Chapter Two

Getting There the Second Time Around

The first launch of the mighty Ares V. (art by author)

When the first Ares V thundered into the Florida skies in 2018, the booster trailed not only a column of incandescent smoke but also a rich heritage spanning half a century. From the simple Scouts to the complex shuttles, from the diminutive Redstones to the mighty Saturn Vs, Ares topped a vast family tree whose roots stretched back to ancient

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Chinese fire arrows a millennium before. Thousands of engineers and technicians labored to transform blueprints into boosters. And after years of development, static firings, wind tunnel tests, and computer simulations, it was finally time to set sail on the translunar sea.

Engineers and strategists have visions of hardware twinkling in their eyes. They dream of foil-encrusted cargo vessels settling upon spindly legs into billowing lunar dust. They revel in thoughts of glistening spacecraft carrying crews across the void, Moonward after a forty-year exploration drought. They pour over blueprints of bigger and better boosters, of faster ships steered by more powerful computers and advanced technologies. They are the dreamers, and realities begin with dreams. But behind those visions, there must be substance. There must be reason. And so the questions come: What happened in those years since the last *Apollo?* Why haven't we gone back to the Moon? *Should* we go back? Don't we know enough about this cold, dead world? Are there reasons to return beyond national pride, keeping up with the international Joneses, or a few dusty rocks? And should we instead be looking farther afield…to places such as Mars?

REASONS TO RETURN

To NASA Goddard's Chief Scientist Jim Garvin, "Space matters. We live in space, after all. Yes it's inspirational (look at the Hubble), but look at where space affects us. It's given us an understanding of our own planetary climate system and the dangers from space. Going to the Moon enables us to build a platform for technology that is transformational to our society, and that's not just Teflon. One example of those transformational things is the information technology for high reliability in space systems that has been applied to many aspects of our society."

Those applications have had four decades to sink in. No humans have returned to terra luna in that time. The reasons are a complex stew of finances, technological challenges, and political will. But across those years, technology has matured, seasoned by advances in computers, robotics, and materials. Many analysts suggest that the time is right to build a permanent human presence on the Moon. The scientists want to go back. *Apollo* left us with intriguing puzzles and mysteries, and it also left us with the understanding that knowledge of the Moon gives us insights into Earth. But reasons for a return go far deeper.

Technological Reasons

"We're still riding the wave of innovation that came out of the *Apollo* program," says Constellation Manager Jeff Hanley. "It wasn't so much the widgets that got built, but rather the precision, the way of going about building widgets of high precision and high reliability. That was the true benefit of the *Apollo* program. It infused industry with ways of doing business and standards of building things that were unparalleled at the time, because they had to be incredibly high in reliability, incredibly simple, incredibly low mass. That drove miniaturization." Hanley joins a widespread chorus of voices declaring the benefits of space technology to the general population. And while some analysts argue that certain areas of American technology are stagnating today, many believe that a vibrant lunar program will drive technology in new directions that will benefit the world's population and economy.

Constellation EVA Systems Project Manager Glen Lutz points out that, "The brakes in my car are better today because of the heat rejection problems NASA had to solve for reentry into Earth's atmosphere." Lutz believes the benefits to society are seldom seen ahead of time, but the applications are numerous. "For example, why spend this money on spacesuits? The resulting technology has given us cooling for medical procedures, techniques for radiation treatment, miniaturization of components for health industry, materials research, and the list goes on."

Added to that list are the commercial aspects of a return to the Moon. In 1991, commercial and governmental space spending was at $11.5 billion; by 2007 it had reached $251 billion.[11] Companies such as Google and Virgin Galactic are tapping into a new arena of private exploration and space tourism. The infrastructure built by NASA, ESA, and other spacefaring communities will enable commercial ventures only hinted at today.

Cultural Reasons

"Science and space exploration will drive humanity's search for knowledge in the coming generations, and we must recognize there are only so many things we can learn here on Earth, and give NASA the tools to explore the rest." These observations were not made by a scientist or space strategist but by Tom DeLay, then house majority leader, in a 2005 press conference. DeLay's comments came on the heels of a congressional act, signed into law, assuring funding for NASA. The NASA Authorization Act of 2005 (HR 3070) received overwhelming support from both sides of the aisle and found form in NASA's Vision for Space Exploration. The congressional act states, in part, that Congress must have a "clear policy and funding provisions to insure that NASA remains a multi-mission agency with robust R & D activities in science, aeronautics, and human space flight." The act also called for "support for the goal of human space exploration beyond low Earth orbit and guidelines to insure it is properly paid for and not funded at the expense of other important NASA programs." The bill was approved 383-15.

Does space matter to the American people, as Jim Garvin believes? A 2004 Gallup Poll showed that 68% of Americans supported the Vision for Space Exploration. By 2005, that approval number had jumped to 77%.

Gene Cernan has often remarked that the last Moon flight, his *Apollo 17*, was "the end of the beginning" of lunar exploration. NASA's vision for a return to the Moon is an attempt to put truth to his remark. But to get there with a new generation of explorers and equipment, an advanced series of

11. Reuters, Wednesday, April 9, 2008.

Apollo 16's John Young: Saving Earth through Lunar Exploration

Captain John Young is one of the most experienced space travelers in history. He flew a total of six missions in the Gemini, Apollo command codule, lunar module, and space shuttle vehicles, and spent three days on the lunar surface in the Descartes Highlands with astronaut Charlie Duke. Recently, Young has focused public attention on the migration of the human species into space, and how application of the technology needed for such migration will assure its survival.

We're going back to the Moon not because we want to but because we must. It's to save civilization. If you look at the geologic record, single-planet species don't last. Take a look at the 300-mile diameter crater at the end of the Permian, 250 million years ago. [The asteroid that created that crater] wiped out everything on the planet, 90% of the species. There's nothing we can do to handle something that's going to make a 300-mile-wide crater, and there are plenty of asteroids and comets out there that can do it.

Going back to the Moon is very practical for the long haul of civilization. You industrialize the Moon. You're able to live and work up there. You're able to terraform (change an environment into an earth-like one). You have the kinds of things you need to protect people if bad things happen on planet Earth. I think going back to the Moon is really the key to our future. Just having a moon makes it possible for us to survive; once we industrialize the Moon, develop alternate energy sources, and generate solar power and ship it back to Earth we'll totally change the way people live on this planet. If you just look at the fossil fuels we'll be using when China and India [become completely industrialized] we'll be using so much that we're not going to make it. At the rate we're going, we're not going to last. Something has to change. [A return to the Moon] will give us the technology we need to control our own destiny.

The Moon is also the key to Mars. Once you learn to live and work on the Moon you can handle stuff on Mars. Now, Mars is going to be a little different because the dust floats. We have to learn how to deal with it on the Moon before we go to Mars. Having an airlock [on the Altair and rover] will help. Maybe you have an inner place where you clean up—a pre-airlock—or a place outside where you clean up before you even get into the airlock. Another possibility is an outer suit that you take off. We've been working on it. At this point, dust is in a lower category, but it would sure wipe you out. But I think going back to the Moon is the key to preserving civilization on this planet. The more we can do to industrialize the Moon, to learn to live and work up there, is really the key to our future.

crewed orbiters and lunar transports must be produced. Carrying the load will be the next generation of boosters, christened Ares.

ARES: THE NEW WAY UP

Instituting a new family of launch vehicles is a daunting task, and one that designers do not take lightly. The logical question asked in the beginning was, why not simply upgrade the expendable boosters we already have? To answer the question, NASA and independent study groups considered three areas: performance (necessary lift capability), risk (comparative reliability and track record of various existing systems), and cost of all approaches and systems.

The new boosters must enable *Orion* to take the place of the space shuttle. The shuttle is a powerful machine. To match its role, the *Orion* spacecraft will need to carry substantial human and cargo payloads into low Earth orbit. *Orion* will also be tasked with getting crews to the vicinity of the Moon. Ares Earth-orbit capacity must surpass 20 metric tons to orbit. It must also be able to transport 23.3 metric tons into a translunar orbit, a path that leads out of Earth's gravity and ends at the Moon.

These were the requirements. The next step was to see if any available launch systems could be modified to fill the bill, which involved scrutiny of commonly used systems such as the space shuttle's main engines (SSMEs) as well as evaluation of what are known as the evolved expendable launch vehicles (EELVs). Since the SSMEs were in relatively constant use, the powerful engines seemed a good bet for use in the next generation boosters. But other boosters were in contention with good track records and hardware that was available. Both the Delta IV and Atlas V, current workhorses of the U. S. space program, were in the running for adaptation to Ares.

Studies showed that both the Delta IV and the Atlas V have insufficient power to boost the large payloads called for in a Moon mission. Could they be safely modified, not only to carry humans but also to carry the extra weight into space? Engineers determined that a new upper stage would be required with high performance engines, but even this would not be sufficient. Planners then looked to strap-on boosters, smaller versions of the shuttle's solid rocket boosters that strap to the side of its external tank. The problem is that such solid fuel strap-ons lower the safety of the system and add complexity.

In fact, safety became the major concern. The most powerful EELVs were never designed to carry humans. In a speech to the Space Transportation Association, NASA administrator Mike Griffin said, "Significant upgrades to the Atlas V core stage are necessary, and abort from the Delta IV exceeds allowable g-loads. In the end, the probabilistic risk assessment…indicated that the shuttle-derived Ares I was almost twice as safe as that of a human-rated EELV."

Steve Cook, director of the Ares Project Office at NASA's Marshall Space Flight Center,[12] agrees. "The Atlas V and the Delta IV were designed as a low cost system to get cargo into space. It's about a wash when you compare costs to modify Ares I for a crew, but Ares I is much safer and more reliable because you have fewer propulsion systems—two versus four in the case of Delta IV—and the system is already designed for a crew. The EELV family just doesn't lend itself well to growing into a system that can throw 300,000 pounds into low Earth orbit. In a sense, we've pulled in the best from Delta (the RS-68 engines), but transforming the system of EELV's into Earth departure stage is not practical. It doesn't get you where you need to go, ultimately. "

Costs turned out to be the final nail in the EELV coffin. Studies showed that the cost of an EELV-based launch system was nearly 25% higher than the Ares I and V boosters. Griffin concluded, "While we might wish that 'off the shelf' EELVs could be easily and cheaply modified to meet NASA's human spaceflight requirements…the data say otherwise."

Once EELVs were out of the running, it was time to consider other approaches. Steve Cook tasked his team with evaluating space shuttle main engines. The SSMEs are made more complex by virtue of the fact that they are designed for reuse. On Ares, these engines would be used only once. In short, Ares main engines did not require the complexity of the reusable SSMEs. So designers turned to the tried-and-true J-2, the engine that powered upper stages of the Saturn V through a decade of successful flights.

12. Marshall Space Flight Center is in Huntsville, Alabama.

The Delta IV EELV, built by Boeing. (Photo taken by Carleton Bailie and courtesy of United Launch Alliance.)

Lockheed Martin's Atlas V EELV. (Photo courtesy of Lockheed Martin.)

"Our baseline [study for Ares I] called for an upper stage with an SSME and a first stage that used a four-segment solid rocket booster similar to what we use today on the shuttle," Cook explained. "Ares V had a five-segment solid booster, and a core stage with five SSMEs." The baseline second stage, which was the Earth departure stage, would have a single J-2 derivative. J-2 won on the merits of cost, reliability, and safety. But as Cook's team moved beyond the initial study, it became evident that Ares I and Ares V had far too many different propulsion systems, including solid rockets, strap-on solids, the Ares V's SSMEs, and Ares I's J-2 engines. Cook wanted to minimize the number of developments required for new propulsion technologies. One way to streamline the system was to get more commonality between the Ares I and Ares V.

Designers settled on the J2-X, an advanced version of the *Apollo*'s J-2, for both the Ares I upper stage and the Ares V upper stage. The J-2 was less powerful than the SSME, so planners needed more power from the first stage. They got it by expanding the stage from four fuel segments to five. This made the size of Ares I's first stage identical to that of the Ares V, so both launchers shared common hardware. This not only saves money in manufacturing but in processing as well. Building and launch facilities now could share common size for the first stages of both Ares I and V. But, according to Cook, there was still an issue. "We still had SSMEs running around on the first stage of the Ares V, so we said 'how can we get rid of those?' Some of our guys got really creative and said, 'We'd really like to use the largest liquid oxygen/hydrogen engines commercially available today, the RS-68 (used on Delta IV heavy lift vehicles). It's a lot cheaper than the shuttle engines; it's proven.' The problem was that those engines weren't giving us enough power." The solution was to give the engines more propellant. Ares designers scaled up Ares V to be 33 feet in diameter (rather than the original 27.5 feet), allowing them to put more propellant on board. This gave Ares V a diameter nearly identical to the Saturn V, and the new engines will actually perform better than the original projections for SSMEs. Just as important to the budget, launch processing sites such as Kennedy and Michoud [where shuttle external tanks are processed] still had structures originally scaled for Saturn V *Apollo* Moon rockets, so the new Ares V would fit without extensive modifications. "Now we have direct traceability from Ares I to Ares V in two key propulsion systems," Cook explains, "and we're using a core stage for the Ares V, which is already flying today, so we won't have to do a lot of development work. In doing so, we ended up saving several billion dollars over the life-cycle of this program without compromising the safety or reliability of these systems."

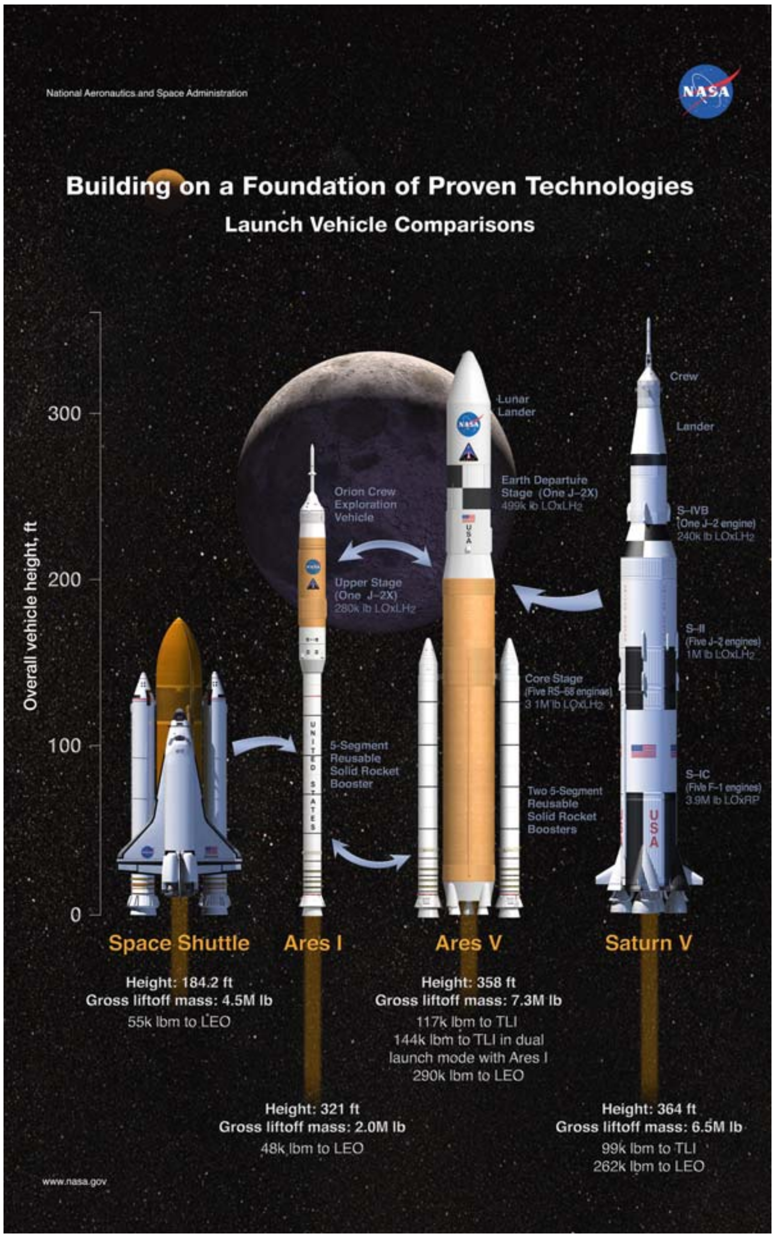
It was a fast-paced, dynamic decision process, but Cook "had already looked at hundreds of different options, so we were already running at a fast pace and we just kept going." The speed with which the Ares design decisions were made reflects the pace at which the *Orion* project—and the Constellation

Designers of the Ares family have selected upgraded J-2 engines, whose heritage reaches back to the upper stages of Saturn V, like this one on the Saturn's third stage. (Photo by author.)

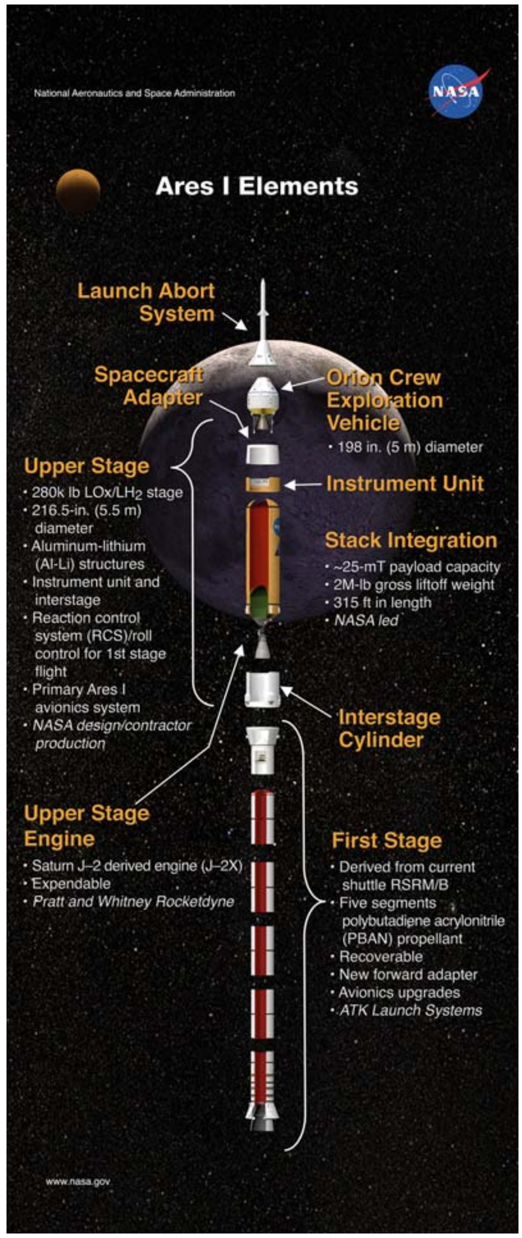
program in general— is progressing. Johnson Space Center's Wendell Mendell explains that NASA Administrator Mike Griffin "felt he needed to get things embedded and going during his tenure, so Constellation was born." The pace was fast and steady, akin to the *Apollo* days, Mendell says. "Jeff Hanley was put in place as the head of it and designed the organization after the *Apollo* management organization, which was very successful."

Having reliable human access to space—with the flexibility to use the transportation system either for people or for cargo—is a complex and difficult goal. But it is essential that Ares affords reliable, consistent, sustainable access to space, particularly far-off destinations such as the Moon and Mars.

Ares I and V compared to the shuttle and Saturn V. (Photo courtesy of NASA.)



Critical elements of the Ares I, which will carry the Orion *CEV to orbit. (Photo courtesy of NASA.)*



"The Moon is our first deep space frontier," says NASA's Jim Garvin. "We are really trying to build something very new, and it's going to be revolutionary. We're putting in place the capacity for humans to have access anywhere on the Moon. Anywhere."


ATK technicians prepare the new Ares I rocket first stage segment for launch. (Photo courtesy of NASA/MSFC.)

Ares goes a step beyond the *Apollo* era in many ways, not the least of which is that it must be done with a significantly thinner slice of the budget pie than the shuttle was. Constellation is a generation beyond *Apollo,* Jim Garvin says, "particularly because we have to do it for less money. This is a different environment, a different climate. We have climate change on our planet; there's also climate change in space policy. That environment dictates that NASA has to be smarter, and better and more creative."

Part of that creativity plays out in the way elements of Constellation are developed and tested, according to Marcia Ivins, head of the Exploration Branch of NASA's astronaut office, and a veteran astronaut of six flights. "When we build this mass simulator that will be the second stage of [the first Ares test flight], they're going to assemble it in the Vehicle Assembly Building, and what they don't want to do is have to reconstruct all the platforms around it. They've figured out a way to assemble it from the inside out. You build a ring, crawl inside it, and bolt it all together from the inside out. There's a ladder structure on the inside, so you climb up and out and build the next level."

To keep costs down and efficiency up, NASA has adopted a test-as-you-go approach for much of the project, Jeff Hanley says. "We start with the end in mind. Ultimately the end that we have in mind is a human Mars mission. So we work backwards. What do we need to learn at the Moon? True, we can get back in three days, but we can put our systems out there and actually run them for a long time in an alien environment and see how they really perform. All of the tools and techniques that we develop, are those really, in practice, effective, or is there something about it that we don't understand? Then, we apply the developing technologies along the way."

This approach has led to the framework for the first full-up launch test of the Ares I, the Ares I-Y, the maiden flight of which is scheduled for early in 2013. Ares I-Y will focus on the first stage's flight characteristics, controls, and the critical separation of the first stage from the second one, which, in future flights, would carry the crew. Flight engineers will use a fully functional first stage. The stage is based on the shuttle's solid rocket boosters, which are strapped to the sides of the large external tank. In the case of Ares, the booster will be a "single stick," a configuration never flown before. The second stage is called a "mass simulator," but instead of dead weight, the stage will carry sensors to detail the flight path of the Ares I stack. As Steve Cook puts it, "There is nothing better than getting flight data as early as possible. For the first time, we will do a development test flight of our launch vehicle early enough in the development of Ares I to inform the design. That's what the Ares I-Y is all about. You can't beat flying in the environment that you're going to operate in, so we said, 'What can we do early? We're not going to have an upper stage available, we know we won't be ready with a full five-segment booster, but we can still reduce a lot of our risk early on in the project, as they did with Saturn. We looked at why they ran these tests and why they flew these vehicles the way they flew them, and it made a lot of sense to us so we took that approach. We've taken a page from the Saturn V playbook."

The Grand Plan: Second Generation

The *Apollo* Project used lunar rendezvous to get crews to the Moon, launching all vehicles on the same Saturn V booster. The new Constellation strategy bears closer resemblance to the original Soviet plan, in that the crews will use Earth orbit rendezvous to get the job done. For the new generation of lunar explorers, the Ares V booster will carry the *Altair* lunar lander into Earth orbit. *Orion* links up with the upper stage and *Altair* after a separate launch aboard the smaller Ares I. Once *Orion* and *Altair* are safely docked together, the upper stage of the Ares V sends them toward the Moon. In *Apollo,* the main engine of the *Apollo* CSM did all the work, settling the CSM and LM into lunar orbit. It is the powerful lower stage of *Altair*—the lunar lander—that will slow the *Orion/Altair* stack into lunar orbit. *Orion* carries far less fuel and will use its engine only to get crews back home from lunar orbit after *Altair*'s ascent stage returns crews from the surface.

Another cost-saving feature of Ares I is reusability; the first stage uses the shuttle's solid rocket booster technology, developed and built by ATK launch systems. As such, the lower sections of Ares I are recycled for future launches. The Ares I first stage separates from the upper stage at an altitude of 189,000 feet, roughly 126 seconds after liftoff. After freefalling to 16,000 feet, it deploys a small drogue parachute, halving the stage's 400 mph rate of descent and tipping the booster into a vertical position. At that point, three main parachutes, each 150 feet in diameter, open to carry the booster safely to waiting recovery ships below.

Boeing is heading up the Ares I's upper stage, which can carry a 25-ton payload into Earth orbit. Boeing is also building instrumentation for the booster based on its extensive experience with the Delta IV launchers. Transition from Delta IV construction to that of Ares I will also save costs.

The Ares I is designed to eventually carry the *Orion* crew exploration vehicle, America's newest human-rated spacecraft, into orbit. *Orion* will service the ISS during the last four years of the station's lifetime, and will carry large payloads into orbit. *Orion* will also ferry crews to and from lunar orbit, but to carry out that role will require Ares I's massive sibling, the Ares V. The maiden flight for Ares V is now projected for 2018.

ORION: THE NEXT SHUTTLE

The Rocky Mountains serve as birthplace for a high-tech progeny. It is here, nestled in the unlikely setting of deer-trod foothills and granite peaks, that Lockheed Martin Astronautics has built launch vehicles, Mars orbiters and landers, and a host of defense systems. Now, LMA is producing the *Orion* crew exploration vehicle (CEV), replacement for the American space shuttle.

To many observers, *Orion*'s arrival is none too soon. The aging space shuttle fleet is the U. S. lifeline to space. It is the only American transportation system able to carry humans to the International Space Station. Its flexibility has enabled it to serve as an orbiting research laboratory, an interplanetary space delivery system, and a satellite rescue and repair platform. The fleet has been flying for a quarter century, and it's showing its age. Two of five orbiters have been lost to catastrophic failure, *Challenger* during launch and *Columbia* during reentry. The loss of human life was emotionally devastating, not only to NASA but also to all of the United States. Technicians must constantly scour the remaining three orbiters, looking for stress fractures, metal fatigue, and other safety hazards that naturally occur in an elderly flight system.

As NASA's Jim Garvin observes, "The shuttle has been a miracle of engineering, and it's done tremendous stuff, but because of the requirements levied on it after the heyday of *Apollo* it was expected to do too much. It's kind of like the Spruce Goose. It had too many things to do rather than a focus. When one tries to do that, the machine becomes very complicated."

"With the shuttle, they solved technical problems right and left in its design and development," Johnson Space Center's Wendell Mendell observes, "but they neglected to worry about what the operations costs of the final vehicle would be. If you look at drawings of the shuttle from the seventies, you see shuttles that look like airplanes with about six people walking around them, but if you look at the picture today in the bay, you can't actually see the shuttle because it's covered by scaffolding with armies of people around it like ants, doing things. That is one of the reasons it is so incredibly expensive to operate. They're working hard to make [the vehicles of Constellation] not that way."

Around 2010, after 28 years of flight, the shuttle will fly its last mission. The *Orion* may fly to the ISS as early as 2015, with Russian *Soyuz* craft—and possibly European or private vehicles—filling the gap in the interim. NASA hopes to fly the return mission to the Moon by 2020.

TICKET TO THE MOON

A flight to the lunar neighborhood aboard *Orion* will be carried out in several steps. The Ares I will put *Orion* into a ballistic trajectory, so the spacecraft must use its main engine to do one burn. This circularizes the orbit. At that time, the solar-powered *Orion* will deploy its solar panels. Says Lockheed Martin's Chief Engineer and Technical Director for *Orion,* Bill Johns, "We're not in any big hurry; we have about ten minutes before we do the burn. The current baseline is that I make sure both of my [solar] arrays deploy before I do that burn. If neither one deploys, I do an abort-once-around," returning the craft to Earth.

Once the spacecraft is in orbit and determined to be healthy, it will dock with the Earth departure stage (EDS) and *Altair* Moon lander, carried into orbit atop the Ares V, which is launched separately. *Orion* secures itself to the *Altair* on the front of the EDS, and the Ares V upper stage sends the entire stack of vehicles toward the Moon. But *Orion*'s delicate solar panels must be protected from the forces of that launch from Earth orbit to the Moon, Johns explains. "You can pivot the solar panels so they can find the Sun when the spacecraft is turning. But we typically will lock them in place when we are moving. We move them at the 'shoulder' to point aft by about 60 degrees during that Earth departure stage firing. We rotate them during that high acceleration burn to limit stresses on them."

After casting off the empty EDS, *Orion* and *Altair* coast to the vicinity of the Moon. It is *Altair* that drops the two craft into lunar orbit with its huge descent stage, but *Orion* must serve as the orbital base for lunar operations. The craft will be tasked with one of two missions. The first, called a sortie mission, sends *Orion*'s four-member crew to the surface in *Altair* to carry out up to ten days of surface exploration. For this type of mission, *Orion* spends up to 21 days in orbit autonomously. The second mission class is called the outpost mission. In this scenario, *Altair* lands at the lunar base. The crew stays on the surface for six months while *Orion* flies solo in orbit, monitoring its systems and caring for itself, awaiting the crew's return and the trip home. Although the missions differ significantly in length, Johns says, "We're trying to develop one configuration to cover both the 21-day [sortie] and outpost (210-day) missions." *Orion* returns the crew to Earth, skipping on the upper atmosphere to bleed off speed before coming into the denser atmosphere. It lands using three parachutes and a series of airbags.

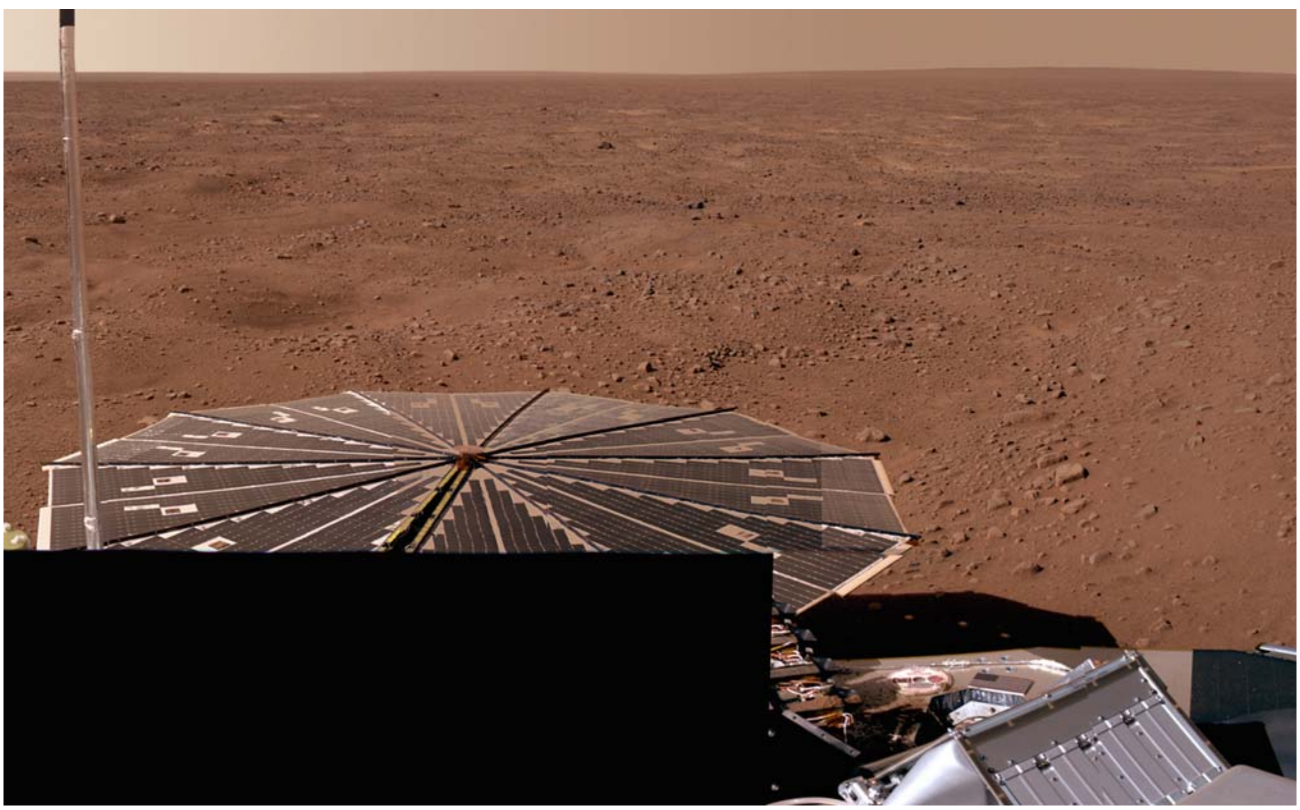
ADVANCES

To the untrained eye, the *Orion* looks like a step backward from space shuttle technology, an oversized *Apollo* capsule. But a closer look reveals important advances over both the *Apollo* Moonships and the shuttles.

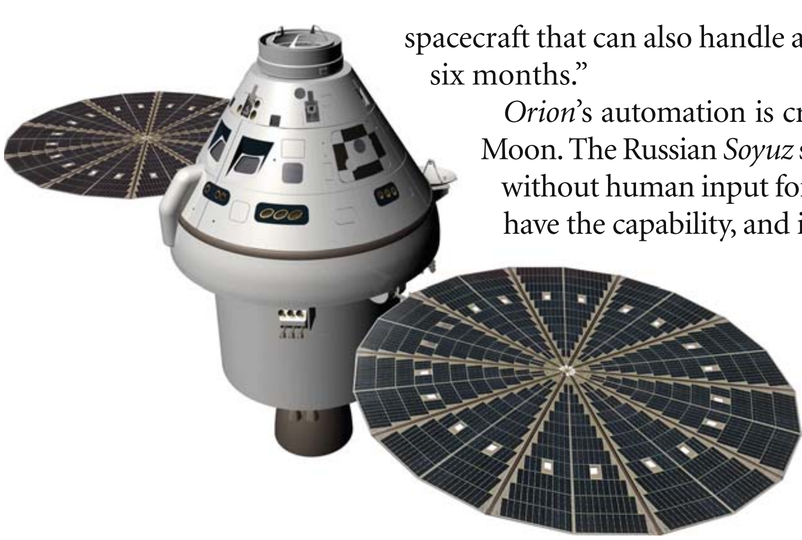
The most obvious difference is *Orion*'s solar panels, a departure from all previous U. S. human-rated spacecraft. Like *Apollo* before it, *Orion* consists of a crew module, a launch abort system, and a service module. The robust service module houses the main engine for *Orion*'s on-orbit maneuvering, along with a different type of power regime. *Apollo* and the shuttle are powered by cryogenics—liquefied gas—that cannot be stored for long periods. *Orion* carries solar panels that will enable the craft to endure its long flight times. Mark Kirasich, Deputy Manager for the *Orion* Project, says the decision was necessary because of weight constraints and long mission duration. "Fuel cells take consumables. They're heavy. We don't have enough throw-away to toss six months of hydrogen and oxygen toward the Moon. Instead we have a reusable energy source in solar arrays." The fan-like arrays are larger, more efficient cousins of the panels used on the Mars *Phoenix* lander, so they have a good track record of development and operation.

Orion is significantly larger than earlier Moon ships, spanning 16.5 feet across (*Apollo* was 12' 10" in diameter), with 691 cubic feet of interior space. Although the cabin is roomier than *Apollo* command modules, former shuttle astronauts may find themselves feeling a bit cramped, says Lead Cockpit Engineer Jeff Fox. "You're going from an over-sized Suburban SUV to a small mini-van." But *Orion* has more tricks up its technological sleeve. *Apollo* was fitted for two-week flights; *Orion*'s solar power enables it to stay in Earth's or the Moon's orbit for six months. It can carry a crew of six to the ISS, along with supplies, or a crew of four to the Moon. The craft can be tethered to the ISS and left to fend for itself for months or can hibernate in orbit around the Moon while crews spend half a year at the lunar outpost or on long-duration exploration sorties.

These features were built into the initial requirements of the spacecraft, Lockheed Martin's Bill Johns explains. "One fundamental requirement was for it to be a lifeboat for the ISS. But we also will design the craft with commonality between lunar missions and low Earth orbit. You do six month rotations on ISS, so you say, 'We'd sure like this thing to be able to look after itself for six months, docked to the ISS. The amount of power we can gain docked to ISS isn't a whole lot different from what we can get at the Moon, so why not do six-month rotations at a lunar base?' There's a lot to be said about one design for multiple missions. Six months at ISS lends itself to a



The solar panels of the Phoenix *Mars lander, seen here in July of 2008, are smaller cousins of those on* Orion. *(Photo courtesy of NASA/JPL-Caltech/University Arizona/Texas A&M University.)*

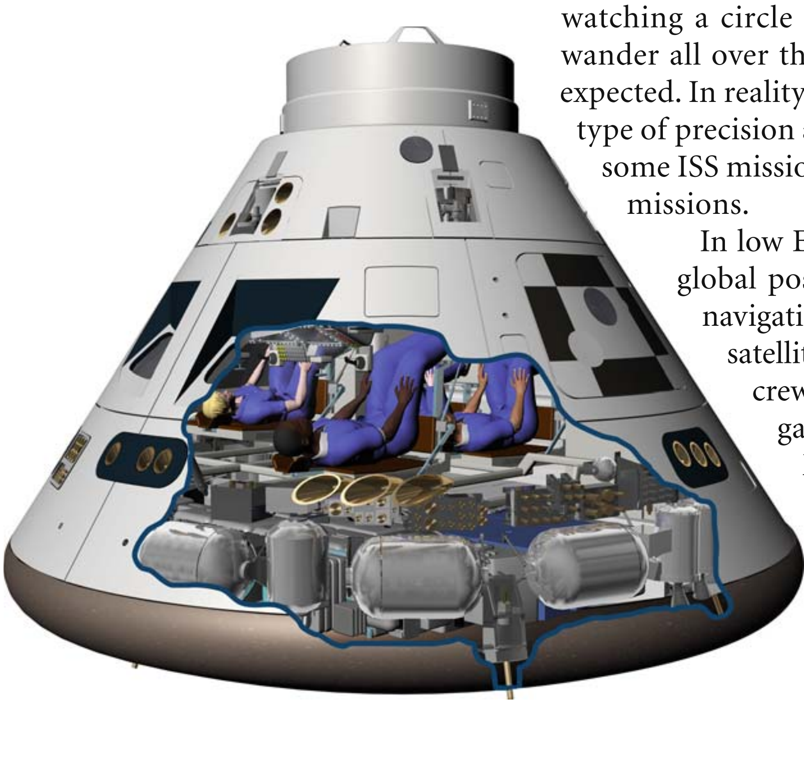


Artist rendering of the Orion *spacecraft with deployed solar panels. (Photo courtesy of Lockheed Martin Astronautics.)*

spacecraft that can also handle autonomous flight around the Moon for six months."

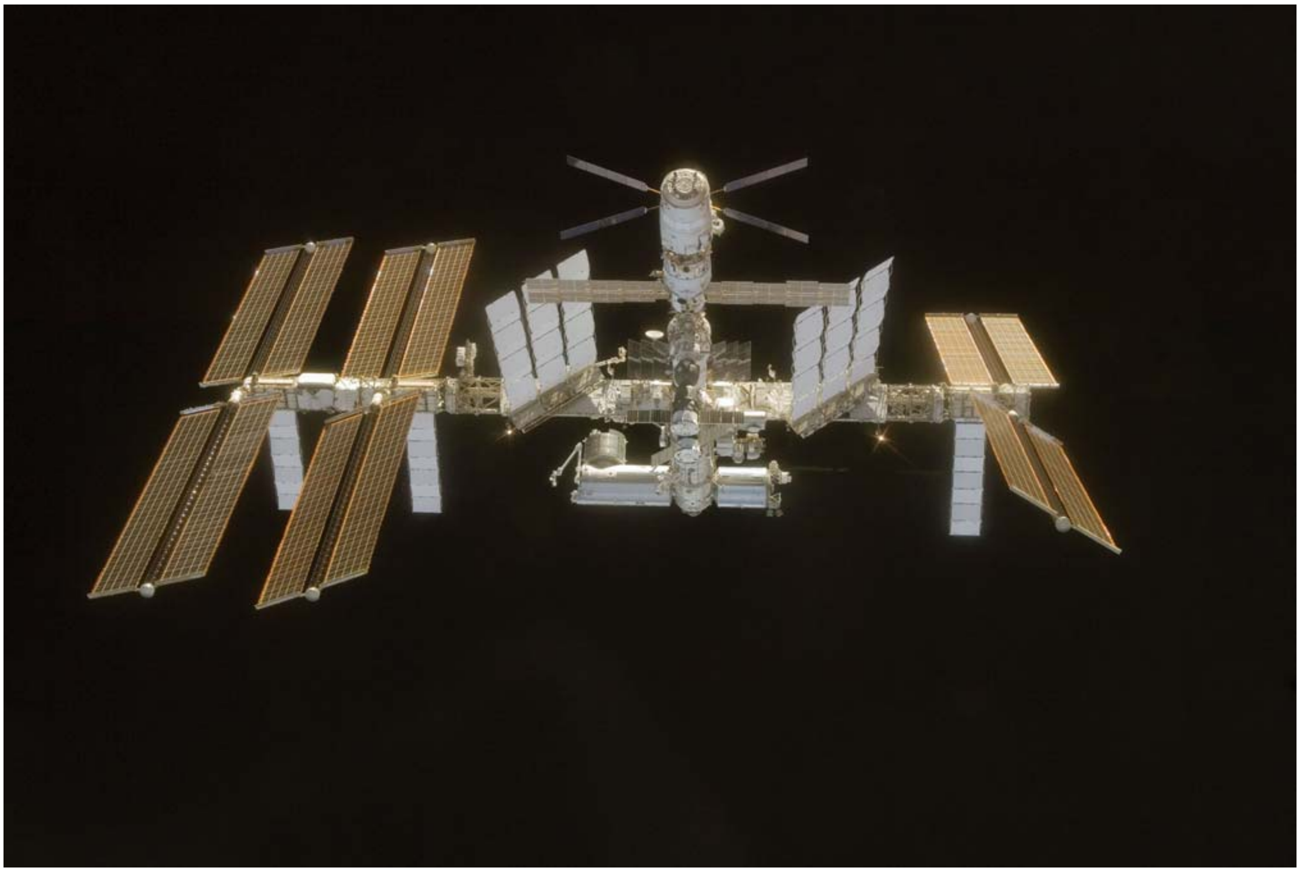
Orion's automation is critical to its missions near Earth and the Moon. The Russian *Soyuz* spacecraft have had the capability to dock without human input for decades, but this is the first U. S. craft to have the capability, and its talent for untended orbital moves will be unparalleled. JSC's Mark Kirasich says, "Technology makes a huge difference. Computers and data networks are affecting things across the vehicle. Now, we have 100 megabit and gigabit speed data buses. Back in *Apollo*, it was analog. In the shuttle era, it was much slower rates with raw numbers and data values. Here, it's going to be images and plots and video. We can pump a lot of data around." As an example, Kirasich cites the shuttle's flight data file, a series of thick books like instruction manuals, a sort of user's guide to the spacecraft operations. Those thousands of pages will now be on a screen, and the same screen will enable the astronaut to execute the operations that the manual calls for.

Kirasich's team was watching closely when, in April of 2008, the European Space Agency's fully automated transport vehicle *Jules Verne* delivered cargo and fuel to the ISS. If the shuttle is vintage 70's technology, *Jules Verne* is 2000's technology, Kirasich says. "The shuttle used radar (invented in WWII), as well as optical sensors. That was state of the art in 1970. *Jules Verne* uses GPS and laser. The accuracy is phenomenal. In its final approach, the crew watches as it comes in. They have a camera watching a circle of 5 degrees. In training, simulators wander all over the circle area, which is what everyone expected. In reality, it never came off the centerline." This type of precision automated docking may be needed for some ISS missions, and will be critical for future lunar missions.



Artist rendering of the interior of Orion, *showing the four-astronaut configuration. (Photo courtesy of Lockheed Martin Astronautics.)*

In low Earth orbit, spacecraft can make use of global positioning satellites (GPS) for accurate navigation. But once outside of those orbiting satellites, the system no longer works. *Orion* crews must use another approach to navigation as they come and go from the Moon. Engineers have selected a single technology that will work in both arenas, Mark Kirasich explains. "We use our S-band system that we use for communications, but we embed navigation information into the radio signal so that the two vehicles



The European Space Agency's Automated Transport Vehicle (ATV) Jules Verne, *docked at the center of the ISS. The European ATV can carry three times the cargo of a Russian* Progress *tanker, roughly 7.7 tons to low Earth orbit. (Photo courtesy of NASA/JSC.)*

can do ranging and Doppler measurements. It's clearly a step up from what we could do in the seventies."

With its full automation, *Orion* can serve as an uninhabited cargo vessel for the ISS. It will also be capable of taking over the docking events with *Altair* landers on their return trip from the Moon, should *Altair*'s rendezvous systems fail or the crew members become incapacitated.

Bill Johns believes that temperature is as great a challenge as long-duration autonomy. He points out that commercial spacecraft have been taking care of themselves for fifteen years or more. But he says there are some unique things associated with the heating environment around the Moon that make two weeks as challenging as six months. "If you're orbiting over the poles, you are basically in the Sun almost the whole time, and you're getting solar reflection and heating coming up from the Moon, so you have a fairly hot environment that you have to accommodate. But once you size for that case, the duration isn't a long putt."

The dual nature of *Orion*—serving both the near-Earth space and lunar environment—necessitates two subtly different versions, referred to as "Block One" and "Block Two." The Block One craft functions as a crew and cargo ferry to the ISS, and carries up to six astronauts. It runs at a slightly higher cabin pressure than Block Two, matching the ISS's nitrogen/oxygen mix of 14.7 pounds per square inch (psi), equivalent to air pressure at sea level.

The reason: the Moon-bound Block Two *Orion*, with a crew of four, must interface with the *Altair* Moon lander, which has lower pressure and a higher percentage of oxygen. *Altair* and the lunar version of *Orion* operate at a pressure of 10.5 psi, similar to a mountain community at 8,000 feet altitude. The lower pressure enables Altair to be a much lighter craft, as it can carry less air for its long missions.

Another difference between Earth-orbiting and lunar *Orion*s has to do with the heat shield, an ablative surface that protects the crew and craft as it burns up upon return through Earth's atmosphere. Entry speeds are considerably higher when a spacecraft comes from the Moon. Designers must add roughly 500 lbs of material to the heat shield for lunar CEVs. But the aerodynamics remain the same, so adding mass to the heat shield is not difficult.

The MMU: Going It Alone

In February of 1984, Bruce McCandless became the first human "satellite," flying untethered some 320 feet from the space shuttle Challenger. Here, he reflects on that experience, and on post-shuttle advances.

The Manned Maneuvering Unit (MMU) served as a pathfinder and a demonstration for the SAFER (Simplified Aid For Extra Vehicular Rescue, now used at the ISS). SAFER is intended for self-rescue in case you get separated from the station. SAFER has versions for both the ISS and *Orlon* suits, and snaps on. It's much more compact than MMU was, but it has enough gas to get you back. If you crouch down and shove off of the station, you end up with about a 3 feet per second velocity. SAFER is designed to take that velocity out and get you back. It has about an 8 foot per second change in velocity. It's just to get you back to where you can grab something.

During my MMU test flight, I had anticipated some solitude and being able to turn my back to the shuttle to gaze out at creation. I never got the chance. The communications were too good. We had three channels going at once. I had Commander Vance Brand reminding me not to go too far away, and not to go under the wing where he couldn't see me, and to stay away from the engines. Then there was Mission Control wanting to know how much nitrogen [fuel] and battery power I had left. And [fellow astronaut] Bob Stuart wanting to know 'When's my turn?' In the middle of all that, I never really got the chance to stop and do a Walden Pond type thing. But it was very impressive and beautiful. At one or two points I got to look down. I had no idea where we were until, at one point, I looked down and saw that we were right over Florida. You cannot mistake any other place on Earth. It was reassuring to see the Cape [launch] complex, and the Florida Keys and the Bahamas.

For the next generation of [spacecraft] software, we've come a long way. To take it to a down-to-earth level, one of my nieces gave my wife an iPod for Christmas with two gigabytes of flash memory. If you clock back to the late seventies when I got my first laptop, it was a Zenith: twin floppy disk drives, a bit bulky. After a year, I finally had saved up enough money to buy one megabyte-worth of additional ram. It cost $1,000. If you scale that, this two-gigabyte iPod would have been a $2 million purchase, and you would have needed a little trailer to carry it around. We've made such fantastic strides. (*Apollo* astronaut) Charlie Duke's son is flying the 777. They make absolute zero-zero landings hands-off. My understanding is that they have a three-channel autopilot system and a three-channel ILS altitude type system, and when the weather gets crummy, you approach until you're on the ILS glideslope, and you engage the system and put the gear down. As long as you have six green lights, you sit there with your hands folded while the system takes the airplane in, lands it, and throttles back and applies the brakes and says 'Here you are.' There is no reason why *Altair* shouldn't have triple or quadruple redundancy. On *Altair,* the basic decision has been to wait about ten years and see what happens to electronics in the meantime. That's probably a pretty good plan. One of the things that we continually do to ourselves is we lock something in, and by the time we go fly it's antiquated. Last fall, there was some complaint that somebody had hacked into the e-mail system on the space station. NASA put out a call for help to Microsoft, and Microsoft replied, 'Gee, we'd really like to help you, but all the people that are familiar with Windows 3.1 are retired, and believe it or not, our people are really gainfully employed debugging Windows Vista right now.'

AT THE CONTROLS

Orion's flight deck is like nothing before it in human spaceflight. Instead of bulky switches and dials, the primary interface for pilots consists of three flat screens, similar to cockpits in today's 787 commercial airlines. The arrangement and layout of the modernized controls is the responsibility of Johnson Space Center's Jeff Fox. "We're looking at taking the twelve or fifteen hundred switches that are on the shuttle—taking all those manual control points, and putting them in the software. We've got all that contained in three pieces of glass." Each 10" x 8" horizontal screen is split into two areas, so astronauts will have a total of six screen areas in which to carry out diverse functions. "We'll have maybe fifty switches. Everything else is in the software."

Fox's cockpit working group must take into consideration *Orion*'s operations, engineering, human factors, and life sciences. "We're looking at every aspect of what the crew touches in the pressurized volume," Fox says. "Displays, windows, lights. How are things laid out, how you strap in, how you do your procedures, because it's no longer paper, its electronic. It's a huge integration job." Fox and his team of engineers have studied past spacecraft, including shuttle, *Apollo* and *Soyuz,* and have consulted with airline companies to come up with the best arrangements for *Orion* crews. "We've looked at all those spacecraft. We've been in the *Apollo 17* command module here at Space Center Houston—I've lost track of how many times—climbing around in there, thinking about what they did and how they did it, talking to the astronauts and the *Apollo* Human Factors/Habitability folks. Then we compare to what we've got on shuttle."

While spacecraft architects toil over computer screens, Fox's team builds out of plywood and plastic. "You need to have a physical environment," Fox asserts. "There's only so much you can do on paper. We have found that the [computer] modelers come over and verify how we laid it out, and go back to make changes. There is a lot of give and take."

Fox's fabricators built three different venues. The first was a roughed-in, low fidelity foam-board version to ascertain gross placement of systems and crew. A second is medium fidelity. It uses real adjustable seats and is an aluminum structure instead of foam board. Designers are able to build operational workarounds, making changes early and cheaply. A third mockup is chopped off just below the crew deck. This one is a physical study of tanks, boxes, access panels, and plumbing. The mantra of crew safety is everywhere: seats and other structures are outfitted with struts, braces, and shock absorbers to attenuate the landing jolt. To Fox, it's a game of trying to outsmart the things that can—and often do—go wrong. "You come in at an angle, and that attenuates the [landing stress]. But what if the angle isn't perfect? What if you hit the side of a wave? What if you wind up on the land and there's a burm instead of a flat space, or what if you get a damaged parachute? All kinds of things can come up, so how do we protect the crew better?" Fox points to a seat resembling something that Danica Patrick might use, with racecar-like lateral support. "We'll have something to help

The low-fidelity mockup of Orion *has rudimentary couches and is useful for fleshing out the interior space of the CEV. (Photo by the author.)*

keep the head from moving too much, and to support the spine in relation to the body. We teamed with the racecar industry to build conformal seating. If we do that, maybe we won't need struts on the couches [which was the approach in *Apollo*]."

Hanging from the ceiling are ping-pong balls on strings. Capsule builders use them to get the right "eye point" for test subjects in the couches. It's important, Fox says. "If you're not in the right sweet-spot, the windows don't work, the displays are all in the wrong place; the reach, the visibility, the access to critical areas all has to work. When you talk about something like changing the seat thing, we always say, 'be mindful of the eye-point.'"

In the crew exploration vehicle design business, everything is a trade. If CEV builders push one thing, something else pops out and it changes the overall shape. Power, weight, functionality, habitable volume: every time designers tug on one, it affects something else. The system must also be

Mockups enable crews to test visibility and placement of windows. Note the ping pong balls attached to the upper sill of the window frames. These help designers locate the best position for crew eye placement. (Photo by the author.)

Orion *mockup used for arranging systems carried below the flight deck, adjacent to the heat shield. (Photo courtesy of Marianne Dyson.)*

flexible in all sorts of flight regimes. The crew may be restrained in a suit, operating systems during launch. They may be experiencing extreme vibration of spacecraft maneuvers or in crisis situations, in pressurized and depressurized conditions. Fox must envision all the possibilities. "It's got to work in an emergency. Say I'm in an emergency entry, so my suit is puffed

Technicians use cables, hoses, and boxes to size the interior cabin space of Orion. *Note manikins for couches and inflatable figures for overhead surfaces used in weightless conditions. (Photo by the author.)*

up now, and I'm all strapped in real tight because I'm trying to protect myself, and I'm not really going to be able to reach up [to the screen panel] to do this kind of stuff, so I have to have a device down here by my gloved hand—like a cursor or a track ball—that can interface with the software that's on the display." Screens will probably not be touch-screens, because in the microgravity of space they can be bumped. Instead engineers are considering bezel keys, trapezoid-shaped buttons similar to those used on commercial airliners.

Although *Orion* may seem cramped by shuttle standards, its quarters will never be inhabited for more than sixteen days. In lunar orbit, when the vehicle is in an automated configuration, the ground will have a great deal of control. They'll be able to look at all the data in the vehicle, talk to it, and monitor certain automated systems. The vehicle is out of contact for half of every orbit (when it passes behind the Moon), so it has to be smart enough to take care of itself. Astronauts on the lunar surface will make sure it's a "good vehicle" before returning to it.

REUSABILITY

Unlike *Apollo*, elements of *Orion*'s crew module may be used up to ten times. But the reuse of space flight-worthy equipment requires a fairly delicate landing. Originally, the intent of CEV designers was to end each flight on dry land, with water landings only as an emergency contingency. Studies indicated that a dry landing would enable the reuse of the entire outer structure of the CEV, along with about 75% of the overall spacecraft components. But a lot can go wrong when you land on dry ground. Mark Kirasich's engineers considered the stresses on the spacecraft if one of the three parachutes failed. What damage, they wondered, would the spacecraft sustain during high winds, or landing on steep slopes? "We found that we needed a very robust system so that we could still end up reusing the spacecraft."

The initial solution engineers came up with was to deploy airbags with a parachute system. To preserve the spacecraft, designers considered a rugged airbag system around the entire vehicle. The bags would have deployed in a cushioning ring around the entire heat shield, which would need to detach in order to free the bags for inflation. "That adds complexity," Kirasich says. "You've got to have a mechanism to blow the entire heat shield off—and a lot of mass. We just couldn't take all that mass to the Moon and back."

The Russian space program has landed its crews on land for decades. But the difference is that *Soyuz* spacecraft don't go to the Moon, and they are not reused. The design team backed off and went for a water landing, but even that requires at least some minimal design to cover contingencies involving land landings.

Water, especially salt water, changes the reuse equation dramatically. Although the goal for *Orion* was 75% reuse, ocean landings pushed the figure down to 20 or 30 percent. Bill Johns says, "In a water landing, it's very difficult to be able to seal everything against the saltwater and air. They start to do their work electrochemically on the surface. That can ultimately result in microcracks. You just can't get to every exposed surface to clean it out. For the nominal water landing, we can protect everything inside of the pressure vessel, but the pressure vessel itself is difficult to preserve." Adding to the problem is that after several hours in the water, *Orion* crews would begin bringing fresh air in with a snorkel, infusing electronics and materials with damaging salt fog. After being soaked in seawater, the craft would then sit on the recovery ship for several more days, in the salt air. "That gets expensive. We're throwing away half the cost of the spacecraft each time," says Kirasich. Waterproofing the spacecraft by putting coatings on the metal, sealing certain interfaces, and keeping the hatch closed as long as possible brought reusability up toward the 50 percent mark. But the cost of a water landing still seemed too high.

Engineers went back to the drawing board and came up with a design solution for landing on land. After looking at crushable structures, different types of seats and other parachute designs, Bill Johns' team came up with a modified "toe" airbag system—so-called because it wraps around the leading edge—that would not require detaching the heat shield. Johns describes the process: "We scratched our heads for a couple weeks and said, 'What is it, short of a full airbag system, that would make sense if you're going to drift over land?' That's when we conceived of the toe airbag system." By adjusting the parachute risers, the CEV hangs at an angle of 28°. Airbags deploy only on one side of the craft, exiting through a panel in the side. Airbags can inflate in stages, so that they wrap around the edge of the spacecraft like a chain of grapes. These are bags within bags, so that the outer bag vents upon impact to avoid bounces. The additional benefit is one of weight savings: the toe airbag system is less than half the mass of the earlier study.

The elements of water, air, and earth are not the only dangers facing the delicate workings of *Orion.* Another is vacuum. While salt water corrodes materials, a vacuum tends to preserve materials. But *Orion* must be prepared for any emergency, including the loss of air in the cabin. A failure in a pressurized tank, an explosion, or a micrometeoroid hit could contribute to a deadly loss of pressure. Researchers projected a certain size of hole that is most likely to result from such a failure. Engineers were then tasked with designing the pressure vessel of the spacecraft—the portion housing the living and working areas for the crew—in such a way as to hold the pressure for 45 minutes to one hour. Jeff Fox outlines the scenario: "What if I'm up in orbit and all my stuff is stowed. My seats are behind these panels. I have access to the storage under the floor like food and laptops. So I've got everything out, and then I get a leak in the cabin. In a certain amount of time I've got to get back into my suit and get the seat in. So I get in my suit and put my umbilical on, so now I've got all these umbilicals all over. The suit's starting to puff up a little because the pressure's dropping. Now I've got to maneuver around everybody and put my seat back together."

Once the spacecraft pressure drops down to the vacuum of space, there is a new challenge. All the electronic boxes that relied on air circulation to keep cool are now in danger of failure from their own heat. "Those flat panel displays are going to overheat just like that," says Johns. "So everything inside that pressure vessel that has more than about 15 watts going to it is all going to be on cold plates. We've had to design everything [that dissipates heat] to be on a cold-plate so you have a way to remove the heat in a vacuum." As *Orion* moves from its preliminary design phase to the critical design phase, in which 90 percent of the actual blueprints are completed, engineers are hopeful that they can hit the 75% reusability mark given to them at the start.

THE SCHEDULE, FOR NOW

The first production CEV will launch on Ares I-Y, the first full-up test of the Ares I booster. It is unmanned and will demonstrate a high-altitude abort and water landing. This *Orion* will not have a service module. It was scheduled to launch in September of 2013 and has already suffered several delays due to budget and scheduling issues. The next flight is also uncrewed and will conduct most of an ISS mission. Planners are still debating whether it will dock or not. The third mission carries two crew members and will dock to ISS. It will deliver the next-generation docking adapter called the low-impact docking system, or LIDS.

LIDS was developed for the entire lunar architecture. Bill Johns describes LIDS as "a common, very efficient, and very mechanically redundant docking system." The ISS docking system currently in use is the Russian APAS (the androgynous peripheral adapter system). The first time *Orion* shows up at the ISS, it will carry an adapter with the APAS docking system on the front side to attach to the ISS port, but when it separates, it will leave behind the new LIDS system on the exterior. The first two missions will leave this new connector on two docking ports now reserved for U. S. craft. At this point, ISS will be able to completely interface with NASA's next generation of Constellation space vehicles.

Concurrent to, or shortly after, the first two *Orion*-ISS missions, the *Altair* Moon lander will carry out uncrewed tests. Current plans call for *Orion* and *Altair* to carry out the seventh lunar landing sometime in 2020. In the forty-some years that have passed since the first landing, materials, strategies, and technology have changed. Lockheed Martin's Bill Johns is amazed by what has come before. "What I learn, every day, about what we did forty years ago is really impressive. Their big challenge was that they were the first to do it. Our big challenge is to do it in a sustainable way. It's all about sustainable human exploration."

THE ALTAIR MOON SHIP

If aerospace is a game of Monopoly™, Lauri Hansen has a get-out-of-jail-free card. With the work ahead, she may need it. Hansen is the Lunar Lander Project Manager for NASA. Her assignment: design a vehicle that can be

European Partners

The European Space Agency (ESA), a community of 17 spacefaring nations, is engaged in an ongoing study of projects and advanced technologies that could support a human-inhabited Moon outpost. A recently completed assessment called the NASA/ESA Comparative Architecture Assessment resulted in detailing concrete ways in which NASA and Europe could collaborate on various scientific and exploration scenarios. ESA has built a rich heritage of human spaceflight experience with the shuttle and ISS, including its massive *Columbus* station module. ESA has also developed the cargo-carrying *Jules Verne* automated transport vehicle (ATV), which has direct applications to future automated cargo capabilities. Europe's largest aerospace company, EADS Astrium, recently unveiled another variation: a *Jules Verne*-style ATV that could carry 3-person crews on lunar missions.

ESA is considering, in detail, such concepts as a lunar cargo landing system to be launched aboard the *Ariane V* (ESA's largest commercial booster), European communication and navigation systems for spacecraft, and lunar outpost elements, ESA-developed human-rated craft that would launch aboard *Ariane V,* orbital outposts, and lunar surface habitats and rovers. In a recent ESA release, ESA Exploration Program Manager Bruno Gardini said, "After the satisfaction of the successful deployment of *Columbus* and ATV we are looking forward to enhancing our role in the partnership for a sustained and robust space exploration program where human spaceflight is the cornerstone. The Moon is surely an important case study and a useful testbed to thoroughly prepare for more distant destinations."[13]

Michael Bosch, president of the Hamburg University of Applied Sciences, is part of a fourteen nation International Space Exploration Coordination Group, which includes member nations of ESA. Bosch says, "NASA's strategic transportation infrastructure does not allow for international work, so ESA and the Russian Space Agency are studying options based on their own launchers. The goals of the ISECG include sustained and self-sufficient human presence beyond Earth orbit. We are after interoperability between systems." Strategists are considering upgrading ESA's ATV to carry a crew of three. This would involve adding a return module with heat shield and an escape system for the launch phase. First launch could be as early as 2013. "ESA believes Europe should have its own human exploration infrastructure with full access to the Moon and Mars." This access would provide redundancy of human access, a backup in case of failure or delays in other projects, and the capability of international rescue operations. A second option under study is called CSTS and would modify a *Soyuz* for a crew of six. It would launch on a Soviet booster from Baikonur. Recent meetings have resulted in the tabling of Europe's involvement in this option, at least for the foreseeable future.

13. Excerpts of this July 9, 2008, release can be accessed through the ESA exploration portal at www.esa.int/exploration.

launched atop a booster that does not yet exist, make that vehicle compatible with another spacecraft that is still in design stage, and build enough flexibility into the lander's nature that it can transport tons of cargo to the lunar surface to build a lunar outpost whose plans are amorphous at best. Astronaut Marsha Ivins comments, "Laurie's project gets a pass on some of the constraints so she can think outside the [corporate] box, whereas the more classically run projects [like *Orion*] are constrained by the box."

Hansen's project has been named Altair. It's a moniker full of symbolism. "Altair is the eleventh brightest star in the sky," she says. "The star's name comes from an Arabic phrase for 'the flying one.' Altair is in the constellation of Aquilla (the Eagle), so it has a nice futuristic feel but acknowledges our heritage back to *Apollo.*"

The symbolism is fitting: Altair has some large and complex shoes to fill, serving several roles in the Constellation architecture. To fulfill its mission, the craft must be massive. While *Apollo*'s Lunar Module was designed for flight to and from the lunar surface from lunar orbit, Altair's huge descent stage must slow the *Orion*/Altair stack into lunar orbit as well as taking payloads to the surface. This added role requires a great deal of fuel, especially when the landed cargo capacity of the craft approaches 17 metric tons. While *Apollo*'s Lunar Module stood at a height of 21.3 feet (7 m), Altair will tower over the lunar surface at a height of 32.5 feet (9.9 m). Most of the height is in the descent stage. The top of the descent stage, where astronauts will step out from their cabin, stands 6 meters above ground. The deck is just under 9 meters across.

Altair must serve three roles, each unique.

Sortie Variant

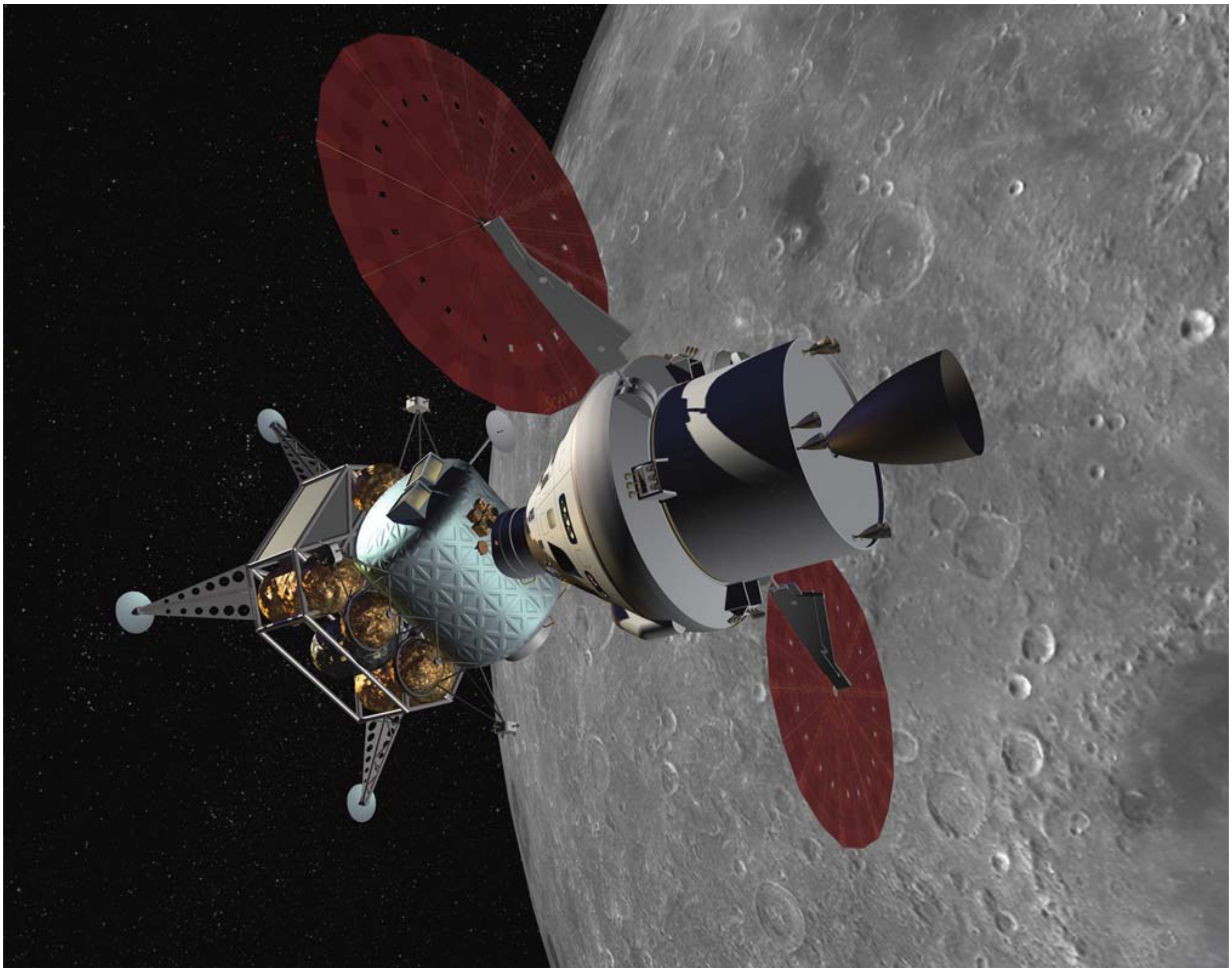
The first form Altair takes will be the sortie variant. While *Apollo* ferried a crew of two to the Moon for stays up to three days, and had a range limited to equatorial regions, Altair's sortie variant provides a crew of four with access to the entire globe for missions lasting up to seven days. These sorties will provide scientists with access to rugged highland areas and polar regions never before accessible. Constellation's Jeff Hanley says, "With a crew, it can take a 2 ton payload. *Apollo*, at maximum, took 500 kg, so we're talking about up to 4 times that, to places *Apollo* couldn't get to with twice as many crew for twice as long." Designers liken the sortie variant to a camping trip, where crews live out of the module for a short period.

Apollo 16's Charlie Duke spent three days on the lunar surface. For a longer stay, he suggests several areas important to designers. "A good operational layout of the crew module is important: ease of operation, ease of systems operation and maintenance, handling of emergencies. Good visibility is another consideration. Then once you land four folks in that thing, you've got to think about habitability. How do you sleep? Where's the stowage? You think about ingress and egress through the airlock. Those practical design elements make things livable and doable."

When Altair launches, it leaves behind the descent stage as well as the airlock. Elements of both may be reused, depending on their design and robustness.

OUTPOST VARIANT

Altair's second identity is that of an outpost variant. Its role is primarily transportation, a Moon bus to get the crew from orbit to a settlement. Unlike the sortie variant, this craft does not need an airlock, as the crew cabin is small enough to decompress easily. Instead of living in the Altair lander, the outpost variant sees a crew exiting once to live at the outpost. The small crew cabin and less crew-supporting supplies frees up space for more cargo. The Altair would hibernate on the surface for up to six months before taking a crew back up to an unmanned *Orion* for the return home. "In some ways, this is the most difficult from a design standpoint," Hansen feels. "It has to sit dormant for six months." Keeping a complex, untended craft healthy in the lunar environment for a long period will require more insulation and more power, and systems will need to self-evaluate periodically. Some lander



Orion *and the* Altair *lander in orbit around the Moon. (Photo courtesy of NASA/Lockheed Martin.)*

protection might come in the form of deployable tents, stored at the base and reused for each new outpost Altair vehicle.

Cargo Variant

The third Altair type is the cargo variant. As its name implies, this craft's sole purpose is a one-way supply trip to the outpost. Instead of a crew, the fully automated ship would transport up to 17 tons of cargo to the surface. Typical flights could carry entire habitats, rovers, construction vehicles, oxygen, and other consumables, or heavy equipment to support power or communications.

The descent stage on all three Altair types is powered by cryogenic (super-cooled liquid gas) fuel. The prime candidates for fuel are a combination of liquid hydrogen and liquid oxygen. Cryogenic fuel has more power than types of fuel that can be stored at lunar temperatures. This bigger bang for the buck comes with a price: fuel must be refrigerated, and that costs power. The ascent stage cannot afford to have cryogenic fuel, as it will stay on the lunar surface for weeks or months before being ignited to return. Refrigeration over those long periods is not practical. Instead, proven hypergolic[14] fuels—fuels that

14. The term "hypergolic" refers to fuel that ignites upon contact with an oxidizer. Hydrazine and nitrogen tetroxide are commonly used in spacecraft.

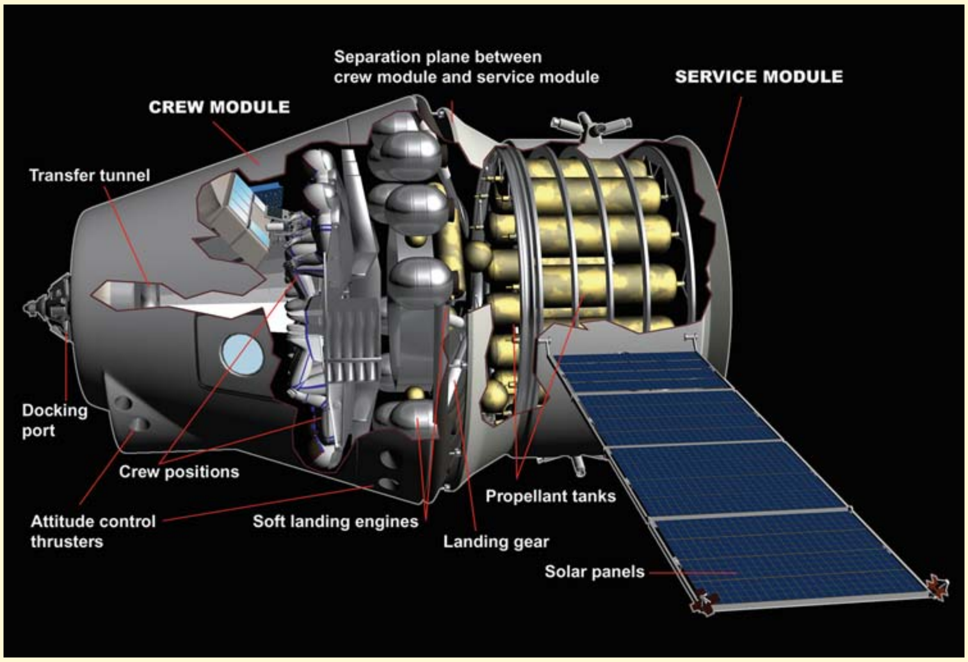
Moscow's Moon Tourism

Perhaps in response to America's new lunar plans, Russian companies are again exploring the possibility of space tourism, this time to the Moon. The goal would not be to land but rather to circumnavigate the Moon. The Moon tour is envisioned by designers at RKK Energia, the company that builds a family of successful launchers and the *Soyuz* and *Progress* spacecraft. A retooled *Soyuz* spacecraft would carry a three-person crew—one of which would be a paying tourist—coasting in a free-return trajectory around the far side and back again. The European Space Agency is studying involvement in the project, including the manufacture of a habitation module based on its designs of the *Columbus* space station module and the *Jules Verne* resupply craft.

The trip is envisioned as taking place after the *Soyuz* completes a routine service call to the International Space Station. Some elements of the Soyuz would be modernized and upgraded, like communications and heat shields. The craft would need added power to leave Earth orbit, so it would meet up with a booster stage, launched separately. Once in orbit, the two craft would link up for the lunar journey. Reservations will be required in advance.

Beyond tourism, Russia is studying the ACTS spacecraft, a *Soyuz*-derived lunar lander that could carry a crew of six to the lunar surface. Joint discussions between potential Russian and European partners are currently on hold.[15]

15. See the Planetary Society's *Planetary News: Spaceflight, Europe and Russia Join Forces to Study Advanced Crew Transportation System* by A.J.S. Rayl, June 28. 2008. http://www.planetary.org/news/2006/0628_Europe_and_Russia_Join_Forces_to_Study.html



The Russian Moon orbiter ACTS. (Art ©Anatoly Zak/Russian SpaceWeb.com)

can be stored without refrigeration—will be used. Although less powerful, they also take up less room and are stable over long periods.

At this stage of development, all scenarios are being pursued, from the practical and mundane to the strange and creative. One future variation under consideration is a sortie *Altair,* whose descent stage is equipped with wheels and navigation equipment. This scenario envisions a future science expedition voyaging north of an already established outpost at the south pole. This sortie mission descends from orbit to its scientific target area. The crew carries out a week-long exploration and then returns to the *Orion* CEV in orbit overhead, leaving the descent stage as usual. But this descent stage has a different bag of technological tricks. The craft points itself south, heading toward the Shackleton base while gathering data along the way. When it arrives at Shackleton, the outpost now has another rover or cargo carrier. Marcia Ivins believes that mobility is a key to efficiently building an outpost.

Google Space

The latest—and most well-funded—private sector attempt to generate interest in the Moon comes from the Internet giant Google. A total of $30 million is up for grabs in Google's Lunar X-Prize initiative. The rules stipulate that the entrant must be at least 80% privately funded. To win, the team must successfully land a rover on the lunar surface, and that rover must travel a minimum of 500 meters. Rules also call for video and still images to be transmitted to Earth. The grand prize of $20 million covers the successful roving mission, but bonuses are to be had. If the craft images man-made artifacts such as *Apollo*, *Surveyor,* or *Luna* landing sites, the team will receive an additional $5 million bonus. An additional $5 million second place will also be awarded. In a Google Lunar X-Prize press release, CEO Peter Diamandis said, "The Google Lunar X-Prize calls on entrepreneurs, engineers, and visionaries from around the world to return us to the lunar surface and explore this environment for the benefit of all humanity…We are confident that teams from around the world will help develop new robotic and virtual presence technology, which will dramatically reduce the cost of space exploration."

Altair project manager Laurie Hansen says, "Any advances in industry—particularly small companies—helps feed the excitement, it helps feed advances with good ideas. We haven't seen anything drastically new yet, but just the fact that it's feeding the thought process and getting everybody excited is great." And while Google's competition promotes advances in technology, its cultural implications may be even more important, Hansen believes. "NASA has moved from a very small engineering organization without a lot of process controls and so on—which is the way people envision the *Apollo* days—to this big monolith of getting things done. There's always a happy medium somewhere. As you add bureaucracy, you lose some things, and you have to keep asking what can you learn from the smaller guys? Frankly, they can take a lot of risks that we can't. If they go and build a lander and it crashes, as it did recently with the X-Prize contest, everybody says, 'Well, they gave it a good shot, and man were they close.' If NASA builds a lander and it crashes, that's not the reaction that we're going to get. It used to be that way, back in the good ol' days." Hansen suggests that in the *Apollo* era, people understood that the space program was experimenting, pushing the envelope, and that the essence of this exploration was not only technology advancement but danger.

Today, the culture at NASA emphasizes risk management and astronaut safety. With the loss of two shuttles, many feel these attitudes are prudent and reasonable. The direction NASA takes is largely dictated by social and political mores. Whatever the drivers, some analysts believe NASA has lost momentum in terms of the kind of dramatic exploration that leads to great discovery. Diamandis wants to change that equation, not only by inspiring entrepreneurs, but by feeding new technology and design into the pipeline where NASA—and the rest of the world—will benefit.

"At the end of the day, I've built an outpost and I ask how many missions did it take me to do it. If I can drive the parts around, that's fewer parts, ultimately, to send, and the cost of the project goes down."

HAPPY LANDINGS

The *Altair* crews will face challenges that *Apollo* crews did not. Although the wide rim of Shackleton crater is fairly smooth and rounded, providing a large landing area, the surrounding terrain is rugged. Many shadowed craters will spread a confusing landscape below the astronauts piloting their landers. Adding to the visual confusion will be low lighting angles. The long periods of solar energy for the base also mean long shadows. *Apollo 14* Lunar Module pilot Ed Mitchell contrasts *Apollo*'s landing conditions: "We were trying to land such that the Sun angle was equivalent to seven o'clock in the morning. The Sun was at eight or ten degrees [above the horizon]. The fact that you have a long shadow is very helpful in the landing process. We used the long lander shadow to help with depth perception, as well as using the altimeter."

At Shackleton, astronauts will not be able to use *Altair*'s shadow to judge distance, as it will be too far to the side. Another complication is the large descent stage under the crew, Hansen says. "With that big platform under us, you really can't see that well. *Apollo* couldn't see that well, either, but they didn't have this big front porch."

To that end, engineers are setting up various window placements and then flying simulations. Although this process can be done analytically on a model, researchers have found through experience that the human eye and human reflexes are best put into the design mix early, Hansen says. "It's very different—dynamically—having someone looking out the window and flying it."

Because of the visibility limitations of both *Altair* and the lunar environment, designers envision some form of augmented hazard detection. Possibilities range from floodlights to infrared cameras to scanning LIDAR laser systems. Ultimately, *Altair* will require a completely automated hazard detection system for the unpiloted cargo lander variants. Once the first landers have blazed the trail, electronic landing beacons or visual cues will be deployed to aid future flights.

Bruce McCandless, veteran of two shuttle flights, plays out the scenarios. "A simple approach is that you give the people already at the outpost some of these cans of orange highway paint. Now the problem is that you can't see just below you [from the *Altair* deck]. What you really need to do is sneak up on this thing and then let the automatic guidance take over in the end. You might use an electronic system or something like a GPS system around the Moon, but even now, the inertial guidance systems are up to the task. If you have an *Altair* landing and you look out the window and, lo and behold, the X on your heads-up display happens to be on top of this big international X someone has painted, you've made it. But if you're not, you run your track ball over to it to guide the craft to the right spot."

Just what will those flights look like? Current plans call for *Altair 1* to be a propulsion test on Ares 5Y, which is also the first test flight for *Ares V.* The unmanned mission will go into low Earth orbit. Flight designers are considering doing a trans-lunar burn, or perhaps a simulated burn long enough to get to the Moon without actually going. Hansen sees the first flight of *Ares V* as a golden opportunity. "To do a meaningful test of Ares 5Y, you need to at least send a mass equivalent to *Altair*, so why not get some good data?"

Altair 2 will actually have a more ambitious plan than the early *Apollo*s. The unpiloted craft will either touch down on the lunar surface or demonstrate an abort to lunar orbit, simulating a flight that is abandoned during an emergency on the way down. Either way, the second *Altair* will achieve lunar orbit.

Altair 3 will be the equivalent of *Apollo 11,* staging a landing of a crew on the Moon. *Altair 3* is designated HLR, "Human Lunar Return."

Plans are in flux for *Altair*'s design. Several industry partners have been tasked with evaluating the overall design concepts and safety of *Altair.* These companies are Andrews Space of Seattle, The Boeing Co. of Houston, Lockheed Martin Space Systems Company of Denver, Northrop Grumman Corporation of El Segundo, Calif., and Odyssey Space Research of Houston.

The New NASA: *Altair*'s Alternative Approach

Marcia Ivins is head of the Exploration Branch of NASA's Astronaut office at the Johnson Space Center. She has flown on five shuttle missions, spending over 1,318 hours in space. Her flights included work on both the Russian space station Mir and the International Space Station. Her many years of experience have given her insights into the way individuals and organizations contribute to a large-scale project such as Constellation.

We [at NASA] are an organization that is decades of tradition unimpeded by progress or lessons learned. We put together the *Orion* project and Ares and all these other things, and they are classically formed programs/projects/hierarchies of the way you do things. One of the unfortunate byproducts from a couple administrators ago was to remove the technical competence of the civil service agency and hand it to the contractor. So here, it used to be that civil servants actually built things. Their hands were dirty. They understood the mechanics. We had shops here and we built things here. Over the period of about fifteen years, that was eradicated. The effect of that has been that nobody in this agency in the past thirty years has built anything. Nobody in the contractor world has built anything for manned spaceflight. The shuttle was built in the mid-seventies. People have managed it, they've maintained it, they've fiddled around with the paperwork for it, but they have never actually built anything for it, particularly here at JSC. So when they formed Laurie's [Hansen, manager of *Altair*] lander project, the thought was, *Let us form this as a small, skunk-works kind of a thing where you are exempt from the program process that is imposed on the other projects. You get a pass.* So Laurie's group actually works above the radar but underneath the process line, the intent being, can we regrow—in this agency—the capability to actually build something. The thought is that when the day comes, we can actually do the design in-house so that what we hand to the contractor is a build-to-print, rather than a set of requirements where they can charge us for whatever we didn't think of. So she's the rogue organization out there. We're sort of an experiment in progress here, in the way Laurie does business, and the way Constellation program does business. We [astronauts], as the crew, cross all borders and boundaries. We are the ones—as we have been historically—to cross every line and do much of the program's integration. We sit in the trench. We sit on the program boards. We sit in Laurie's group and Chris's (Culbert, NASA's Lunar Systems Project) group. We've got a finger in everybody's pie, and we become almost the only organization that integrates, to say 'do you know what they're doing? Do you know that that's not going to be convenient?' We become the connective tissue, and that is the role the crew has always served, because at the end of the day, we're stuck with whatever 'tissue' you put together. We *hope* it connects, because if not, it's us dangling on the end of it. So we have a very vested interest in connecting the tissue.

Studies are currently under way. *Altair*'s schedule is also in a dynamic phase, as it is dependent on its "mother ship," *Orion*. *Orion* still awaits its maiden flight, half a decade hence. But manufacturing of final flight hardware for the new *Altair* Moon ship may begin as early as 2015.

With the successful launching of the new Ares booster family, and with shakedowns of *Orion* and *Altair*, the first Moon mission is now slated for 2020. For the first time in half a century, humans will break the bonds of Earth's gravity and venture across translunar space. To NASA's Bret Drake, Chief Architect for Systems Engineering and Integration on Constellation, reestablishing that exploration capability beyond low Earth orbit is the priority. "Getting beyond Earth and to the Moon is a real big first step. It shows that we're serious about it and we're making great strides. [A lunar landing] is nearly twelve years away, so there's a lot of work between now and then, but that will be a good first step toward great new endeavors."

But returning to the Moon is only half the battle in creating a permanent human presence. To stay, we must build infrastructure, setting down a permanent outpost with power, communications, and transport. How—and where—will it all come together?

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