WE ARE GOING!

Stepping Stones to the Moon and Beyond

by Janet G. West

Sept. 21—In March 2019, speaking before the National Space Council, Vice President Mike Pence announced the goal to send the first woman and the next man to the Moon by 2024, and to develop a sustainable human presence on the Moon by 2028. In July 2019, NASA announced that this new mission would be named "Artemis," who, in Greek mythology, is the twin sister of Apollo and the goddess of the Moon. Fifty years ago, the Apollo project landed the first men on the Moon, so it is fitting that the next phase be so named.

NASA/SAIC Pat Rawlings

An artist's conception of the NASA Orion spacecraft.

Numerous components are key to the success of the Artemis mission, including next-generation lunar modules/landers, habitats for long-term human activity, and power/propulsion initiatives. The program will involve the Orion spacecraft, the Gateway lunar orbiter, and the Space Launch System rocket (SLS), with a focus on reusable spacecraft and architecture, and an eye towards future colonization of Mars. This program is an outcome of Space Policy Directive 1, signed by President Donald Trump in 2017.

"Similar to the 1960s, we too have an opportunity to take a giant leap forward for all of humanity," NASA Administrator Jim Bridenstine said as part of the July NASA announcement. "President Trump and Vice President Pence have given us a bold direction to return to the Moon by 2024 and then go forward to Mars. Their direction is not empty rhetoric. They have backed up their vision with the budget requests needed to accomplish this objective. . . ."

The Gateway Mission

NASA is already engaged with a number of partners to design and build the Gateway, a small way-station that will orbit the Moon. It will be much smaller than the International Space Station, and will provide short-term living quarters, scientific and research laboratories, and docking ports for visiting spacecraft, supporting both human and robotic missions. Astronauts will use it in going to and from the surface of the Moon, staying for perhaps a few weeks at a time, but not long-term.

Gateway will be a sustainable and reusable command and service module, capable of remaining in orbit for 15 years. It will have solar-electrical propulsion, making it maneuverable, and making more areas of the Moon accessible than ever before. The Gateway could even be transitioned into different orbits as needed. The power and propulsion systems for Gateway are the first components that NASA is working on, to establish a firm foundation to go forward.

On September 13, NASA announced it had awarded a contract with a company in Colorado, Advanced Space, to develop a small "CubeSat" to test the dynamics of an unusual orbit planned for the use of the Gateway mission. The orbit is known as a "near-rectilinear halo orbit" (NRHO)—in other words, an extremely elliptical orbit—which passes over the poles of the Moon, with one of the foci of the ellipse being the south pole of the Moon.

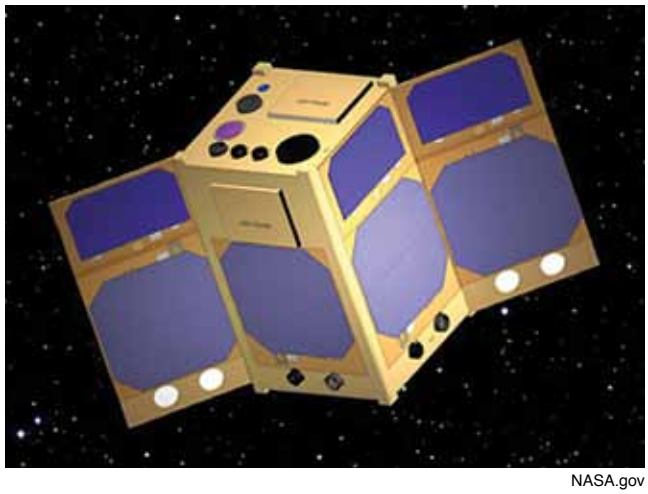
The south polar region is of great interest to many nations, since it is there where large amounts of water ice have been found, and appears to be the most hospitable area of the Moon for staging human and/or robotic landings and explorations. In this orbit, the spacecraft will rotate with the Moon as it orbits Earth, and will pass as close as 1,000 miles and as far as 43,500 miles from the lunar surface.

"This mission is highly ambitious in both cost and schedule—and taking that deliberate risk is part of the objective of this mission—alongside the rapid technological advancement in cislunar navigation and the opportunity to verify orbital trajectory assumptions and retire unknowns for future missions," Jim Reuter, associate administrator for space technology at NASA, said in the September 13 statement announcing the contract.

The test project using the CubeSat is named CAPSTONE (Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment), and could be launched as soon as December 2020. It will not only test the NRHO, but also a navigation system that will measure its position relative to NASA's Lunar Reconnaissance Orbiter, and how that distance changes over time, allowing the CubeSat to measure its position without relying on ground stations. Another company, Tyvak Nano-Satellite Systems, will partner with Advanced Space, providing the spacecraft while Advanced Space will handle the overall project management, as well as some of the crucial technologies, such as the navigation system—known as the Cislunar Autonomous Positioning System (CAPS).

The chief executive of Advanced Space, Brad Cheetham, commented, "The CAPSTONE mission will be an opportunity to demonstrate core components of CAPS as well as other capabilities we have been working on.... We see this work as a pathfinder for NASA as well as future missions to the Moon by others."

FIGURE 1



NASA.gov

Artist's illustration of the CAPSTONE CubeSat.

This particular CubeSat will be about the size and shape of a large microwave oven, and will be the first spacecraft to test this orbit. The orbit will used by the Gateway way-station for establishing permanent colonies on the Moon, both for their own sake—the exploration and development of the Moon—and also as a potential launching point for Mars and beyond. CubeSats are a class of nanosatellites using a standard size and form factor. "One Unit" (1U) is a cube measuring 10 cm (about 4 inches) on an edge, and can be scaled up to 12U. The development of CubeSats has developed into its own industry, with academia, government and industry collaborating on design and development, and is a cost-effective platform for new technology demonstrations and science investigations (see **Figure 1**).

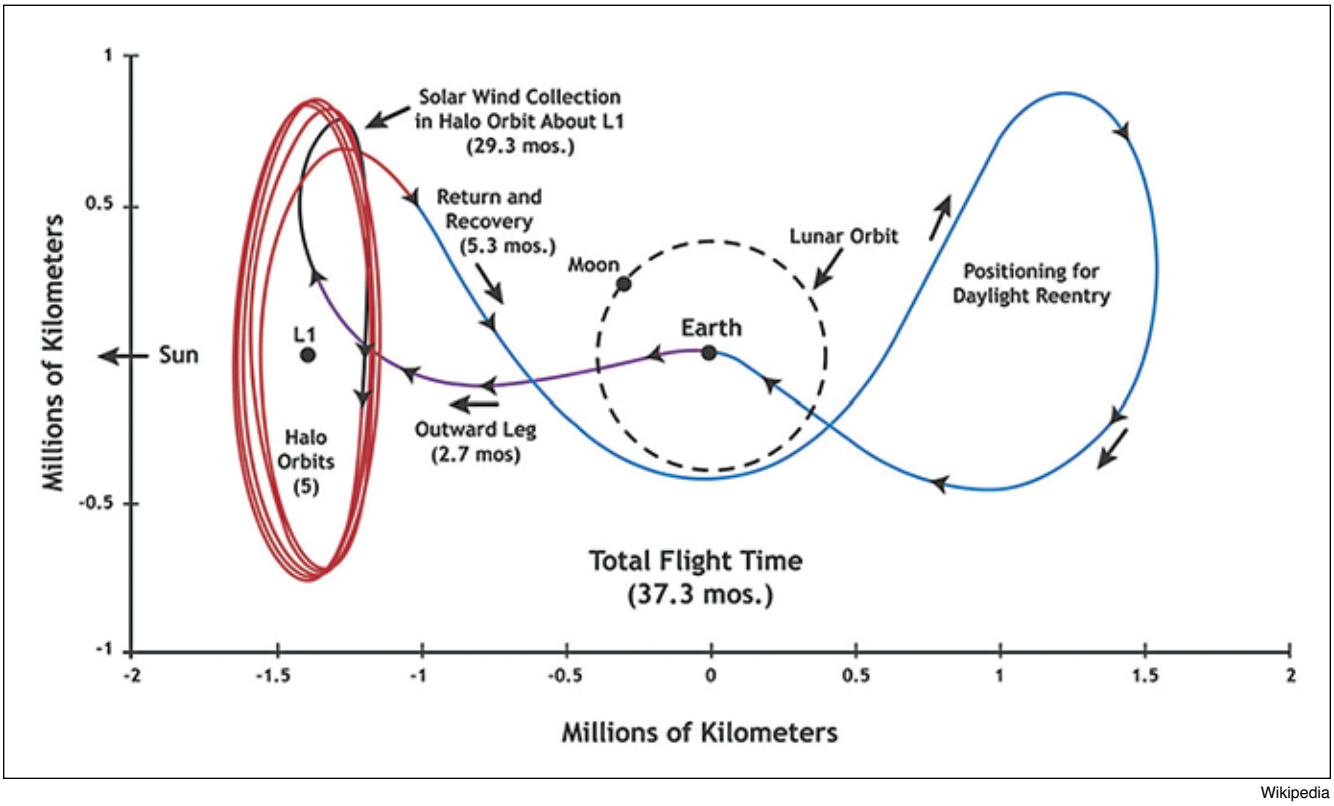
The launch of the CAPSTONE is crucial to demonstrate the stability of the NRHO.

Why an 'NRHO'?!

Who devised the NRHO, and why do we care what it is? It is a highly elliptical orbit ("nearly a straight line"), and is considered to be in "cislunar space." "Cislunar" is Latin for "on this side of the Moon" and refers to the volume of space between Earth and the orbit of the Moon. It includes other orbits with familiar terms such as LEO (low Earth orbit), Medium Earth Orbit, and GSO (geosynchronous/geostationary orbit).

Dr. Kathleen Howell, inspired as a youth by the first Moon Landing to investigate orbits, made it her life's

FIGURE 2



Wikipedia

The flightpath of Genesis around L1—Halo Orbit is in red.

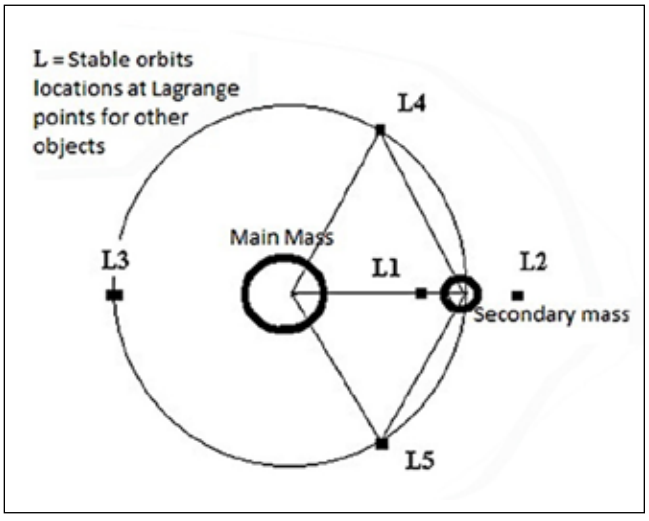
work. She earned her PhD from Stanford University in 1983, and is currently the Hsu Lo Distinguished Professor at Purdue University in the School of Aeronautics and Astronautics. Her proposed orbits have already been implemented by NASA with the Genesis mission of 2001, which was a sample-return probe. The Genesis probe collected solar wind particles in an area beyond the orbit of the Moon, and was placed in a stable orbit around L1 (Lagrange point 1). Currently, this is where the Solar and Heliospheric Observatory Satellite (SOHO) is located, since it always has an unobstructed view of the Sun (see **Figure 2**).

Lagrange points are positions in space at which gravitational forces (as well as centrifugal forces) are in balance, so these areas can be used by a spacecraft to reduce the fuel consumption needed to remain in the same position. There are five Lagrange points for the system of the Earth, Sun and Moon; the Lagrange points are different for the other planets. Of these five, three are unstable and two are stable. The unstable points are known as L1, L2, and L3. Even though unstable (spacecraft at these points must have regular course and attitude corrections), L2 is ideal for astronomical exploration because spacecraft can be close enough to readily communicate with Earth, and it also provides an unobstructed view of deep space. L2 is the future home of the James Webb Space Telescope (expected launch, March 30, 2021; see **Figure 3**).

Howell's doctoral thesis examined a family of orbits around these Lagrange points (so-called "halo orbits" because they appear to form a halo about the point they're orbiting). Besides the advantage of less fuel consumption to maintain location and recalibrate orientation, this type of orbit can have unobstructed lines of sight with Earth and the Moon at all times, and therefore can maintain communication with astronauts, even on the far side of the Moon.

Most experts in the 1980s considered halo orbits to be interesting, but eccentric and erratic novelties, of little use. Howell saw something else. She continued to explore the family of orbits represented in computer simulations. When she moved the elliptical orbit

FIGURE 3



Wikimedia Commons

Schematic of Lagrange points for the Sun-Earth-Moon system.

around the Moon closer to the vertical, and placed one of the foci of the ellipse closer to the Moon (instead of having the Moon at the center), she discovered that the orbit became metastable: A spacecraft could stay on course with a minimal use of thrusters, allowing it to stay in orbit for extended periods of time. It is this kind of orbit that the CAPSTONE will test; NASA anticipates that CAPSTONE's CubeSat will reach lunar orbit in about three months, and the primary mission will last six months. A video animation, "Near Rectilinear Halo Orbit Explained and Visualized" is available here.

The World Needs Genius

America is not alone in this endeavor—NASA is working in cooperation with the ESA (European Space Agency) and other entities—but because of our particular revolutionary world view, America once again has a unique opportunity to lead the world into a bright future, and to inspire the current generation. When the U.S. first began manned space exploration, *everything* had to be designed, engineered and fabricated from scratch—giving a boost to American industries from Playtex to Raytheon to Grumman, and others. In many cases, these components were handmade with superb precision.

With expanded exploration will come new demands for more versatile space suits, habitats and space transport vehicles that can spark the imaginations of our young people. And, like the explosion of activity in wake of President John F. Kennedy's September 12, 1962 speech at Rice University, "We Choose to Go to the Moon," this renewed commitment, not just to space exploration—but to *colonization*—can jump-start the productive economy, the demands for education, and a change in our culture in America towards the New Paradigm.

Genius is not simply a matter of IQ—it is an exceptional quality of a creative intellect that also engages the deep expression of *agapē*, which is not a "feeling," but an act of the Free Will. One prerequisite for even an element of genius is *curiosity*, and curiosity of a particular species. It isn't an aimless "what if" for idle purposes, but an intense search for a solution to a problem that can affect the well-being of mankind.

One is reminded of Friedrich Schiller's poem, "Columbus":

> Steer, bold mariner, on! albeit witlings deride thee,
> And the steersman drop idly his hand at the helm.
> Ever and ever to westward! there must the coast be discovered,
> If it but lie distinct, luminous lie in thy mind.
> Trust to the God that leads thee, and follow the sea that is silent;
> Did it not yet exist, now would it rise from the flood.
> Nature with Genius stands united in league everlasting;
> What is promised by one, surely the other performs. (*Anonymous translation*)

Wherever mankind goes in the Universe, we take this noble quality and culture with us, to joyfully reach out to new frontiers.

For Further Reading

Near Rectilinear Halo Orbit Explained and Visualized: https://www.youtube.com/watch?v=X5O77OV9_ek
Artemis mission: https://www.cnn.com/2019/07/24/us/nasa-artemis-program-scn/index.html
Space News website article: https://spacenews.com/nasa-cubesat-to-test-lunar-gateway-orbit/
NASA: "We are going …" https://www.nasa.gov/specials/moon2mars/#top