AIAA

AEROSPACE MICRO-LESSON

Easily digestible Aerospace Principles revealed for K-12 Students and Educators. These lessons will be sent on a bi-weekly basis and allow grade-level focused learning. - AIAA STEM K-12 Committee.

THE LATER APOLLO PROGRAM

The Apollo project did not end with Neil Armstrong's landing on the moon and his and Buzz Aldrin's successful return to Earth. Six more Apollo missions sent astronauts to the Moon, with five of them landing successfully. Another Apollo launch did not go to the Moon, but instead docked with a Soviet Soyuz space capsule in Earth orbit, illustrating—now that the race to the Moon was over—a desire of the American and Soviet space programs to work together more. Finally, some left-over Apollo hardware was transformed into Skylab, America's first space station. This lesson describes these later efforts.

Next Generation Science Standards (NGSS):

- Discipline: Engineering Design
- Crosscutting Concept: Influence of Science, Engineering, and Technology on Society and the Natural World
- Science & Engineering Practice: Planning and Carrying out Investigations

GRADES K-2

K-2-ETS1-3. Analyze data from tests of two objects designed to solve the same problem to compare the strengths and weaknesses of how each performs.

While many people know that crews from the Apollo program and later NASA missions were trained in science and mathematics, they may not realize that there was an artist on the moon. Astronaut Alan Bean was the Lunar Module Pilot on the Apollo 12 mission and walked on the Moon. He went on to participate in the Skylab program, serving as commander of the second mission and spending 59 days in space.

But he was also an artist and his fellow astronauts encouraged him to use those skills to share what he had seen. In 1981, he retired from NASA to devote his time to painting scenes of the lunar mission and his fellow explorers on the moon's surface. You can see many of his paintings and read brief stories about them on his website. There are also several short videos about him, such as Astronaut Alan Bean: Moonwalker, Skylab Commander, Artist and Astronaut Alan Bean in his studio. Besides his personal connection to the subject of his artwork, his methods were also unusual. To add a bit more of the lunar landing experience to the paintings, he sometimes covered the canvas in modeling paste and then used a space boot and the geological hammer he used on the moon to add texture to the image. Imagine stomping, hammering, and scraping your paintings to give them

more of the feel of those experiences.

GRADES K-2 (CONTINUED)

As he says in his interview, wouldn't it have been great if Columbus had brought an artist along on his voyage so that we could see what the other ships' captains looked like, what the sailors looked like? Alan Bean has done that service for us, preserving his memories and impressions of the Apollo moon landings for future generations. (Images above show Bean and Pete Conrad locating the Surveyor III lunar probe and Bean on a spacewalk during his Skylab mission.)

You may wish to read the picture book biography, The Astronaut Who Painted the Moon by Dean Robbins, with your class.

GRADES 3-5

3-5-ETS1-2. Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.

Science data from the Apollo missions is still being used in current research. Moonquakes recorded from seismometers placed on the lunar surface by Apollo missions are still being analyzed. A new theory suggests that the quakes are caused by slippage along fault lines; to test the theory, scientists went back to the half-century-old Apollo seismic data and re-analyzed it. Even though the readings are from 1969-1977, a new mathematical algorithm was able to determine the locations of the quakes more precisely and the locations were matched to fault lines visible in reconnaissance photos of the moon's surface. Scientists

studying the data say that the interior of the moon is cooling and the moon itself is shrinking as the cooling continues (a bit like a cake deflating when it comes out of the oven).

GRADES 3-5 (CONTINUED)

NASA has some images of the resulting fault scarps (cliffs) and a more detailed explanation of the work on the seismology data. Imagine what else can be learned as scientists continue to study data from the missions.

An astronaut on Apollo 15 took the time to test a theory of Galileo's, which could not have been tested in his own time since there was no space travel then. Galileo had speculated that two objects dropped in a vacuum would fall at precisely the same rate and land at the same time, because there would be no drag (air resistance), to interfere. Commander David Scott dropped a feather and a geological hammer and proved that Galileo had been correct.

Skylab was the first United States space station, built using parts left from the Apollo program. (The Soviet Union launched a space station of its own, called "Salyut," two years earlier.) Until the shuttle era, Skylab crews held the record for the longest duration American space missions, with the longest at 84 days in space. The crews were also responsible for completing 270 experiments - including many on themselves to see how the human body adapted to living in space. Nobody had ever lived in a weightless environment before and so nobody knew how the human body would react without gravity pulling it down.

Bean using the BMMD to measure his body weight

Garriott monitoring his cardiovascular system in the LBNP device

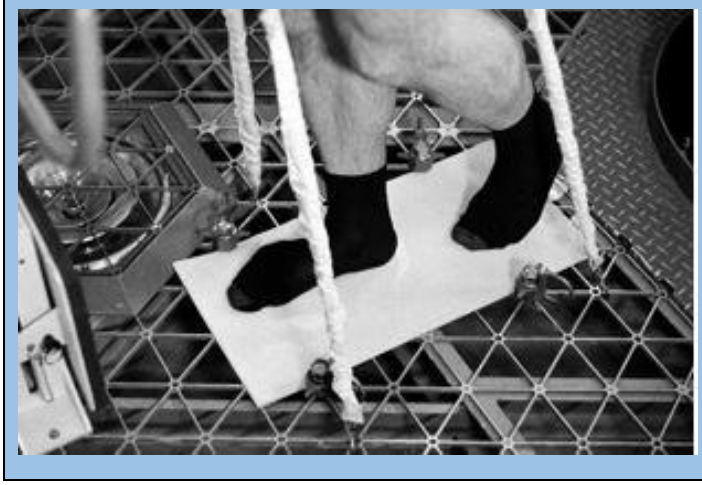
They tried out many new types of equipment, too. A solar telescope was used to study solar flares and astronauts were able to capture vivid images of them. (One, taken during the final

Skylab mission, is shown on the next page.) Commander Alan Bean tried out the Astronaut Maneuvering Unit inside the Orbital Workshop (also shown on the next page.)

Studies on the first two Skylab missions determined that the astronauts were not getting enough exercise while in freefall to maintain the muscle mass in their backs and legs.

GRADES 3-5 (CONTINUED)

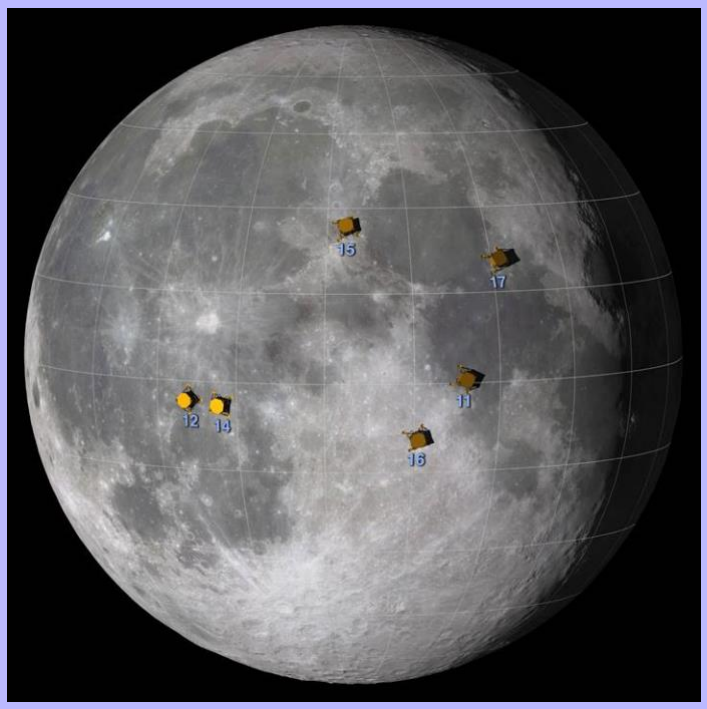
(Consider that whenever you are standing up, your leg muscles are supporting the weight of your entire body above them. In space, they do not have to do that.) To solve this problem, a treadmill was designed for use by the last crew (shown in the picture being tried out in sock-feet on Earth). Today's astronauts on the ISS have a 2-hour daily workout with machines like the treadmill seen below, complete with bungee cords to hold them in place while they run.



There are many excellent web sites which give information about Skylab. Here are two of them.

GRADES 6-8

MS-ETS1-1.Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.



As mentioned in the previous section, the Apollo astronauts left seismometers on the Moon to sense moonquakes. Even though they stopped sending information long ago, those seismometers and the readings collected from them are still providing scientists with data to form new theories.

One reason the landing sites on the Moon were spread far apart was to provide more widely dispersed seismic data. When a moonquake happens, scientists use the times that the seismic waves arrive at the different seismometers to triangulate back to find their source. (The process works on Earth with earthquakes, too.) If all the seismometers are near each other, the waves will arrive all at about the same time and the uncertainty in the source location will be greater.

As with most scientific research, the amount of data available is a limiting factor. If there had been more devices to collect readings, or if the existing devices had survived longer to send back more information, then there would be more data to examine. The seismometer set up during Apollo 11 failed due to overheating after it was covered in dust kicked up by the lunar module's departure. NASA learned from that experience and placed the seismometers on later missions at much greater distances from the landing area. But they were also very inventive in thinking of ways to increase the amount of data they could collect. Crashing spent upper stages of the spacecraft into the moon allowed the crew to do

a controlled test of the seismometers. Science Friday has provided an activity in which students can look at the evidence and decide if future astronauts should be worried about moonquakes.

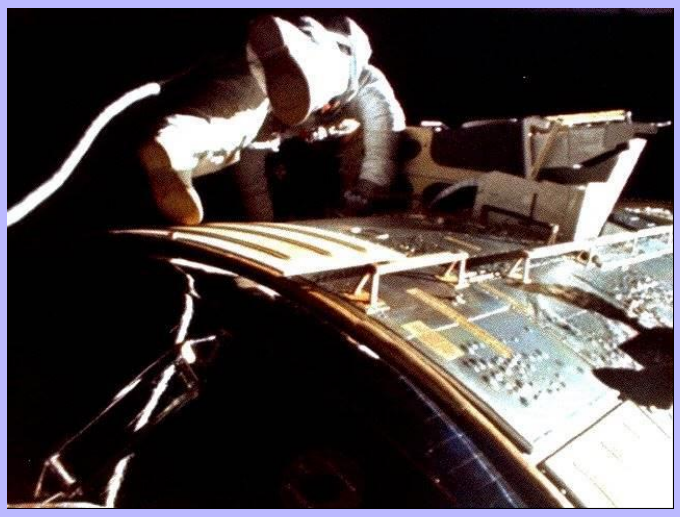
While Apollo 11 stands out as being the first manned landing on the Moon, each of the later missions had its own unique stories. Apollo 12, far from being an uneventful

GRADES 6-8 (CONTINUED)

repetition of a great achievement, was almost cancelled at its start when lightning struck the rocket less than a minute after launch. On Apollo 14, astronaut Alan Shepard (the first American to fly in space) provided a light-hearted moment when he got out a pair of golf balls and a makeshift club to perform the first golf drive on the Moon. Apollo 15 saw the first use of the Lunar Roving Vehicle, which allowed the astronauts to travel much farther than they could on earlier missions. Apollo 17, the last, was the only mission to include a professional scientist in its crew.

Apollo 13 deserves much attention of its own. An explosion in an oxygen tank while the crew was on its way to the Moon caused the cancellation of the planned mission; suddenly all attention was focused on bringing the crew home alive. It was called the "successful failure" because the crew did return unharmed, thanks in large part to a tough and focused ground crew that thought its way through problems as they arose. This was the mission that is the source of the quote "failure is not an option"—although that specific sequence of words was not, to anybody's knowledge, actually spoken then.

A little-emphasized event in the last three Apollo missions was the EVA (extra-vehicular activity—walking in space) of one of the astronauts to retrieve film from a camera mounted on the side of the Service Module. One of the astronauts who did this spoke later of the sensation of looking over and seeing a crescent Earth in the distance, then turning his head and seeing an almost full Moon in the opposite direction, and seeing the "velvety" blackness of space. It is a sensation that only three people in all of history have experienced.



GRADES 9-12

When a person has accomplished something very difficult and strenuous, what does he do next? Sometimes he will do the same thing over again to show that the first accomplishment was not a fluke—that he did not just get lucky the first time. And if something goes wrong on the second or third time, he will need to do it a few more times to

GRADES 9-12 (CONTINUED)

show that the failure was not the norm. While most people know about Apollo 13's "successful failure" and cliff-hanging "there and back" to the Moon in a crippled spacecraft, it is less well known that Apollo 12 almost ended before it left the Earth's atmosphere when lightning struck the spacecraft twice.

Of course, showing off is not the only reason the United States went back to the Moon with Apollo 12-17 missions. Once you have gone through all the time, trouble, and expense to design and build a system it would be a colossal waste of resources only to use that system once. Building the second copy of something is always much cheaper than buying the first one because you do not have to repeat all the work that went into designing it. Building more copies increases the savings from the economies of scale.

The Apollo missions also carried science experiments to the Moon. While most of these have stopped giving data, some are still in use. The Laser Ranging Retro-Reflector experiments, for example, are still where the astronauts left them. These are arrays of "corner reflectors" which reflect light back in exactly the direction from which it came. When scientists on the Earth shine laser beams on the devices, they can measure the time that the laser light takes to make the trip to the Moon and back—actually to the reflector and back. By measuring this time, they can calculate the distance between their light source and the reflector to the nearest centimeter. Scientists in Europe and North America have used these measurements to demonstrate that the two continents are moving apart by about an inch per year.

Another Apollo science experiment were a set of seismometers, devices that measured the shaking of the Moon's surface from moonquakes, asteroid impacts, and other sources. To help calibrate the seismometers, the Lunar Modules and spent Saturn upper stages of later Apollo missions were deliberately crashed into the Moon and the resulting seismic responses were measured. To everybody's surprise, the Moon continued to "ring like a

bell" for more than an hour after each impact; earthquakes on Earth usually die out after a minute or so.

Even as the Apollo 11 mission was taking off in July 1969, there was pressure from parts of the American public for the United States to stop wasting money on a manned Moon shot and to spend the money solving problems at home. This is an example of the "either-or" fallacy, the idea that a person can do one thing or another thing but not both (or something else entirely). There is a common complaint that one should not spend money

GRADES 9-12 (CONTINUED)

on space until our problems on Earth are solved. One proper response is to ask the complainer when this will happen: at what point does he think our problems will be solved well enough for us to start going into space again? (Another proper response is to suggest that one should not spend money on frivolities like candy, movies, and jewelry until our problems on Earth are solved.)

Indeed, those who wanted money from the Apollo program to be spent elsewhere got their wishes. The last three planned Apollo missions, Apollo 18-20, were cancelled to save money. Whether the money saved was in fact put to better use elsewhere is open to debate.

As the Apollo program was being brought to a close, it was suggested that the United States and the Soviet Union could launch a joint space mission. The idea was that the Americans would launch an Apollo Command Module into Earth orbit, the Soviets would launch a Soyuz capsule, and the two spacecraft would dock with each other. This was part of a larger change in relations between the two countries: both governments were realizing that they could not afford the continued arms race and Cold War. American president Richard Nixon began a policy of détente, or of easing relations, between the two countries.

The Apollo-Soyuz Test Program, as it was called, fulfilled all of its missions. The Soviet Union launched their Soyuz capsule from their Baikonur cosmodrome at 5:20 PM on July 15, 1975; seven and a half hours later—and ten time zones away (nine, counting daylight saving time)—the United States launched their Apollo module from Cape Kennedy at 3:50 PM. Two days after the separate launches, the two spacecraft approached and docked with each other using an American-made docking module. The hatches between the two spacecraft opened and Soviet mission commander Alexei Leonov and American mission commander Thomas Stafford floated through the tunnel to shake hands with each other. After performing various scientific experiments for two days, the two spacecraft undocked and separated from each other. The Soyuz capsule landed 30 hours later; the Apollo

module spent six more days in space before splashing down.

Compatibility between American and Soviet systems was a significant issue for the Apollo-Soyuz project. The issue extended even to the question of what language the astronauts—or cosmonauts, for the Soviets—would speak while on the mission. It was decided that the Americans would learn Russian and speak it during the mission and the Soviets would learn English and speak it during the mission. It is much easier for a person to understand a broken version of his own language than to catch nuances in a foreign language.

GRADES 9-12 (CONTINUED)

The selection of the two mission commanders was significant. Alexei Leonov, the Soviet commander, had been the first person to "walk" in space outside of a space capsule. This had been a major step forward in working in space. Thomas Stafford, the American commander, had commanded the Apollo 10 mission to the Moon; this had been the dress rehearsal for the Apollo 11 landing. Between them, they symbolized both sides of the space race that their two nations had been engaged in. For them to shake hands in space showed that a new day was dawning there.

Sixty Years Ago in the Space Race:

August 21, 1959: The American "Little Joe 1" test of the Mercury capsule's launch escape system failed when the escape rockets fired half an hour early.

August 1959: The Mercury astronauts started their testing at the Johnsonville centrifuge to see how well they could withstand high accelerations.