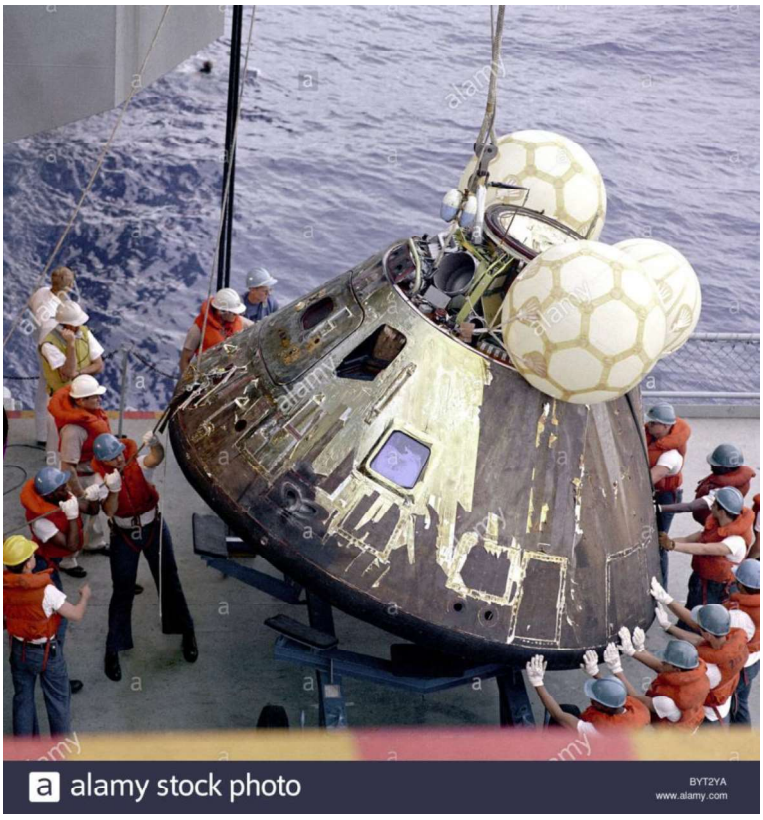
Apollo 13 Command Module "Odyssey"

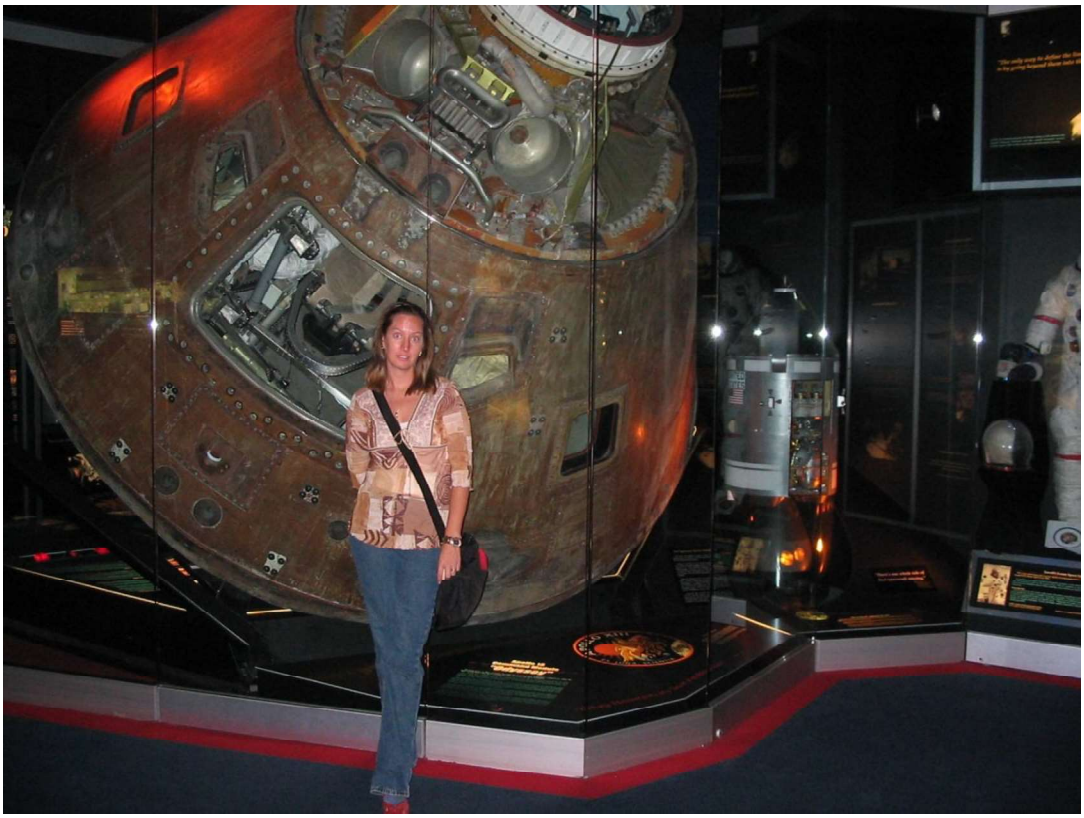
(The "successful failure," seen immediately after shipboard recovery.)



The Apollo 13 Command Module, "Odyssey"

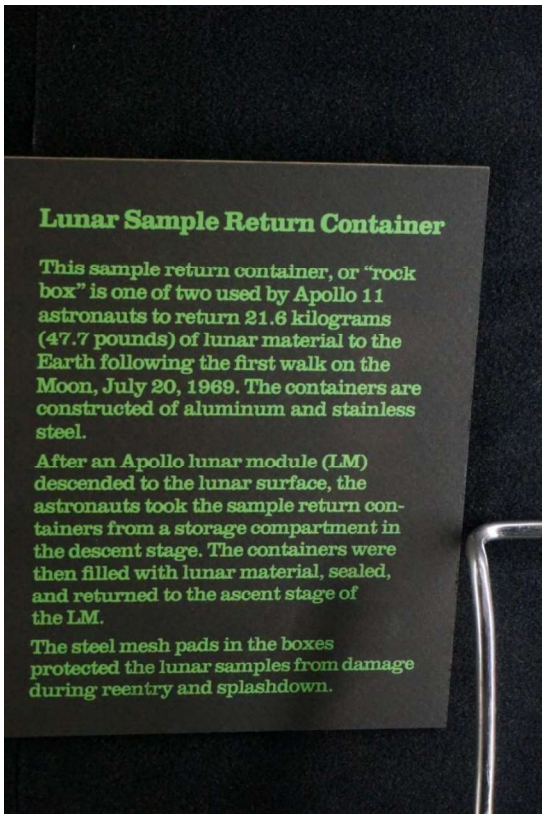
[On Display in Hutchinson, Kansas at the *Cosmosphere* Space Museum]

(A fitting memorial to the professionalism and expertise of all NASA Flight Control personnel and supporting staff in the Apollo Era.)



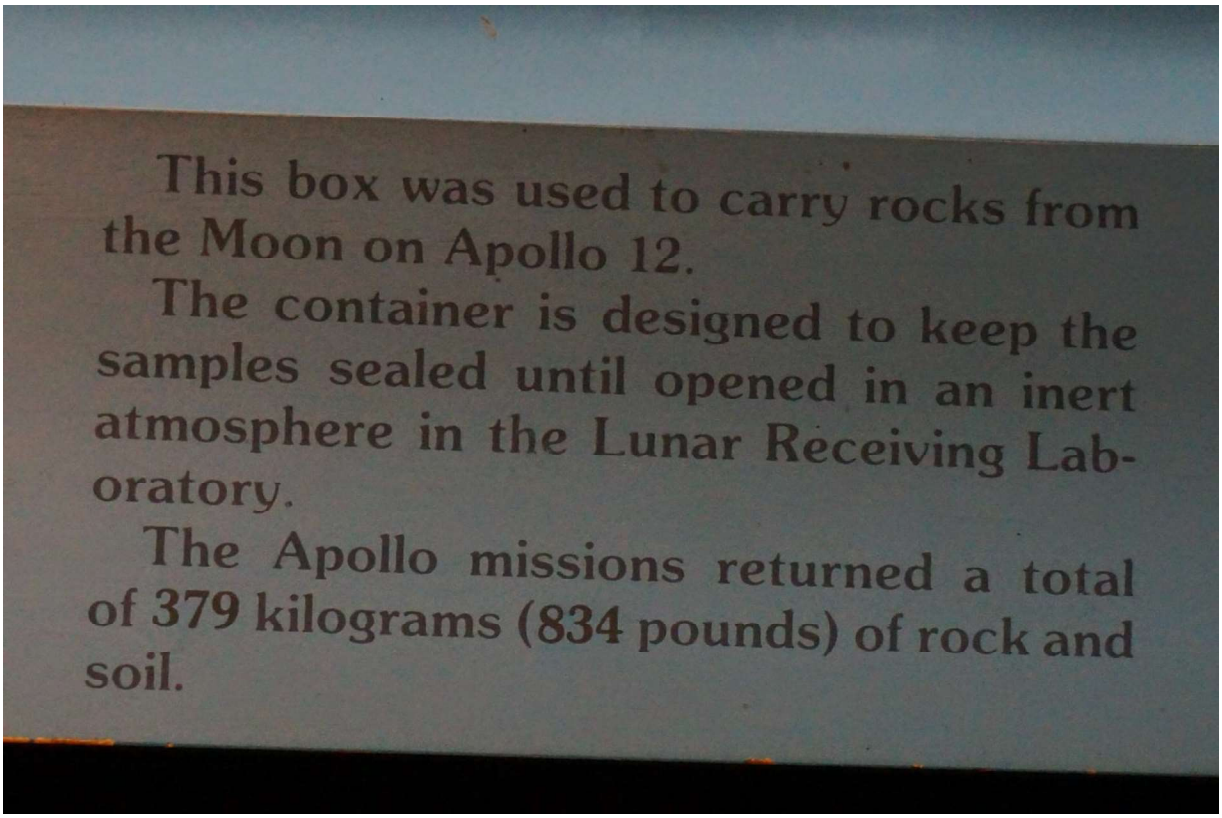
Lunar Sample Return Container Used by Apollo 11 Crew [NASM]

Legend for Apollo 11 Lunar Sample Return Container [NASM]



Lunar Sample Return Container Used by Apollo 12 Crew [NASM]

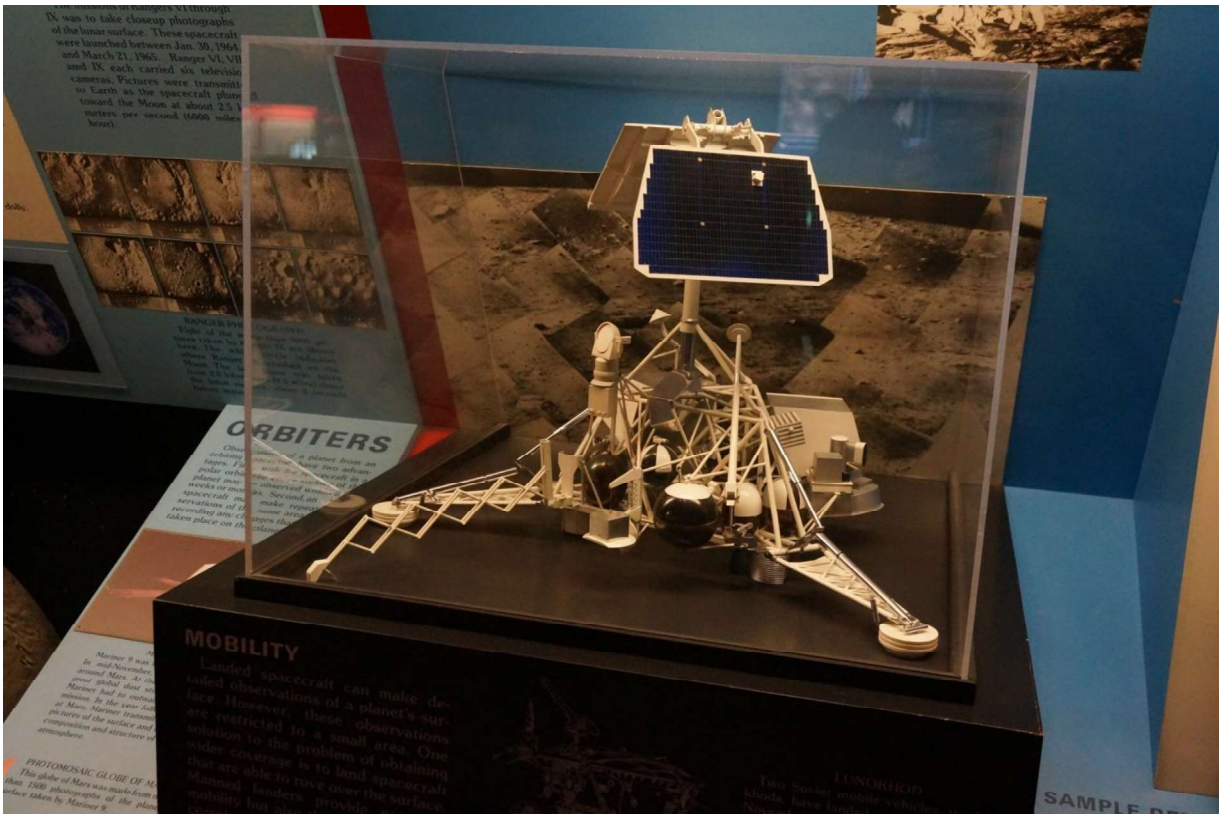
Legend for Apollo 12 Lunar Sample Return Container [NASM]



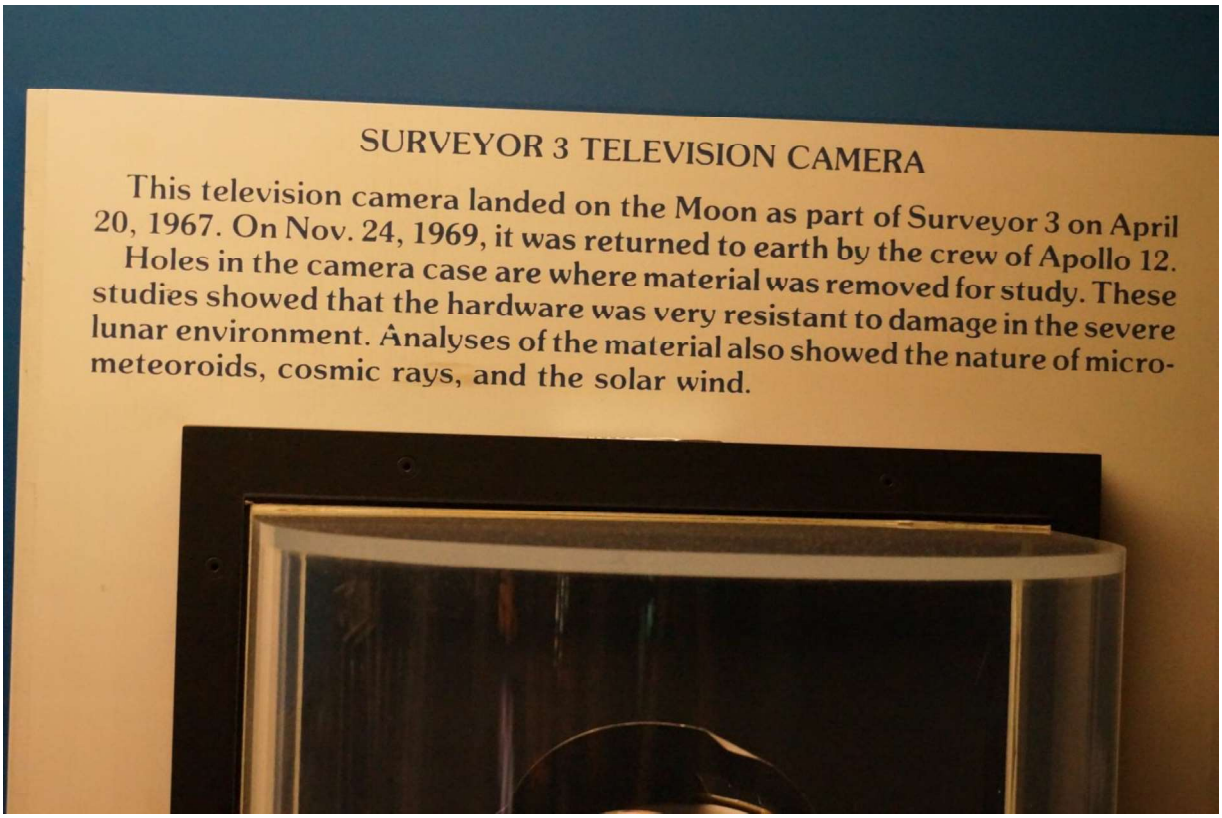
“Surveyor 3” T.V. Camera Returned to Earth by Apollo 12 [NASM]

Model of "Surveyor 3" Lander on Moon [NASM]

(Showing location of television camera returned by Apollo 12 crew.)



Legend for "Surveyor 3" T.V. Camera Exhibit [NASM]



The Last Man on the Moon [NASM]

(Eugene Cernan, the Commander of the Apollo 17 mission, was the 11th of the 12 American astronauts to set foot on the Moon, and was *the last man to walk on the Moon;* red stripes were added to the Commander's helmet, sleeves, and legs for the Apollo 13-17 missions, for identification purposes back on Earth.)

Close-Up of Eugene Cernan's Spacesuit [NASM]

(The "J" missions---Apollo 15-17---employed a *redesigned spacesuit* that permitted *greater flexibility at the waist and knees, and a wider bottom in the pressure suit;* this was necessary to permit the lunar astronauts to sit down in the Lunar Roving Vehicle. Note that the 6 connection ports on Eugene Cernan's suit are located differently from those on "Buzz" Aldrin's spacesuit.)

Redesigned EVA Spacesuit Connection Ports:

Compare Edwin Aldrin's Apollo 11 Suit with James Irwin's Apollo 15 Suit

(Relocated zippers in the pressure suit drove this change.)

The A7-L Suit Connectors on the Apollo 11-14 EVA Suits Were Arranged *Vertically*

The A7-LB Suit Connectors on the Apollo 15-17 EVA Suits Were Arranged *Diagonally*

The Apollo Lunar EVA Spacesuit (1 of 2)

- **The Apollo Lunar EVA Spacesuit** was a two part affair: the **A7-L (and later, the A7-LB) Extra-Vehicular Suit** made by the International Laytex Corporation (ILC); and a backpack containing the life support system, or Environmental Control System, called the **PLSS (Personal Life Support System),** made by Hamilton Standard. The two systems combined were designated by NASA as the **EMU,** or **Extravehicular Mobility Unit.**
- **The ILC Extra-Vehicular Suit** was a **three-part garment** (beginning first with the liquid cooling undergarment; over which was worn the pressurized inner suit or "pressure suit;" over which, in turn, was worn the white outer garment designed to protect the astronaut from temperature extremes, chafing, and micrometeoroids. **Overall, as explained below, the Apollo astronaut wore a spacesuit that consisted of 25 layers of clothing:**
  - **The Liquid Cooling Garment** consisted of a nylon-spandex mesh "long-john" type undergarment into which were embedded numerous flexible **polyvinyl chloride (PVC) tubes** that carried cooling water around the astronaut's torso, to prevent overheating; this was the first layer of the 25 layers of clothing that constituted the A7-L Apollo EVA suit.
  - **The Pressurized Inner Suit** consisted of a pressure suit (70% rubber and 30% neoprene) worn over a thin, inner anti-chafing liner (and thus constituted the second and third layers of the 25 layers of clothing worn by each Apollo astronaut on the Moon). The design of the pressurized inner suit was characterized by a relatively form-fitting garment with narrow shoulders, and ribbed "convolutes" or segmented joints, which permitted added flexibility in the shoulders, elbows, waist, and knees. Steel cables running vertically through the suit, and nylon "tunnel and cording," prevented it from expanding under pressure and "ballooning" during use. Loops and laces could be adjusted to improve fit. **The pressure suit maintained a working pressure of 3.7 to 3.9 psi of pure oxygen;** this maintained an adequate partial pressure of oxygen in the astronaut's bloodstream, while still not overly restricting the flexibility of his suit. [The higher the pressure in a suit, the less was its flexibility.]
  - **The White Outer Garment consisted of 22 layers of protection:** namely, 21 layers of micrometeoroid protection and temperature insulation (composed of aluminized Mylar, Dacron, and Kapton film), covered by a **single white outer suit layer** of tough **Beta cloth,** which was a fireproof, anti-abrasion outer cover made of woven fiberglass strands, each strand coated with Teflon. [Temp. specs: -120 deg. C to +154 deg. C]
  - **Gloves:** The EVA gloves consisted of an anodized aluminum disconnect ring (red for right and blue for left) that attached to the forearm of the pressure suit, to which was connected a pressure bladder for the entire wrist and hand, made of rubber/neoprene, covered by insulating layers of aluminized Mylar, Dacron, and Kapton film. Outside these insulating layers was an outer, anti-chafing layer of **Beta cloth** covered by **Chromel-R,** a **specially woven chromium-steel cloth** that cost $2,000.00 per yard to manufacture. The finger tips of the EVA glove were made of light-blue colored silicone, which allowed a surprising amount of feeling at the end of the astronaut's fingers. A pair of EVA gloves weighed three pounds. The **IV (or Intra-Vehicular) gloves,** worn only inside the Command Module at launch, or when piloting the Lunar Module, were made of neoprene and rubber, and were black---and lacked the protective layers, the **Beta cloth** and **Chromel-R** anti-abrasion covering, and the silicone fingertips of the EVA gloves.
  - **Boots:** The astronaut's feet inside the Command Module and Lunar Module (when piloting, and not performing EVAs) were covered by boots that were part of the one-piece pressure suit. The **Lunar Overshoes** for EVAs on the Moon were worn over the "booties" that were an integral part of the pressure suit. The **Lunar Overshoes** consisted of **Chromel-R** "uppers," **Beta cloth** tongue and lining, and thirteen layers of aluminized Mylar and Kapton film, for insulation and additional protection. The light-blue silicon soles of the **Lunar Overshoes** had a further two layers of **Beta cloth felt** in between the layers of Kapton film to help guard against temperature extremes and sharp rocks on the lunar surface. A pair of **Lunar Overshoes** weighed 5 pounds. **The only two pairs of lunar overshoes brought back to Earth were those worn by Apollo 17 astronauts Cernan and Schmitt.**
  - **"Pressure Bubble" Helmet:** The **Pressure Bubble** was made of tough **polycarbonate** and allowed the astronaut the freedom to turn his head from right to left inside his suit; the pressure helmet itself did not rotate. The neck connect/disconnect ring was made of anodized aluminum.
  - **The EVA Helmet:** This Extra-vehicular gold-visored "over helmet" fit over the top of the **Pressure Bubble,** and was loosely anchored to the **Beta cloth** outer suit layer by Velcro. It was made by LTV (Ling Temco Voight) under subcontract to ILC, and weighed about 4.5 pounds. The EVA helmet had two visors: **the interior visor** was made of ultraviolet-stabilized polycarbonate, which provided micrometeoroid and UV protection; and the **exterior visor,** made of polysulfone with a 24-karat gold coating, reduced the amount of visible light and glare, and also lessened heat buildup inside the helmet. The "over helmet" was covered with **Beta cloth**. **The only 6 helmets returned to Earth were worn by the crews of Apollo 11, 15, and 17.**

The Apollo Lunar EVA Spacesuit (2 of 2)

- **The PLSS (Personal Life Support System):** This backpack-mounted Environmental Control System made by Hamilton Standard was a marvel of engineering, that delivered a maximum of oxygen to the lunar astronaut via a minimum of weight involved in the apparatus. The **PLSS** contained an ***oxygen rebreathing system*** that was about 20% more efficient than a traditional aqualung. It contained an oxygen supply; a lithium hydroxide canister ***oxygen filtration system*** for removing **carbon dioxide** from the returned oxygen supply; cooling water, fans, a pump, and an evaporator cooling system for management of the astronaut's cooling water supply; a communications and telemetry unit; a radio antenna; and a battery. At the top of the **PLSS,** in a separate compartment from the rebreathing system, was an ***emergency oxygen supply*** (rated for 30 minutes on the early versions of the **PLSS**), called the **Oxygen Purge System;** if the rebreathing system failed for any reason, the astronaut could breathe pure oxygen directly from the two small tanks in the **Oxygen Purge System.**
  - **Six (6) connecting hoses connected each ILC EVA spacesuit with each Hamilton Standard PLSS:** one was for cooling water; one was for oxygen entering the pressure suit ("good air"); one was for the return of oxygen that had already been breathed ("bad air," containing carbon dioxide waste product) to the rebreathing system in the PLSS; one electrical cable was for radio voice communications and life-monitoring-system medical telemetry; and one additional pair of "good air" and "bad air" hoses connected the EVA suit to the *emergency oxygen supply* in the Oxygen Purge System. [The Oxygen Purge System was not used unless the rebreathing system failed for some reason, so these two hoses were always in "standby," and were never employed.]
  - **Suit connectors on the chest of the IV (Intra-Vehicular) suit:** there were **3 connectors**---one **(blue)** connector for **electrical connections (medical telemetry) and communications;** one for "good air" **(blue);** and one for "bad air" **(red);** both air connectors on the IV suit for the Command Module Pilot were connected to the Command Module's oxygen supply.
  - **The EVA suits had 3 additional connectors on the front of the suit:** one additional "good air" connector **(blue);** one additional "bad air" connector **(red);** and one **(blue)** water port for EVA cooling water. The additional "good air" and "bad air" connectors on the EVA suit allowed the Lunar Module astronauts to *either* remain hooked up to the LM's oxygen supply *until just prior to exiting* for the lunar EVA (to save the oxygen supply in the PLSS), *or* were used later---after the final EVA on the Moon had been completed---to connect the returning astronauts to the LM's oxygen supply so that each of them could disconnect and discard his own expended **PLSS,** and literally "throw it out the front door" of the Ascent Stage after the final EVA, prior to liftoff from the lunar surface. [All **PLSS** backpacks were discarded---left on the surface of the Moon---to shed weight prior to liftoff of the LM Ascent Stage.] These two extra **blue**/**red** connectors were also the ones used during EVA to access the *emergency oxygen supply.*
- **The A7-L EVA Suit versus the A7-LB EVA Suit:** The LM crews of Apollo 11 through 14 were outfitted with the **A7-L EVA Suits.** The **A7-LB EVA Suits** were developed for the final three Apollo missions---Apollo 15, 16, and 17---**to provide extra flexibility at the waist, a wider bottom to the pressure suit, and extra flexibility in the knees---all considered essential to riding in the Lunar Roving Vehicle.**
- **Weight of the A7-L EVA Suit Used on Apollo 11-14:** The ILC EVA spacesuit for Apollo 11-14 weighed **56 lbs.** on Earth; **the total EVA suit weight of the complete EMU---including the PLSS---was 189 lbs. on Earth.**
- **Weight of the A7-LB EVA Suit Used on Apollo 15-17:** The ILC EVA spacesuit for Apollo 15-17 weighed **67 lbs.** on earth; **the total EVA suit weight of the complete EMU---including the PLSS---was 201 lbs. on Earth.**
- **What the Astronauts Wore When Not Wearing Their Spacesuits:** The Apollo astronauts usually only wore their pressure suits during a Saturn V launch; inside the Lunar Module during descent to, or ascent from, the lunar surface; during EVA; or during docking, in lunar orbit. **During the trans-lunar coast phase, lunar orbit, or the trans-Earth coast phase, the astronauts had two choices of what to wear:** *either* (1) their so-called **constant wear garments,** which were made of cotton and resembled long-john underwear; *or* (2) **an in-flight coverall** consisting of a jacket, pair of trousers, and booties (made of a white Teflon fabric that was flame resistant).

The "Extended-Stay," or "J" Missions:
Lunar Science Becomes the Primary Objective for Apollo 15-17

- **Apollo 11** had met President Kennedy's goal of landing a man on the moon and returning him safely to the earth, and **Apollo 12** proved that a precision landing could be made at a designated target area. **Apollo 12** also demonstrated that NASA wasn't just "lucky" with **Apollo 11.** With the successful conclusion of the Apollo 11 and 12 missions, NASA came under increasing pressure from the scientific community to place much more emphasis on science in future Apollo missions.

- **Apollo 13** was sent to the Fra Mauro highlands, but failed to land because of the near-fatal explosion in oxygen tank # 2. **Apollo 14,** by default, therefore assumed the responsibility for exploring Apollo 13's prior destination in the Fra Mauro highlands.
  - However, in the wake of the Apollo 13 disaster, the primary goal of Apollo 14 became to once again simply demonstrate American competence in traveling to, and landing on, the Moon. Commander Alan B. Shepard's primary goal (in his mind) was simply to journey safely to the Moon, land safely on the Moon, and return safely to the Earth---and thereby "save" or revive the Apollo Program. Furthermore, he had little interest in geology or in conducting scientific experiments; his narrow focus was on flying the Lunar Lander "Antares" to a safe landing, becoming the sole Mercury astronaut to do so, and then returning safely to the Earth. His mind-set was "pure flight test," much the same as Wally Schirra's had been for the Apollo 7 Earth orbital mission: namely, demonstrating flight competence after a major accident. (Neither Schirra, nor Shepard, placed a priority on science or scientific experiments as part of their missions.)
  - Consequently, the scientific (i.e., geological) returns from the Apollo 14 mission were inferior to the science done on either Apollo 11 or Apollo 12, to the vexation of lunar geologists. The frustration of the scientific community after the Apollo 14 flight led NASA to reevaluate its goals for the program, since President Kennedy's goal had already been met.

- **Lunar Science,** therefore---not simply continuing to demonstrate flight competence---would become the primary goal of the Apollo Program for the final three missions: Apollo 15, 16, and 17. (Congress had cancelled the Apollo 18-20 missions, so NASA had to maximize its return from the final 3 lunar landings.) Improved hardware would facilitate this goal:
  - Saturn V thrust was slightly improved (2% higher than the Apollo 8 thrust), and weight was stripped from the booster rocket by removing some of the unnecessary retrorockets (used at staging) on the first and second stages;
  - Propellant tanks in the LM were increased in size, and the engine bell for the descent engine was increased in size as well (resulting in an increase in thrust);
  - Extra batteries and quantities of consumables (oxygen and water) were added to the LM's descent stage, allowing for extended human stays on the Moon;
  - A lunar vehicle was under development as well---it was to be an electric car or buggy which would carry both lunar astronauts, and tremendously increase the range of territory that could be explored and sampled on the Moon. This was a crucial development to pursuing expanded science on the Moon; the Apollo 14 crew had proven through experience that the MET (Modular Equipment Transporter)---a two-wheeled cart that was pulled by the lunar astronauts at Fra Mauro---was not at all practical on the bumpy, potholed lunar surface. Furthermore, extended traverses on the lunar surface, while pulling the MET along with them, had exhausted the two astronauts. So a lunar vehicle was essential, if only it could be folded to fit inside the cramped descent stage of the Lunar Module.

Highlights of the Three "Extended Stay" Missions

- **The Lunar Roving Vehicle (LRV)** was completed on time by prime Contractor Boeing, and amazing as it seemed, was folded up to fit in one corner of the LM Descent Stage. The LRV passed its shakedown tests in the field with flying colors. The astronauts training for Apollo 15-17 were delighted with the vehicle, as were the lunar geologists guiding the Apollo Program. **The LRV for the Apollo 15 mission to Hadley-Apennine covered 15.7 miles, over three times the traverses covered *by all previous missions on foot.***

- **Lunar geology training was beefed up and made more practical and interesting for the astronauts** by Professor Lee Silver of CALTECH, and by astronaut/geologist Harrison H. ("Jack") Schmitt (who enthusiastically assisted in training his peers even though he had no guarantee of ever going to the Moon himself, since he was not a military test pilot). Commander Dave Scott of the upcoming Apollo 15 mission proved to be the most interested in geology, and science, of anyone in the astronaut corps, which was a good start for the "J" series of "science missions."

- **Each "J" mission would now be able to stay on the Moon for almost three full days; and three (3) EVAs, or Moon walks, of up to seven hours each, would now be possible on each mission** because of the additional batteries, oxygen, and water carried by each LM in its Descent Stage. Additionally, the quality of the color T.V. cameras sent to the Moon increased with each "J" mission.

- Increased tankage for propellants in the LM, and slightly increased thrust and payload capacity on the Saturn V booster, meant that **the Saturn V could now launch a Lunar Module that weighed 36,000 lbs., which was 3,000 lbs. heavier than the first two lunar landers.**

- NASA was now confident enough in its SPS engine on the Service Module (and its fuel usage history), and in its own mastery of orbital mechanics, that it could schedule landings in locales that were not on or near the lunar equator---***destinations on the Moon that required a plane change to the Apollo spacecraft lunar orbit*** (and thus required the expenditure of more fuel by the SPS engine).

- **The astronauts** being trained for the Apollo 15-17 missions were confident enough in the Lunar Module and in their own abilities as pilots that they **were eager to attempt landings in valleys surrounded by mountains (e.g., Hadley-Apennine and Taurus-Littrow), and in high-altitude, highland areas (e.g., Descartes) on the Moon.**

- Eventually, political pressure from the scientific community became so intense that **NASA was compelled to place a scientist-astronaut, Dr. Harrison H. Schmitt (a geologist), on the final Moon landing flight, Apollo 17.** Although this created grumbling among the regular test-pilot astronaut corps---because competition for the few remaining slots was fierce---Schmitt performed fine as Lunar Module Pilot on Apollo 17, and made a unique and valuable contribution to the Apollo program as the only geologist that NASA sent to the Moon.

Apollo 15 LMP Jim Irwin at "Hadley Base"

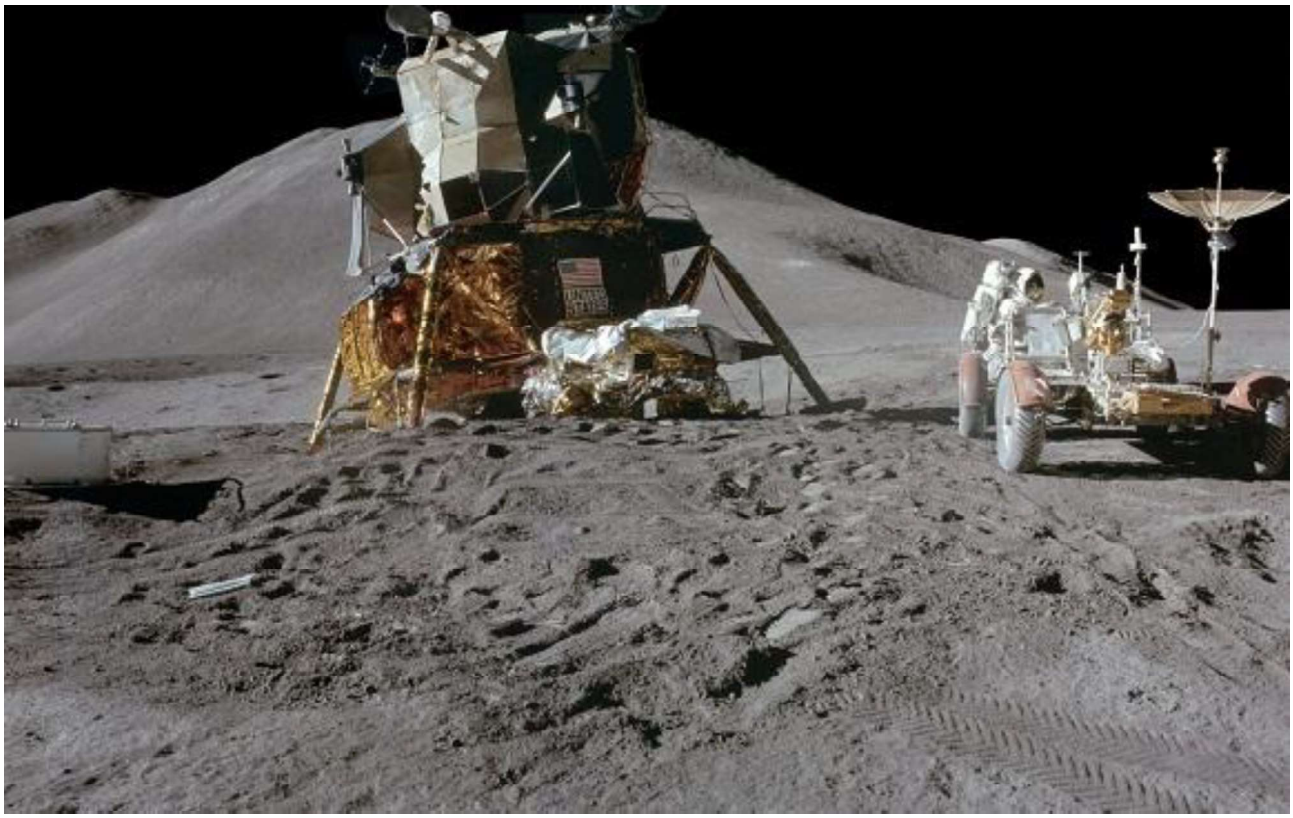
(Photo credit: Commander Dave Scott.)

Apollo 15 Commander Dave Scott at "Hadley Base"

(Photo credit: LMP Jim Irwin.)

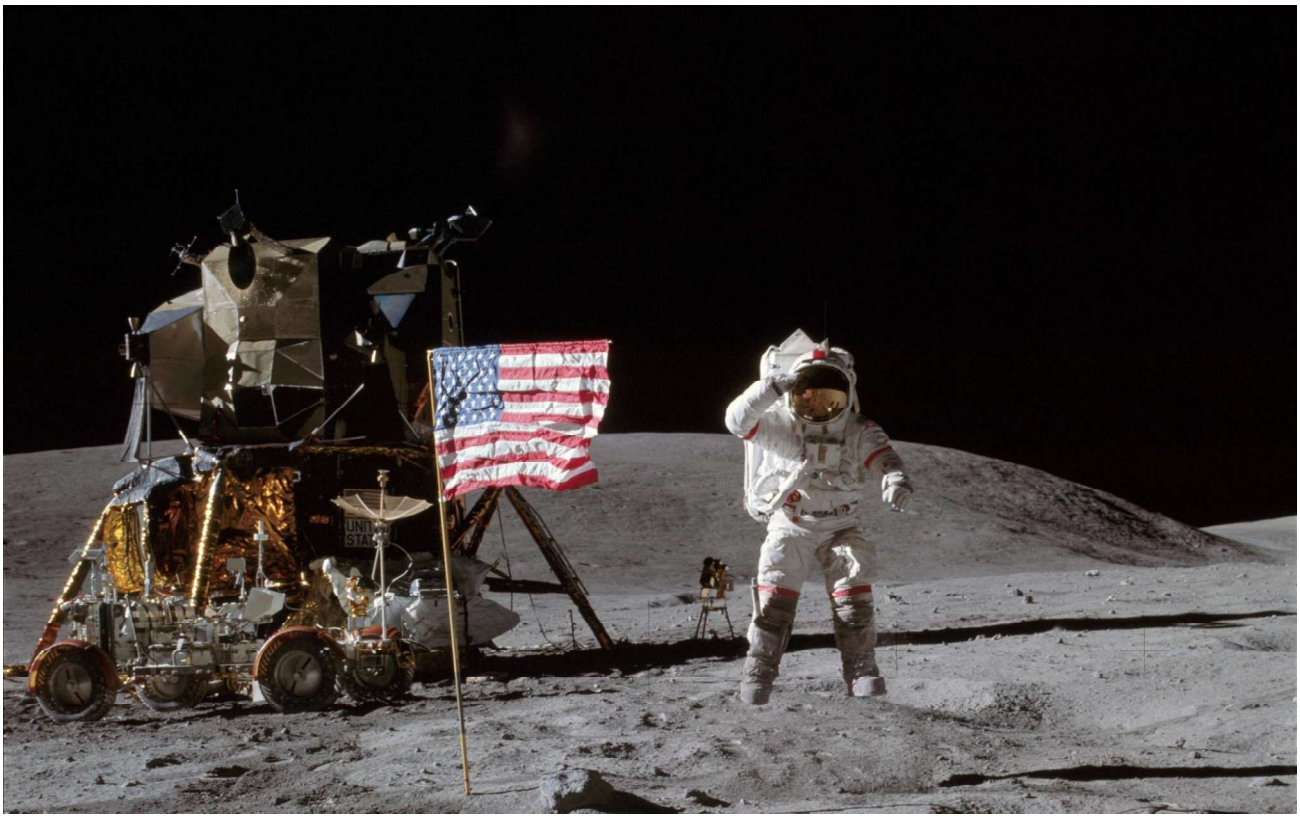
(Mount Hadley towered 14,800 feet above the plain at Hadley Base, and Mount Hadley Delta was an 11,000 foot peak.)

The Lunar Landscape at Hadley Base Was Undulating Terrain, and Was Not Level; Apollo 15 LM "Falcon" Landed on a Slope

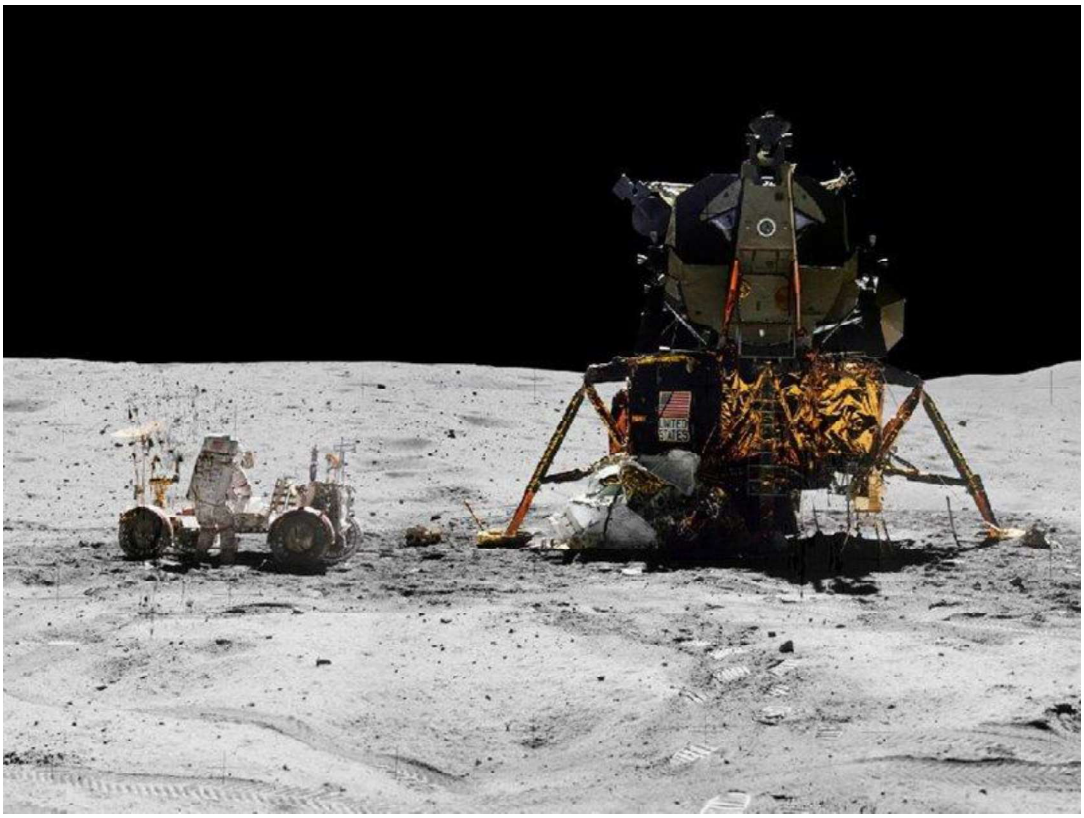


Apollo 16 LM "Orion" Landed at the Descartes Highlands

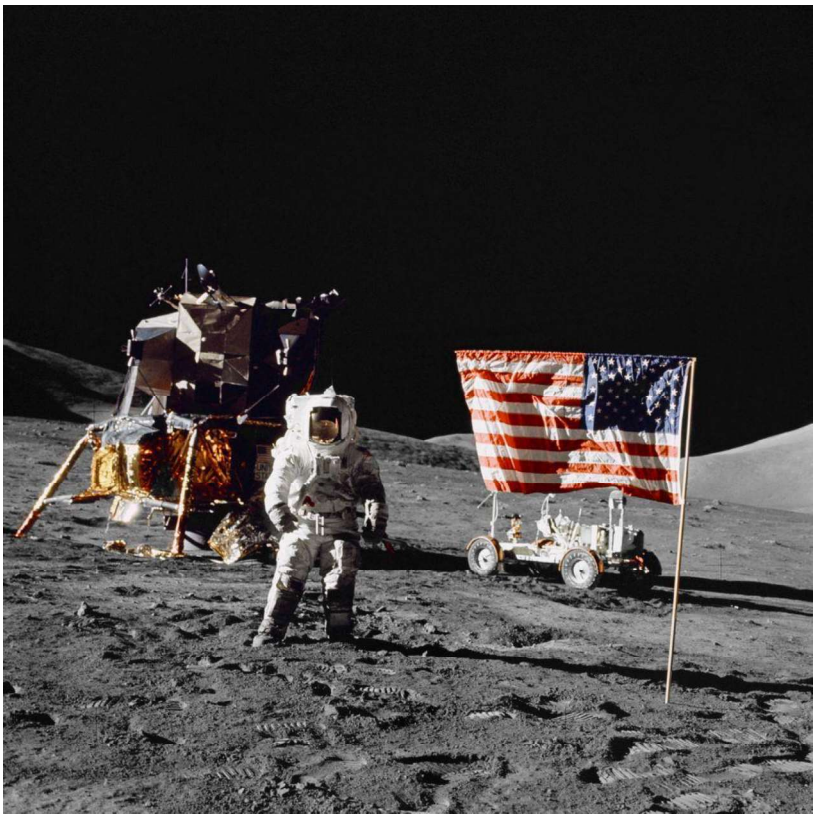
(Lunar geologists hoped to find volcanic sources for craters at Descartes, but did not; one lesson of Apollo is that virtually *ALL* lunar craters were caused by impact.)



“Orion” and the Apollo 16 Lunar Rover at Descartes

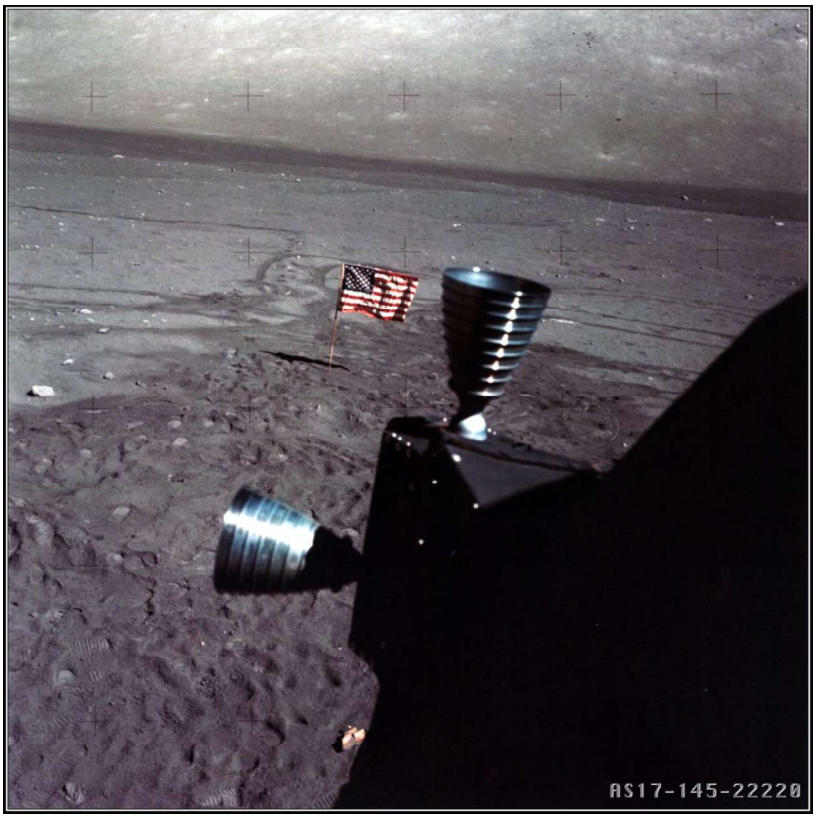


Apollo 17 LMP (and Geologist) Harrison Schmitt at Taurus-Littrow
(Photo credit: Commander Gene Cernan.)



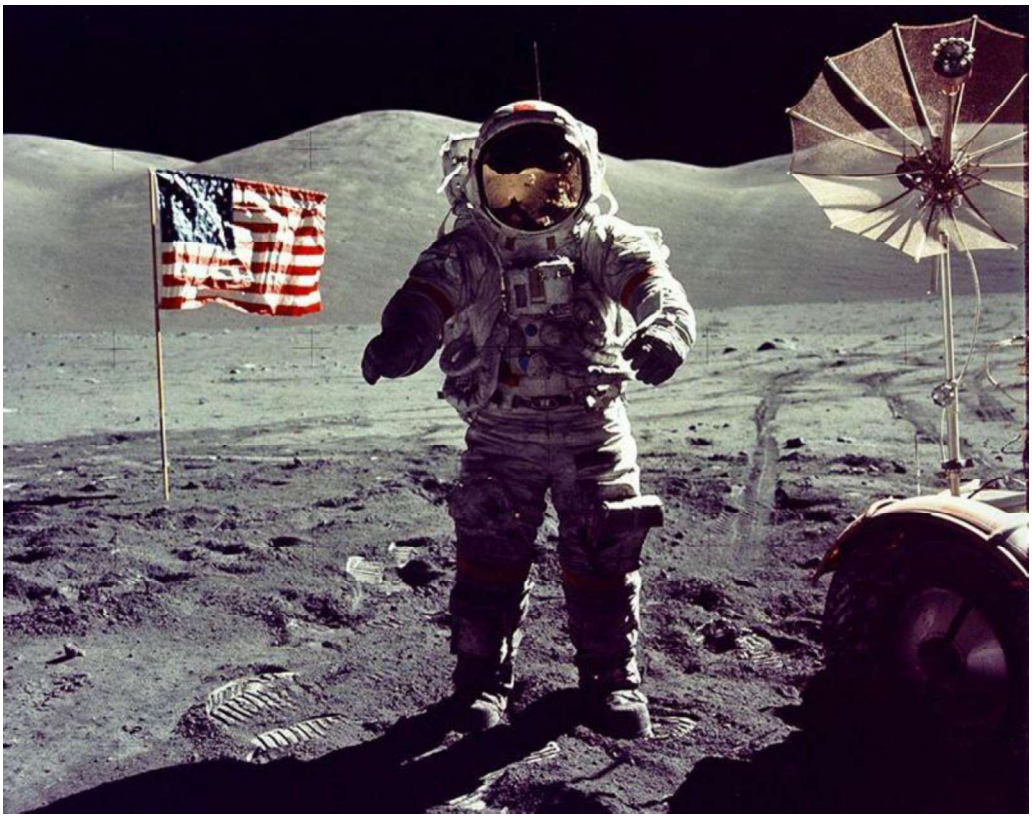
A View Out the Window of Apollo 17 LM "Challenger" at the Taurus-Littrow Valley and Surrounding Mountains

(The nearby mountains were as high as 7,500 feet in altitude.)



Mission Commander Gene Cernan at Taurus-Littrow

(Photo credit: LMP Harrison Schmitt.)

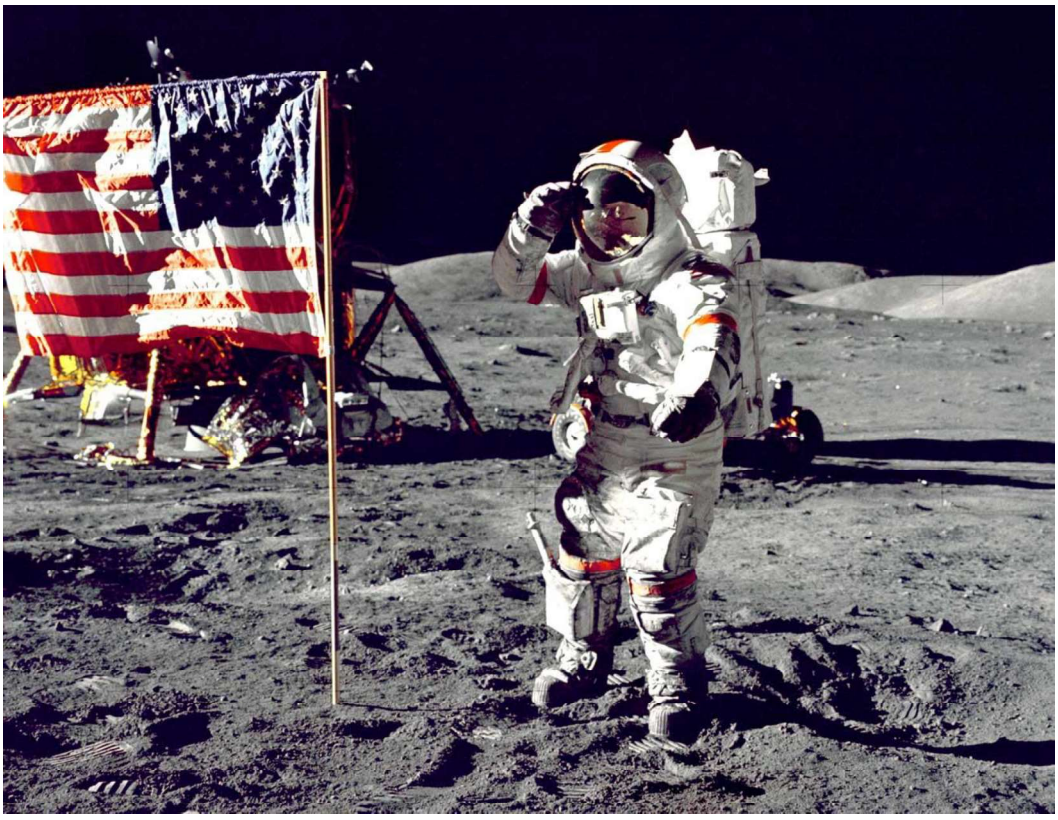


Apollo 17 Geologist "Jack" Schmitt at Taurus-Littrow

(Notice how the lunar regolith clings to the outer beta-cloth layer of the Apollo space suit.)

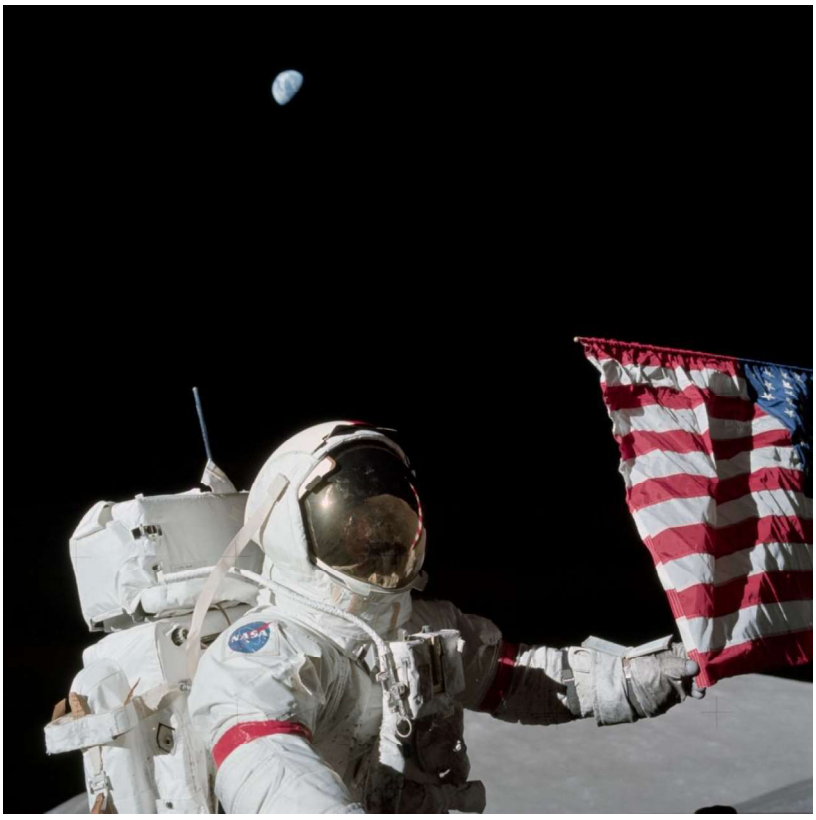
Apollo 17 Commander Gene Cernan Salutes the American Flag at Taurus-Littrow, To Honor the Nation and People Who Sent Him There

(Photo credit: LMP Harrison "Jack" Schmitt.)



Apollo 17 Commander Gene Cernan at Taurus-Littrow

(Photo credit: LMP Harrison "Jack" Schmitt.)



Apollo 17 Geologist Harrison Schmitt at Taurus-Littrow
(Photo credit: Commander Gene Cernan.)

The Grandeur of Taurus-Littrow Valley

(Commander Gene Cernan in the LRV, Lunar Module *"Challenger,"* and the Panoramic Backdrop of the 7,500 foot South Massif at Taurus-Littrow.)

The Apollo 17 Crew at "Shorty" Crater in the Taurus-Littrow Valley

(Note the orange soil in several locations in the photo. Geologists had hoped to find evidence of craters formed by lunar volcanism, since they had not done so at Descartes; but they did not. The failure to find volcanic caldera, at either Descartes or Taurus-Littrow, forced lunar geologists to concede that the Moon's craters were formed by impacts, not by volcanism.)