

SUMMER 2008

SPECIAL REPORT

Back To The Moon

PLUS

ISDC 2008 PREVIEW

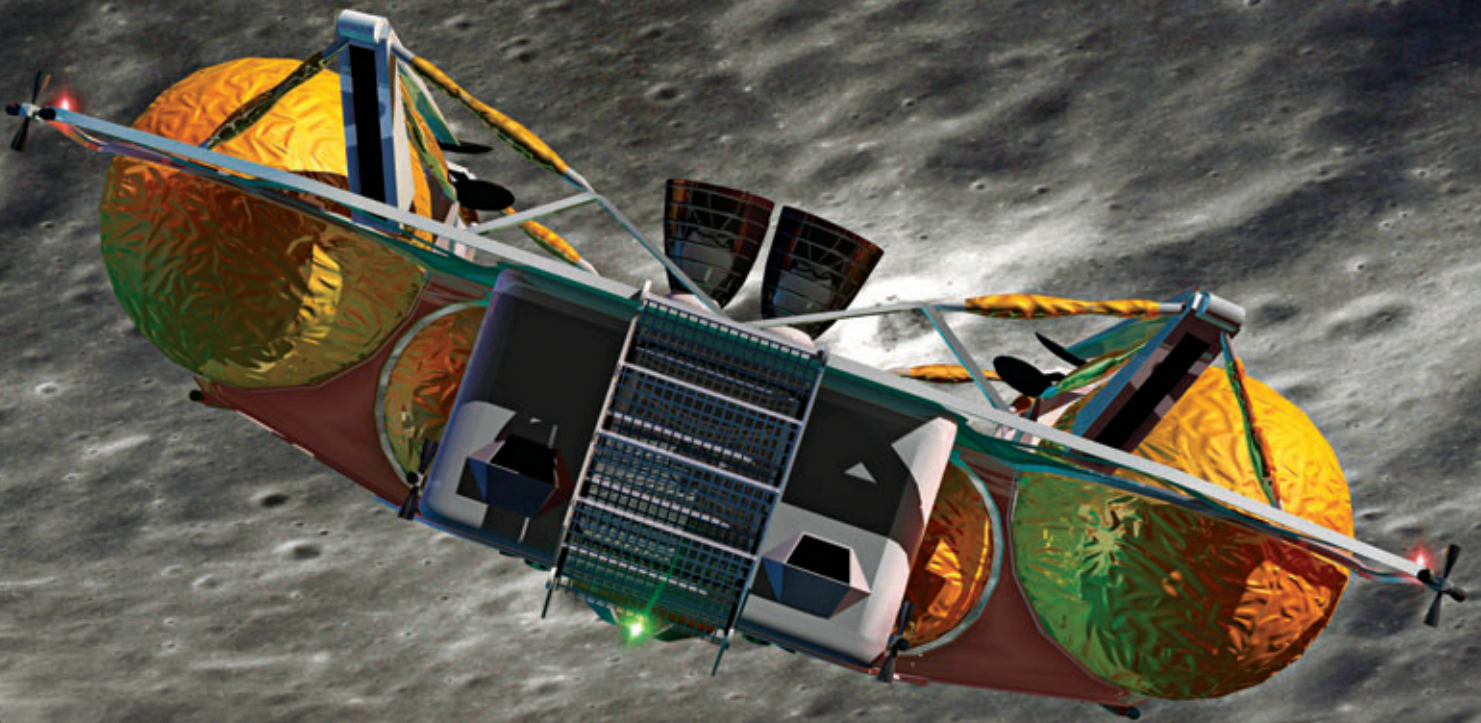
NSS BANNER CONTEST WINNERS

A TRIBUTE TO
ARTHUR C. CLARKE

COMMERCIAL SPACE
AND THE 21ST CENTURY



FEATURES



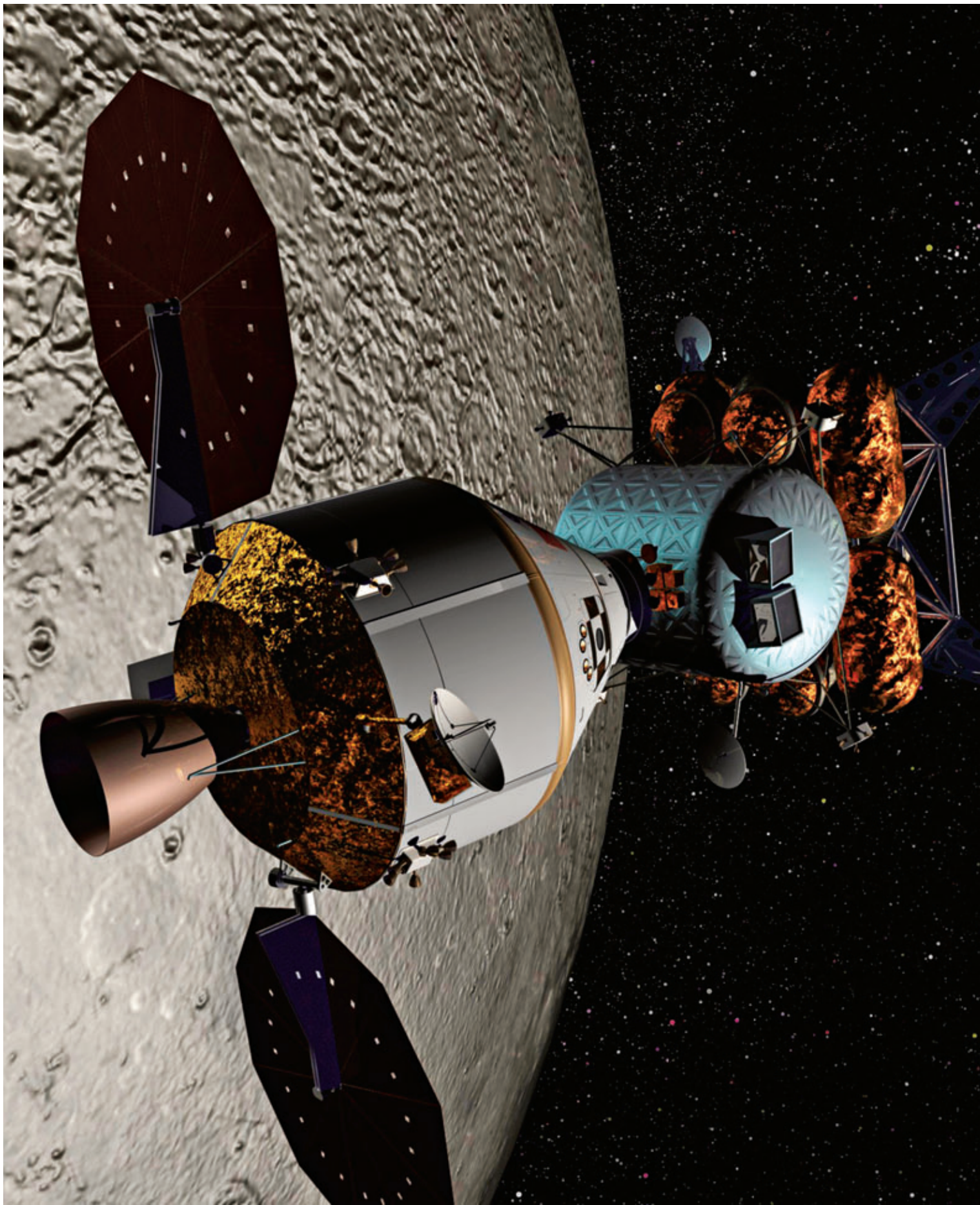
The Moon isn't a very hospitable place,

as the Apollo astronauts who landed there can attest. But the 12 men who walked on the lunar surface and the others who voyaged around it in the Apollo command module seemed to agree with Buzz Aldrin's now famous description, "Beautiful. Beautiful. Magnificent desolation."

And while Apollo underscored humankind's ability to journey to the Moon, NASA is determined to show that we can stay there as well. Plans for a permanent base on the Moon have drawn widespread attention, and criticism, but the National Space Society views these plans as the next step in the ultimate goal of space settlement.

Within these pages, we chronicle the many reasons for returning to the Moon, the international support for it, and examine the lunar materials that will help us stay there permanently. Enjoy.

A LANDER APPROACHES THE LUNAR SURFACE
IN THIS NASA ARTIST'S RENDERING





RETURN TO THE MOON

NASA's Constellation program may have its roots in Apollo, but there are distinct upgrades and environmentally-conscious differences as the agency moves forward with its next great adventure

BY JOHN F. KROSS

Artemis, Diana, Cynthia, Selene, Luna—she has many names. Men and women in every age have been drawn to her cool, remote beauty. Keats, Shelley, Shakespeare (“a silver bow new bent in heaven”) all wrote of her spell. Across centuries and continents, dreamers, scientists, and engineers have also been captivated by the Moon’s seductive pull till “men from Earth,” prodded by competition, temporarily won her.

A human return to the Moon is a critical part of NASA’s Constellation program, which arose from the Vision for Space Exploration proposed by the current administration in January 2004 in the wake of the loss of Space Shuttle Columbia. Under the Constellation program, Orion crew vehicles and Altair lunar landers will launch to Earth orbit on Ares I and Ares V rockets, respectively. An initial return to the Moon is targeted for launch before 2020.



Unlike Apollo, when the Saturn V lofted the crew in their command module and the lunar module as well, Constellation will use two launch vehicles in NASA's Return to the Moon program—the Ares I will ferry the crew into space aboard the Orion command module, and the heavy lifting Ares V (shown above) will haul the Altair lunar lander into space. Preceding pages: Orion and Altair orbit the Moon.

John Connolly leads vehicle engineering for the Altair at Johnson Space Center. At a meeting this past February, he said that the Vision for Space Exploration (now called the U.S. Space Exploration Policy) clarified a number of questions that had been lingering in the halls of NASA. How long was the shuttle to keep flying? "Till the end of 2010." What would happen to the International Space Station (ISS)? "We will complete it and use it to study the effects of long-term exploration on humans." What would be the next step in human spaceflight? "A new vehicle to send crews and cargo to ISS and return crews to the Moon by the end of the next decade."

Although there are good scientific reasons for going back to the Moon, the stated purpose is to serve as a stepping stone for exploring the frontier, and pushing the envelope to reach Mars and other destinations.

To minimize cost and risk to astronaut crews, NASA adopted a "building block" approach that uses common elements as part of a flexible architecture resting on a legacy of experience. "As we put this whole architecture together, we wanted to call on components that were very reliable and had proven flight history," explained Connolly. "So the system we'll use to get people to station, and then to take crews to the Moon, and eventually to Mars, all have common pieces to them."

The Moon is seen as a good intermediate goal for NASA to relearn the art of exploration lost over the past 35 years and to "get our exploration legs back," Connolly said. The Moon is close in astronomical terms and provides a convenient place to accumulate

experience before taking the giant leap from Earth-Moon space to interplanetary space.

NASA'S CONSTELLATION PROJECT— BUILDING BLOCKS TO ISS, THE MOON, AND BEYOND

While NASA Administrator Michael Griffin disparages the tag "Apollo on steroids," the Constellation Project can, in fact, trace much of its lineage to the Apollo era. Like the Apollo spacecraft, the Orion vehicle divides into a capsule-shaped command module (CM), which reenters the atmosphere; and a service module (SM) containing the main propulsion system, avionics, and consumables. A launch abort system atop the Orion capsule will pull the spacecraft and its crew to safety in case of an emergency during launch.

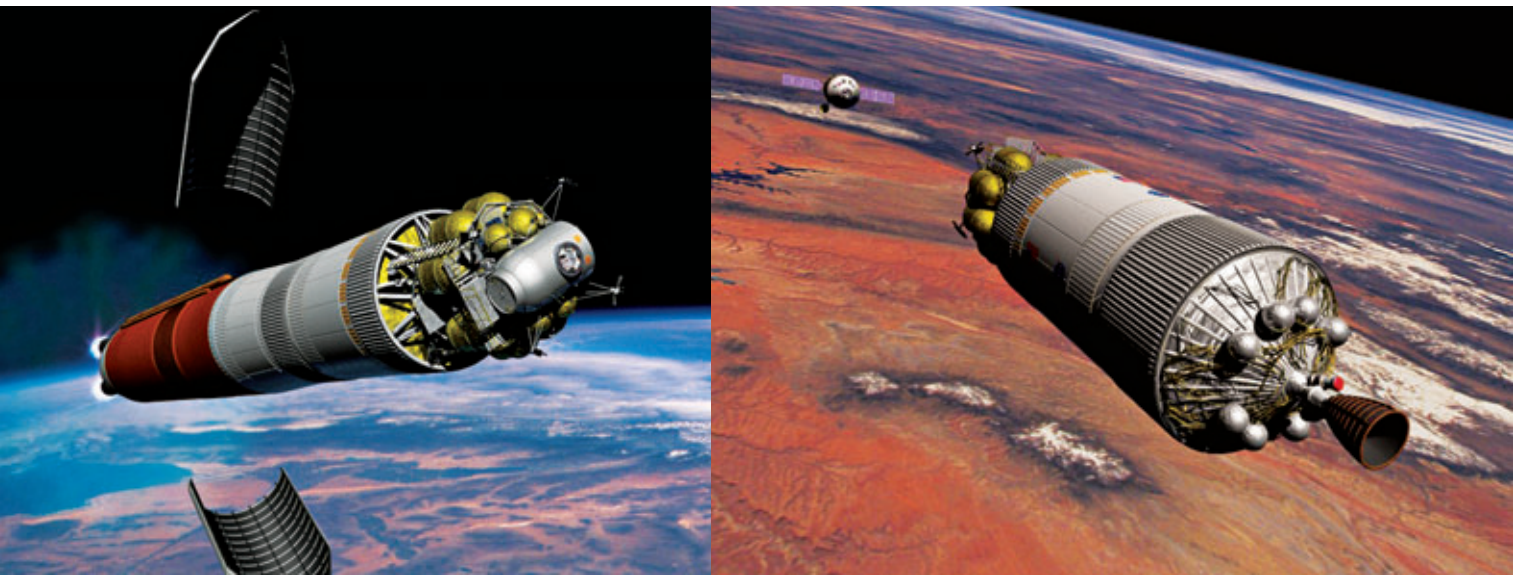
Unlike previous U.S. human spacecraft (including the shuttle), the Orion SM will use solar panels for power. "This is our first green space vehicle," said Connolly. In addition, the Orion CM will have 2.5 times the internal volume of an Apollo capsule and weigh about 21,000 kilograms (46,200 pounds).

The craft will ferry three to six astronauts and cargo to the International Space Station for stints of up to six months, and serve as an emergency ride home in case something happens in orbit. Orion is also a central element in the lunar mission architecture, able to carry four astronauts to the Moon.

For missions to the Moon, NASA will use two separate launch vehicles, each derived from a mixture of systems with heritage rooted in Apollo, the shuttle, and com-

**"IT'S KIND OF THE LEGO BLOCKS
APPROACH TO EXPLORATION."**

— JOHN F. CONNOLLY



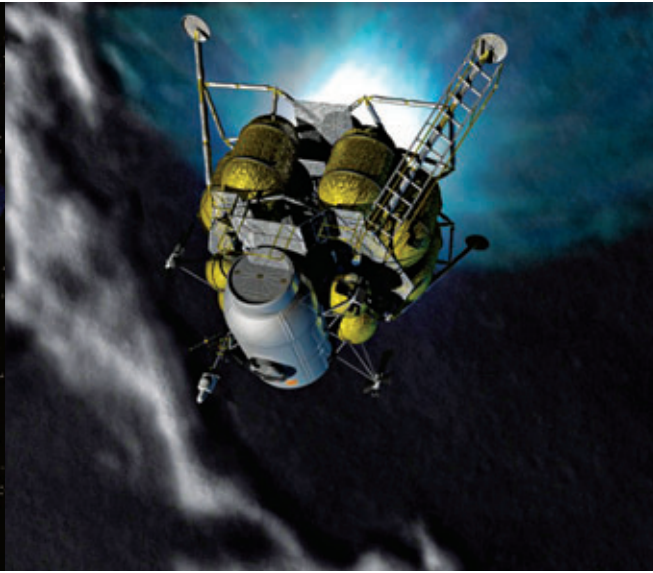
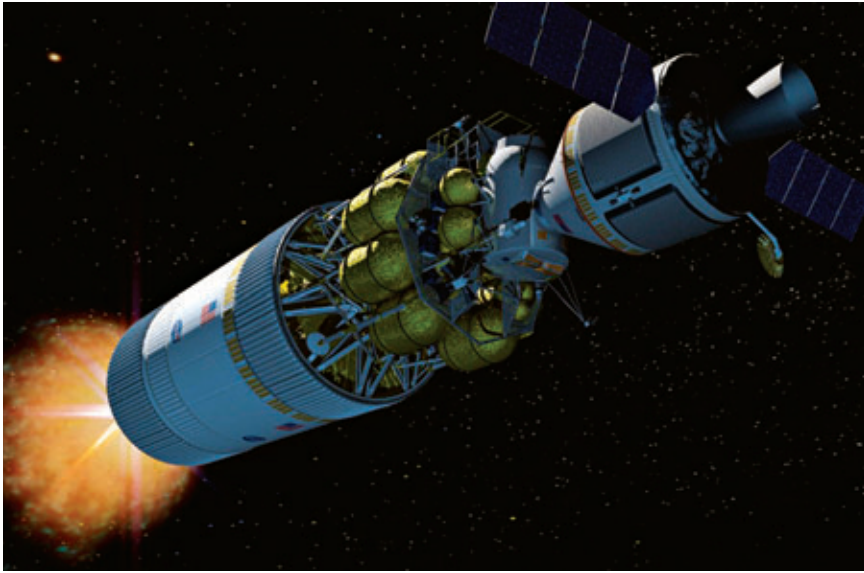
Above: The Ares V lifts the Altair lunar lander into Earth orbit. The Orion command module, with the crew aboard, will rendezvous and dock with Altair before making the journey to the Moon. At left, Orion roars into space aboard the Ares I launch vehicle.

mercial launch vehicle technology. “The shuttle and the Saturn V are our heritage vehicles, and we’re borrowing the best understood parts of these vehicles to create the most reliable new launchers that we can,” Connolly said. Ares I, the Orion launch vehicle, will deliver up to 25 metric tons to low Earth orbit using a solid rocket booster (much like the shuttle boosters) as the first stage. The second stage is powered by a liquid hydrogen/liquid oxygen (LH2-LOX) engine called the J-2X, derived from the J-2 engine used in the second and third stages of the Saturn V. “We actually had some of these J-2 engines still in storage and flyable condition. We’re running them in test stands right now,” Connolly said.

Altair, the companion lunar lander craft, will transport the crew and cargo to the lunar surface. “Its job is very simple,” Connolly said. “Get four people from lunar orbit down to the surface of the Moon, have them live there for up to seven days or have them translate to an outpost, and then get them back up into orbit where they rendezvous again with the Orion vehicle.” Altair, named after the brightest star in the constellation Aquila (“Eagle” in Latin), bears a striking, if oversized, resemblance to the Apollo lunar modules for a good

reason. “They don’t look very much different because the physics are the same,” Connolly noted. “Moving around in space is basically a physics problem, and even though some technologies, like computers, have improved dramatically, others, like propulsion, are essentially the same as back in Apollo. The propulsion system will dictate what the vehicle looks like, because physics are physics.” Like the Apollo lunar module, Altair has an ascent and descent stage and is thoroughly un-aerodynamic. Therefore, “it can be as ugly as you want it to be,” Connolly joked. However, to paraphrase a 1960s car commercial tied to the lunar landings, “it may be ugly, but it gets you there.”

The giant Ares V launch vehicle has the Herculean task of launching Altair and, potentially, other heavy cargo. This “stacked” or “in-line” vehicle has the fuel and oxidizer tanks and payload directly below. “We are using heritage components all through these vehicles,” Connolly said. “The external tank that comes from the shuttle stack is going to become the core of our Ares V.” Five RS-68 LH2-LOX-fueled engines, designed for Boeing’s Delta IV, comprise the base of the Ares V. Flanking them will be a pair of shuttle-heritage solid



Engines ignite on the Ares V's upper stage, called the Earth Departure Stage, in the artist's conception, above, as the crew voyages to the Moon. Once in lunar orbit, Orion will undock from Altair before the lunar lander begins its descent, shown at right.
ALL ILLUSTRATIONS COURTESY NASA

rocket boosters. A single J-2X engine will power the Ares V second stage, like the Ares I second stage. Altogether, the combination will launch up to 130,000 kilograms (286,000 pounds) into low Earth orbit (about 1.5 times the weight of an empty shuttle orbiter) and 65,000 kilograms (143,000 pounds) to the Moon.

EARTH ORBIT RENDEZVOUS REDUX

Perhaps the biggest difference from Apollo is the choice of mission architecture: that is, the selection of the Earth orbit rendezvous technique once championed by NSI-founder Dr. Wernher von Braun. "A mission requires two launches," Connolly explained. "It requires the crew to go up on the crew launch vehicle, the Ares I, and the lander to go up on a heavy-lift launch vehicle, the Ares V." Those two pieces rendezvous in low Earth orbit. As currently envisioned, the Orion-Ares I stack launches first, followed as soon as 90 minutes later by the Ares V bearing an Altair. This technique was employed in the Gemini era to chase down the Agena target vehicles. Orion can remain in Earth orbit for several days if the Ares V launch is delayed.

Once both vehicles are in Earth orbit, Orion (CM plus SM) will dock with Altair. The pair will be thrust to the Moon by the Ares V upper stage, called the Earth

Departure Stage. The departure stage is then discarded. During Apollo, the SM's engine provided the thrust to slow the combined spacecraft down for lunar orbit insertion. In Constellation, the descent stage of the Altair does this job. This choice allows the same Orion CM and SM stack to be used either for missions to low Earth orbit or for missions to the Moon.

Following an interlude in lunar orbit, Altair's descent engine will take the crew to the surface. At the end of their surface activities, astronauts will ignite Altair's ascent stage back to lunar orbit and rendezvous with Orion. The Altair descent stage will remain on the Moon (where it can be salvaged by the outpost).

Another big difference between Apollo and Constellation is that no "caretaker" astronaut is required to remain onboard the Orion while it loiters in lunar orbit. Computers and ground controllers will take care of it (for up to six months), possibly also operating cameras and experiments. Following ascent from the lunar surface and docking with Orion, the crew will jettison Altair's ascent stage. Orion's SM provides the thrust for the trans-Earth injection burn required to return home.

The SM is ejected just before the Orion CM enters the atmosphere. Friction with the atmosphere will bleed

**"FOR THE FIRST TIME IN A LONG TIME ... WE WON'T HAVE TO CALL GENE CERNAN THE LAST MAN ON THE MOON. I THINK OF HIM AS THE MOST RECENT MAN ON THE MOON BECAUSE I THINK WE ARE FAR FROM EVER SEEING THE LAST MAN ON THE MOON."
- JOHN F. CONNOLLY**



off most of the kinetic energy of Orion's 40,000 km/h (25,000 mph) lunar return velocity. Though an ablative heat shield is in the plans, this Apollo-era technology has never been used for a vehicle the size and weight of Orion. Therefore other options, including the shuttle's heat-resistant tiles, are under consideration.

Orion will parachute down and either splashdown in the ocean to be recovered by ship, or use an innovative air-bag system to plop down in the California desert. Reentry and landing options are still in flux as engineers balance weight, cost, and performance issues.

A POLAR OUTPOST ON THE MOON

Although these mission milestones sound eerily reminiscent of Apollo, Constellation's proposed lunar mission architecture can shoulder more astronauts, more cargo, and more consumables. Also, lunar landings will not be restricted to the equatorial regions. With its large lunar orbit insertion/descent engine, Altair can target any location on the lunar surface, including the mysterious polar regions.

Shackleton crater near the lunar South Pole is the leading choice for an outpost location. According to Connolly, "The rim of Shackleton crater... may be near the most desirable piece of real estate in the solar system. From there you have the best view of the Sun as it circles the horizon, and you're looking down into a permanently shadowed crater that is potentially full of resources." Unlike other parts of the Moon that have two weeks of light and two weeks of darkness, data from the Clementine spacecraft and NASA's Goldstone radar show that the elevated rim of Shackleton crater "sticks up" into the Sun like the axis of a spinning top. It is thus illuminated from one side and then the other for 70 to 80 percent of a month-long lunar day. The low Sun angles also create permanently shadowed craters with temperatures a few degrees above absolute zero. Gas or ice caught in these "cold traps" could serve as



a vital resource of life support and fuel for a lunar outpost. "Early American explorers didn't chop down trees on the East coast and drag them along ... to build log cabins," Connolly said. "The idea is not to carry everything you need with you, but to find and learn to use the resources where you land." Experience gained in "living off the land" and surviving in such a remote outpost will help pave the road to Mars.

Orion was to be operational by 2014 with "boilerplate" tests by 2009, and unmanned flight tests of the vehicle by 2012. Current reports indicate that the planned delivery date of the first Orion spacecraft has shifted from August 2011 to December 2013, delaying the first human flight to March 2015. Despite the inevitable delays and funding shortfalls, Project Constellation offers the best chance in two generations to finally get humans beyond low Earth orbit. Block by block, a permanent path to the solar system is being built.

John F. Kross is an oral pathologist and medical writer/editor at Lincoln University, Pennsylvania—though his day job is often interrupted by daydreams of going to the Moon. Dr. Kross has been a member of NSS since 1983, and a contributor to *Ad Astra* since 1989.

Above left: Following the voyage back from the Moon to Earth's orbit, Orion ejects its service module just before reentry into the atmosphere, above right. At left: The Altair lunar lander.

BACK TO THE FUTURE

NASA's Return to the Moon program is a necessary step toward the ultimate goal of space settlement

BY MARIANNE DYSON

For most members of the National Space Society (NSS), the reason for returning to the Moon is obvious: it is a necessary and vital step on the road to our goal of establishing a spacefaring civilization with the vision of "people living and working in thriving communities beyond the Earth, and the use of the vast resources of space for the dramatic betterment of humanity."

This is the same reason, worded somewhat differently, that the president and Congress gave to NASA as part of what was formerly called the Vision for Space Exploration (VSE, now called the U.S. Space Exploration Policy): "as the first step in human exploration of the solar system."

Just as NSS developed the rationale (survival, growth, prosperity, and curiosity) to go with our

Vision, NASA also set about defining its rationale to support the Vision for Space Exploration given to them by political leaders. The VSE directive recommended that NASA invite commercial interests and other nations to participate in determining the goals and objectives for returning to the Moon.

STRATEGIC THEMES FOR WHY NASA SHOULD RETURN TO THE MOON

1. Exploration Preparation

To use the Moon to prepare for future human and robotic missions to Mars and other destinations

2. Scientific Knowledge

To pursue scientific activities addressing fundamental questions about Earth, the solar system, the universe, and our place in them

3. Sustained Presence

To extend human presence to the Moon to enable eventual human settlement

4. Economic Expansion

To expand Earth's economic sphere to encompass the Moon and to pursue lunar activities with direct benefits to life on Earth

5. Global Partnership

To strengthen existing international partnerships and create new ones

6. Inspiration

To engage, inspire, and educate the public



ILLUSTRATION: ALEX AURICCHIO

NASA Administrator Michael Griffin therefore solicited input from a thousand individuals representing space exploration experts from Australia, Canada, China, the European Space Agency, France, Germany, Great Britain, India, Italy, Japan, Russia, South Korea, and Ukraine. Wendell Mendell, chief of NASA's Office for Lunar and Planetary Exploration for Constellation, observed during an interview in March that, "They collected a bunch of opinions, and in typical NASA style, they created a spreadsheet with more than 800 objectives."

Griffin then turned to the elite 24-member NASA Advisory Council (NAC), first chartered in 1977 and currently chaired by Harrison Schmitt (a member of the NSS Board of Governors) to help sort through the collected opinions and develop rationale and objectives to go with the VSE. By December 2006, six strategic themes emerged from the review: exploration preparation, scientific knowledge, sustained presence, economic expansion, global partnership, and inspiration (see "Strategic Themes").

"Meanwhile," Mendell said, "the NASA administrator made certain decisions about the transportation system—Orion, Ares I, Ares V. All those were givens to the group thinking about what we're going to do on the

This artist's rendering by NSS member Alex Aurichio, entitled "Moonbase One," features an advanced outpost built into the rim wall of a crater, creating vast reservoirs for future lunar settlers. The design was a winning entry in the 2009 NSS Space Settlement Design Contest.

Moon. To their credit, they looked at all this huge list of objectives, and asked, "What kind of choices can we make that would be most consistent with the wishes of everybody?"

One such choice was whether or not to do multiple Apollo-like landings to sample different locations, or a more in-depth study of one area. Mendell said, "It was the feeling [of the participants] that going for an outpost early would be a symbolic step toward civilization off-planet... that would have direct application to the idea that we're learning how to explore the solar system with Mars as a hypothetical next destination."

As a result of this process, in December 2006, NASA changed its initial architecture to include the buildup of a lunar outpost, most likely near the lunar South Pole. Vehicle and lunar orbiting mission designs were modified to reflect and support this plan.



A crew exploration vehicle, docked with a lunar lander (its legs extended), voyages toward the Moon, in this artist's rendering.

COMMUNITY INPUT REQUESTED FOR LUNAR EXPLORATION ROADMAP

The NASA Advisory Council's Science Committee is overseeing the continued development of detailed objectives that undergird the six strategic themes. The Science Committee chartered the Lunar Exploration Analysis Group (LEAG) to "analyze scientific, technical, commercial, and operational issues associated with lunar exploration." At the Lunar and Planetary Science Conference in League City, Texas, LEAG Chairman Dr. Clive Neal of the University of Notre Dame explained that LEAG is developing a Lunar Exploration Roadmap. Initial results will be released at the Lunar Science Conference at NASA Ames in California, July 20–23, 2008. "Then we hope to unveil the Roadmap at the LEAG meeting which is October 28–31 at Cape Canaveral [Florida] that hopefully coincides with the launch of the Lunar Reconnaissance Orbiter," Neal said.

At the Lunar and Planetary Science Conference, Neal revealed the group's recommended goals to accomplish the first three of the six strategic themes (see "Goals"). He said that three action teams are being formed to take comment on the themes and their objectives. "We need the community to comment," Neal said. NSS members who wish to participate should fill out an "Indication of Interest" on the LEAG Web site (www.lpi.usra.edu/leag).

STEP UP TO EXIT

Neal discussed the need for NASA to have "a transition strategy from the Moon that allows it to go to Mars and beyond that doesn't abandon the infrastructure it has built up—which can still be used for scientific and commercial purposes."

STRATEGIC GOALS

1. Exploration Theme Goals

- Identifying and testing technologies on the Moon to enable robotic and human solar system science and exploration
- Use the Moon as a test-bed for systems, flight operations, and exploration techniques to reduce the risks and increase productivity for future missions to Mars and beyond

2. Scientific Knowledge Theme Goals

- Understand the formation, evolution and current state of the Moon
- Use the Moon as a witness plate for solar system evolution
- Use the Moon as a platform for astrophysical, heliophysical, and Earth-observing studies
- Use the unique lunar environment as a research tool

3. Sustainability Theme Goals

- Identify, develop, and mature technologies, and deploy initial infrastructure capabilities
- Reduce cost of resupply and dependency on Earth
- Keep humans healthy and safe off-planet
- Facilitate development of self-sustaining economic activities

Mendell agreed, citing the lack of such a strategy for the space station. "If we had, at the very beginning, found a group of people who believed that a presence in low Earth orbit was really important, we should have partnered with those people. They could take it over, so NASA could move on to other things."

The question now is who might those people be, and how can the Roadmap be adjusted to enable their science or business plans? In-situ resource utilization (ISRU) has already been identified as an obvious component of any sustainable operation. Neal said, "ISRU capabilities are important not only for a sustained presence on the Moon, but also for the feed-forward to Mars."

Additionally, the science community has identified the need for surface mobility. "Scientists want to put automated monitoring stations on different parts of the Moon—like seismometers for example," Mendell said. "If you can't fly Apollo-like missions to different places, then the strategy for global access is to have some sort of long-range surface mobility, which implies pressurized rovers."

Mendell further explained, "All of those kinds of elements are being discussed as part of a lunar outpost largely in response to a desire to enhance the scientific capability of the site as much as possible."

An artist's rendering depicts astronauts—and their pressurized rover—at work on the lunar surface.

If the commercial or public sectors would like the outpost similarly enhanced to facilitate their plans, the LEAG wants to hear from them. Neal said that three action teams are being formed to take comment on the themes and their objectives, and heartily encourage the space community to provide input. For example, business leaders may ask NASA to designate certain areas off-limits to foot and vehicle traffic, and confine crew to paths to maintain the alien beauty and also the property value of the landscape surrounding the outpost.

NSS members know why the United States should return to the Moon and invite others to join in the adventure. Now, we have an unprecedented opportunity to participate in further defining and planning how the creation of a spacefaring civilization will unfold; whether as scientists preparing experiments to delve into the mysteries of permanently-shadowed craters, engineers designing ways to turn lunar rocks into solar power stations, or lunar pioneers who for their own unique and creative reasons want "return to the Moon" to eventually mean they are returning home from a trip to Earth.

Marianne Dyson is the assignments editor for *Ad Astra*, chairman of the NSS Space Books Committee, treasurer of the Clear Lake/Houston Area chapter, and a member of the NSS Policy Committee. She is an award-winning children's author, program book coordinator for the RNASA Foundation, a former NASA flight controller, and a black belt in Kuk Sool.

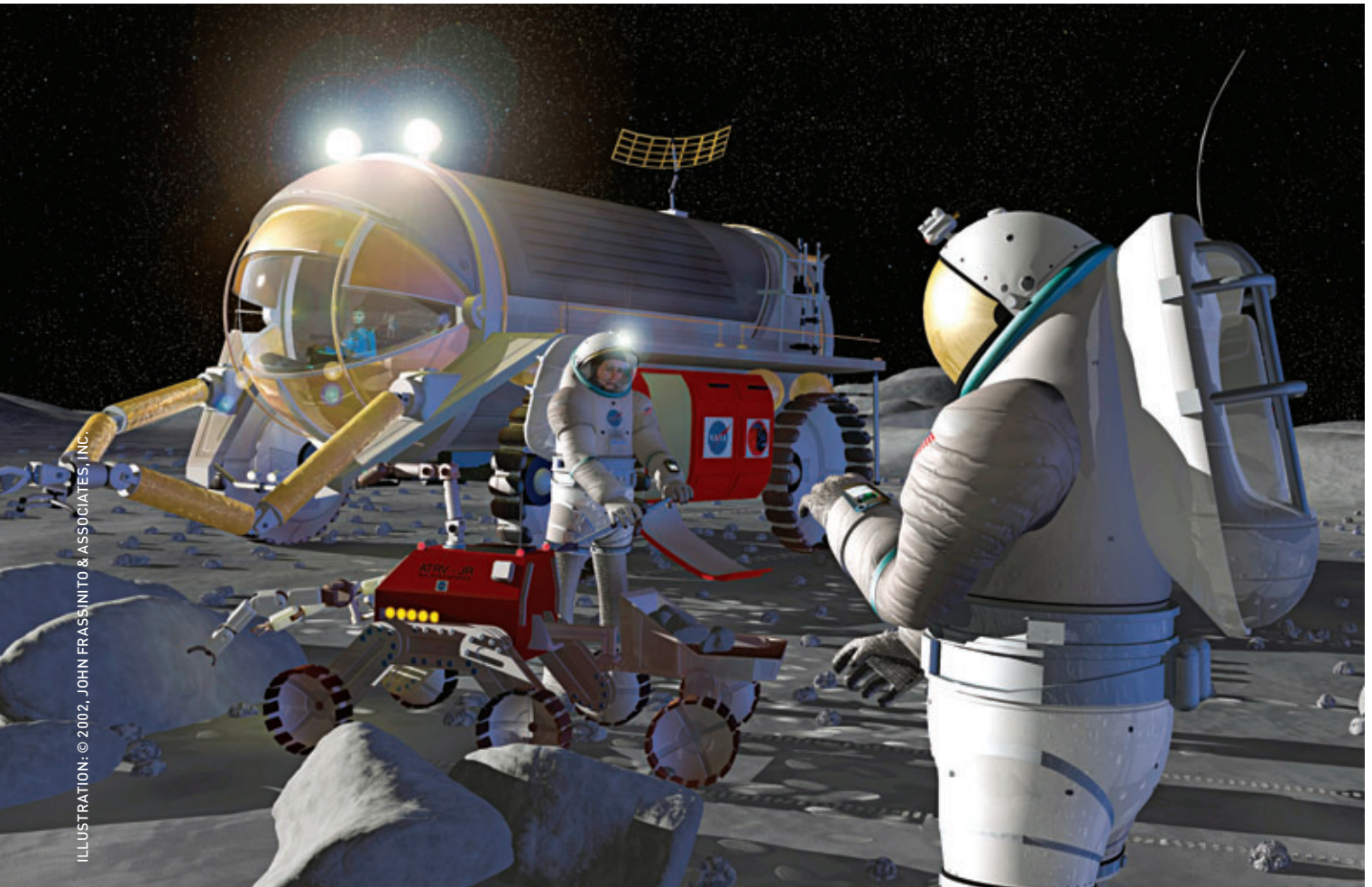


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LUNAR FLY-IN

ONCE AGAIN, THE MOON IS THE PLACE TO BE

BY JOAN HORVATH



After a decade with only two lunar missions—the United States' Lunar Prospector in 1998 and the European SMART-1 in 2003—two new spacecraft now orbit the Moon, with more nearing launch. These two robots hail from Japan and China, and India's entry will come this summer. The United States will rejoin the club this October with the launch of two missions on a single rocket.

But where has everyone been? After Mars landings and outer planet orbiters, the Moon can seem like a Route 66 diner bypassed by the interstate—a little retro

and a little awkward to reach. Despite its relative proximity, however, getting to the Moon is far from easy. The Moon has a complex gravity field, which makes navigation challenging. Basics such as whether the Moon has a distinct core, molten or not, remain controversial. As new players prove they can get in the game and old ones return, will we learn enough to support a long-term presence this time around?

First off the pad was Japan's Kaguya, formerly known as SELENE. Kaguya launched on September 14,

The Earth rises over Shackleton Crater at the Moon's south pole in this image taken by the Japanese Kaguya spacecraft earlier this year.

JAXA, 2008



中国首次月球探测工程第一幅月面图像



2007, and arrived in lunar orbit about three weeks later. According to the Japanese Space Agency (JAXA) mission Web site, the crucial objective is a thorough survey of the Moon to understand its evolution. Three spacecraft will carry out the mission. First, there's the main orbiter, whose HDTV camera has been the real crowd-pleaser to date. Along with the HDTV camera, the Kaguya orbiter carries a radar sounder that can take data up to a few kilometers below the surface. Other instruments will be used to deduce detailed topography. Two small satellites accompany the orbiter, relaying data and helping to develop better maps of the Moon's gravity field. Combining all that will give an unprecedented "big picture" (or, at least, a less grainy picture) of our neighbor, the Moon.

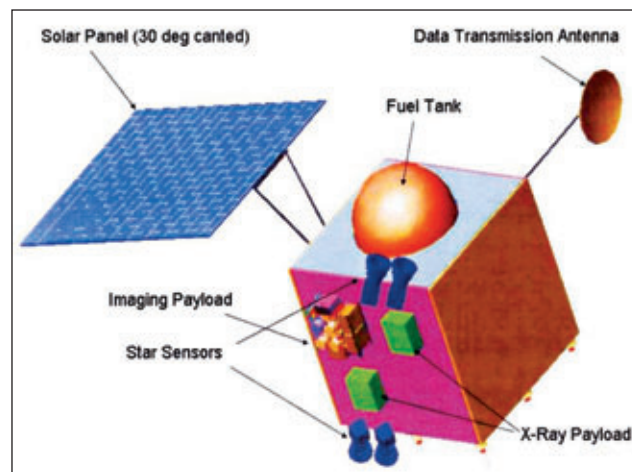
Next up was Chang'e 1, the Chinese contribution. Launched October 24, 2007, it arrived in November 2007. Its goal is to take stereo imagery, and to study the lunar surface and nearby environment with an array of spectrometers, a radiometer, and an altimeter.

This summer the Indian Space Research Organization (ISRO) launches Chandrayaan-1. Speaking at the

March 2008 Lunar and Planetary Science Conference (LPSC) in Texas, science team member Cassandra Runyon said, "Our primary science goal is to characterize and map the lunar surface in the context of its geologic evolution." Runyon enthused, "We're looking to unlock the mysteries of the Moon through mapping."

"If you look at the impact craters on the Moon, each is unique," Runyon said, noting that an impact crater "very naturally" gives insight into the Moon's interior since materials are brought up from underneath. A variety of instruments (described in detail on the mission Web site) will each provide a different piece of this picture.

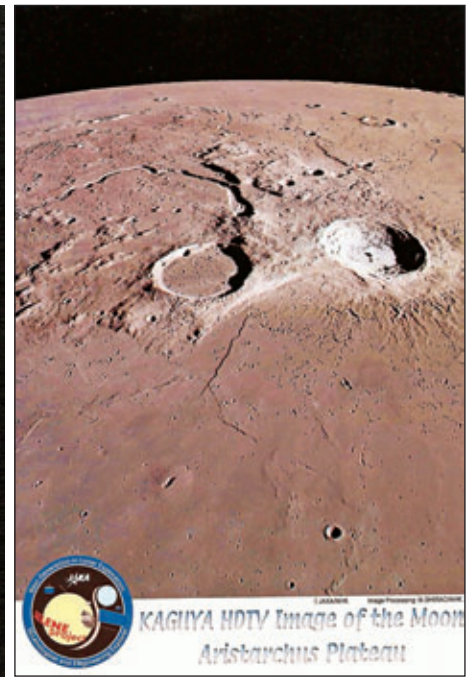
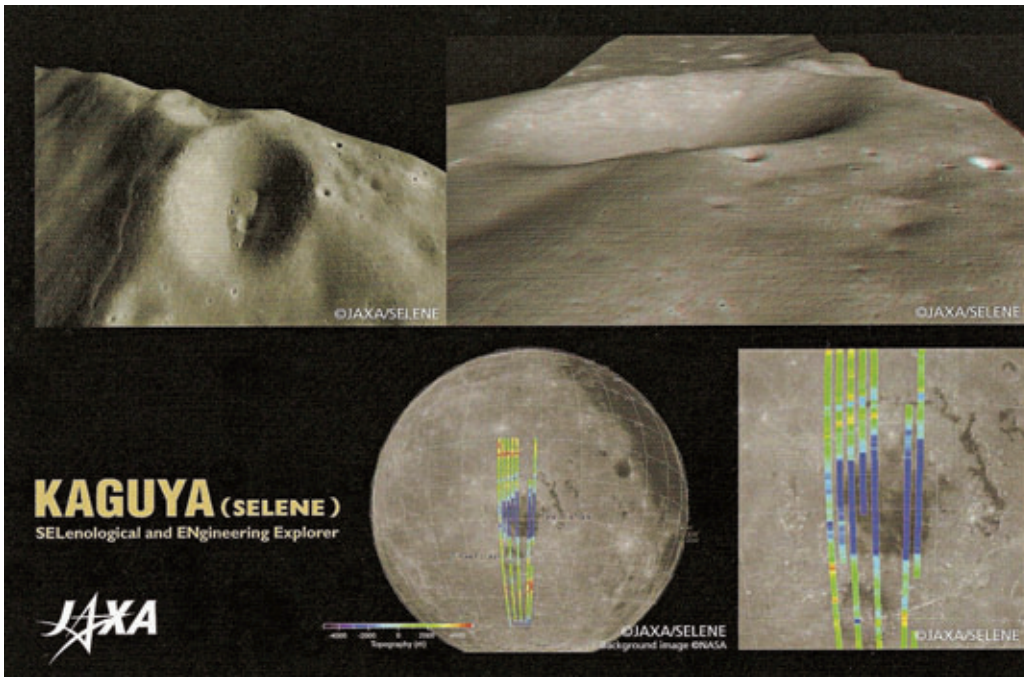
The U.S. space program is about to join in this return to the Moon with several missions. Alan Stern, at the time the associate administrator for NASA's Science Mission Directorate, gave a talk at LPSC reviewing the planned missions. In October 2008, Lunar Reconnaissance Orbiter (LRO) and Lunar Crater Observation and Sensing Satellite (LCROSS) will be launched together; and in 2011, Gravity Recovery and Interior Laboratory (GRAIL) and Lunar Atmospheric and Dust Environment Explorer (LADEE) will share a ride.



At right, an artist's rendering details the components of the Indian Space Research Organization's Chandrayaan-1 spacecraft.

Above, left to right: China published this first photo of the Moon taken by Chang'e 1 in November 2007—marking the success of that nation's first lunar project. The large crater on the left is Pontecoulant, 58 degrees S, 66 degrees E. Japan's Kaguya spacecraft was launched on September 14, 2007 and arrived in lunar orbit three weeks later.

LRO Education and Public Outreach Lead Stephanie Stockman, also speaking at LPSC, characterized LRO as "our first step back to the Moon." LRO will orbit "pretty darned close" to the lunar surface, in a 50-km (31-mi) altitude polar orbit. LRO's six instruments will provide high-resolution imagery as well as information about topography and rock abundance. Since it will be in a polar orbit, it will obtain more frequent data in the polar regions and may be able to confirm evidence of possible water there. Stockman said that the mission will be able to resolve the Apollo lunar landers, perhaps silencing the conspiracy theorists who do not believe we ever landed on the Moon!



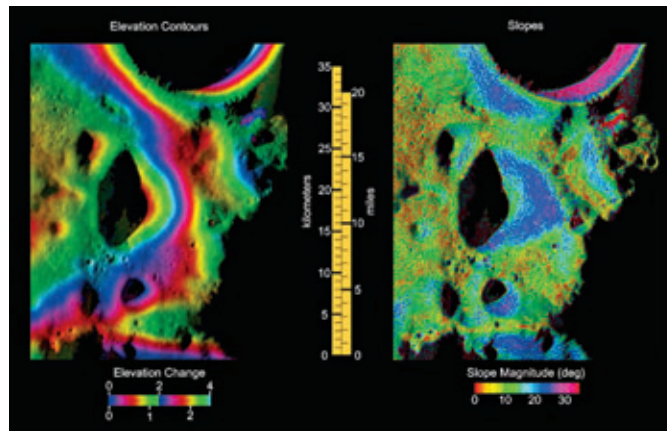
The LCROSS mission will launch on the same vehicle as LRO, as coinvestigator Jennifer Heldmann described in her talk at LPSC. Shortly after launch, LRO will separate from the launch vehicle and LCROSS and go its own way. The upper stage of the launch vehicle and a shepherding spacecraft will fly together for a check-out period. Then, the upper stage will be guided into a lunar-impact trajectory by the shepherding spacecraft. The shepherding spacecraft itself flies through the upper stage's impact plume for about four minutes and then impacts in turn, allowing for analysis of the subsurface material that will be kicked up by the first impactor. Heldmann says that only a 10- to 12-inch telescope is needed to see the event from Earth; the team wants every observation they can get, professional and amateur alike. It is expected that museums, science centers, and astronomy clubs in areas with a good view (mainly the Americas and Hawaii) will hold public events.

GRAIL is planned for launch in September 2011, with a travel time of about three and a half months. GRAIL's two spacecraft will make a gravity map of the Moon with dramatically better resolution than Kaguya, according to a recent *Ad Astra* interview with GRAIL Principal Investigator Maria Zuber of MIT. In a way, GRAIL will improve the fuel efficiency of all later spacecraft by providing information for far more accurate trajectory planning. More fundamentally, GRAIL can help answer whether or not the Moon has a core, and, if so, its composition.

GRAIL has a strong heritage from the similar spacecraft Gravity Recovery and Climate Experiment (GRACE), which studied the Earth's

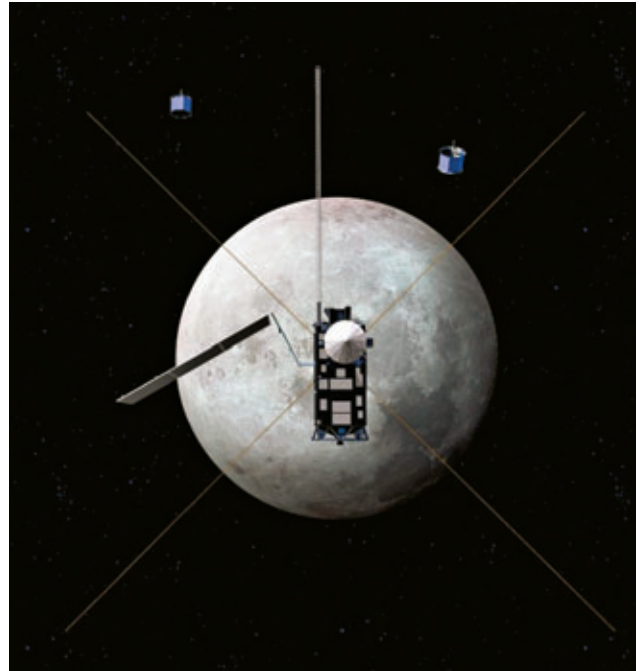
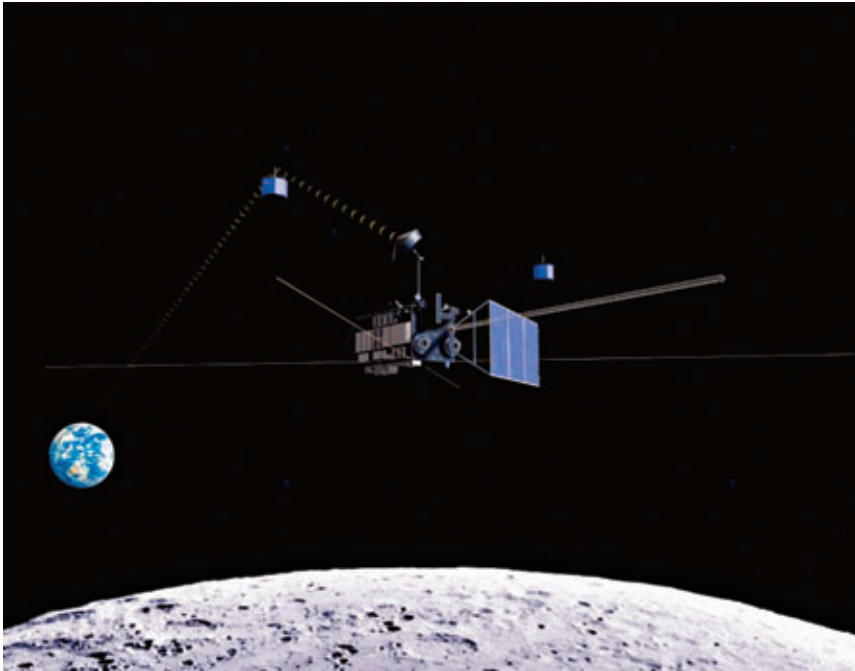
gravity field, and Zuber is comfortable that the technology will translate well for this low-budget "Discovery" mission. The payoff is high: she says engineers planning other missions had not asked for gravity data as good as GRAIL is expected to produce because they did not know it was possible! Zuber says that GRAIL is a "dream come true—to do an experiment that should have been done before Apollo," and adds, "I can't believe I'm getting to do it." GRAIL also has another side: each of the two spacecraft will have several cameras. Former astronaut Sally Ride is partnering with GRAIL to develop some infrastructure for the public to interact with those cameras.

GRAIL, like LRO, turned out to be light enough to allow another spacecraft to ride along on its launcher. A small orbiter, LADEE, will carry two or three instruments and take that slot. Stern said that LADEE's objective is to "document the state of the lunar atmosphere, low mass as it is, before rocket traffic builds up in the latter part of the next decade and begins to significantly perturb that environment."



Left: This graphic is an elevation map of Shackleton Crater produced using ground-based telescopes for NASA. Above left: Japan's space agency released some early data on the Moon's Orientale Basin on the far side near the Western terminator, and, on the right, an HDTV image of Aristarchus on the near side.

TOP LEFT: JAXA, 2008; TOP RIGHT: JAXA, 2008; BOTTOM: NASA/JPL



Above Left: This image shows a small RSAT satellite from Japan's Kaguya mission as it transmits data to Earth.
Right: Kaguya departs from Earth on its way to the Moon.

Stern noted that there is a request starting in the FY09 NASA budget for a lunar science flight program for years to come. Looking beyond the quartet of missions just described, Stern emphasized the need to get the nations of the world to band together and build an International Lunar Network. One option is to have two small landers as anchor nodes at the two poles of the Moon in 2013–14 and add a second pair later when resources permit.

What does all this activity mean, and where should it go in the future? In the United States, bodies such as the National Academy's National Research Council set lunar science priorities. Science recommendations, exploration technology needs, and a host of other issues all go into planning the overall NASA budget. But is there (or should there be) a worldwide big picture, at least to answer the basic science questions? Some of the spacecraft mentioned in this article are international collaborations at the instrument level (LRO has a Russian instrument, for example, and Chandrayaan-1 has several international ones). But should there be any top-down coordination instead of depending entirely upon instrument investigators to bubble it up from below?

Ad Astra asked Alan Binder, principal investigator of the 1998–99 Lunar Prospector mission, for his perspective on what lunar exploration should study next, and whether or not he thought the current crop of missions would get us there. "My real goal," he said, "is pushing toward a commercial lunar base." Binder would like to see the Moon being our "natural harbor" for the rest of the solar system, using lunar resources to build a base and colony. His biggest concern is that the data accumulated by all these spacecraft will take a back seat to the drama of the flights themselves. Binder notes that there is a large community of lunar and planetary scientists who can use this data. How will the data be

used most effectively? And how can the United States and other nations create an economically sustainable presence on the Moon for years to come?

Like going to the Moon, none of these issues are easy. However, now that many countries are competing to supply answers, the best solutions will perhaps emerge to let humans stay on the Moon—and use it as a stepping-stone onward.

RESOURCES:

NASA survey of worldwide lunar missions and data:

nssdc.gsfc.nasa.gov/planetary/lunar

JAXA Web site for SELENE/Kaguya:

www.jaxa.jp/projects/sat/selene/index_e.html

ISRO Web site for Chandrayaan-1:

www.isro.org/chandrayaan/htmls/home.htm

NASA Web sites for LRO and LCROSS:

lunar.gsfc.nasa.gov

lcross.arc.nasa.gov

Joan Horvath is the CEO of management consulting firm Takeoff Technologies LLC in Pasadena, California. She is a strategist, engineer, and writer. Her latest book, *What Scientists Actually Do*, was released in January 2008 by Stargazer Publishing.



FROM LUNAR OUTPOST TO PERMANENT MOON BASE

BY MARK N. LARDAS

For Sale: Lunar Outpost. Prime Shackleton Crater location. Lunar South Pole view. Property “as is,” no warrantee. Make an offer. If interested, contact NASA Constellation Office.

Far-fetched? Maybe not.

In the near future, NASA is planning a lunar outpost to act as a prototype for future Mars habitation. The 1997 Mars Reference Mission requires hosting eight people for up to 20 months. It is logical to test that capability closer to Earth, even if Mars and the Moon are very different celestial bodies. Once NASA finishes using its lunar outpost to develop Mars habitat technology, NASA will want to transfer the outpost to a new occupant—an organization other than NASA.

This is not altogether unprecedented. The national government releases control of federal installations all the time. Sometimes they go to local governments or private owners. For example, the United States Navy established McMurdo Station, America’s Antarctic base, in 1956, and then transferred it to the National Science Foundation in 1975.

A NASA lunar outpost may not be

immediately capable of supporting a permanent presence. However, an outpost equipped to support a crew of eight may instead become a lunar science lab run by the National Science Foundation, or an engineering test bed and spaceflight participant destination operated by a commercial or nonprofit corporation.

While concepts for the lunar outpost are not yet fully developed, NASA’s current Constellation plans offer opportunities for intelligent speculation about converting an outpost into a permanent home for humans. This is a very exciting concept to work with, and the resources on the Moon make these possibilities all the more plausible. But there are many challenges ahead.

REACHING RESOURCES

Despite what many have assumed, a lunar outpost prototyping a Mars habitat may not include a closed-loop life support system. Instead, NASA may test habitats intended to draw gases and water and minerals from the environment on Mars. This implies the development of an in-situ resource utilization (ISRU) capability.

Dr. Lawrence Taylor, director of the Planetary Geosciences Insti-

tute at the University of Tennessee, Knoxville, has been studying lunar volatiles for many years. He stated at a conference in March that 100 m³ (103 cubic yards) of Moon dust contains 200 kg (440 lbs) of hydrogen and 1200 kg (2,640 lbs) of carbon. “By heating lunar soil to only 600° C [1100° F], more than 80 percent of the solar-wind particles are released,” according to Taylor.

One hundred cubic meters is roughly the size of a two-car garage. This means that in addition to requiring power to run furnaces to melt regolith, construction equipment adapted to the lunar environment will be needed to support an ISRU capability.

POWER TO EXPAND

In order to survive, a permanently-manned lunar base must have a steady source of electricity. At present, NASA plans a combination of photovoltaic solar panels for lunar dayspan power, and closed-loop fuel cells to provide electricity during the lunar nightspan.

Solar panels have provided power for human space stations since the 1970s. Upon completion, the solar arrays of the International Space

The Moon rises over the frozen Royal Society Range, near Ross Island, Antarctica, above. Vehicles in the foreground are preparing the annual Sea Ice Runway. Below, the South Pole Food Growth Chamber at the National Science Foundation’s Amundsen-Scott South Pole Station. To learn more, visit: ag.arizona.edu/ceac/index.htm. This greenhouse uses artificial lighting and hydroponics. Opposite page, from left: An artist’s conception of astronauts beginning mining operations on the Moon; David Bents with his regenerative fuel cell equipment at NASA Glenn Research Center, Cleveland, in 2005.

PHOTO: ANGELA GARNER, NATIONAL SCIENCE FOUNDATION



Station (ISS) will produce a total of 124 kilowatts, enough to meet the needs of 60 average homes (without A/C)—an amount comparable to the power that will be required to support humans and equipment at a lunar outpost. However, on the station, rechargeable chemical batteries store a portion of this power for use during orbital eclipse. These batteries are heavy and not designed to provide power for more than a short period of time. Therefore, providing power during the two-week lunar nightspan is the first major challenge of setting up permanent residency on the Moon.

David Bents and his research team at Glenn Research Center in Cleveland, Ohio demonstrated a prototype closed-loop regenerative fuel cell in 2005. Water generated from Bents's fuel cell is stored, then broken down into hydrogen and oxygen through electrolysis. Electricity from solar cells runs the electrolysis module.

Unfortunately, Bents's closed-loop fuel cells are not small. For each kilowatt produced, 480 cubic feet (13,600 liters) of tank volume is required to store the necessary hydrogen and oxygen plus an 83-gallon tank for the water produced. Until the outpost is equipped to make storage containers, these tanks will need to be carried up to the lunar facility from Earth. An ability to scavenge tanks from the Orion descent stage would allow a faster buildup of power capabilities. Another challenge!

FINDING WATER

Systems have been developed to recover and reuse water on the ISS. But in order to expand an outpost, recycling is not enough. New water, its components of hydrogen and oxygen, plus nitrogen and other elements are necessary. Developing a capability to extract these resources from the Moon rock is an early priority if the outpost is to become a permanent facility.

Scientists remain hopeful that pockets of hydrogen exist in the permanently-shadowed craters near the lunar poles. However, if that source does not pan out, hydrogen and other volatiles can also be extracted from lunar regolith. The reason most people say there is no hydrogen on the Moon is that it is measured in parts per million, not the oceans of it that are present on Earth. Although hydrogen may not be as plentiful as it is on Earth, there are still resources to be harvested on the Moon.

A source of water, whether from solar hydrogen or extracted from regolith, is vital to a long-term presence on the Moon. Besides its use in fuel cells and for human consumption, water will be required to grow fresh food to promote crew health and reduce imports from Earth. Significant progress has been made recently in providing fresh food for the isolated population at the South Pole Station. A greenhouse using hydroponics and artificial lighting,

designed by the University of Arizona in cooperation with Sadler Machine Company, and operated by the National Science Foundation, recently produced enough green vegetables to provide a salad every few days for more than 50 people wintering over at the Amundsen-Scott South Pole Station. This same technology can be used on the Moon or Mars.

MCMURDO ON THE MOON

Equipped with power and the ability to extract most of the resources it needs, the first permanent lunar outpost may soon resemble an Antarctic research station. Diesel mechanic Harry Dyson was responsible for the power system at McMurdo Station on America's Antarctic base during two separate year-long tours.

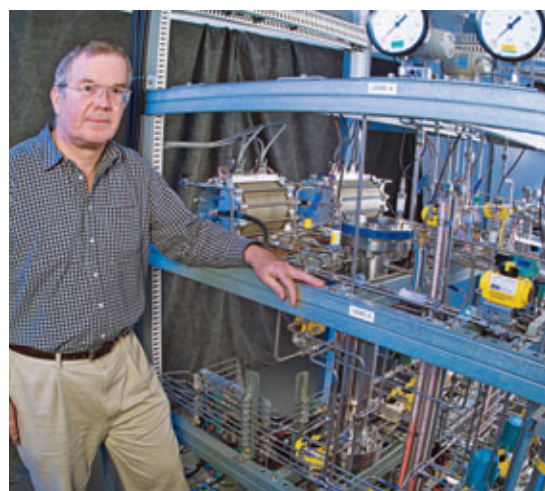
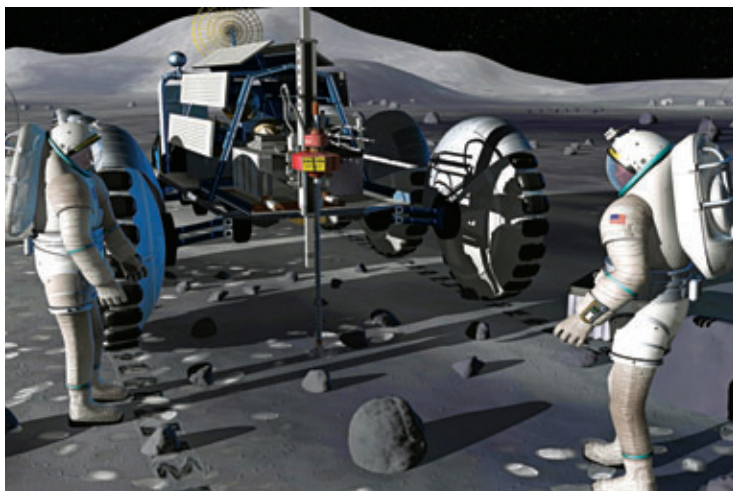
"We were not cut off from the world," Dyson says. "A satellite uplink provided phone and Internet service. I even called in a radio request once, since I was able to listen over the computer. There was a bowling alley, ceramic studio, and a dark room. The population was large and diverse enough to put on plays, classes, concerts, and art shows."

Mark Lardas, an engineer, freelance writer, amateur historian, and model-maker, works for a major NASA contractor doing work in space navigation. He has published five books, including a history of the space shuttle. He lives in League City, Texas.

Today, 200 people spend the winter at McMurdo annually. History shows that people can adapt to desolate environments—offering hope for a future lunar civilization.

Like McMurdo or the South Pole Station, a permanent lunar base need not be self-sufficient, or even economically neutral. Many countries, including the United States, survive quite well despite large trade deficits. For the lunar presence to become permanent it merely needs to provide something that people consider worth the cost of maintenance. Early products of an outpost are likely to be the knowledge gained from science and the inventions spun-off from meeting the challenges of living on the Moon.

Byproducts of extracting oxygen from lunar regolith include high-value metals such as titanium, as well as aluminum for spacecraft structures and silica for glass and solar cells. Silica, heated in microgravity, produces glass as strong and tough as metals. These materials may be used in the construction of lunar or space-based factories, tourist centers or space-based solar power stations that will bring benefits and prosperity to Earth.



TEAM SPIRIT

The Google Lunar X PRIZE is generating lots of interest.

So far, ten teams have registered, and more are on the way. BY WILLIAM POMERANTZ



Above: On February 21, 2008, Peter Diamandis announced the first ten teams to register for the Google Lunar X PRIZE. They are shown here at Google headquarters in front of a full-scale replica of SpaceShipOne. Opposite: The poster announcing the contest.

On September 13, 2007, two events half a world apart signaled the dawning of what some consider to be the second era of lunar exploration. That morning, on an elaborate stage in the Los Angeles Convention Center, Google and the X PRIZE Foundation announced the new, \$30 million Google Lunar X PRIZE. A few hours later, an H-IIA rocket blasted off from Japan's Tanegashima Space Center carrying SELENE (now called Kaguya), the first of a batch of new lunar spacecraft launched by governments around the world.

It has been 36 years since the last Apollo mission departed the lunar surface. After 15 years of groundbreaking firsts, the door to the first era of lunar exploration was slammed shut. For decades, the barren lunar surface was forgotten, overlooked not just by the general public, but by the space agencies themselves, who turned their attention to other projects and other worlds. In recent years, visitors to the Moon's orbit have been infrequent and most of their stays were brief. For many of them, like Hiten (1990), Clementine (1994) and SMART-1 (2003), the Moon seemed almost to be a novelty destination for programs that were really about technology or mission operations concept demonstrations. The Moon, which captured the imagination of so many throughout Ranger, Surveyor, Zond, Luna, and Apollo, was once again a dead place.

Though 1972 may not seem all that long ago, it is

sobering to realize that approximately half of the people currently on this planet were not yet born the last time imagery was beamed back from the lunar surface. For two generations of world citizens, the glory days of Apollo and other robotic missions are simply images in a history text book. While the story of humanity's first tentative steps out into the solar system are without a doubt inspiring even for those who weren't alive to witness them, the connection is removed: it is a bit more academic, a bit less visceral. Is it any wonder, therefore, that studies show that today's younger generations exhibit lackluster support for plans to return humans to the lunar surface?

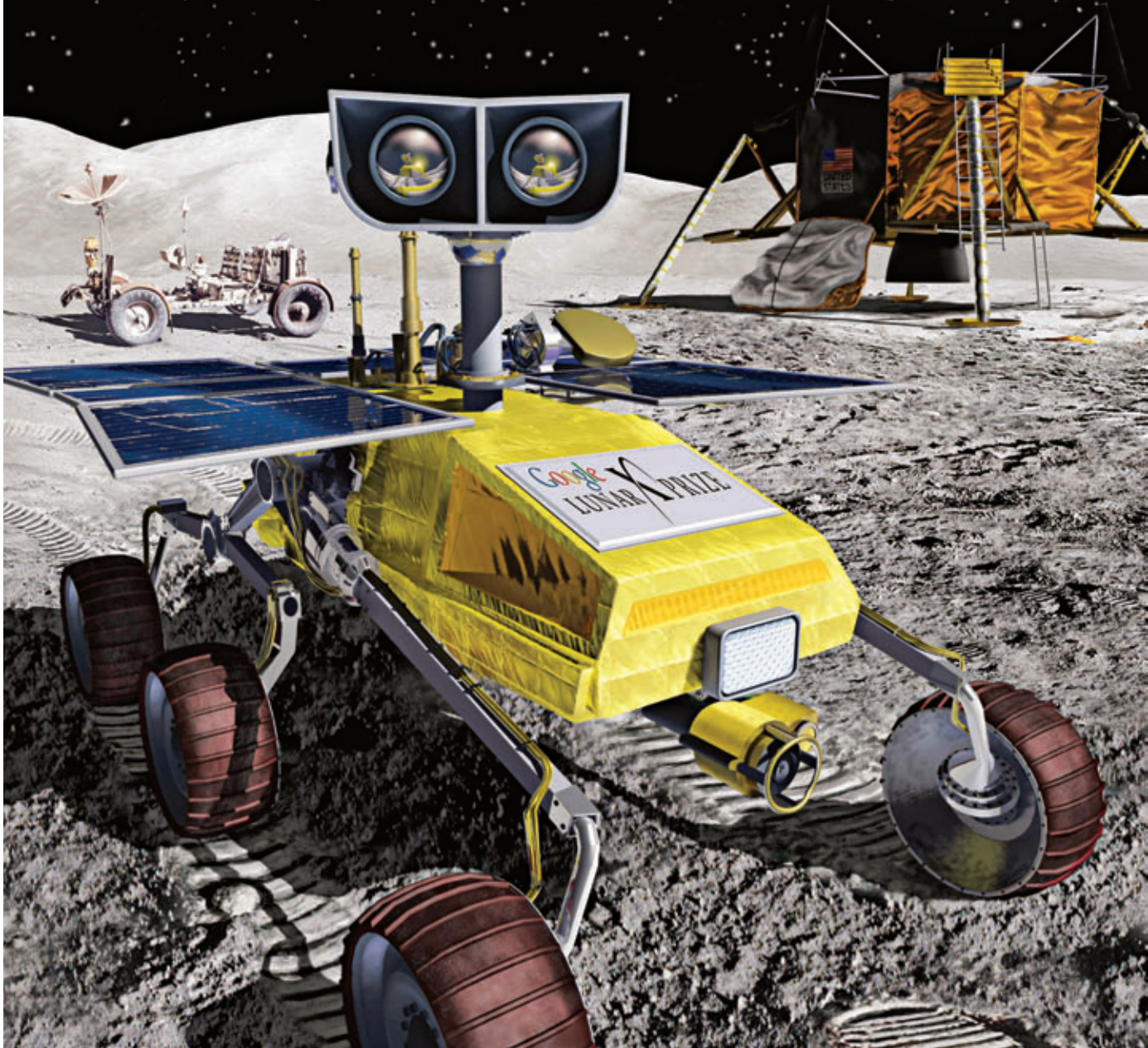
The dawn of the second era of lunar exploration—Moon 2.0, if you will—may change all that.

Kaguya is not Japan's first mission to the Moon—that honor goes to the Hiten mission. But Kaguya is special for two reasons. The first is that Kaguya is responsible for beaming back the first ever high definition videos of the Moon—breathtaking images that truly reopen our eyes to the stark beauty of the lunar landscape. The second reason is that Kaguya's was the first launch of a veritable flotilla of new spacecraft bound for the Moon, many launched by new Asian space powers.

Chang'e, China's first lunar probe, launched in October 2007. India's Chandrayaan-1 is scheduled for launch in

Google
LUNAR X PRIZE

MOON 2.0
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googlelunarxprize.org





July 2008 and NASA's Lunar Reconnaissance Orbiter will follow in October. Unpopulated for so long, lunar orbit will boast four occupants come the end of this year. Whereas the first era of lunar exploration was a space race between two global superpowers, this second iteration has much more of a cooperative flavor, with many nations sending their own crafts, and more collaboration between them.

Near the end of 2007, the Washington, D.C. office of the Japanese space agency (JAXA) held an event to show the first movies from Kaguya in their full resolution on a wide screen. As soon as the video began (run off a PlayStation3—as good a sign as any of a new era in planetary exploration), the room became as silent as the vacuum of space. Seeing the Moon in high definition was almost like being there. For all of those present, the Moon was no longer a conceptual destination: it was a highly personal obsession.

The Moon has also become a personal obsession for a whole new class of individuals: private entrepreneurs. Spurred on by the new, global, \$30 million competition, a new cadre of privately funded lunar explorers around the world is now helping to make the Moon the hottest destination in the solar system. Over the next few years, a whole new group of people will bring innovative technical solutions as well as fresh business ideas to lunar exploration. The Google Lunar X PRIZE represents an even more radical departure from the norms established by “Moon 1.0”—a contest that will connect lunar exploration to the world through the thrill of competition and the plethora of outreach tools employed by private teams eager for support and investment.

The strong start to the Google Lunar X PRIZE serves as evidence that we will reach our lunar destination soon. At the time *Ad Astra* went to print, 10 fully registered teams had been announced in the six months since registration opened. These teams represent a stunningly diverse set of people, backgrounds, and ideas. Based in four different countries (the USA, the Isle of Man, Italy, and Romania), with work being done in more

than 30 nations, each team is engaging a new group of local sponsors and enthusiasts, building support for their efforts. They represent longtime space luminaries like Dr. Harold Rosen of the Southern California Selene Group, who lead the team that launched the world's first geostationary satellite; well known prize winners, like Astrobotics' Red Whittaker, winner of the DARPA Urban Challenge; Ansari X PRIZE legacy teams, like ARCA and Micro-Space; and complete newcomers to the space industry, like energy entrepreneur Adil Jafry's Chandah, or the open-source team FREDNET.

No one can say which of the Google Lunar X PRIZE teams will be the first to make it there—the first group to beam back pictures from the lunar surface in more than three decades. But what we do know is that whenever the prize is claimed, the winning mission (or missions!) will generate a new, stronger connection with a legion of space enthusiasts new and old around the world.

In a sense, that link is already being formed. Visitors to www.googlelunarprize.org will see that each registered team is blogging at least weekly, talking about everything from technical trade studies to each team member's inspiration and motivation. Following along with the early entries has been a fantastic way to become engaged in the program—and as the teams transition from paper studies to hardware tests to flying missions, the story will only get better.

William Pomerantz is the director of Space Projects for The X PRIZE Foundation. He holds a bachelor's degree in earth and planetary sciences from Harvard University, and a master's of science from the International Space University in Strasbourg, France. Pomerantz also serves as a coach for the Zero Gravity Corporation, joining passengers in weightlessness on parabolic flights. For the past three years, he has served on the joint NSS/SEDS/Space Gen Scholarship committee.

Above: Los Angeles-area children pose with, left to right, X PRIZE Vice Chairman Robert K. Weiss, Google Cofounder Larry Page, X PRIZE CEO and Chairman Peter Diamandis, and Apollo 11 Astronaut Buzz Aldrin. Opposite: A display from the 2007 press conference.



THE DETAILS

To win the Google Lunar X PRIZE, a team must successfully land a privately funded craft on the lunar surface and survive long enough to complete the mission goals of roaming about the lunar surface for at least 500 meters and sending two data packages, called “Mooncasts,” back to Earth.

A Mooncast consists of digital data that must be collected and transmitted to the Earth. They are composed of high resolution, 360° panoramic photographs; self portraits of the lunar vehicle; low resolution videos beamed back to viewers on Earth in near real time; and high definition video. The first Mooncast will detail the team’s arrival on the lunar surface; the second

will include imagery and video of their journey roaming the lunar surface. All told, the Mooncasts will represent approximately a gigabyte of stunning content returned to the Earth.

The total purse of the Google Lunar X PRIZE is \$32 million and growing!

- GRAND PRIZE: \$20 million
- SECOND PRIZE: \$5 million
- BONUSSES: \$7 million in bonus prizes can be won by successfully completing additional mission tasks such as roving longer distances (> 5,000 meters), imaging man-

made artifacts (e.g. Apollo hardware), discovering water ice, or surviving through a frigid lunar night (approximately 14.5 Earth days). Space Florida has contributed an additional \$2 million bonus if the winning team launches from the state of Florida.

Registration for the Google Lunar X PRIZE is open through the year 2010. Prospective teams may learn more and request registration forms online at www.googlelunarxprize.org.