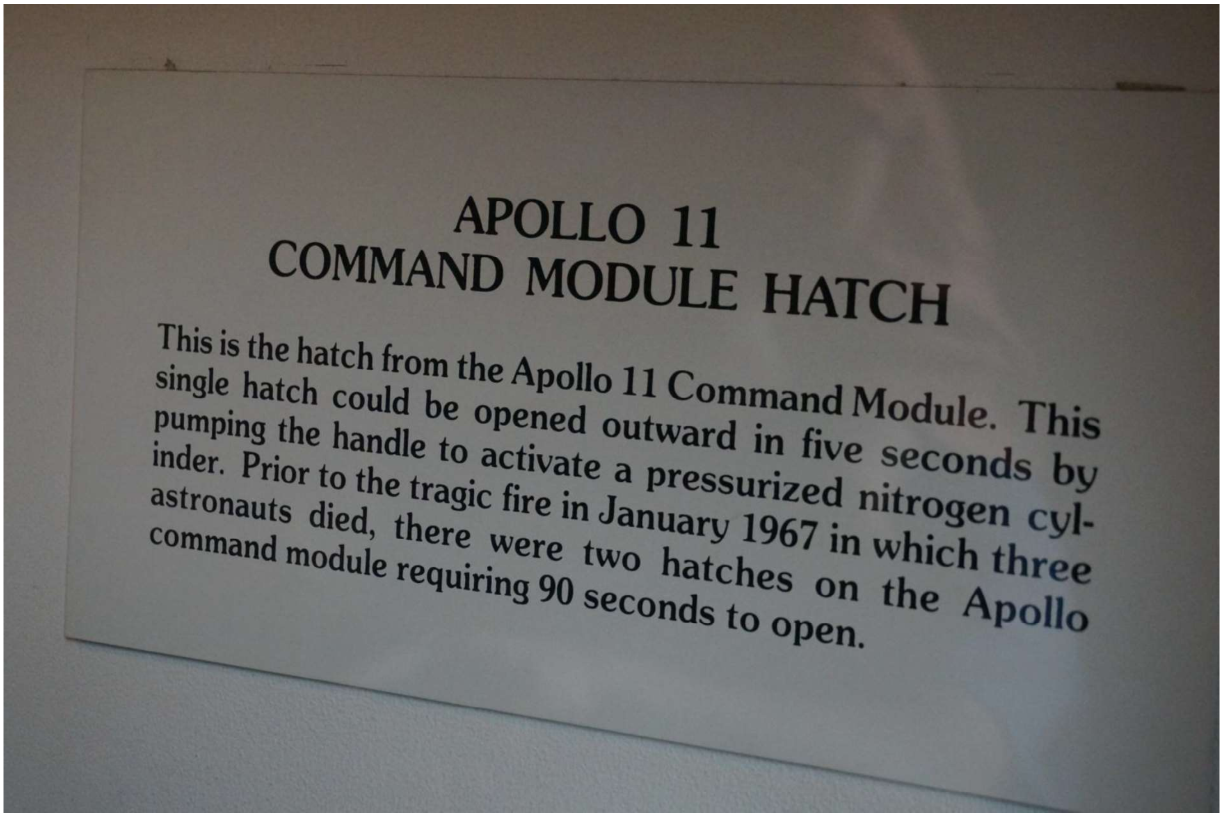
- **Occurred on January 27, 1967** during the "plugs out" countdown demonstration test; astronauts "Gus" Grissom, Ed White, and Roger Chaffee lost their lives on the ground in a routine test previously considered non-hazardous.
- **Principal culprit:** ***NASA's decision in late 1958 (reinforced in 1962 for Apollo) to use a single-gas system (oxygen) in all manned spacecraft designs (and to perform ground tests with 100% oxygen at sea-level pressure).***
  - **Advantages:** Less weight than a two-gas system (i.e., oxygen and nitrogen), and less complexity/higher reliability;
  - **Disadvantage:** Many items that will not burn (or not burn easily) in a sea level oxygen-nitrogen atmosphere (22% oxygen, 78% nitrogen), burn readily---even explosively---in 100% oxygen at sea level pressure. [Two examples: *velcro, and aluminum.*] On-the-pad leak checks in the Apollo One spacecraft were conducted at **16.4 psi in a pure, 100% oxygen environment.** Previously, all Mercury and Gemini spacecraft had also utilized 100% oxygen for all ground tests until reaching orbit, where the working environment was a safe 5.5 psi pure oxygen. NASA had been lucky with Mercury and Gemini, resulting in complacency.
  - **North American Aviation (the Command and Service Module contractor), to its credit,** had proposed both a two-gas system (nitrogen and oxygen), and an explosive hatch, in its technical proposal to NASA prior to contract award. Both of these proposals were driven by safety concerns: fear of fire in the spacecraft, and the desire to provide the astronauts with safe emergency egress. ***To its discredit, in 1962, NASA officials*** (Bob Gilruth and Maxime Faget of MSC)---following heated arguments with North American engineers and management officials---***insisted on the same one-gas system (pure oxygen) it had been using, and disapproved the concept of an explosive hatch*** (because of the near drowning of "Gus" Grissom in July 1961 when his explosive Mercury capsule hatch "blew" unexpectedly after splashdown).
- **Secondary culprit:** ***North American Aviation; its errors included:***
  - Faulty wiring/poor insulation;
  - Too many flammables in the spacecraft (velcro, nylon netting, foam pads); approximately 5000 square inches of velcro were installed in the Apollo One CM (per astronaut desires), whereas only 500 square inches had been authorized.
  - Generally sloppy workmanship (inadequate quality control, exacerbated by frequent design changes by NASA and heavy schedule pressure).

The Apollo One Fire (2 of 2)

- **Cause:** Frayed wiring created a short and a spark in the lower equipment bay beneath Grissom's couch; the spark created a fire in the 100% oxygen atmosphere at 16.4 psi, *fed by environmental control system coolant fumes (glycol)*, which spread rapidly through *70 lbs. of nylon Raschel netting, velcro, and foam pads*. Details follow:
  - Only 18 seconds elapsed between the astronauts' first call of "fire in the spacecraft," and the explosive rupture of the spacecraft's hull;
  - Temperatures inside the Command Module reached as high as 2,500 degrees F, and the pressure hull burst when the overpressure reached about 30 psi;
  - The crew died of asphyxiation (carbon monoxide poisoning and toxic fumes), not burns;
  - From the AS-204 Review Board's report**: "Consciousness was lost between 15-30 seconds after the first suit failed."** The first suit (its air hose) failed about the same time the hull ruptured (i.e., 18 seconds after the fire began).
- **Fixes:**
  - NASA directed installation of a **two-gas system (40% nitrogen, 60% oxygen)** for all ground testing, and throughout ascent to orbit; a 5.5 psi pure oxygen environment would be retained in the space environment.
  - **An outward-opening, quick-release hatch which opened in 5 seconds** was installed [replacing both the previous inward-opening hatch on Apollo One, which took at least 90 seconds to open---and the outer (heat shield) hatch which also took at least 90 seconds to unbolt].
  - All Command Module systems were re-examined and re-designed where necessary; **there were over 1,341 design changes implemented.** The most notable included:
    - Improvements in wiring and insulation, and protective wire bundling;
    - Non-flammable materials were introduced throughout the spacecraft (more than 2,500 individual items were removed or replaced), most notably:
      - Flame resistant Velcro introduced (the quantity was reduced also, and the spacing increased);
      - Paper (all paper was henceforth non-flammable);
      - Paint (all paint was now flame resistant); and
      - Space suit outer fabric was replaced with non-flammable Beta-Cloth.
- **The Apollo 7 earth-orbital flight of Schirra, Eisele, and Cunningham from October 11-22, 1968 was the "shakedown cruise" for the redesigned, "Block II" Apollo Command Module,** following a 19.5 month delay in the flight schedule; there were no notable hardware problems during this flight---only crew (attitude) problems---which allowed the radical mission proposal for Apollo 8 (a lunar circumnavigation) to proceed in December 1968.
  - NASA was so confident in the new Command Module that it committed the safety of three astronauts (and the future of the Apollo program) to a lunar voyage in the redesigned spacecraft on the very next mission, *just two months later;*
  - Everyone at NASA lost their innocence following the Apollo One fire; but the rededication and increased cooperation of the government-contractor team ensured the success of America's lunar landing program.

Redesigned Apollo CM Quick Opening Hatch [NASM]
(This is the Apollo 11 Command Module hatch.)

Dataplate for Apollo 11 CM Hatch (NASM, Washington, D.C.)



Apollo Program Test Flights Continued In-Between the Apollo One Fire and the Launch of the First Manned Flight of the Apollo CSM, Apollo 7

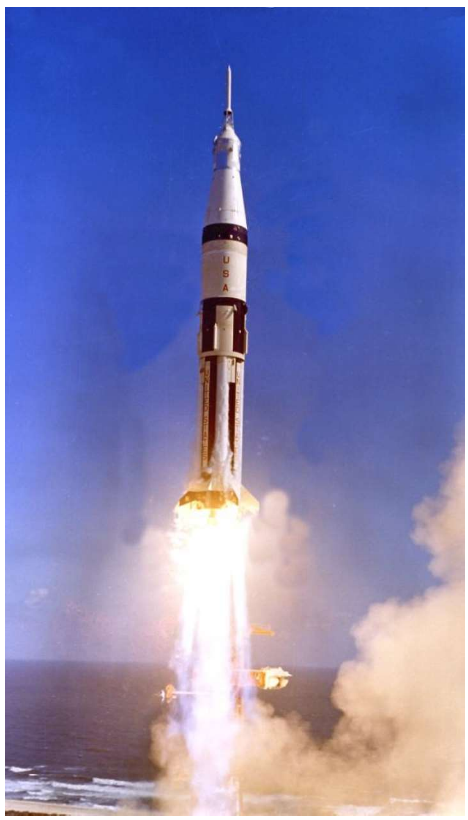
- The Apollo 1 flight had a technical designation of SA-204 (indicating it was to be the fourth Saturn IB booster flown). The Press had designated the flight as "Apollo 1" because it was to be the first manned Apollo flight.

- Three *previous* unmanned flights of "Block I" Command Modules atop Saturn IB boosters (in February, July, and August of 1966) had been designated SA-201, SA-202, and SA-203. **AFTER THE APOLLO 1 FIRE, THOSE FLIGHTS WERE RETROACTIVELY DESIGNATED APOLLO FLIGHTS 1, 2, and 3.** Accordingly, the next Apollo Program test flight after the Apollo 1 fire was then designated "Apollo 4."

- Apollo Program Test Flights following the SA-204 Fire, and leading up to the first manned flight of the CSM, are listed below:

Flight Designation	Date	Description
Apollo 4 (SA-501)	November 9, 1967	First launch of a Saturn V rocket (unmanned), and the first use of Pad 39A at KSC. "All-up testing." Successful.
Apollo 5 (SA-204)	January 22, 1968	First space flight of a Lunar Module (unmanned)---in Earth orbit. Launch vehicle was the same Saturn IB originally intended to launch Apollo 1 into space (before the fire). LM descent stage, staging, and ascent stage successfully tested.
Apollo 6 (SA-502)	April 4, 1968	Second launch of a Saturn V rocket (also unmanned). Three serious launch vehicle problems were experienced during the flight, and the CSM payload barely reached Earth orbit. [Details in a later slide]
Apollo 7 (SA-205)	October 11-21, 1968	This was the first manned flight of an Apollo Command and Service Module---the redesigned "Block II" Command Module. The design and engineering in the new Command Module was a tremendous success, paving the way for use of the "Block II" CM in cislunar space. This was the first manned Apollo flight in the 20.5 months since the Apollo 1 Fire. Launch vehicle was the Saturn IB.

The Launch of Apollo 7 on October 11, 1968 Atop a Saturn IB Rocket:
The "Shakedown Cruise" for the New Block II Command Module



The Saturn V Space Vehicle (Launch Vehicle + Spacecraft Stack) Makes the Slow, 10-Second Climb Past the Launch Umbilical Tower

"NOVA"---The Rocket That Never Was

- NOVA designs proliferated between 1959-1961, when **direct ascent** seemed the most likely mode for sending men to the Moon. They included all-liquid propulsion stages; mixed solid-and-liquid propulsion stages; and all-solid propulsion stages (in early 1962). Some engineers believed the NOVA was too dangerous to launch from land-based facilities because a catastrophic failure at liftoff could destroy all of the launch facilities; other engineers favored launching from platforms at sea because they did not believe the rocket could withstand the sonic vibration of a land-based launch.

  – **April 1961**: NOVA-C (all-liquid propellant stages) was a 5-stage rocket (not counting the spacecraft), 43.3′ in diameter and 337.9′ tall. It planned to use the following engine configurations in each of the stages:
    - First stage: 8 ea F-1 engines (kerosene and oxygen)
    - Second stage 2 ea F-1 engines (kerosene and oxygen)
    - Third stage 4 ea J-2 engines (hydrogen and oxygen)
    - Fourth stage 6 ea RL-10 engines (hydrogen and oxygen) [*Centaur* program]
    - Fifth stage 2 ea RL-10 engines (hydrogen and oxygen) [*Centaur* program]

  – **July 25, 1961:** Another NOVA design (all-liquid propellant stages) planned on the following engine configuration (in only 3 stages, vice 5):
    - First stage: 8 ea F-1 engines (kerosene and oxygen)
    - Second stage: 8 ea J-2 engines (hydrogen and oxygen)
    - Third stage: 2 ea J-2 engines (hydrogen and oxygen)

  – **November 20, 1961:** The final NOVA all-liquid propellant design envisaged a truly gargantuan launch vehicle with a 50-foot diameter first stage, which promised to pose significant development and testing problems:
    - First stage: 8 ea F-1 engines (producing 12,000,000 pounds of thrust)
    - Second stage: 4 ea M-1 engines (producing 4,800,000 pounds of thrust)
    - Third stage: 1 ea J-2 engine (producing 200,000 pounds of thrust)

"NOVA" vs. Saturn V: A Comparison

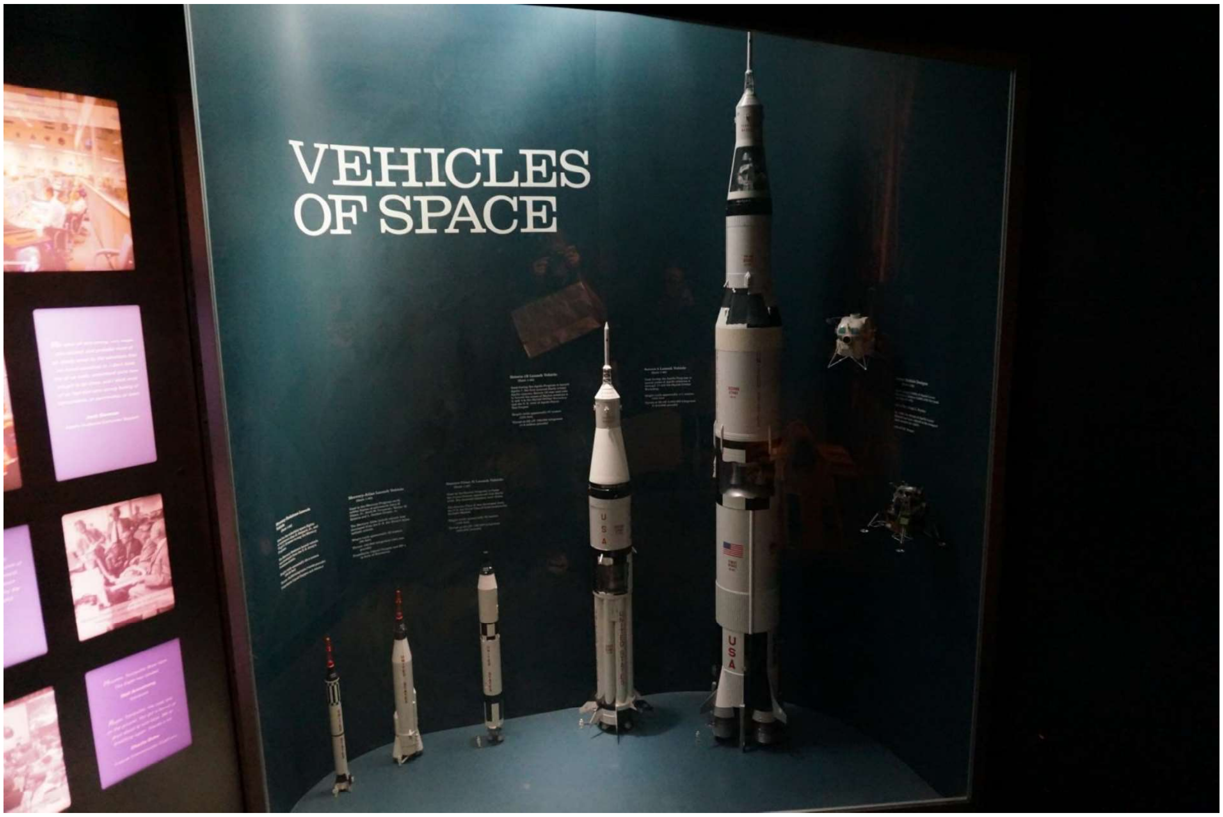
	1st Stage Diam.	1st Stage Thrust	1st Stage Engines	2nd Stage Diam.	2nd Stage Thrust	2nd Stage Engines	3rd Stage Diam.	3rd Stage Thrust	3rd Stage Engines
NOVA (Nov 20, 1961)	50′	12 million lbs.	8 F-1	40′	4,800,000 lbs.	4 M-1 (never built)	22′	200,000 lbs.	1 J-2
SATURN V (1969)	33′	7.6 million lbs.	5 F-1	33′	1,000,000 lbs.	5 J-2	22′	200,000 lbs.	1 J-2

American Launch Vehicles for Manned Spaceflight

Launch Vehicle	Height	Thrust	Propellants	Payload
Mercury-Redstone	83′	78,000 lbs.	Alcohol/LOX	Suborbital
Mercury-Atlas	95′3″	360,000 lbs.	Kerosene/LOX	1.6 tons to Earth orbit
Gemini-Titan	109′	430,000 lbs.	Hypergolics (“Aerozene 50” and Nitrogen Tetroxide)	3.75 tons to Earth orbit
Saturn IB	224′	1,640,000 lbs.	(1) Kerosene/LOX (2)Hydrogen/LOX	20 tons to Earth orbit
Saturn V (thru SA-503) (Thrust for SA-504 thru SA-508)	363′9″	7,500,000 lbs. 7,610,000 lbs.	(1) Kerosene/LOX (2,3) Hydrogen/LOX	125 tons to Earth orbit, 47.5 tons to the Moon
Saturn V-Skylab (Thrust is for SA-509 thru SA-513)	333′7″	7,650,000 lbs.	(1) Kerosene/LOX (2) Hydrogen/LOX	84 tons to Earth orbit
Space Shuttle	184′2″	7,454,000 lbs.	(3 ME) Hydrogen/LOX and Two SRBs	32.5 tons to Earth orbit

NASM Models of American Manned Launch Vehicles (1/48 scale) (1 of 2)

NASM Models of American Manned Launch Vehicles (2 of 2)



The Spacecraft "Stack" Defined

- **The spacecraft "stack" was defined as follows: SLA (LM inside) + CSM + LES = "stack"**
  - The conical **SLA** (Spacecraft-Lunar Module Adapter) sat on top of the Instrument Module (IU), which in turn sat on top of the third stage of the Saturn V launch vehicle (the S-IVB).
  - The **Lunar Module,** with its legs folded down underneath its descent stage, sat inside the SLA; the legs of the Lunar Module hung down inside the hollow IU, and extended to a point just above the hydrogen fuel tank of the S-IVB.
  - The **Command and Service Module (CSM)** sat on top of **the SLA;** the huge engine bell of the SPS engine on the Service Module was positioned just above the top of the **Lunar Module.**
  - The **Launch Escape System (LES)** was attached to the top of the Command Module; the LES consisted of the **Boost Protective Cover (BPC)** and the solid fuel **Escape Rocket.**
- **The height of the spacecraft "stack" was <u>82 feet</u>;** the "stack" sat atop the Saturn V's first three stages and the Instrument Unit (IU), which totaled 281.8 feet high. <u>Total height of the Apollo-Saturn V Space Vehicle was 363.8 feet</u>.
- The solid fuel **Escape Rocket** had a nominal thrust of 150,000 lbs. and was designed to fire for 8 seconds, producing an acceleration of 7 gravities; the jettison rocket had a thrust of 31,500 lbs.
- The **Boost Protective Cover (BPC)** covered the Command Module during launch, until the Escape rocket was jettisoned shortly after the first stage (the S-IC) was jettisoned. It was made of fiberglass and cork.
- The **Launch Escape System** (i.e., the Escape Rocket and its tower) was 33 feet tall.
- The **Command Module** was 10'7" tall/12'10" wide and the **Service Module** was 24'7" long/12'10" wide.
- The **Lunar Module** (with legs extended for landing) was about 23' tall.
- The **SLA (Spacecraft-Lunar Module Adapter)** was approx. 28' tall overall (the lower section was about 7' tall; each of the 4 upper panels was about 21' long; the LM was bolted to 4 "hard points" on the upper rim of the lower SLA section; when the LM was cocooned inside the SLA, its legs hung down below the bottom of the lower SLA section, and dangled inside the hollow instrument unit, just above the upper dome of the S-IVB hydrogen tank)
- <u>When docked</u>, the **CSM + Lunar Module (LM) Apollo Spacecraft "stack"** (in lunar orbit) was approx. 57'8" tall.

THE SPACECRAFT "STACK": SLA, Command and Service Module, and Launch Escape System,

With Launch Umbilical Tower in Background

(Note Swing Arm # 9 Used for Astronaut Ingress/Egress, and "White Room")

Apollo-Saturn V Launch Vehicle Model at NASM, Featuring the spacecraft "stack" atop the 3rd Stage (S-IVB) and IU (Note Swing Arm #9 w/White Room; LM is hidden inside SLA)

Note Boost Protective Cover, Escape Rocket, and Radiators on Skin of the Service Module

The **Boost Protective Cover (BPC)** was made of fiberglass and covered with cork, and was designed to protect the skin of the Command Module from atmospheric heating during launch, and from the potential blast of the **escape rocket** (if used).

Note the **white radiators** on the skin of the Service Module. The small white radiators on the fairing atop the Service Module ***shed heat from the fuel cells and electrical generating system;*** the large white radiators at the lower end of the Service Module ***shed heat from the interior of the Command Module.***

Photo taken from **Launch Umbilical Tower**, showing the **Mobile Service Structure** in the background [more on the LUT and MSS later].

Atop the Saturn V, Each LM Had to be Carefully Positioned (With Its Legs Folded-Up Underneath the Descent Stage) Inside the Conical SLA (Spacecraft Lunar Module Adaptor); the CSM Was Perched on Top of the SLA in the Spacecraft "Stack," and the SLA Sat On Top of the Third Stage/Instrument Unit of the Saturn V [NASM]

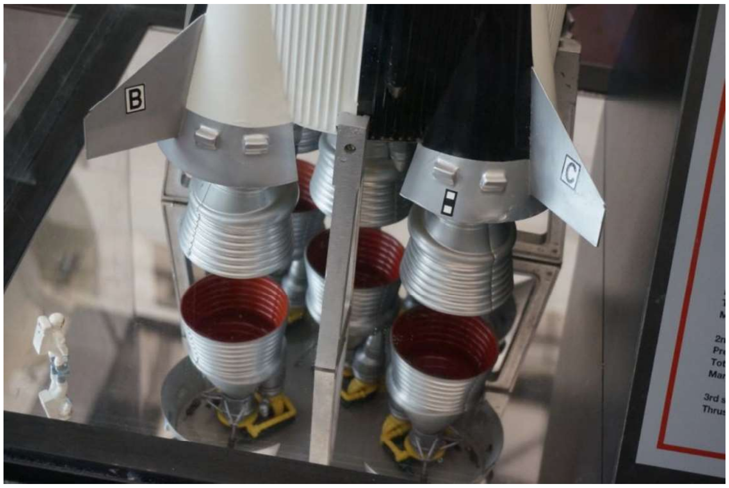
NASM Apollo-Saturn V Model (Left) Depicts the LM Inside the SLA

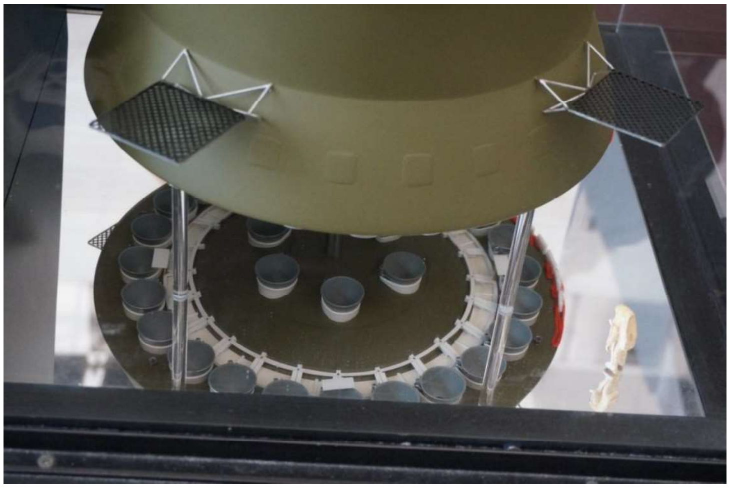
(Note Instrument Unit, below SLA, painted black, atop 3rd stage;
the IU was only 3 feet high, and was 21.7 feet in diameter.)

Model Details of First Stage Engines [NASM]
(Saturn V vs. N-1 Booster)

The Five (5) F-1 Engines Powering the Saturn V's First Stage Were a Marvel of Engineering, and Could Not Be Replicated by the USSR

The "Plumber's Nightmare"---the 30 First-Stage Engines in the N-1 Were the Reason the USSR Never Landed on the Moon: Too Many Pumps, Too Many Fuel and Oxidizer Lines, Too Much Vibration, Too Many Leaks





The Saturn V Launch Vehicle (Booster)

- The ***Apollo-Saturn V*** ***Space Vehicle*** was 363.8 feet tall (281.8′ booster + 82′ spacecraft stack = 363.8′);
- The ***Saturn V*** ***Launch Vehicle*** ***(the booster)*** was 281.8 feet tall, and was comprised of three stages and an Instrument Unit:
  - **First Stage was called the S-IC** (built by Boeing): 138 feet tall, 33 feet in diameter
  - **Second Stage was called the S-II** (built by North American Aviation): 81.5 feet tall, 33 feet in diameter
  - **Third Stage was called the S-IVB** (built by Douglas Aircraft): 59.3 feet tall, 21.7 feet in diameter
  - **Instrument Unit** (built by IBM): dimensions were only 3′ tall, but like the third stage, was 21.7 feet in diameter (hollow in center), and was called the Saturn V's "most important stage" by Wernher von Braun.
- **Stage Propulsion and Engines** (all engines tested individually, for full duration, before stages assembled)
  - **S-IC: Five (5) F-1 Engines** (fuel: kerosene RP-1; oxidizer: liquid oxygen); center engine stationary but outer four engines could be gimbaled for steering purposes; 2 min., 45 sec. of operation (31% of orbital velocity);
  - **S-II: Five (5) J-2 Engines** (fuel: liquid hydrogen; oxidizer: liquid oxygen); center engine stationary but outer four engines could be gimbaled for steering purposes); burned for about 6.5 min. (53% of orbital velocity);
  - **S-IVB: One (1) J-2 Engine** (fuel: liquid hydrogen; oxidizer: liquid oxygen); it was unlike the J-2 engines in the S-II stage, in that **it could be restarted.** The restart was necessary for translunar insertion (TLI) after about 1.5 earth orbits. It could be gimbaled to control pitch and yaw of the S-IVB; two APS units controlled the S-IVB's roll. Its first burn lasted for 2.43 minutes, and provided 11% of the required orbital velocity; its second burn (TLI) lasted for almost 6 minutes, and boosted the Apollo spacecraft's speed from 5 miles/sec to about 7 miles/sec.
- **Stage Assembly and Testing** (all completed stages underwent a full-duration static firing test, before sent to KSC)
  - **S-IC:** Built at the Michoud Assembly Facility, in Louisiana; moved by barge to the Mississippi Test Facility (MTF), where the entire first stage was tested as a unit; moved by barge from MTF to the turning basin at Cape Kennedy opposite the Vehicle Assembly Building (VAB).
  - **S-II:** Built at Seal Beach, California; moved by barge through the Panama Canal to MTF for static firing test; then moved by barge to the turning basin at Cape Kennedy opposite the Vehicle Assembly Building (VAB).
  - **S-IVB:** Built at Huntington Beach, CA; tested at the Sacramento Test Facility, CA; flown to Cape Kennedy in the B-377-SG "Super Guppy" airplane (converted from C-97J Turbo Stratofreighters).
- **Instrument Unit** (flown from MSFC in Huntsville to Cape Kennedy in the B-377-SG "Super Guppy" airplane)
  - ***Sat atop the third stage of the booster, the S-IVB*** (prime contractor was IBM); **the Saturn V's "brain."**
  - **The IU's instrumentation was arranged around its inner surface;** ***the center was hollow, to allow room for the Lunar Lander's legs*** (the SLA, with the Lunar Lander inside, sat directly on top of the IU);
  - Principal instrumentation included:
    - ST-124 Inertial Guidance Platform (3 gyros, 3 accelerometers, 4 gimbals), built by Bendix Corporation.
    - LVDC (Launch Vehicle Digital Computer): ferrite core memory, 32K words (of 28 bits each), all RAM;
    - Launch Vehicle Data Adapter Unit (communicated with LVDC and vice-a-versa, thence to booster);
    - Divided into 24 sections; 16 cold plates (part of an environmental control system); batteries; and numerous telemetry units.

Apollo-Saturn V Space Vehicle Model at NASM, Washington D.C.

[The Space Vehicle Sits Atop the Mobile Launcher, Attached to the Launch Umbilical Tower]

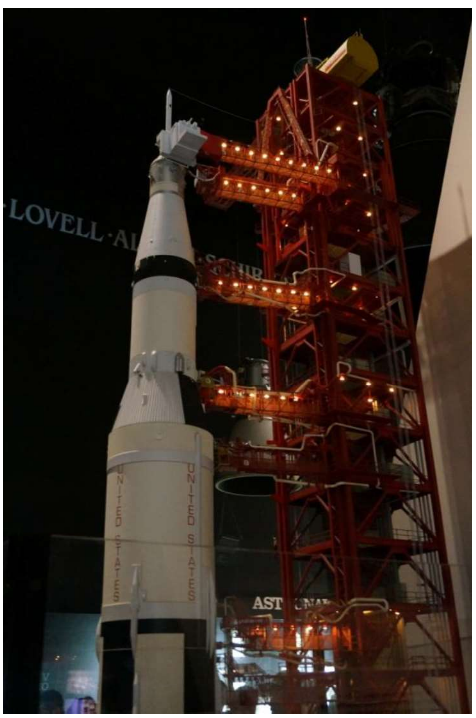
Apollo-Saturn V Space Vehicle Model at NASM (1 of 3)

Note the single Tail Service Mast and three Hold-Down Arms (green) at the bottom of the First Stage

Note two Hold-Down Arms (in green) and the other two Tail Service Masts

Apollo-Saturn V Space Vehicle Model at NASM (2 of 3)

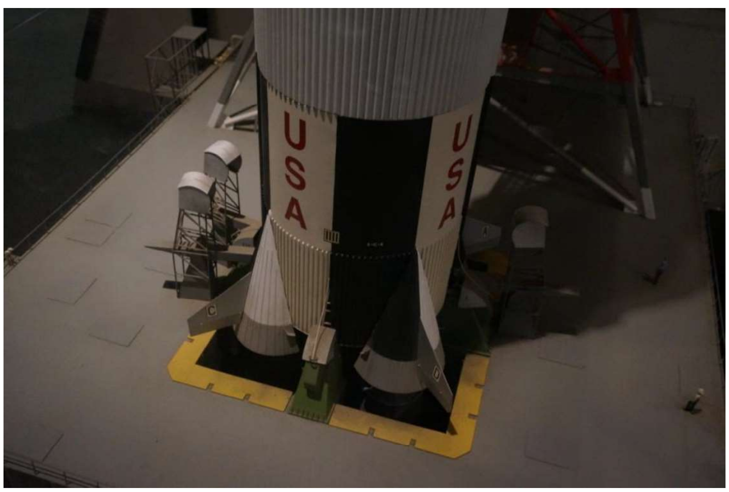
Note the "White Room," Used for Astronaut Loading, at the end of Swing Arm 9

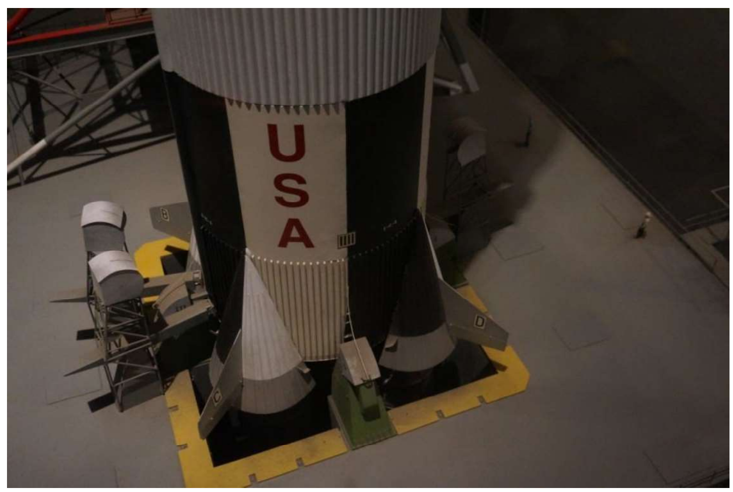


Good Detail of Swing Arms 5 thru 8 (Swing Arm 9 is Obscured)

Apollo-Saturn V Space Vehicle Model at NASM (3 of 3)

Note the 3 Silver Tail Service Masts, …and Green Hold Down Arms





Instrument Unit Functions/Tasks

- The Instrument Unit was built by prime contractor IBM at its Huntsville, Alabama facility.
- **The IU was 3 feet tall, and 21.7 feet in diameter; it weighed 4,280 lbs. at launch.**
- **IU Functions** included monitoring all propellant systems and engine thrust and temperature; gimbaling the outer F-1 and S-II engines in the S-IC and S-II stages; controlling the attitude of the S-IVB stage by gimbaling its single J-2 engine and controlling its two APS units; commanding changes in fuel mixture ratios in the S-II and S-IVB cryogenic stages during burns; monitoring the vehicle's velocity and attitude; sending copious amounts of telemetry to Mission Control in Houston, and receipt of instructions from the ground. Its various functions were divided into eight time bases, as decribed below:
  - **Time base 1: Liftoff** (included "let me go" command to the four LUT hold-down arms; the visually disconcerting "yaw manuever" of 1.25 degrees south, away from Launch Umbilical Tower; and subsequent in-flight gimbaling of the four outer F-1 engines to control roll and pitch);
  - **Time base 2: S-IC Cutoff Coordination** (included center engine F-1 shutdown at 2 min. 15 seconds, ensured that propellants were indeed depleted, armed pyrotechnics for staging);
  - **Time base 3: Staging and S-II Control** (began with shutdown of 4 outer F-1 engines at 2 min. 45 sec.; initiated dual-plane staging---first of separation of S-IC, and then of interstage 30 seconds later; gimbaled the four outer J-II engines as necessary; included center engine shutdown);
  - **Time base 4: Staging and S-IVB Control** (initiated by cutoff signal for S-II's four outer engines; fired single plane pyrotechnics for staging; started single J-2 engine in S-IVB stage; controlled pitch and yaw of S-IVB by gimbaling the single J-2 engine, and roll of S-IVB stage through use of two Auxiliary Propulsion System or "APS" units);
  - **Time base 5: Transition to Orbital Coast** (began with termination of orbital insertion burn or "SECO"; the vehicle was put in a "safe" condition for its orbital coast prior to the TLI burn, 1.5 orbits later);
  - **Time base 6: S-IVB Restart for Translunar Injection or "TLI"** (began 9 min. 38 sec. prior to reignition, and included repressurization of propellant tanks and chill down of turbopumps);
  - **Time base 7: Begin Translunar Coast** (relieved tank pressures after shutdown to stabilize vehicle for transposition, docking, and LM extraction, or "TD & E");
  - **Time base 8: Propulsive Dump** (after TD & E, this primarily involved the dumping of excess LOX to propel the stage on a desired trajectory away from the CM/SM/LM stack---either into solar orbit, or toward lunar impact)

Apollo-Saturn V Space Vehicle Weight Statistics
(for Apollo 14, from *Countdown to a Moon Launch,* by Jonathan H. Ward)

- **Total weight of the Apollo-Saturn V Space Vehicle (Saturn V Booster plus Spacecraft Stack):**
  - **6,465,035 lbs.**
  - **92% of total space vehicle weight was the propellant in the three (3) Saturn V stages**
  - **94% of the Saturn V booster weight was propellant in its three (3) stages**
  - **After first stage separation, the remainder of the Apollo-Saturn Space Vehicle weighed only 22% of its weight at liftoff.**

Stage or Component	Dry Weight	Weight at Launch (Fueled)	Propellant as % of Weight
S-IC	288,650 lbs.	5,030,720 lbs.	94% [S-IC]
S-II	80,220 lbs.	1,060,420 lbs.	92% [S-II]
S-IVB	24,881 lbs.	260,070 lbs.	90% [S-IVB]
I.U.		4,280 lbs.	
SLA		3,960 lbs.	
Service Module	10,507 lbs.	51,110 lbs.	
Command Module		12,365 lbs.	
Launch Escape System		8,900 lbs.	
Lunar Module		33,210 lbs.	
TOTAL WEIGHT		**6,465,035 lbs.**	

Thrust Data for F-1 and J-2 Engines

Engine	SA-501 thru SA-503 (SA-503 = Apollo 8)	SA-504 thru SA-508 (Apollo 9 thru 13)	SA-509 thru SA-513 (Apollo 14-17, & Skylab)		Burn Time
F-1	1,500,000 lbs.	1,522,000 lbs.	1,530,000 lbs.	(2% increase over Apollo 8)	2.75 min.
J-2 [S-II stage]	225,000 lbs.	230,000 lbs.	230,000 lbs.		6.5 min.
J-2 [S-IVB stage]	204,000 lbs.	204,000 lbs.	204,000 lbs.		(EO) 2.43 min. and (TLI) 6 min.

Note:
The two percent upgrade to the original efficiency of the F-1 engine made the extended-stay, "J" missions (Apollo 15, 16, and 17) possible; the Lunar Modules for the "J" missions weighed about 36,000 lbs. (vice the 33,000 lb. weight of early LMs), and the SM included a SIM Bay.