Air and Space this Week

Item of the Week

APOLLO 16: FIFTY YEARS AGO

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Apollo 11 *was the first;* Apollo 17 *was the last.* Apollo 12 *visited* Surveyor 3*;* Apollo 15 *was first to rove.* Apollo 13 *almost ended tragically;* Apollo 14 *got us back on track. But what of* Apollo 16? *What is its legacy? More than you might think!*

Since the 50th anniversary of the landing of Apollo 16 *is this week, it is my choice for the Item of the Week. Of course, the Apollo program in general, and any Moon landing specifically, is much, too much, for a short synopsis, but I hope you enjoy the summary below.*

THE DECISION TO GO TO THE MOON

A confluence of reasons led to the success of the Apollo program. Political, economic, and social factors were all in play. The Cold War, the Space Race that began with the launch of *Sputnik 1*, the Cuban Missile Crisis, a genuine interest in Scientific advancement, and more were factors, and the debate on which was more important can go on a long time. Three things are certain, however. The money and human capital invested in the Moon missions has repaid us many, many times over in dollars, jobs, education, and national prestige! A tremendous amount of good science was conducted, and we know much more about our home planet now than we would have without Apollo. And the Nation turned to and answered the call when President Kennedy challenged us to "… go to the Moon, before the decade is out…"!

OPERATIONAL CONSTRAINTS

A number of overarching criteria based on engineering, safety, and other factors restricted the choice of potential lunar landing sites. NASA created a Site Selection Board in 1966, charged with the selection of the best landing sites from a scientific perspective, but constrained by the following considerations (from here, with my comments in brackets):

Smoothness of the area: The sites should have relatively few craters. [Craters and their blocky ejecta could pose a hazard to the landing.]

Approach paths: There should be no large hills, tall cliffs or deep craters which could cause incorrect altitude signals to the landing radar.

Propellant: The sites were selected to allow for the expenditure of the least amount of propellant. [Landing fuel was limited, and a reserve was needed to allow the landing astronauts to avoid dangerous conditions that were too small to detect ahead of time. *Apollo 11* really needed their reserve; they almost ran out of fuel just before landing!]

Recycling during countdown: The sites were selected to allow for the recycling time of the Saturn 5 if the countdown were to be delayed.

Free-return: the sites must be within reach of the Apollo spacecraft in the free-return trajectory, that is a path that would allow a coast around the Moon and safe return to Earth without any engine firings should a problem arise on the way to the Moon. [Later Apollo missions relaxed this requirement a bit and allowed for a non-free-return to approach the Moon; doing so almost did in *Apollo 13*…]

Lighting: For optimum visibility during the landing approach, the Sun angle should be between 7 and 20 degrees behind the LM; for any given site, this results in a one-day launch window per month. [Low Sun means long shadows, making obstacles easier to see.]

Slope: The general slope of the landing area must be less than 2 degrees. [The Ascent Stage of the LM could not handle a non-vertical (or nearly so) take-off safely.]

A far side landing site was so unsatisfactory that it wasn't mentioned in the criteria list. Communications with Earth was line-of-sight, making the landing unobservable by Mission Control – and the worldwide audience!

The ASSB returned five candidate sites; only two of which were actually flown.

The work of the ASSB was followed up two years later by the Group for Lunar Exploration Strategy, who considered and evaluated nine potential landing sites. Farouk El-Baz was Chair (he would later be a founding member and force behind NASM's Center for Earth and Planetary Studies). Their report is large (8 MB); see References. Two of the nine sites they evaluated, Hadley Rille and the Marius Hills, were visited by *Apollos 15* and *17* respectively.

LANDING SITE SELECTION STRATEGY

Engineering and operational constraints dictated the landing sites of *Apollo 11* and *12*, as discussed in more detail below.

Apollo 13 would be the first to land in a scientifically-important area, so much so that *Apollo 14* was sent to 13's intended site.

The near side of the Moon is marked by a number of interesting geological areas. The most visibly-dramatic are several large impact basins, including Mare Imbrium, Serenitatis, and Tranquilitatis. Each of them spewed ejected material over a large area in a layer that could be identified and mapped from pictures acquired from the Lunar Orbiter missions. Imbrium was the youngest, based on the population of craters on its surface.

Geologist always try to work out the geological history of an area by first understanding the processes that have shaped the surface and zone beneath, and then by determining just when in time those processes operated.

The Earth's surface is very active, and erosional, tectonic, and volcanic forces cause alteration on time scale small compared to geologic time. The surface we see today is the result of the interplay of forces that create uplift and those that destroy uplifted materials. Therefore, features like impact craters are obliterated quickly on Earth; very few are young enough to still have their original crater form (think Meteor Crater in Arizona). The other few hundred impact craters known to us are really the eroded roots of a long-gone crater.

The Moon, however, has no atmosphere or hydrologic cycle, so its surface remains largely unchanged for very long periods of time. The Moon's surface retains craters much longer than on Earth, and we can get a pretty good idea of how old different surfaces are on the Moon by counting the number of craters they contain – the more craters, the older the surface.

We could see that the material ejected from Imbrium and other large craters had fewer craters than the surround surface, and was therefore younger, but we could not give an age in years, since we didn't know the cratering rate. We could only show the relative ages between the surfaces. This isn't rocket science; anything covered by Imbrium ejecta was older than Imbrium, and anything on the Imbrium ejecta had to be younger! The only way we could get actual ages would be to collect samples of the basin ejecta and bring it back to Earth to be dated accurately. Getting that sample was one of the most important objectives for *Apollo 13*; so much so that *Apollo 14* was tasked with getting the samples when *Apollo 13* failed.

Geologists break down Earth's geologic history into Eras and Periods based primarily on fossils of paleo-life. For the Moon, the breakdown is based on larger-scale events, like the formation of the Imbrium Basin. Very young craters, post-dating Imbrium and still having a "pristine" look were considered to have the same approximate age as the crater Copernicus. Other craters, still younger than Imbrium but having undergone some erosional degradation, were considered to have the same approximate age as the crater Eratosthenes. Imbrium ejecta marked the age boundary line between Copernican and Eratoshenean and older materials/surfaces.

Ejecta from the Serenitatis Basin was similarly important as a widespread dividing age between materials older than Imbrian. Geologists really wanted to put an actual age on its ejecta, too. Markers like those were not the only scientific objects worth a mission, and the planning process got torqued a bit during the Apollo Program because the final three missions were cancelled.

SKILL BUILDING

One does not merely walk down to the Spacecraft Store, buy a Moon rocket off the rack, and head on out. There were many technological and operational developments and skills that had to be perfected first!

PRE-APOLLO

NASA tailored the Mercury and Gemini programs to provide those basic skills. When JFK gave NASA the charge to land a person on the Moon "before the decade is out," they rolled up their collective sleeves and planned a series of progressively-advanced missions that would accomplish the mission. [I would pedantically point out that NASA landed on the Moon with a year and a half to spare, because 1970 is, technically, part of the 1960s, for the same reason that the present Millenium started on January 1, 2001, not 2000! However, in the Court of Public Opinion, that would have been an unsatisfactory excuse! Moot point anyway.]

Project Mercury showed us how to build a capsule, spacesuits, and the other infrastructure needed to put humans into low Earth orbit safely.

Project Gemini showed us how to build more robust spacecraft, capable of operation in Space for up to two weeks (longer than the typical Moon mission would require), and to rendezvous with other objects in orbit and even dock with them.

The first four manned Apollo missions were a shakedown of the Apollo Command/Service module (Apollo 7), actually leaving Earth orbit and orbiting the Moon (Apollo 8), a test of the Lunar Module (Apollo 9), and a full dress-rehearsal without landing on the Moon (Apollo 10). Apollo 8 was originally scheduled to be for the test of the Lunar Module in Earth orbit, but delays in the development and delivery of the LM required that the objectives of Apollos 8 and 9 be switched.

THE FIRST TWO

Some skills remained to be developed for the scientific success of the Apollo program could be assured. We had to be able to land on the Moon and successfully return, and we also had to be able to land exactly where we wanted to, otherwise, any scientific planning would become useless.

Apollo 11's objectives were, therefore, rather simple: Land on the Moon, collect a few rocks, plant the Flag, and return safely, thereby fulfilling JFK's pledge. The mission was a resounding success!

Apollo 12's objective was similar, but to also land in the location planned, within walking distance. And that proved to be a problem for planners.

The five Lunar Orbiters all performed well, and sent back many pictures of the potential Apollo landing sites. But seeing them from orbit was one thing, being able to navigate the surface was another one entirely. There was no lunar GPS or other aid to precise navigation, so how would *Apollo 12* astronauts fine-tune their landing, and how could Mission Control be certain they had landed on the intended spot?

The Lunar Orbiter satellites were not the only Moon missions sent out during the mid-60s; there was also a series of soft landers that were to characterize the lunar surface from up close. They were called (Lunar) Surveyors, and unlike the Orbiters, they had several failures in the seven landing attempts. One of the successful ones was *Surveyor 3*, which landed in the Ocean of Storms in 1967. We knew exactly where it had landed, so it would make an ideal target for the *Apollo 12* landing, too, to demonstrate we could land where we wished. Not only did *Apollo 12* land very near *Surveyor 3*, its Moonwalkers (Conrad and Bean) visited the *Surveyor 3* and removed its camera and other pieces for analysis on Earth to see how well they stood up to over two years on the harsh lunar surface. The *Surveyor 3* camera is now in the collection of the National Air and Space Museum and was one of my most favorite of artifacts in the entire NASM collection!

***APOLLOS 13* AND *14*: DATING IMBRIUM**

The importance of the acquisition of samples of the material ejected from the Imbrium Basin during its formation gave the Apollo 13 mission its destination, an area outside Imbrium near a crater known as Fra Mauro. After the failure of the mission, the Apollo program underwent a brief hiatus to figure out and correct the problem, and make other upgrades.

Mercury veteran L. Gordon Cooper had been slated to be the commander of the Apollo 14 mission. Gus Grissom had died in the tragic *Apollo 1* fire; Wally Schirra had commanded *Apollo 7*; Scott Carpenter had left NASA; and John Glenn and Alan Shepard had gone off flight status during Gemini for medical reasons. NASA had taken a black eye with *Apollo 13*, ameliorated only by the safe return of its intrepid crew. NASA wanted Apollo 14 to restore its lunar momentum, and that meant having a well-known mission commander. Shepard had largely recovered from the medical problem (Meniere's Disease) that had kept him out of Gemini, so he ended up getting the Apollo 14 commander assignment. Cooper left NASA soon thereafter.

[PERSONAL: In my opinion, and strictly only in my opinion, Shepard was a poor choice. He was far more concerned about piloting than science, and frankly, did not adequately train as hard the other Moonwalkers for the tasks that would face him on the lunar surface. He also was less physically fit than he should have been. He got lost on the Moon, not in the sense that he couldn't find the LM, but he couldn't find some of the specific sampling sites the scientists selected, and he got so winded looking around that his EVA was curtailed.]

Apollo 14 would be the last of the first-generation lunar missions. Apollos 15-17 would use an upgraded "extended lunar module," and be termed "J-class" missions. The ELMs had the capability of staying on the lunar surface longer than the original LMs and carried the Lunar Roving Vehicle that would allow Moonwalkers to become Moonriders, covering much more ground than they could on foot. Here's an illustrative example of the difference: If *Apollo 11* had landed at the Washington Monument, Neil and Buzz would not even have left the National Mall. If *Apollo 17* had landed in the same spot, Gene and Harrison would have been able to drive as far away as the Beltway!

***APOLLO 16*: TO THE HIGHLANDS!**

The Apollo 11, 12, 14, and 15 missions all targeted materials associated with the Imbrium impact and/or post-Imbrium large-scale flows of basaltic rock. None had sampled the older materials found in the lunar highlands.

The Apollo spacecraft, especially after *Apollo 13*, was now a "known quantity," and the ELM and rover had a relatively-flawless performance on *Apollo 15*, so the planners for the Apollo 16 and 17 missions could focus more on science. Another group, the Ad Hoc Apollo Site Evaluation Committee, was convened to consider the best candidates. They recommended a highlands site near the crater Descartes for Apollo 18 and the crater Alphonsus for Apollo 17; the latter was not flown in order to try to get the best science that had been planned previously for Apollos 17-20, and the Descartes site went to Apollo 16. One of the things that made it attractive was the presence of two craters near the landing site that, it was hoped, would have ejected relatively-pristine highlands materials.

Synopsis of Results

The mission planners were looking to test the hypothesis that the lunar highland material was produced by volcanic activity. Sometimes Science marches onward on the back of a negative result, and this was one of those times. The A16 Moonwalkers did recover two anorthosite samples that were representative of highland material. They covered almost 17 miles on their LRV traverses, deployed nine lunar instruments, and brought back 212 pounds of lunar material for analysis.

The anorthosite rocks returned by Apollo 16 may have disproved the notion that the highlands were volcanic, but they were igneous, a fact that had important implications for the formation and evolution of the Moon. Anorthosites are composed almost entirely of feldspar, and solidify slowly from molten rock deep underground. The prevailing model for the formation of the highlands became one where the Moon was initially largely molten after its formation, with a deep "ocean" of molten rock. As the rock cooled, the heavier components of the melt sank, leaving a feldspar-rich upper layer to solidify last. Subsequent impacts battered the highlands, which accumulated the crater population we see today. Some of the impact ejecta from those impacts scattered material, bits of which were recovered at other Apollo landing sites. Later, but still ancient, outpourings of magma that had been relatively-depleted of feldspathic minerals formed the basaltic plains that the early astronomers thought were seas.

Two glitches marred the otherwise wildly-successful mission. The first was an accident that disabled the lunar heat flow experiment, part of the package of instruments to be left on the surface. Knowing the rate at which heat flows from a planet/moon's interior is an important factor in understanding its origin and evolution. Alas, Mission Commander Young tripped over a wire leading to the instrument, which had been driven into the lunar regolith, rendering it beyond repair.

The mission plan called for the *Apollo 16* Ascent Module to be intentionally crashed into the lunar surface to create a "moonquake" that could be detected by seismometers placed previously on the Moon by earlier landings. However, the Module began to tumble uncontrollably, and they had to leave it as-is when they departed lunar orbit; it crashed on the Moon soon thereafter, too far from the seismic stations to be useful.

By the way, Apollo 16's American Flag is still waving proudly over the landing site! See: https://www.history.nasa.gov/alsj/a16/a16FlagStillAloft.html.

THE CREW

Twelve astronauts walked on the Moon; the final footprints made on the lunar surface (for now!) were those left by Gene Cernan of Apollo 17. Alas, there are as of this writing only four left with us: Buzz Aldrin, the *Apollo 11* Lunar Module Pilot; Dave Scott, *Apollo 15* Command Pilot; *Charles Duke*, the Apollo 16 Lunar Module Pilot; and Harrison Schmitt, the *Apollo 17* Lunar Module Pilot.

John Watts Young, was the Command Pilot for *Apollo 16*. He was born on September 24, 1930, in San Fransisco, then his family moved to Georgia during the Depression. His father became a Navy Seabee for WWII, and young Young spent the War years starring in high school sports, graduating in 1948. He then earned a B.S. in Aeronautical Engineering from Georgia Tech before joining the Navy. His midshipman assignment was on the battleship *Missouri* where, oddly, one of his shipmates was future astronaut Thomas Stafford. He applied to be a naval aviator, and eventually was assigned to flight school at NAS Pensacola. After several deployments, he went to Patuxent for flight test in 1959. He was selected in the second NASA astronaut group, and was the pilot for *Gemini 3* (commanded by Gus Grissom) and served on the *Apollo 7* back-up crew and then the was the Command Module pilot for *Apollo 10*. That set him up to be the back-up Commander for *Apollo 13* and then the Commander for *Apollo 16*. After Apollo, Young was the Commander of the first Space Shuttle mission, *STS-1* (which landed on April 14, 1981). He became Chief of the Astronaut Office and commanded *STS-9*. He publicly expressed concern over NASA's safety management in the wake of the *Challenger* disaster, and oversaw the redesign of the Shuttle's solid rocket boosters that caused it. He retired from NASA on December 31, 2004, after 42 years of service, and passed away on January 5, 2018.

Charles Moss Duke, Jr., the *Apollo 16* Lunar Module Pilot, was the youngest of the twelve to walk on the Moon (born October 3, 1935). He graduated from the U.S. Naval Academy in 1957, but transferred over to the then-new U.S. Air Force. He served three years in an F-86 squadron based in Germany, then became a test pilot instructor for the F-101, F-104, and T-33. He selected for the fifth astronaut group in 1966. He is well known for role as Apollo 11 Capsule Communicator, where he responded to "The *Eagle* has landed," with "Roger, Tranquility Base, we copy you on the ground. You got a bunch of guys about to turn blue. We're breathing again. Thanks a lot!" He was the back-up Lunar Module Pilot for *Apollo 13*, which put him in line to be the Prime LM Pilot for *Apollo 16*.

Thomas Kenneth Mattingly II was the Command Module Pilot for *Apollo 16*. He was born in Chicago on March 17, 1936. His father was a pilot for Eastern Airlines, and young Ken was smitten by aviation from an early age. He obtained a B.S. in Aeronautical Engineering from Auburn, and then joined the Navy (which would give *Apollo 16* an "all-Navy" crew). He flew a number of aircraft types from carriers. He accompanied a colleague on a reconnaissance flight for the launch of *Gemini 3* (Young's mission), and then applied for flight test at Patuxent. He was not accepted, but did get a place in flight test at Edwards AFB. He was selected for NASA's fifth astronaut group in 1966. He served as Capcom for *Apollo 8*, back-up Command Module Pilot for *Apollo 11*, and was slated to be the Command Module Pilot for *Apollo 13*. He was removed from that flight because of a possible exposure to measles and was replaced by Jack Swigart. He was then assigned to be the Command Module Pilot for *Apollo 16*. After Apollo, Mattingly commanded *STS-4*, the final crewed test flight of the Shuttle before it went fully operational. He also commanded *STS-51C*, the first DoD Shuttle mission. He retired from both the Navy and NASA in 1986, with a number of important honors.

BUT WAIT….

Didja Know that the examination of previously-untouched Apollo samples continues to this day? Well, it is. Two months ago, scientists with the Apollo Next-Generation Sample Analysis team carefully opened a sealed core sample of the lunar surface obtained by Gene Cernan in 1972. The gases released have been sent to several labs for detailed analysis, which will allow a better understanding of the origin and evolution volatiles on the Moon and the history of the Apollo 17 landing site. For more information, see: https://phys.org/news/2022-04-image-apollo-core-sample-vacuum-sealed.html.

And Finally: The U.S. Space and Rocket Center will celebrate the 50th anniversary of the Apollo 16 mission with an event, "Apollo to Artemis," on Wednesday, April 20. The event is sold out, but it will likely draw media coverage. Here is the notice they distributed on April 15 (emphasis theirs):

"April 15, 2022

HUNTSVILLE, Ala. – The U.S. Space & Rocket Center will celebrate the 50th anniversary of the Apollo 16 mission to the moon with an *Apollo to Artemis* event Wednesday, April 20, 2022. Apollo 16 command module pilot Brig. Gen. Charles "Charlie" Duke is the honored guest for the evening under the Saturn V rocket in the Davidson Center for Space Exploration.

In addition to remarks from Charlie Duke, NASA Marshall Space Flight Center Director Jody Singer, and NASA Associate Administrator for Exploration Development James Free will share updates on the Artemis program and next steps on the journey back to the moon and beyond. **Tickets are sold out for this event, so this is for media planning purposes.**

The Rocket Center will also highlight the Apollo and Artemis missions with a Lockheed Martin-sponsored Apollo to Artemis Earth Day, with hands-on activities highlighting the achievements of the Apollo era, Friday, April 22, from 10 a.m. to 4 p.m. NASA Marshall Space Flight Center, the National Space Society and the HAL5 Society will also have activities and information about the Artemis program. The Apollo to Artemis Earth Day event is included in museum admission.

The week caps off with a special Cocktails and Cosmos in the *INTUITIVE*® Planetarium at 7 p.m. The show focuses on the Descartes Highlands, an area Apollo 16 astronauts explored with the Lunar Rover Vehicle, increasing our knowledge of the lunar surface. More information and tickets are available at rocketcenter.com.

Apollo to Artemis media opportunities: Media are invited to attend Charlie Duke's presentation to Space Camp students, Wednesday, April 20, at 1:30 p.m. Brig. Gen. Duke will also be available to speak to the media at 2 p.m.

Media is also invited to cover the dinner at 7. To reserve a spot at the media table for dinner, please contact Pat Ammons by Monday, April 18."

OK, ONE MORE!

The *Sky and Telescope* website just posted a piece called, "Apollo 16 in Pictures: 'The Most Dazzling Place.'" It's a series of photos associated with the mission, with abundant documentation and analysis. ***The pictures are fantastic – Check it out here: https://skyandtelescope.org/astronomy-news/apollo-16-pictures-the-most-dazzling-place!***

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NASA SP-4223: "Before the Decade is Out": https://history.nasa.gov/SP-4223/contents.htm and its annotated bibliography: https://history.nasa.gov/SP-4223/biblio.htm

NASA History Series: https://history.nasa.gov/SP-4223/series.htm

Operational Constraints and Landing Site Selection Strategy

NASA ASSB: https://www.nasa.gov/feature/50-years-ago-lunar-landing-sites-selected

Lunar Module: https://en.wikipedia.org/wiki/Apollo_Lunar_Module

Group for Lunar Exploration Planning: https://www.hq.nasa.gov/alsj/alsj-SiteSelection.html

Apollo 16

Wikipedia: https://en.wikipedia.org/wiki/Apollo_16 [A very thorough treatment!]

NASA: https://history.nasa.gov/SP-4029/Apollo_16a_Summary.htm

NASA: https://solarsystem.nasa.gov/missions/apollo-16/in-depth

Apollo Flight Journal: https://history.nasa.gov/afj

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The Crew

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