NASA's Apollo and Artemis Missions to the Moon

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via ZOOM

Welcome! This course will convey many of the stories and major scientific results from each of the six Apollo missions that landed on the Moon. Videos from the lunar modules during their descent to the lunar surface will show what the astronauts saw during their landings, and convey the excitement and intrigue of each mission. The scientific results will be described with minimal jargon. For example, chemical analyses of the Moon's rocks, soils, and glasses show that the most abundant element is oxygen, which is tightly bonded to other elements (e.g., silicon, aluminum, iron, magnesium, and calcium).

Upon completion of the course, it is hoped that the extraordinary accomplishments of the Apollo program will be understood and appreciated. The goals of NASA's Artemis program for returning American astronauts to the lunar surface will also be described. The web resources listed on page 4 are for your consideration.

Class #1 on March 22, 2021

Introduction to the Space Race (1957-1969)

Russia and the United States competed in a space race that was a quest for international prestige and advancement in rocket technology. Cosmonaut Yuri Gagarin was the first human to orbit the Earth on April 12, 1961. The following month (May 25, 1961) President John Kennedy addressed a joint session of Congress proposing that the United States set the remarkable goal of landing a man on the Moon before the end of the decade. Audacious! The boldness of that vision can be appreciated by noting that the United States did not put the first American into Earth orbit until the next year (John Glenn on February 21, 1962)! During the ensuing years between 1961 and 1968, the Soviets consistently achieved significant achievements in space ahead of the United States. Although the Russians built the huge N1 rocket to send cosmonauts to the Moon, its four unmanned test-flights all resulted in catastrophic failures in 1969-1972. The United States took the lead in the space race in 1968, most notably with the successful mission of Apollo 8 that orbited the Moon on Christmas of that year. NASA's rationale for the risky Apollo 8 mission reflected both (i) the intensity of the competition between the United States and Russia and (ii) American spy satellite images of a Russian N1 rocket.

Apollo 11 mission (16-24 July 1969)

The Apollo 11 mission was a real nail-biter. It marked the first time that humans stepped onto another world. The 13-minute powered descent to the Moon by the lunar module, *Eagle*, was skillfully accomplished by Neil Armstrong, Edwin Aldrin, and engineers at NASA's mission control as the spacecraft landed with less than 20 seconds of fuel remaining. A video with voice-transmissions showing what Armstrong and Aldrin saw during their descent to the lunar surface will be shown during this class. The landing occurred 4 miles away from the intended site in Mare Tranquillitatis (0.67 N, 23.47 E). The causes for that error were subsequently identified and fixed before Apollo 12 would be launched three months later. The Apollo 11 samples (48 pounds) returned to Earth were a diverse trove of rocks and soils. In addition to lavas (3.7 billion years old), analyses revealed that the Moon had undergone global-scale events 4.4 billion years ago.

Apollo 12 mission (14-24 November 1969)

The launch of Apollo 12 was associated with a significant problem that occurred less than 60 seconds after liftoff. The rocket was struck by lightning, which resulted in electrical circuits throughout the Command Module being interrupted during a critical phase of the launch. You will see and hear those tense moments. The lunar module, *Intrepid*, landed at the intended site in Oceanus Procellarum (3.01°S, 23.42°W). Astronauts Pete Conrad and Alan Bean conducted two Moon walks during which they collected samples (76 pounds) of ancient lava flows (3.3 billion years old) and soils, and also set up a complex set of scientific instruments.

Class #2 on March 29, 2021

***Apollo 13 mission* (11-17 April 1970)**

Apollo 13 suffered a catastrophic failure while traveling to the Moon. Heroic efforts by the astronauts (Jim Lovell, Fred Haise, Jack Swigert), NASA engineers, and aerospace contractors resulted in the safe return of the crew. Since Apollo 13 did not land on the Moon, it will be only briefly covered in this course. Nonetheless it was a remarkable success that captured much of the world's attention during the nearly week-long ordeal. The 1995 movie entitled *'Apollo 13'* (Ron Howard, Director) captured the challenges and heroism of this mission.

***Apollo 14 mission* (31 January – 9 February 1971)**

The Apollo 14 lunar module, *Antares*, landed at the intended site on Fra Mauro (3.65°S, 17.47°W). Astronauts Alan Shepard and Edgar Mitchell conducted two Moon walks, collected samples, and set up instruments. Shepard was not only the first-and-only millionaire to visit the Moon, but also was the first to hit golf balls (2) on the Moon. Although astronaut Shepard said at the time that the balls had traveled "miles and miles", they in fact went less than 30 yards. The 94 pounds of samples from this site contained information about much of the Moon's history in that area.

***Apollo 15 mission* (26 July – 7 August 1971)**

Apollo 15 was the first of three so-called 'J missions' that used an electric rover for transporting the astronauts during their 3 Moon walks in the Hadley-Apennine region (26.13°N, 3.63°E). Videos of the landing and ascent of the lunar module, *Falcon*, will be shown. The lunar module landed with an orientation that caused initial concern. The samples collected (170 pounds) by astronauts David Scott and Jim Irwin, as well as the instruments they deployed on the surface, provided a wealth of new information about the Moon. Apollo 15 returned the so-called 'Genesis Rock' and the 'Seat Belt Rock', the significance of which will be discussed.

Class #3 on April 5, 2021

***Apollo 16 mission* (16-27 April 1972)**

The landing of the Apollo 16 lunar module, *Orion*, was delayed for nearly six hours due to failure of the lunar module's steerable antenna. It landed in the ancient Descartes highlands (8.99°S, 15.51°E). Astronauts John Young and Charlie Duke explored the area during their three Moon walks with the use of an electric rover and collected 211 pounds of samples that were returned to Earth. Although the area had been originally thought to be ancient lava flows, the samples were not volcanic in origin and were far more complex and interesting, as will be evident in the images to be shown in the course. This region contained pieces of the 4.4 billion year old crust.

***Apollo 17 mission* (7-19 December 1972)**

The Apollo 17 was the only nighttime launch of a Saturn V rocket that was utterly spectacular! John Delano witnessed the launch near Cape Canaveral and will recount his personal experience. A video of that launch, as well as 'colorful' comments by the crew during the launch, will be presented. The Apollo 17 astronauts (Gene Cernan and Jack Schmitt) landed the lunar module, *Challenger*, in the Taurus-Littrow Valley (20.18°N, 30.76°E). The 'Orange Soil' was found during the second of three Moon walks. Video of its discovery will be shown, and its scientific significance discussed. The suite of soil and rock samples (244 pounds) deepened our understanding of the Moon's origin and history. This was the last Apollo mission to the Moon, and the only mission to have a scientist (Schmitt; Ph.D. in Geology from Harvard University).

***Artemis program* (currently in development)**

The Artemis program is a multinational effort led by NASA to return astronauts to the Moon. The United States and China are independently planning to establish scientific bases on the Moon. Prime real estate for a lunar base has been identified on the rim of Shackleton crater located near the Moon's south pole. The scientific and engineering rationales for that specific site will be presented. In December 2017 the Trump

administration issued its 'Space Policy Directive 1' that called for NASA to return American astronauts to the lunar surface by 2024, which was four years ahead of the previous goal that NASA had been working toward. As of March 2021, some of the essential systems needed to achieve that goal by 2024 have yet to even be designed. Although the Biden administration has affirmed its support for the Artemis program, Congress has not approved the level of funding required to achieve the 2024 goal.

China, India, Israel, and the United States are currently designing and building robotic landers to search for resources, including water ice, on the Moon. China has successfully landed three robotic spacecraft on the Moon (Chang'e 3 in December 2013; Chang'e 4 in January 2019), including a robotic mission that returned samples to Earth (Chang'e 5 in December 2020). In 2023-2027, China has three more robotic missions planned to explore the resource potential of the Moon's south polar region. NASA, in collaboration with commercial partners, is scheduled to begin sending robotic landers to the Moon in late 2021 as a prelude to sending astronauts.

Some of the questions that have been largely answered from analysis of Apollo samples

How and when did the Moon form? What is the significance of the light- and dark-colored areas of the Moon's nearside that form 'The Face'? How old are the lunar samples? How deep inside the Moon did the samples come from? What caused all of the craters on the Moon? Is the Moon's orbit changing? Is the Moon still active? What makes Shackleton important as a key-site for a lunar outpost? Are samples from the Moon much different from those on the Earth? Are there any other sources of samples from the Moon, besides those collected by the Apollo astronauts? What kind of challenges will astronauts encounter during extended visits? What caused the Earth to be tipped on its rotation axis by 23°? Why are gold and platinum, although costly, still affordable? Why are no stars visible in photographs taken by the Apollo astronauts from the lunar surface? How would the Earth be different if the Moon had not been formed? Were any new elements or isotopes found on the Moon? How long will the astronauts' footprints remain? Does the Moon have substantial quantities of water anywhere? Does the Moon have a metallic core? Did the Moon ever have a magnetic field?

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5-part documentary about the Soviet N-1 Moon rocket and development of its closed-cycle engines

*** *The engines that came in from the cold* ***

Although the United States won the race to the Moon, the Soviet Union attempted to develop the largest and most powerful rocket to accomplish the same feat. The Soviet N-1 Moon rocket failed catastrophically in all four launch-attempts during 1969 – 1972. The films and images of the four N-1 launch-failures in this documentary are vivid! Engineering challenges associated with the development of closed-cycle engines were the cause of these launch-failures. The first stage of the N-1 rocket used a cluster of 30 engines to develop nearly 9 million pounds of thrust. When these engines were nearing final development in 1974, the Soviet Politburo abruptly cancelled the Soviet Moon program. Although the Politburo ordered the N-1 rocket and its stock-pile of engines to be destroyed, the chief engineer had the engines secretly stored in a ware house. Twenty years later, these NK-33 engines, and the RD-180 follow-on, were purchased by an American aerospace corporation in the 1990's for use in many commercial launches from Cape Canaveral.

The remarkable story of the Russian N1 program is described in the five-part documentary. Interviews with Russian engineers, NASA officials, and American aerospace engineers provide a glimpse into the once secretive Russian efforts to land cosmonauts onto the Moon. The total length of this extraordinary documentary is 50 minutes.

Part 1: (10 minutes)
https://www.youtube.com/watch?v=vEegtzZMx6c

Part 2: (10 minutes)
https://www.youtube.com/watch?v=79EPZVRME5k

Part 3: (10 minutes)
https://www.youtube.com/watch?v=Amz6VjJEWKU

Part 4: (10 minutes)
https://www.youtube.com/watch?v=Ldh7sZuby0o

Part 5: (10 minutes)
https://www.youtube.com/watch?v=a2SE03yjNzA

Apollo websites

Failure is not an option: A flight control history of NASA (90 minutes) - Interviews with Gene Kranz, Christopher Kraft, and others who vividly describe the history of NASA's Mercury, Gemini, and Apollo missions. https://www.youtube.com/watch?v=7f51Jzm7M4w

Neil Armstrong: First man on the Moon (60 minutes) - Following his death in August 2012, this touching biography of Neil Armstrong was produced using films and interviews with his two wives, brother, sister, sons, close friends, and fellow astronauts. https://www.youtube.com/watch?v=CD-OcW3Qhjg

A rare, in-depth interview with Neil Armstrong in 2011 (50 minutes)
https://www.youtube.com/watch?v=KJzOIh2eHqQ

NASA remembers Neil Armstrong (13 minutes) https://www.youtube.com/watch?v=1pQKZc2AXW0

Video from Apollo 11 lunar module, *Eagle*, showing the descent and landing on the Moon (15 minutes)
https://www.youtube.com/watch?v=RONIax0_1ec

Lunar module pilot, Edwin 'Buzz' Aldrin, talks about the Apollo 11 mission (10 minutes)
https://www.youtube.com/watch?v=9HvG6ZlpLrI

Excellent BBC series about the Apollo 11 and Apollo 13 missions to the Moon: *13 Minutes to the Moon* (more than 20 episodes) https://www.bbc.co.uk/programmes/p083t547

Extensive archive of Apollo images, audio files, video files, and books: http://www.apolloarchive.com/

Descriptions of all samples collected by the six Apollo missions: https://curator.jsc.nasa.gov/lunar/index.cfm

Photomicrographs of Moon rocks: https://www.virtualmicroscope.org/collections/apollo

Description of the Apollo Guidance Computer (1 hour, 21 minutes): https://youtu.be/B1J2RMorJXM

NASA acronyms used during the powered descent of lunar modules to the Moon's surface

(You will hear many of these acronyms during the communications between the Apollo astronauts and NASA's Mission Control Center as the lunar modules descended to the Moon's surface.)

AGS: Abort Guidance System (pronounced 'aggs')

'Bingo' call: If the quantity of fuel in the descent stage of the lunar module became dangerously low, the Commander (Armstrong) must land in 20 seconds or abort. The rule was as follows: **(i)** If the lunar module was hovering 50 feet above a good landing site on the Moon, then the Commander could continue to land; **(ii)** If the lunar module was hovering at 70 to 100 feet above a good landing site on the Moon, it would be risky to land due to the likelihood of exceeding the limiting load of the landing gear; **(iii)** If more than 100 feet above the lunar surface, the Commander was required to hit the abort button, and return to lunar orbit.

Contact Light: At the bottom of three of the four pads on the lunar module's legs were 5-foot-long probes. When those probes touched the lunar surface, the crew was to turn off the descent engine and fall the 5 feet to the Moon's surface. The concern was that the Commander (Armstrong) might lose sight of the surface due to the blowing dust and jeopardize the landing.

Delta H: Difference in altitude of the lunar module above the Moon's surface indicated by two, independent, on-board instruments (AGS and PNGS) during the lunar module's powered descent.

Descent Quantity Light: A warning light indicating that less than 5% fuel is left in the lunar module's descent engine.

FIDO: Flight Dynamics Officer (pronounced 'fy-do') at NASA Mission Control Center in Houston

LPD: Landing Point Designator. The Commander (Armstrong) looks through a set of scribe marks on his window. The value for the LPD angle, which Lunar Module Pilot (Aldrin) gave Armstrong from the PGNS, told the Commander where to look along the vertical scale to observe the place where the computer taking them to land. Armstrong saw that the place was not suitable for a landing, and took manual control to fly the Lunar Module to a better landing site.

MCC: Mission Control Center at NASA Johnson Space Center in Houston, TX

MSFN: Manned Space Flight Network (pronounced 'miz fin') is the system for communicating between the spacecraft and NASA's Mission Control Center.

PDI: Powered Descent Initiation begins the 13-minute descent of the lunar module (Computer Programs 63, 64, and 66) to the lunar surface from an initial altitude of 50,000 feet.

PGNS: Primary Guidance and Navigation System (pronounced 'pings')