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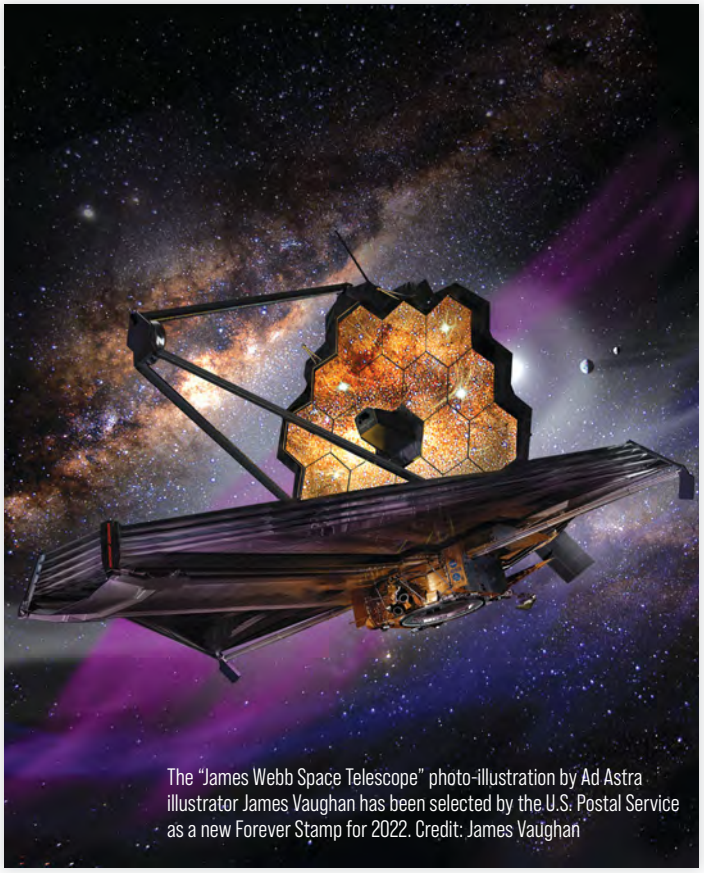
Credit: James Vaughan



The "James Webb Space Telescope" photo-illustration by Ad Astra illustrator James Vaughan has been selected by the U.S. Postal Service as a new Forever Stamp for 2022. Credit: James Vaughan

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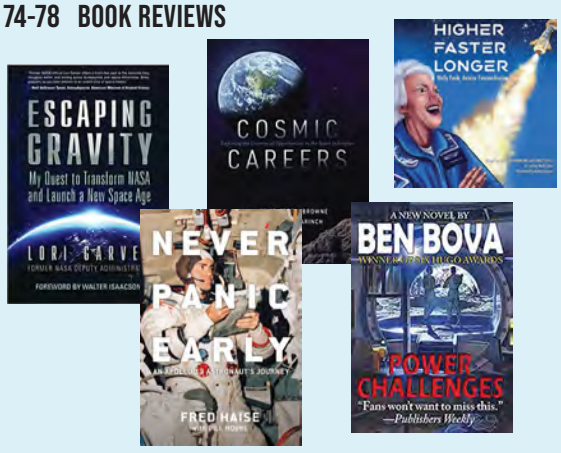

WHEN THE RACE WAS WON

BART COLOMB

In the spirit of The Right Stuff and A Man on the Moon, author Bart Colomb brings you the story in between the Mercury program and Apollo's missions to the Moon—the epic tale of Project Gemini.

From 1965 through 1966, Gemini flew ten times, with each mission accomplishing space firsts at a breakneck pace and finally putting the United States ahead of the Soviet Union after years of toiling in second place. The overall goal? Prepare America for the first human landings on the Moon. This new book covers each Gemini mission in detail from the perspectives of its designers, Mission Control, and the astronauts themselves. It's a part of the Space Race well worth remembering—because there will never be another time quite like it.

When the Race Was Won: The Story of NASA's Gemini Program is available from Amazon.com in both hardcover and paperback.

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IT'S THE YEAR OF NEWSPACE

- Rod Pyle, *Ad Astra* Editor-in-Chief

Welcome to the special edition of *Ad Astra* for 2022. As we do each year, we've added to our page count for this special edition to bring you more features, more imagery, and more reviews. This issue also coincides with the National Space Society's annual International Space Development Conference® (ISDC®), held this year in Arlington, Virginia at the end of May. I hope to meet some of you there.

Our cover image for this edition, provided by illustrator James Vaughan, is quite special. Working from NASA source imagery, Vaughan has provided a stirring image of the James Webb Space Telescope hard at work sometime in the near future. Perhaps most remarkably, this spectacular piece of space art has been selected by the U.S. Post Office as a new stamp for 2022. Big congratulations are due to our primary cover artist!

Inside we have two articles detailing new spaceflight installations. John Vester brings us the story behind the building of SpaceX's Starbase in Boca Chica, Texas. It's a story that has not yet ended, as Elon Musk struggles to gain permission from the federal government to expand operations on the Boca Chica coastline. Mark Armstrong then gives us a guided tour of Vandenberg Space Force Base in central California. First established in 1941, Vandenberg has had many lives, most prominently as a bastion of Cold War nuclear ICBM testing. It was recently renamed Vandenberg Space Force Base and is moving rapidly into the new space age.

For longtime NSS members, we have a treat in an excerpt from former NASA Deputy Administrator (and former NSS Executive Director) Lori Garver's new book, *Escaping Gravity: My Quest to Transform NASA and Launch a New Space Age*. There is also a review of this inspiring, yet sometimes disturbing, look at America's space agency. You can draw your own conclusions.

John Kross, an *Ad Astra* Contributing Editor, provides us with two thought-provoking features. The first is a rundown of what's happening in commercial space, the pathway to a bright future in the final frontier. This is followed by a look at how we will deal with death in space—an uncomfortable, but critically important, aspect of spaceflight and space settlement.

Jordan Strickler tackles NASA's Double Asteroid Redirection Test (DART) mission, an urgently needed first shot at redirecting an asteroid, albeit a small one. The results of this technology demonstrator will inform future efforts toward defending our planet against errant Near-Earth Objects that might threaten our home world. The impact will occur at the end of the summer.

Melissa Silva looks at important new biomedical research taking place on the International Space Station, as well as how women have had pivotal roles in the Space Age and beyond.

Finally, yours truly presents the story of the James Webb Space Telescope's development and capabilities, based on an extensive interview with Philip Stahl of NASA's Marshall Space Flight Center. Special thanks to NSS members Burt Dicht and Larry Ahearn for arranging Dr. Stahl's presentation to NSS members.

A variety of other stories and a package of space book reviews round out this special issue.

One more note: this issue of *Ad Astra* is the first to have an audio podcast companion edition. We're releasing a live read of the entire magazine in audio, both for those who might prefer to enjoy listening to the magazine, and also for those who are visually impaired. Check the magazine's website at adastramagazine.com for more information.

Thanks for reading, and perhaps I'll see you at the ISDC. Ad Astra! ■

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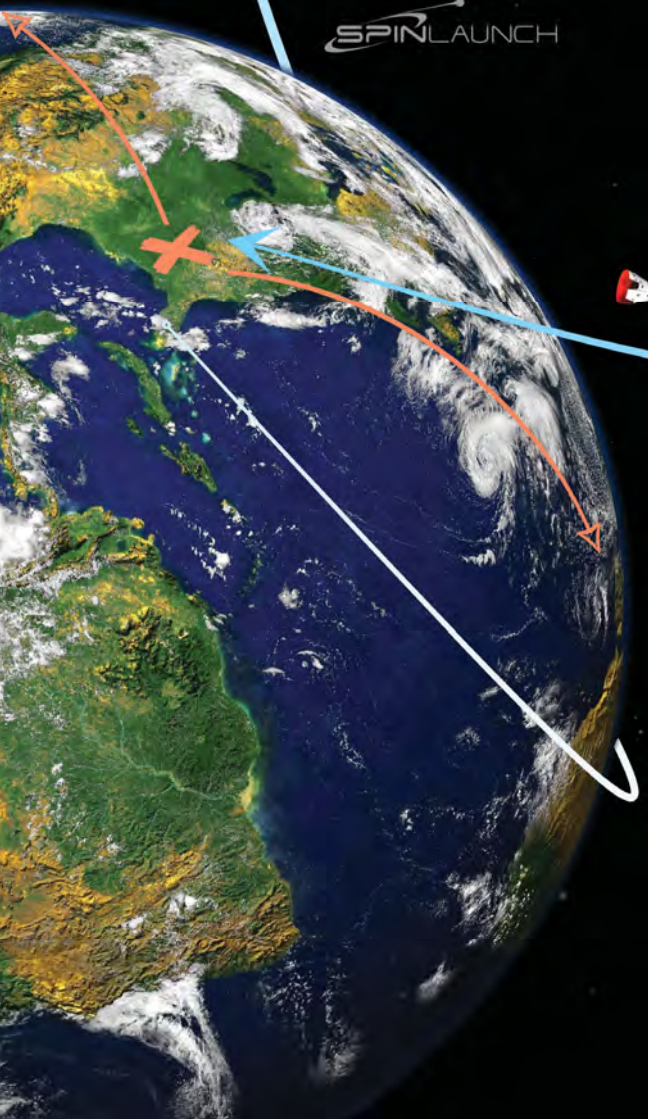
INTRODUCES THE FIRST SPACE BUSINESS PARK WITH GRAVITY THAT'S READY TO LEASE



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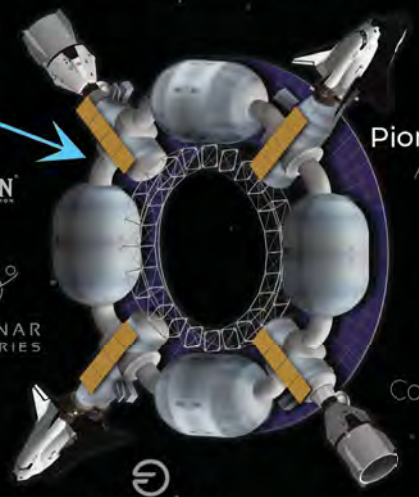

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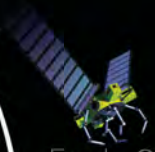

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5

The crew of Ax-1 prepares inside the SpaceX Crew Dragon capsule
Credit: SpaceX

Ax-1 SETS RECORDS: Axiom Space flew the first completely private flight to the International Space Station (ISS) in April. The four private astronauts, led by veteran NASA astronaut Michael López-Alegría, launched aboard a SpaceX Crew Dragon to the station on April 8, where they stayed for 16 days. The Endeavour splashed down on April 25 after an additional day in orbit. During their time on the ISS, the crew conducted 25 science experiments in association with partner organizations that included the Ramon Foundation, the Mayo Clinic, the Cleveland Clinic, and the Montreal Children's Hospital. This maiden flight for Axiom Space is just the beginning of a larger program of privately funded spaceflight to the ISS, and presages the company's larger goal of flying the first private module to the ISS in 2024 in conjunction with NASA's NextSTEP program. Follow-on missions through the 2020s will build up what Axiom Space plans as the first private space station in Earth orbit, to be completed before the ISS is decommissioned around 2030.

4

Illustration of OSIRIS-Rex preparing to sample asteroid Bennu
Credit: NASA/JPL-Caltech

OSIRIS-REX RIDES AGAIN: As OSIRIS-Rex heads back to Earth carrying samples from its history-making rendezvous with asteroid Bennu, it's being rerouted to another astral encounter. The probe will now spend another 18 months studying the Near-Earth Object Apophis, a potentially hazardous asteroid. Apophis will pass by Earth at a distance less than one-tenth that to the Moon in 2029, so the encounter with OSIRIS-Rex (now renamed OSIRIS-APEX, short for OSIRIS-Apophis Explorer) will be a stunning preview for astronomers. While the probe will not make direct contact with Apophis, nor will samples be obtained, it will orbit close-in for months to allow for detailed investigation. Launched in 2016, the probe will be over 13 years old when it encounters Apophis and is in generally good shape with the exception of a component of the onboard laser altimeter that stopped functioning in 2020.

3

The KNaCK prototype being tested in volcanic terrain in New Mexico
Credit: NASA

GOOGLE MAPS FOR LUNA: Well, almost. When astronauts of NASA's Artemis program step out to explore the lunar surface, they will be carrying, at least some of the time, a bizarre looking rig called KNaCK, the Kinematic Navigation and Cartography Knapsack. The prototype, now in testing, mounts on the EVA suit's backpack, extending about three feet (0.9 meters) above the astronaut's helmet. At the top are sensor packages including cameras and a LIDAR rig to chart terrain to an exacting degree, resulting in datasets that will eventually allow NASA to create ground-truth maps of the lunar surface in great detail. Currently rather bulky and weighing in at about 40 pounds (18.1 kilograms), NASA hopes to reduce the package to something about the size of a soda can before it travels to the Moon.

COUNTDOWN

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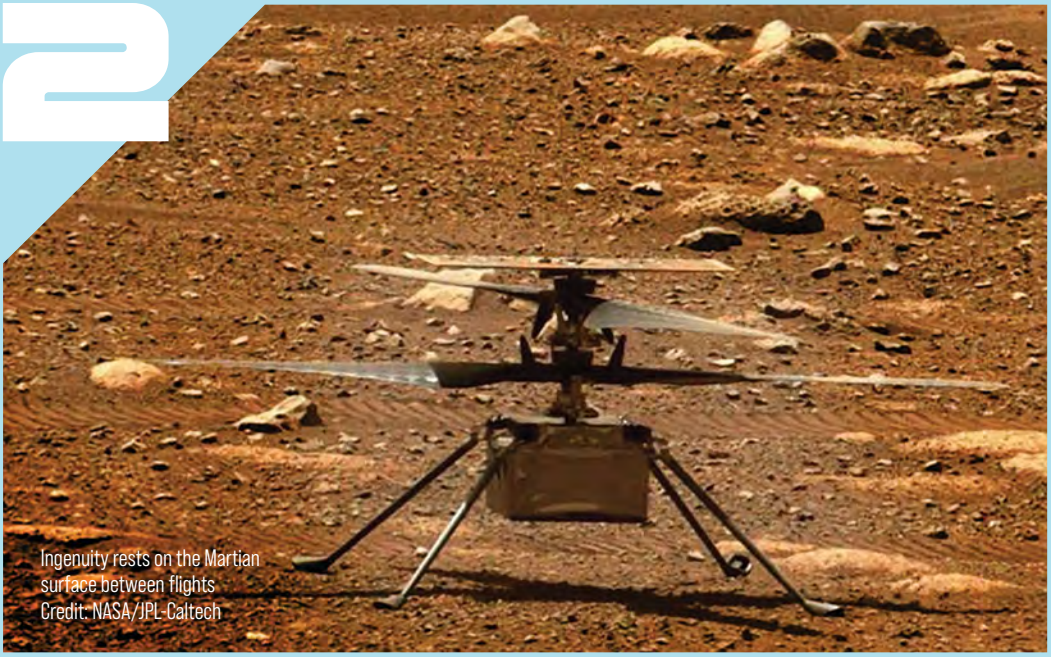

Ingenuity rests on the Martian surface between flights
Credit: NASA/JPL-Caltech

INGENUITY SOLDIERS ON: The Mars Helicopter Ingenuity just keeps on going. Originally intended for just five short flights as a technology demonstrator, the little chopper recently concluded its 28th flight and will likely have conducted more by the time you read this. The four-pound (1.8 kilogram) package was affixed to the underside of the Perseverance rover and deployed on April 3, 2021, shortly after landing on Mars. After a balky first test of the rotors, a software issue was resolved and Ingenuity first took flight on April 19, hovering for about 30 seconds at an altitude of 10 feet (3 meters). Since then, it has stretched out flight times at ever greater altitudes and for longer periods, and with increasingly difficult flight objectives. Ingenuity has now covered almost five miles (8 kilometers) with about an hour of total flight time. The Little Helicopter that Could shows no signs of slowing down anytime soon.

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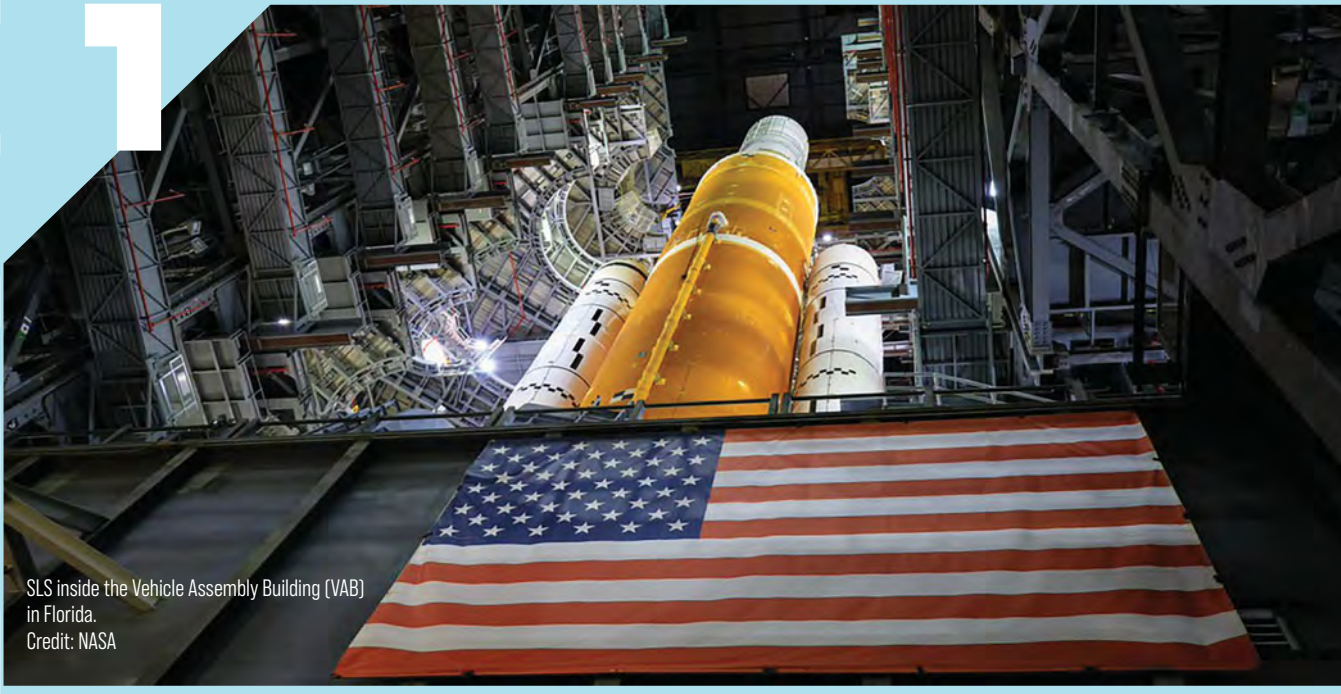


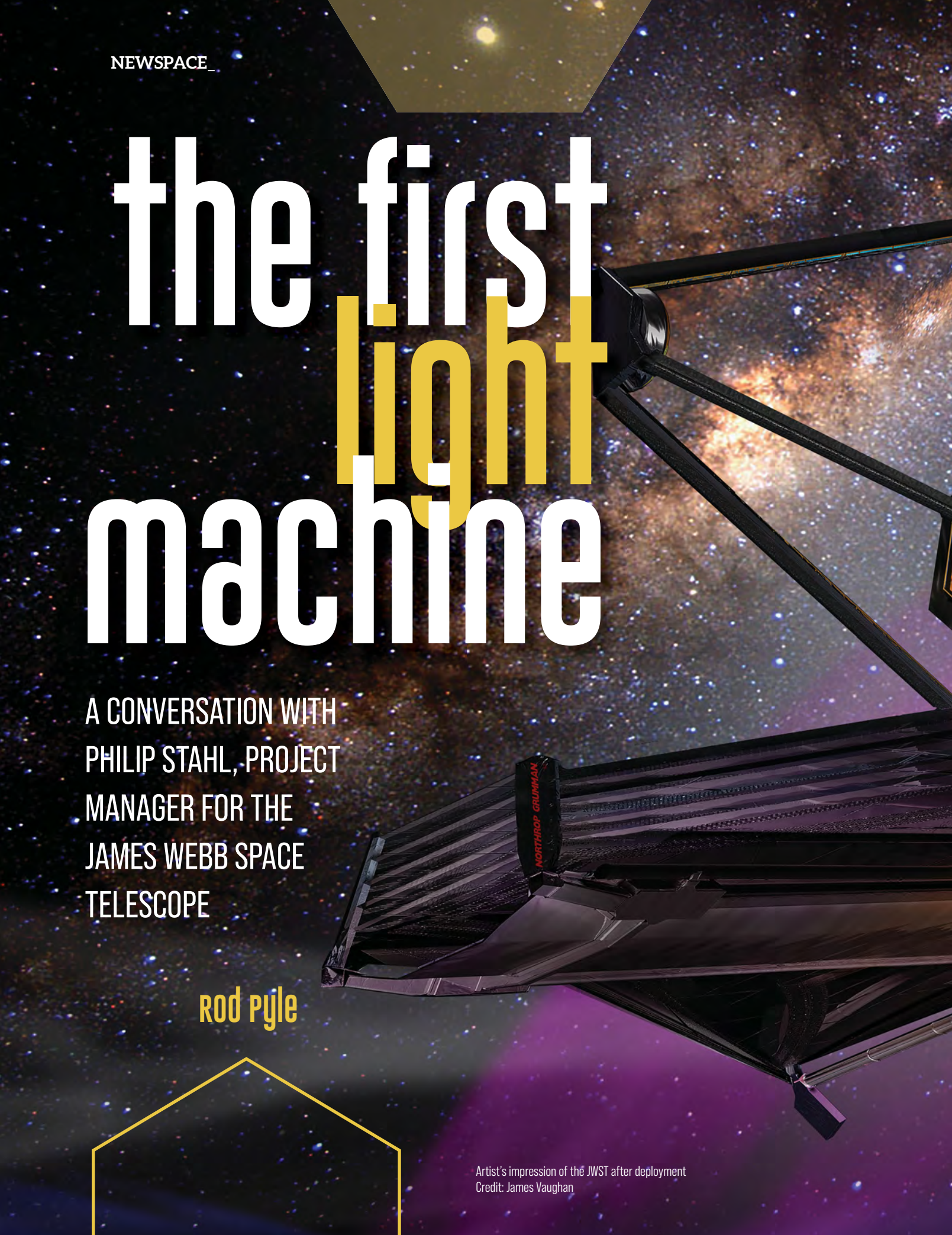
SLS inside the Vehicle Assembly Building (VAB) in Florida.
Credit: NASA

BACK TO THE BARN FOR SLS: After a series of frustrating attempts to complete its wet dress rehearsal tests prior to launch, NASA's Space Launch System Moon rocket was returned to the Vehicle Assembly Building at the Kennedy Space Center in Florida for evaluation and repairs. Rollout for the wet dress rehearsal occurred on March 17, with the actual fueling of the core and upper stages to follow. But the tests ran into problems almost immediately, ranging from valves set to improper positions, to balky fans in the launch complex, to a stubborn helium check valve on the upper stage. The rocket was returned to the Vehicle Assembly Building (VAB) on April 26, over a month later, with only a few objectives met, despite lowering test requirements. NASA remained upbeat, at least publicly, and has not officially stated a new launch date. But the multitude of issues lead SLS observers to presume that the first launch of the mega-rocket, most recently scheduled for early summer, will likely slip into the fall or later.

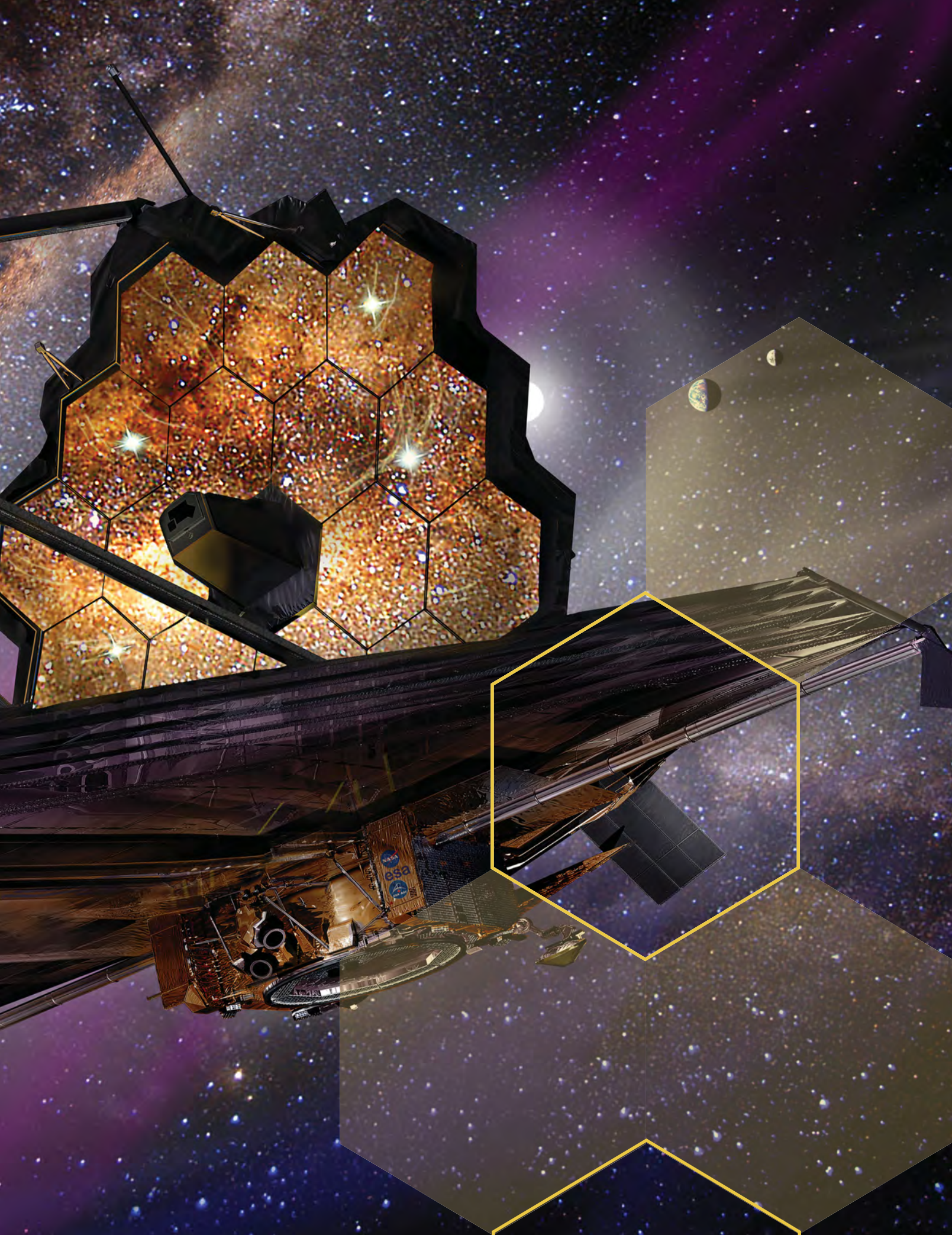
the first light machine

A CONVERSATION WITH PHILIP STAHL, PROJECT MANAGER FOR THE JAMES WEBB SPACE TELESCOPE

Rod Pyle



Artist's impression of the JWST after deployment
Credit: James Vaughan


esa

"My job was to believe that we could make the Webb telescope, when it is still just an idea, and to turn that idea into reality," said Philip Stahl, the senior optical physicist at NASA's Marshall Space Flight Center and a major force behind the James Webb Space Telescope, in a recent interview with Burt Dicht of the National Space Society. Since its launch on Christmas day in 2021, the complex, $10 billion instrument has passed a long set of milestones with—so far—flawless performance. France's Ariane 5 rocket delivered it into a perfect orbit, the upper stage sent it on its way to its final destination beyond lunar orbit, and then the hard part began. Dozens of specific procedures would have to be successfully undertaken, with hundreds of individual parts—many of them single points-of-failure—for the telescope to commission properly and fulfill its tasks.

The previous record-holder for space telescopes, the Hubble Space Telescope, had launched decades earlier with a faulty primary mirror. When the first images came back, they were blurry, and the $5 billion (in 2010 dollars) instrument was considered damaged goods. It would cost a minimum of another $500 million to commission a shuttle mission to deliver corrective optics to fix the telescope, but fix it NASA did, and the results have been spectacular—the Hubble telescope has been the astronomy public relations coup of the 21st century.

But the Webb telescope is infinitely more complex and ultimately far more capable. It orbits a distant point at the Earth-sun L2 (Lagrange 2) point well beyond the orbit of the Moon, and if any major part of the complex deployment of the telescope failed to execute properly, the mission could be jeopardized. The launch and deployment of the most ambitious space telescope in history has been the ultimate white-knuckle moment in NASA's 21st century robotic exploration program.

The major challenge facing the designers early on was how to pack a massive telescope into an existing rocket faring only about 15 feet (4.5 meters) in diameter and about 60 feet (18 meters) long. The telescope's primary mirror would be 21 feet (6.5 meters) in diameter and would have to be divided into 18 individual segments that would unfold and align—perfectly—once in space. Similarly, a basketball-court-sized sunshield, made of five layers of fragile Mylar-like sheets—the actual material is called Kapton—would also have to unfurl, again perfectly, to shade the massive instrument and allow it to operate properly in the infrared spectrum. The list of complex multiple-step procedures grew from there, all to accommodate a massive telescope in a single rocket nosecone. It was a daunting task, to say the least.

Stahl summarizes his role in the project as that of an overall enabler, "I have a Ph.D. in optics ... and my expertise was in how to test things. I am a technologist; I am not a scientist, and I am not an astronomer. In fact, I got an email a couple of days ago from a colleague of mine in Germany, who summarized it very well—that my job was to believe that we could make the Webb telescope, when it was still just an idea, and to turn that idea into reality."

Dr. Philip Stahl, the senior optical physicist at NASA's Marshall Space Flight Center
Credit: NASA/MSFC

The long list of goals for the Webb telescope was equally as challenging. "Its primary science [goals are] to look for the first light of the universe," he explained. "That light is emitted by the first objects; the first stars. It would also look for the formations and the assembly of early galaxies, the formation of their planetary systems, and to ... look for habitable exoplanets." Not a small order.

Beginning in 1999, Stahl oversaw the evolution of the mammoth instrument into its current form. It would undergo countless design changes and modifications, often requiring the invention of new technologies to achieve these goals. "The design requirements, and the science requirements, required us to develop new technologies and fabrication processes, ways to make the telescope, [and] ways to test the telescope and invent these new things," Stahl said.

An additional challenge was that the telescope had to be capable of observing the infrared spectrum, something that cannot be done well from Earth's surface (the planet's atmosphere absorbs infrared light), requires extremely cold temperatures, and which had only been achieved on a small scale with previous space telescopes. "That's the zone where we can't see what's going on with our [Earth-based] telescopes," Stahl said.

"The key question here is the ionization of the universe. Early on, when the universe was just neutral hydrogen, any light that got emitted got absorbed, so the first stars that formed due to fluctuations in gravity that pulled together enough hydrogen to turn into a star, created bubbles in this fog and as the fog slowly cleared the universe slowly became ionized," he explained. "When it was ionized it became transparent and ... you can't see anything but maybe a couple of spectral lines, and as the universe becomes more

Illustration of the faring protecting the Webb telescope being jettisoned prior to deployment of the payload
Credit: NASA/Arianespace

and more ionized, you could see more and more spectral lines. So one of the things that we will look at with the spectrometers is these spectral lines further back so when we see objects where, due to their spectral coverage, we know that they are inside this fog of neutral hydrogen." The telescope will truly be looking back to the beginning of time, just a couple hundred million years after the Big Bang, the creation of the known universe.

Stahl continued, "the first stars were 100 percent hydrogen and were huge; thousands of times bigger than our own star, and because they were so big, they didn't last very long, they blew up. They went supernova and when they exploded they created things like helium and heavy metals, things like carbon and other [elements]."

To look at these early stars, a telescope must operate in the infrared spectrum. "The further away objects are from us the more they are red-shifted. A lot of people think that it is like a Doppler effect," but it's not. "It is actually a space-time stretching effect. When the light was emitted from objects very far away from the blue, the universe was smaller, and as the universe expands, the light gets stretched," moving the light from them into the infrared spectrum. "Although Hubble does a lot of science that's in the visible and the ultraviolet [spectrum], the Webb is going to do basically the same science in the infrared because the light has been shifted into the infrared." In sum, the infrared is where much of the really exciting science can be conducted; where the big questions can be answered.

The oldest galaxies the Hubble telescope was able to image formed about 500 million years after the Big Bang. The Webb telescope will seek out much younger galaxies earlier in their formation. "Webb's mission is to study the origin and evolution of galaxies, stars and planetary systems, this first light, so it is optimized for near-infrared wavelengths," he said.

"There are four science instruments. The Near-Infrared Camera was led by the University of Arizona with participation from Lockheed Martin. For the Near-Infrared Spectrometer, the European Space Agency (ESA) was the lead," Stahl said. The Mid Infrared Instrument was led by NASA's Jet Propulsion Laboratory, and the Canadian Space Agency provided the Fine Guiding Sensor. "Inside the Fine Guiding Sensor is also a coronagraph. The Space Telescope Institute at John Hopkins University will be running the telescopes."

The driving questions behind the mission were easier to summarize. "NASA's fundamental questions are 'How did we get here?' 'Where are we going, and are we alone?'" Stahl said. "The Webb will start at the Big Bang and look for the first light, then we're going to look at galaxy formation, galaxy evolution, planetary formation, star formation, and then hopefully look a little bit for life."

The Webb telescope must operate at extremely cold temperatures for the instruments to function properly. Its position at L2, about a million miles (1,609,344 kilometers) from Earth, allows the telescope to orbit a small, gravitationally stable point in space that is in equilibrium with Earth and the sun. This also helps keep it oriented with the instrumentation side away from the heat of the sun's light, which would interfere with observations.

The telescope is shielded by the aforementioned five layers of Kapton that are stretched out behind it, shielding it from sunlight.

"We have a hot side and a cold side," Stahl said. "Each layer of the sunshade drops the temperature of the telescope by about 15 degrees Kelvin. The requirement was for the telescope to be below 50 Kelvin (about minus 370 degrees Fahrenheit, or minus 223 Celsius). We don't know what it's going to get to, but it's going to be really cold." Complete cooling of the Webb telescope should be achieved in May or early June of 2022.

The large primary mirror is made of beryllium and divided into 18 folding segments. "The reason that we went with beryllium is that it is really stiff and it's got a low mass," he continued. "But one of the other reasons is that once you get below 100 degrees Kelvin (minus 279 degrees Fahrenheit or minus 279 Celsius), its coefficient of thermal expansion is virtually zero, and with glass that is not the case ... and the bottom of the mirror—closest to the sunshade—might be about 50 Kelvin, but the top of the mirror might be at 20 to 30 degrees, and we are not going to actively heat these mirrors, we're going to let them passively cool. With a beryllium mirror, over that temperature range, we had a total change of only seven nanometers." Since the mirrors must maintain alignment within nanometers, beryllium was the only rational choice.

As the telescope was being designed, the misadventure with the Hubble mirror was always in the back of everyone's mind. "One of the questions I get a lot is how do we make sure that the mirrors were made right?" Stahl says. "Well, that was my job, and the way that we did it was to use a redundant test setup. We had two test setups side by side and the mirrors had to get the same answer on both with independent tests." These were repeated at multiple locations to assure perfect curvature, and resultant perfect focus, of the final mirror elements.

Since there are 18 separate mirror elements, they must be adjustable once the entire mirror structure is unfolded and latched into place. So, extending from the framework that holds them is a series of actuators that allow for adjustment of each of the mirror cells, using rods that are positioned with tiny motors. "These rods are connected to each corner of the mirrors ... and then the center of each mirror," he explains. The function of that center strut is akin to pushing on the center of an individual mirror element to change the curvature of the mirror and accomplish the final fine-tuning of each mirror. "In orbit, we match the radius curvature of the mirrors with each other with this mechanism." To assure stability, the entire system was tested across a range of extremely cold temperatures well beyond the expected range of operation.

Northrop Grumman technicians look on as the JWST is folded up for shipment. Credit: NASASFC


NORTHROP GRUMMAN

The surface of each mirror was also rigorously tested for focus to within 25 nanometers (a human hair is about 100,000 nanometers in width). "All the mirrors were tested after they were chrome polished to get them to the 25-nanometer error range," Stahl said. For a sense of how exacting this is, if you took the assembled Webb mirror and expanded it to the size of the continental United States, no bump or variation would be bigger than a grapefruit. "Each one of these segments is about the size of Texas in that analogy. That's the level of the technology that we are working on."

It's important to remember that all this testing took place on Earth in a punishing one-gravity environment—in space, of course, the telescope would be operating in a zero-g environment, so precision in planning and testing was critical. To add to that complexity, the entire telescope had to be able to withstand the vibration and acoustic effects of launch, a very violent process when working with complex technology. Though there are not currently any plans to send servicing missions to the telescope due to its extreme distance from Earth, Stahl noted, "we have built what is essentially a trailer hitch into the Webb, and if at some point we develop a space tow truck, we have given them something to grab hold of so they can drag it back."

"A single year of Webb data is equal to about five years of Hubble data," Stahl said, "and we are expecting Webb to go 20 years. It is going to get approximately a hundred years of Hubble data, and the return on investment on Webb is going to be much higher than the return on investment was for Hubble."

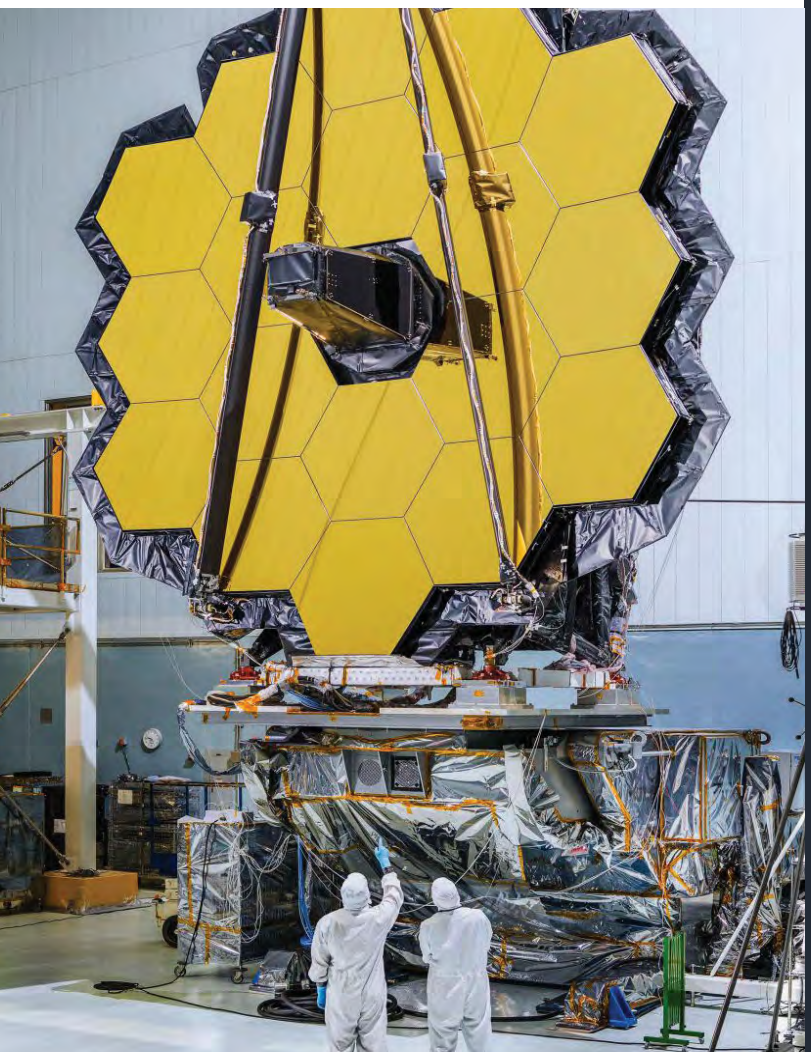
Many of us recall the famous images from the Hubble telescope that show multiple galaxies packed into a single image. Stahl comments that NASA's Chandra X-ray telescope looked at the same area and showed that there were black holes at the core of each of them. "One of the questions is what came first, the black hole or the galaxy? Maybe these black holes are a leftover from the expansion after the Big Bang. Maybe these black holes are actually pieces of the Big Bang that never really fully expanded—these are called primordial black holes." Or, he pointed out, "it could be that those first stars, instead of going supernova, might have actually done a direct collapse into a black hole—imagine a star 25 times the size of our sun completely disappearing without going supernova; just turning into a black hole directly."

For stars that survive, there are other questions. How do planetary systems form that might support life? Existing space telescopes have provided some questions that the Webb should be able to resolve.

The Hubble and the Herschel space telescopes had spectroscopy instrumentation that spotted the building blocks of life in distant star systems. "You can [sometimes] see the circumstellar disk clearing out the debris disk," Stahl said. "Herschel did spectroscopy and looked at all the methane, water, carbon monoxide, sulfur dioxide, and formaldehyde," in addition to hydrogen, oxygen, and carbon. "These are the building blocks for organic chemistry."

"We also look at habitable zones, and for liquid water. We want to find planets that exist in the zone of liquid water. Stars make water—they basically are [shooting] water out of their north and south poles in jets [that collects] in the planetary disks as snow, and that's how you grow a planetary disk." However, that snow isn't limited to water. "That snow can be methane or carbon dioxide." Scientists working with the telescope will be looking for such occurrences.

There are, of course, more questions. "Why do we have so much iron on Earth? You'd think iron would want to gravitate closer to the sun. One of the reasons our planet has so much iron is because we have Jupiter, and its gravity pulled enough iron away from the sun to give us an iron core ... the Webb telescope is going to cover this region of the particles and the dust lines of the planetary system."



The JWST's main mirror, 21 feet (6.5 meters) in diameter
Credit: NASA

But detecting and characterizing exoplanets is still a challenging business, even with a huge telescope like Webb. Current space telescopes use either the transit method, which observes dips in a star's light output when a planet passes between it and Earth, or the radial velocity method, which notices a shift in the star's spectra caused by the gravitational pull of larger planets in orbit around it. However, if one can block the light coming from the star and look to the side, exoplanets can be observed directly. The instrument that enables this is called a coronagraph, which blocks the light of stars, leaving any nearby planets potentially observable, especially if they are farther away from the star.

"Our galaxy has about a hundred billion stars," Stahl points out, "and what we're finding is that every single star, no matter what size, has got planets, and on average, every single star has an Earth-sized planet, so there could be 17 billion Earth-sized planets just in our galaxy alone. The question is how many of those are in habitable zones." This will be the holy grail of observations by Webb. Stahl also noted that planets with large moons are much more likely to be habitable—"it has to do with the tides in pulling the tidal pools and any aquatic life being exposed to oxygen, and with the fact that Earth's Moon acts like an outrigger that stabilizes the spin axis of our planet, allowing relatively stable conditions for life to form over time." It follows that the presence of large moons may aid the formation of life on exoplanets as well.

Once some promising candidates are identified, how should one seek indicators of life? "Do we look for little green men? Do we look for radio waves? Do we look for *I Love Lucy* reruns? Do we look for laser beacons?" Stahl asked. "What you do is look for what it is that life does—it metabolizes. It eats and it poops. So what we have to do is to look for the byproducts of biology.

On our planet, every single chemical reaction that turns one thing into another produces energy for a living organism [and] has byproducts such as ammonia, methane, water, carbon dioxide, and things like that, so we want to use spectroscopy on the atmosphere of exoplanets to look for those markers of biology."

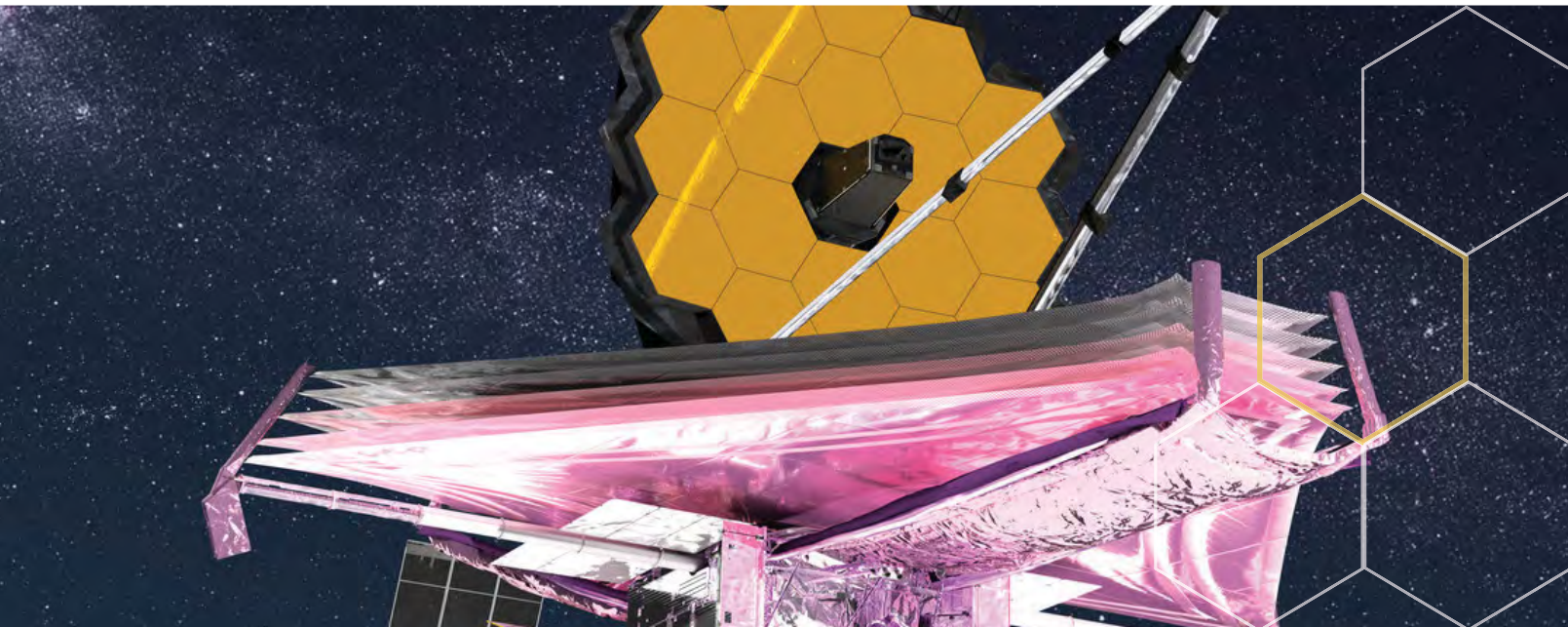
Since launching at the end of 2021, the Webb telescope has sped to its final destination at L2, successfully deploying its sunshade, it's main and secondary mirrors, and all the rest of the components required to work properly. It is now in orbit around the Lagrange point, aligning its mirrors, calibrating hardware, and chilling down to the proper operating temperature.

"The first science image of commissioning is somewhere about six months out from launch, somewhere in June," Stahl said. "There are two kinds of science: there's the early release science that will be released right away." Then, the secondary science is the province of that instrument's principal investigator (PI). "The PI for that instrument has exclusive use of the data that they have signed up for, and they have to publish something within so many months. After that, their data becomes available to anyone through archives that NASA maintains."

At that point, the fantastic science from the James Webb Space Telescope will become available to the world, and who knows what incredible wonders may emerge from the ensuing research. We may even finally answer the question whether or not we are alone in the universe.

Special thanks to Burt Dicht and Larry Ahearn for organizing the National Space Society's Space Forums, a series of public talks on space-related topics, of which Dr. Stahl's presentation was a part. For more information on the Space Forums, go to the NSS website at space.nss.org/nss-space-forums. ■

Illustration of JWST after full deployment
Credit: NASA



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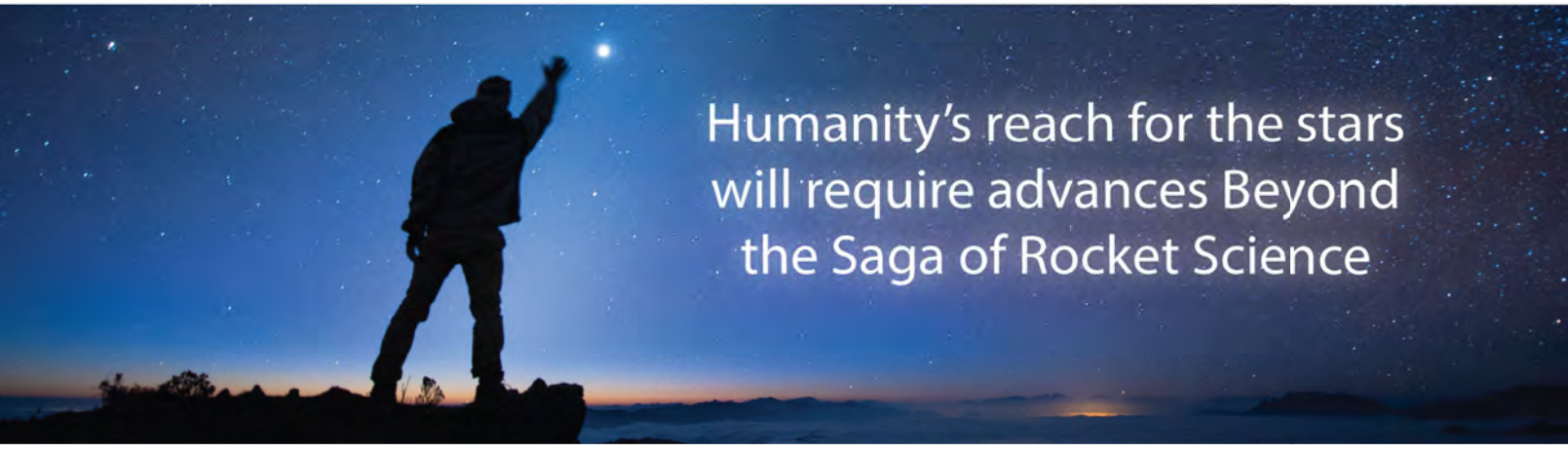

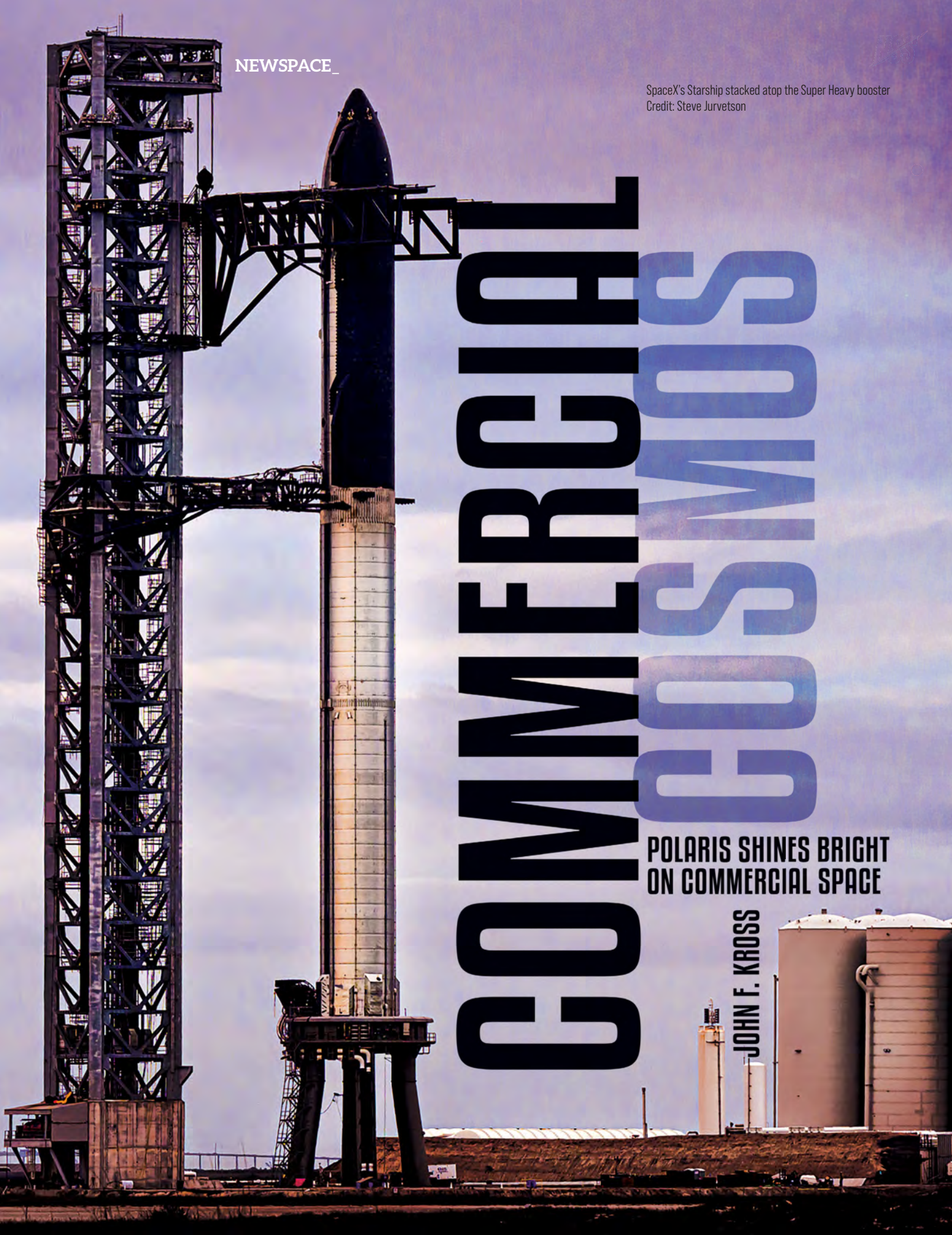

SpaceX's Starship stacked atop the Super Heavy booster
Credit: Steve Jurvetson

COMMERCIAL COSMOS

POLARIS SHINES BRIGHT ON COMMERCIAL SPACE

JOHN F. KROSS

For most of the Space Age, governments shaped space policy and commerce by directly coordinating industrial and technological resources. If they wanted space hardware or services, they inked a contract with a legacy aerospace firm. Increasingly, however, commercial enterprises and private capital are driving space development spurred by government policies. In 2018, NASA issued its National Space Exploration Campaign Report with the aim of making low Earth orbit (LEO) a "marketplace where NASA is one of many customers and the private sector leads the way." The following year, the agency released a five-point plan to achieve a "robust and competitive low-Earth orbit economy." For their part, advocacy groups such as the National Space Society (NSS) have long promoted the commercialization and settlement of Earth orbit and cislunar space

Private investors are pouring cash into start-up space ventures, shattering previous records as increasing numbers of investors fund larger deals. In 2021, start-up space ventures raked in over $15 billion in financing, breaking the $7.7 billion record set the previous year. The amount of private capital in new space enterprises now approaches what the U.S. government spends on civil space. Furthermore, the emergence of NewSpace companies, led by serial entrepreneurs and philanthropic tycoons, heralds the first truly private access to spaceflight. Wealth combined with vision and boldness is recreating the conditions that led to the Heroic Age of Antarctic exploration, when private citizens opened new frontiers. The new space age goes even further—by facilitating access to space and creating a transportation and destination ecosystem, commercial entities are shaping and driving an emerging space economy, and this trajectory is accelerating.

GUIDING STAR

One of the biggest names in private spaceflight is billionaire and entrepreneur Jared Isaacman. He was the inspiration and sponsor behind last September's Inspiration4 mission, billed as the "world's first all-civilian mission to space" with the launch of Crew Dragon Resilience on a Falcon 9 rocket. Joining him were physician assistant Hayley Arceneaux, scientist and educator Sian Proctor, and Lockheed Martin employee Chris Sembroski. "We promised a crew ... exemplifying our mission ideals of leadership, hope, prosperity, and generosity," Isaacman explained before the flight. "We've accomplished that goal."

Inspiration4 targeted a 335 mile (540 kilometer) orbit with the same inclination as the International Space Station (ISS)—51.6 degrees—but 60 miles (100 kilometers) higher. "It should send a message," Isaacman continued, that "we're ready to go back to the Moon, and we're ready to go beyond the Moon to Mars."

While in orbit, Resilience was controlled by the ship's computer, although the crew was coached in emergency and other procedures. Fortunately, the only glitch during

Jared Isaacman, who will command the Polaris missions
Credit: SpaceX/Inspiration4

the mission was a balky toilet that triggered an alarm. In place of Dragon's docking adapter, SpaceX installed an acrylic bubble-top cupola giving 360-degree views outside Resilience's nose. In addition to sightseeing, the crew monitored 365 pounds (166 kilograms) of scientific equipment dedicated to microgravity research including microbial samples and in-flight medical experiments (ultrasound, fluid shifts, ECG activity, blood oxygen levels, heart rates, and more). After three days in orbit, Resilience splashed down in the Atlantic Ocean north of Cape Canaveral and was recovered about 40 minutes later.

Fresh from Inspiration4's stellar feat, Isaacman has teamed again with SpaceX for the Polaris Project. The project shines light on private commercial spaceflight with a series of expeditions including two Dragon missions and the first crewed flight of SpaceX's Starship. "Coming back from Inspiration4, I felt like the bar was really high," Isaacman explains. The Polaris Project "has been purposefully designed to advance long-duration human spaceflight capabilities ... guiding us toward the ultimate goal of facilitating Mars exploration."

The first mission, dubbed "Polaris Dawn," will launch no earlier than the fourth quarter of 2022 from Kennedy Space Center and carry Isaacman, again in the commander role, retired Air Force Lieutenant Colonel Scott "Kidd" Poteet as the pilot, and SpaceX engineers Anna Menon and Sarah Gillis (NASA recently selected Menon's husband as an astronaut). The mission, lasting up to five days, aims for a crewed orbital altitude record with the Falcon 9 second stage thrusting the Crew Dragon spacecraft into an elliptical orbit with apogee exceeding the 855 miles (1,375 kilometers) achieved by Gemini 11 in 1966. "It'll initially be ... a highly elliptical orbit you'll phase down to about 500 kilometers towards the latter part of the mission," Isaacman continues.

Polaris Dawn's flight profile will set in motion several mission milestones such as conducting biomedical research, testing of SpaceX's Starlink satellite laser communications, and performing the first-ever private extravehicular activity (EVA) with modified SpaceX spacesuits. "We're going to test out a new generation suit that will be an evolution of the sexy looking IVA suit that ... SpaceX developed," Isaacman notes. "It's not just the suit design but ... the pre-breathe protocol [as well] ... The development of this suit and the execution of the EVA will be important steps towards the scalable design for spacesuits for future long-duration missions," he said. Which crew members, and how many, will conduct the EVA is still up in the air, but all the Polaris astronauts will don suits to depressurize the cabin. "What we learn during Polaris Dawn will hopefully contribute to SpaceX's development of those future EVA suits ... to explore the surface of the Moon and Mars," Poteet added in a tweet. The Polaris Dawn crew will also be the first to use SpaceX's Starlink system for inter-space communications, evaluating it for future work on crewed flights to orbit, the Moon, and Mars. The goal is to "test out a Starlink laser-based communication [with] ... low latency ... high bandwidth-type communication. [At the] Moon and Mars you're going to need to do that with lasers," said Isaacman.

Polaris Dawn's elliptical orbit will skim the Van Allen radiation belt, allowing researchers to assess the health impact of radiation at high altitudes. In addition, investigators from several institutions will fly experiments on board to advance human health on Earth and during long duration spaceflight. These include using ultrasound to study embolisms (gas bubbles in the blood) associated with decompression sickness suffered by scuba divers and taking blood samples for analyses. Gathering data on changes in eyesight—specifically Spaceflight Associated Neuro-Ocular Syndrome (SANS)—and intracranial pressure is also part of the flight plan. Poteet, a former member of the Air Force Thunderbirds flight exhibition squadron, has volunteered for moderately invasive experiments related to intercranial pressure that require implanting a sensor below his ribcage to monitor the effects on his body.

Picking Starship for the final Polaris mission is fitting, though details are few to date. What is clear is that Elon Musk's stainless-steel spacecraft will be the star from launch to touchdown. "The third mission will be a crewed ascent [to] low Earth orbit ... and a re-entry all on Starship," vows Isaacman. Discussing the mission at a media briefing, Isaacman emphasizes the significance of the Polaris initiative. "I think this should be eye-opening as to what can be achieved through private funding," he said, "and for what that means for future commercial space exploration missions."

IT IS AXIOMATIC

The private space firm Axiom Space is putting its own commercial vision into action by flying history's first private ISS mission and building a commercial space station. Founded in 2016 by aerospace entrepreneur Kam Ghaffarian and former NASA ISS program manager Michael Suffredini, Axiom Space has assembled an industry team—composed of former Boeing, Thales Alenia Space, Maxar Technologies, and Intuitive Machines employees—to provide universal access to LEO.

In 2021, Axiom Space finalized a landmark deal with NASA for the AX-1 mission to fly the first paying commercial crew to the International Space Station. Former NASA astronaut and shuttle veteran Michael López-Alegria commanded AX-1 with Larry Connor in the right seat. Canadian Mark Pathy and Israeli Eytan Stibbe filled out the crew as Mission Specialists. AX-1 docked with the Harmony node on the ISS in April, with the crew boarding the U.S. segment for more than a week to conduct numerous experiments.

Axiom Space's private astronauts shun the label of space tourist. "We absolutely do not believe that we're space tourists," emphasizes Connor. Mission commander López-Alegría stresses that the AX-1 flight was "not a vacation ... [We] focused on ... a mission to promote a benefit to society ... teaming up with various institutions, hospitals and other research entities." Connor, for example, collaborated with the Mayo Clinic to unravel space travel's impact on senescent cells (cells that can no longer respond to damage or stress) linked to age-related disease, and with the Cleveland Clinic to study the effect on spinal and brain tissue. Pathy joined forces with the Canadian Space Agency, Canadian universities, and the Montreal Children's Hospital to study chronic pain and sleep disturbances common in space travel. Stibbe carried out scientific experiments for Israeli researchers and entrepreneurs across diverse disciplines ranging from astrophysics, biomedicine, and agriculture.

AX-1 is just the start of commercial missions to the ISS. In June, NASA announced two more flight opportunities to the space station between the fall of 2022 and the end of 2023. Later missions will follow a six-to-seven-month cadence. In anticipation of these open slots, Axiom Space signed a contract with SpaceX for three more flights. As with AX-1, the company will vie for the chance to fly these private commercial missions to the ISS subject to NASA approval and traffic to the station. "Like everyone, we have to compete for the opportunity," Suffredini explains.

So far, SpaceX is the only builder of commercial crewed vehicles to orbit. Boeing is building two Starliner capsules, but both are pledged to NASA

Retired NASA astronaut Michael López-Alegira, commander of Ax-1
Credit: Axiom Space

missions for the duration of the contract. In contrast, SpaceX has four reusable Crew Dragons with Freedom and Endurance joining Endeavour and Resilience in the fleet. "We are beyond excited to build upon our partnership with Axiom to help make human spaceflight more accessible," Gwynne Shotwell, SpaceX president and COO, said in a statement.

If awarded the second private commercial mission to the ISS, Axiom Space is aiming for a fall 2022 launch. Former NASA astronaut Peggy Whitson would command the AX-2 mission, joined by pilot and champion GT racer John Shoffner and two more paying customers. Prior to joining the company, Whitson spent 665 days on three long-duration ISS missions, becoming the station's first female commander. She still holds the American record for time spent in space. On AX-2, Whitson and Shoffner aim to conduct a slew of commercial experiments including research on single-cell genomic methods for biotechnology company 10x Genomics.

THE LEO ECONOMY

A commercial space ecosystem requires both transportation and a destination, and Axiom Space is pursuing both. "Axiom was founded to push [the]

envelope—first with private astronaut missions to the ISS, followed by the launch and operation of the world's first commercial space station," Suffredini explains. For her part, Peggy Whitson sees LEO on the "precipice of change" from the near-exclusive domain of government bodies to private commercial competition.

The U.S. space agency is trying to promote the commercialization of low-Earth orbit with a near-term strategy of flying private commercial astronauts to the ISS. "As more people fly to space and do more things during their spaceflights, it attracts ... more activities in low-Earth orbit, and reflects the growing market," explains Phil McAlister, director of commercial spaceflight development at NASA. Space advocacy groups like the NSS support these moves. NASA's plans for LEO commercialization and a transition to commercial LEO space stations parallels the positions the NSS has advocated for decades. In early 2020, Axiom Space announced it had raised $130 million from investors, allowing the company to move forward with its long-term goal of creating a private space station. Supplementing these funds, Axiom Space also won a $140 million NASA contract to build and install a commercial module docked to ISS's Harmony node (Node 2) as early as 2024, with the option to become the core of a free-flying commercial space station when the ISS is retired. Thales Alenia Space is currently welding and machining the cylindrical hub module before final assembly and integration in early 2023. The platform will come equipped with its own guidance, navigation, and control system and four ports to which other station elements can connect.

Other companies are also eyeing commercial space stations, attracted by potential profits and government grants. In December 2021, NASA awarded contracts worth more than $400 million to three consortia to spur the transition from the ISS to commercial space stations with its Commercial Low Earth Orbit Destinations (CLD) initiative. The awards allow each consortium to mature the designs of their commercial station concepts through 2025.

Nanoracks, and their partners Voyager Space and Lockheed Martin, received the lion's share at $160 million, to develop their space station concept called Starlab, slated to fly as early as 2027. Starlab's blueprint includes a large inflatable habitat with a metallic docking node attached to one end and power and propulsion bus docked to the other. A regenerative environment control and life support system (ECLSS) will allow continuous habitation by a crew of four living and working in a 12,000-cubic-foot (340-cubic-meter) volume (about one-third that of the ISS). Starlab will feature an ultramodern laboratory and large robotic arm to service cargo and external payloads. Solar cells will generate 60 kilowatts of power, and Starlab will deploy with a single launch. A second contract, worth $130 million, was awarded to a Blue Origin-led team for their Orbital Reef station, scheduled for initial operations in the late 2020s. Boeing, Redwire and Sierra Space round out the Orbital Reef team. Their station concept will start with a "scalable baseline configuration" featuring an "energy mast"—consisting of a single set of solar arrays and radiators—a core module, a LIFE habitat module, and a science module. In this initial configuration, it will host a crew of 10, generate 100 kilowatts of power, and have a volume about 90 percent that of the ISS. "It's of comparable scale to station, and then set up for indefinite growth beyond that," said Brent Sherwood, senior vice president of advanced development programs at

Axiom Space's first private space station module is scheduled for delivery to the ISS in 2024 or 2025
Credit: Axiom Space

Blue Origin. "It is infinitely scalable by ganging together additional core modules and energy masts, and attach modules on the sides," he adds. Blue Origin will contribute the core modules and launch services with its New Glenn rocket, while Sierra Space supplies the inflatable LIFE module and transportation with its Dream Chaser spaceplane. Boeing will add a science module and its CST-100 Starliner crew vehicle.

The final award, valued at $125.6 million, went to Northrop Grumman for development of a Cygnus-inspired station that would leverage work on the company's satellite-rescuing Mission Extension Vehicle and Habitation and Logistics Outpost (HALO) module destined for NASA's lunar Gateway. The as-yet-unnamed facility could support four crewmembers after a single launch, with the ability to expand.

By transitioning from the aging ISS to commercial space stations, NASA hopes to reap billions in savings since costs will be amortized among many customers. "We anticipate ... we're going to save the agency about $1.5 billion" per year, predicts Phil McAlister, director of commercial spaceflight at NASA Headquarters. "That is going to be a key enabler for our Artemis missions going forward." However, keeping a seamless transition on track is vulnerable to both financial and scheduling hurdles.

Last year's NASA Office of Inspector General (OIG) report questioned current funding levels and the end-of-the-decade deadline for commercial stations. NASA's LEO commercialization efforts "show promise," the report said, but "even if early design maturation is achieved in 2025 ... a commercial platform is not likely to be ready until well after 2030."

In addition to the timeline, the report warned about uncertain government funding. Former NASA administrator Jim Bridenstine echoed that concern. "We are not ready for what comes after the International Space Station," Bridenstine told lawmakers. In his written testimony, he recommended Congress fund "NASA's LEO commercialization efforts at $2 billion per year ... If Congress does this, capital markets and entrepreneurs will respond in a way that establishes America as preeminent in LEO human spaceflight at a cost significantly less than the ISS." Unfortunately, current funding falls short of that goal (and is insufficient to even support NASA's $140 million agreement with Axiom Space). Such a shortfall could disrupt the nascent commercial LEO economy and drive companies to alternate platforms. In August 2021, for example, Nanoracks lost a customer to China's Tiangong space station.

Crew Dragon Resilience was fitted with a special hemispherical viewport for the Inspiration4 mission
Credit: SpaceX

The response of other ISS partners, particularly the European Space Agency (ESA), to commercial stations will be interesting as the space agency has a mandate to support Europe's space industry. "ESA will probably not be in a position to buy commercial services from U.S. providers for its research activities in LEO or to fly its astronauts," cautions Sylvie Espinasse, head of ESA's Washington office. Long-term, ESA could adopt a "fully European" commercial station or form industrial partnerships with American or other players to jointly operate a station.

WORLD CIRCLING SPACESHIPS

Elon Musk founded SpaceX to remove the cost barrier to space, with reusability as the key strategy. With about 100 reflights (and counting) of "flight-proven" boosters, the Falcon 9 dominates the commercial medium launch market. Competitors have taken note as both Blue Origin and United Launch Alliance are building reusability into their new rockets, the New Glenn and the Vulcan. These launch vehicles are optimized to deliver school bus-size satellites to geostationary orbit, but the Falcon 9 has also boosted

thousands of small Starlink satellites into medium-to-low orbits.

Microelectronics has shrunk some satellites to the size of a toaster or microwave oven, allowing some rockets to be downsized too. The competition in this market segment is heating up with more than 100 small launch vehicles on a popular industry watch list. Rocket Lab is a frontrunner in this crowded space. The all-black Electron rocket, which can loft 661 pounds (300 kilograms) to LEO, has a record of delivering small satellites to "precise and unique orbits." Since 2017, the company has launched over two-dozen Electron rockets and has plans to reuse its carbon-composite first stage and upgrade to the more powerful Neutron rocket (17,636 pounds or 8,000 kilograms to LEO). Rocket Lab is also strategically moving into the satellite-building business, announcing a $143 million contract with MDA Space to design and manufacture spacecraft buses for Globalstar LEO satellites.

A striking feature of many small rocket startups in the U.S. is their funding by venture capitalists. Silicon Valley-based rocket maker Astra aims to launch its Rocket 3 (441 pounds or 200 kilograms to LEO) from multiple locations (Alaska and Florida to date) and constrain costs by leveraging traditional manufacturing methods. "We're building Hondas, not Ferraris," explains Chairman and CEO Chris Kemp. "We don't use any ... exotic materials ... We're building these rockets out of aluminum so we're bending, we're welding, we're fastening, we're stamping." However, early flights of new rockets have been notoriously troublesome, and Astra's experience fits that trend. The publicly traded company suffered a string of three launch failures (Rockets 3.1 to 3.3) until another Rocket 3.3 launch successfully reached orbit carrying a demonstration payload for the U.S. Space Force in November 2021. The next launch experienced an in-flight anomaly in February 2022.

Cross-state competitor Relativity Space is pursuing the opposite strategy with its Terran-1 rocket (2,755 pounds or 1,250 kilograms to LEO) by fusing 3D printing and autonomous robotic manufacturing techniques. No Terran 1 vehicles have flown yet, but three customer payloads are scheduled including a small NASA satellite. The company will upgrade the Terran 1 rocket with a new main engine following these demonstration flights.

Virgin Orbit, a publicly traded company founded by flamboyant entrepreneur Richard Branson, successfully orbited satellites twice in the first half of 2021 using its air-launched LauncherOne vehicle (1,102 pounds or 500 kilograms to LEO). Texas-based Firefly Aerospace features the Alpha launch vehicle, which will carry 2,205 pounds (1,000 kilograms) to LEO, though its first test flight failed in September 2021 when one of the main engines sputtered seconds after liftoff. ABL Space Systems was founded by former SpaceX employees and is developing the RS1 rocket (2,976 pounds or 1,350 kilograms to LEO) with launches planned from U.S. and U.K. sites. Other small rocket makers are competing in this market segment as well.

Small launchers are suited for placing (or replacing) satellites on demand, but the size of the market niche is debatable. "I don't think there's enough ... for more than two, maybe three of these microlaunchers," SpaceX's Shotwell argues. Musk's company is also crowding this market by piggybacking small satellites on its Falcon 9 rocket. So-called "rideshare" is the difference between ordering a door-to-door Uber ride and taking the bus. For some satellites, getting close to a desired orbit is good enough, and the cost savings of rideshare are important. For others, the price of a dedicated small launch is worth it. Orbiting a 450-pound or 200-kilogram satellite on a Falcon 9 rideshare launch costs only about $1 million.

At the opposite end of the spectrum, SpaceX is busily working on its Starship vehicle which, if fully realized, would revolutionize commercial space by orbiting massive payloads cheaply and reliably. "I don't think people have fully comprehended what that system is going to do for the ... enterprise in space," Shotwell tells *Ad Astra*'s Rod Pyle. "We will deploy capability in satellites ... The global market for leveraging Starship ... will change the world ... [and] we are really on the cusp of flying that system."

Without question, the commercialization of space is accelerating. Manufacturing efficiencies and innovative strategies, such as reusability, together with experience, skill, and engineering competence are lowering costs and promoting investment. In this environment, private companies and individuals are increasingly investing their own resources to develop new capabilities in LEO and beyond, convinced that it will spark market demand and generate revenue. All investments pose risk, of course, but the payoff could be astronomical. ■

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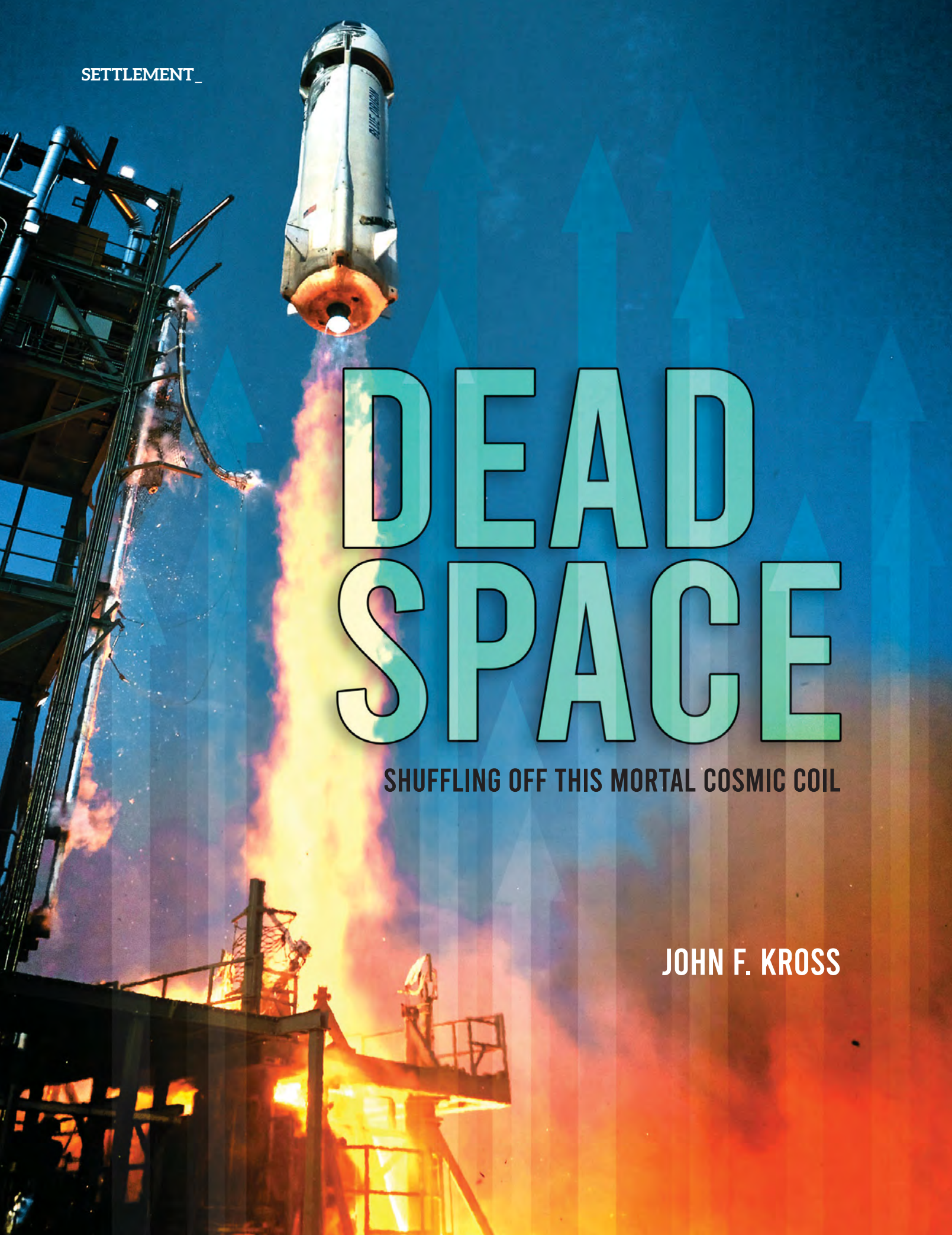

DEAD SPACE

SHUFFLING OFF THIS MORTAL COSMIC COIL

JOHN F. KROSS

"In this world, nothing is certain except death and taxes," goes the familiar adage. One day into the flight of Apollo 13, Jack Swigert remotely applied for an income tax extension lest he run afoul of government tax collectors. A few hours later, however, Swigert and crewmates had more pressing life-and-death concerns—the crippling of their spacecraft's life support and power systems. Fortunately, the crew of Apollo 13 got back alive, but other spacefarers have not been so lucky. Three cosmonauts aboard the Soyuz 11 spacecraft were the first to die in space when they were asphyxiated after a valve opened prematurely on their reentry capsule, allowing it to depressurize (the crew was not wearing spacesuits). It has been 50 years since anyone has died in space, but such a tragic fate is inevitable. People will die during spaceflight in increasing numbers and in far-off places as the tempo of human spaceflight increases, leaving emotional, legal, spiritual, practical, and administrative issues in their wake.

DANGEROUS PURSUITS

At the beginning, NASA's approach to eternity was casual. Just prior to the launch of Gemini 9, as the crew were suiting up, Deke Slayton allegedly whispered advice to commander Tom Stafford should crewmate Gene Cernan become incapacitated during his spacewalk (the tiny Gemini capsule was difficult to climb back into even under ideal circumstances). Slayton's advice boiled down to "cut him loose" and leave "Satellite Cernan" circling as space junk—there were reportedly a pair of snippers on the flight to cut his umbilical line should this be required. Stafford demurred, vowing to decide Cernan's fate himself, should the need arise.

On the eve of Apollo 11, the U.S. government was focused on the public relations aspects surrounding the possible demise of Apollo Moonwalkers, so much so that President Nixon's speechwriter William Safire penned a speech in case something went terribly wrong. It opened with the poignant words, "Fate has ordained that the men who went to the Moon to explore in peace will stay on the Moon to rest in peace." With that, NASA intended to cut public radio communications with the stranded astronauts and commit them to a "burial at sea." More recent official NASA statements take a decidedly bureaucratic tone: "NASA does not prepare contingency plans for all remote risks. NASA's response to any unplanned on-orbit situation will be determined in a real time collaborative process between the Flight Operations Directorate, Human Health and Performance Directorate, NASA leadership, and our International Partners." Such bureaucratic language masks an out-of-sight, out-of-mind attitude towards death in space, and according to former shuttle astronaut Mike

Tom Stafford reflects on the dangers of Gene Cernan's potentially fatal EVA conclusion during Gemini 9a. Credit: NASA

Tribute to the crew of Soyuz 11, lost when their capsule depressurized during reentry
Credit: RPM

Massimino, the agency did not have a protocol for bringing back a fallen space traveler when he was there. "It could happen, but you know out of all the training I had, we never went over that one," he explains. Similarly, Terry Virts, who clocked 213 days on the International Space Station (ISS) and the space shuttle, claims he never trained to handle a dead body in space. "I did quite a bit of medical training to save people, but not for this ... In my 16 years as an astronaut, I don't remember talking with another astronaut about the possibility of dying," Virts said. "We all understand it's a possibility, but the elephant in the room was just not discussed."

That's not to say astronauts don't plan for a worst-case scenario. According to retired Canadian astronaut Chris Hadfield, ISS crews do in fact informally plan for the death of a crewmate. "We have these things called 'contingency simulations' where we discuss what to do with the body," he said. "Should we shove it in a spacesuit and stick it in a locker ... Should we send it back to Earth on a resupply ship and let it burn up with the rest of the garbage on re-entry? Jettison it during a spacewalk and let it float away into space?"

RISKY RIDES

Over the next few years, the number of space travelers should skyrocket as space tourism takes off. Most jaunts will be suborbital, which simplifies things, funereally speaking. The short duration of flights and modest physiologic stress—microgravity and g-forces—portend few deaths from natural causes. Catastrophic launch vehicle or parachute failures are potential killers but would happen on the point of impact and not in space.

Nevertheless, that still leaves the lawyers, insurance solicitors, and government bureaucrats with plenty to do. In the United States, individual states with commercial spaceports—such as Florida, Texas, and New Mexico—have enacted laws to protect firms operating spacecraft from litigation by passengers who waive liability and sign informed consent agreements before they step on board. These laws also indemnify suppliers and manufacturers, so they are not snagged in endless lawsuits following a fatal accident. Firms would still be liable for losses to uninvolved third parties in the event their rocket plowed into neighboring properties.

Based on international space law, including the Outer Space Treaty, individual countries supervise and authorize all national space efforts regardless of whether

An exhausted Gene Cernan after his harrowing EVA on Gemini 9A. Had he not been able to climb back into the cramped capsule, Stafford would have had a terrible decision to make. Credit: NASA

they are private or public. In the United States, the Federal Aviation Administration (FAA) issues licenses for commercial tourist spaceflights and would lead any investigation into a fatal commercial spaceflight accident. The National Transportation Safety Board (NTSB) has helped probe space-related fatalities in the past, including the 2014 in-flight accident involving Virgin Galactic's SpaceShipTwo that killed its co-pilot, but both industry and the FAA strongly oppose a larger investigative role for the board. SpaceX also opposes NTSB's expanded role in commercial spaceflight.

In the wake of a fatal mishap, the FAA would probably shelve further launches by a company if they suspected a mechanical defect pending an investigation. Deadly accidents due to other causes would prompt an evaluation about whether the commercial provider took precautions to prevent the person's death. Either way, the administrative machinery would be set in motion following a fatal accident.

THE UNDISCOVERED COUNTRY

Investigative procedures are less defined for orbital missions sponsored by national space agencies, especially multinational enterprises like the International Space Station. Inquests have been made before, most notably for high-profile tragedies, such as the Apollo 1 fire, or in-flight disasters, including the Challenger and Columbia shuttle accidents that killed all aboard. For example, the Rogers Commission Report summarizing the investigation of the Challenger disaster was specifically created by a Presidential Commission and recruited high-profile commissioners including Nobel laureate Richard Feynman and former NASA astronauts Neil Armstrong and Sally Ride. However, these were specific investigations predominantly involving U.S. hardware and citizens (Ilan Ramon, an Israeli citizen, was the only non-American aboard Columbia in 2003).

As for the ISS, Christopher Newman, a professor of Space Law and Policy at Northumbria University in the United Kingdom, notes that there's been no real discussion of protocols surrounding onboard fatalities "because essentially, it's still very close to Earth." He explains, "I suspect that there will be ... a large terrestrial element" to conventions dealing with the demise of an astronaut near Earth. Newman believes the nationality of the astronaut would dictate the investigating authority in case of a fatality in low-Earth orbit. "If it was an American astronaut, it would probably be an American coroner," he concludes. In the case of commercial missions with international crews, international space law holds that the country in which a spacecraft is registered has jurisdiction over it and any personnel, and that country would have authority to begin an inquest and set procedures surrounding any death onboard. "International treaties ... [such as] article seven of the Outer Space Treaty, hold that states have international responsibility for the space activities [launched from their territory]," explains Newman. "If it was a ... mission authorized by the United States, it would fall on the U.S. government to manage the process." If it was a SpaceX mission, he adds, "the United States will be internationally responsible." However, the influence of terrestrial customs and routines will likely diminish in direct proportion to the distance from Earth. Lengthy deep space missions and distant space settlements will be accompanied by investigative processes to collect information and find the cause of death, learn lessons, and detect patterns. But Newman predicts that as people go farther, Earth will have less influence on death investigations. "Settlements beyond Earth ... even in a lunar context ... would [probably utilize] a very terrestrial solution. But ... once we start moving away from the influence [of] Earth ... hours away [by radio], then who does the investigation? How do we dispose of a body? How do we store a body? How do we process the death?" Mars is a good example. "What happens on a mission to Mars," asks Emory University bioethicist Paul Wolpe, "when it may be months or years before a body can get back to Earth, or where it's impractical to bring the body back at all?" Far from home, new processes and protocols may evolve as people embark on extended deep-space missions and permanently settle other worlds.

Policies and procedures concerning death and the handling of remains should probably be tailored to a specific settlement or mission to account for factors like power, food, and waste disposal. Setting guidelines beforehand to fix expectations will be especially important for diverse crews; think of a multicultural, multireligious, and multinational passenger manifest on Starship enroute to Mars. "A real genuine multinational ... multicultural venture will have to ... put in place arrangements" between the participants for what happens if someone dies, said Newman. These range from disposal of the remains and "zoning" to conducting an inquest, managing the event, communicating with Earth, and informing the family. "Before you set out on a journey ... all this should be laid out so there are no disputes," he adds.

LIVING WITH THE DEAD

Lingering over all these concerns are the practical aspects of dealing with mortal remains. On short missions, the recently deceased will probably be returned to Earth through some form of preservation and storage. Astronauts on board the ISS could take a cue from submariners—if a crewmember dies aboard a submarine on a long patrol, the body is likely to be stored next to the torpedoes where it is cold and

Chis Hadfield, to left, with Tom Marshburn and Kevin Ford aboard the ISS. Risk is never far away. Credit: NASA

isolated from the crew's quarters. Astronauts on board the ISS could adopt a similar tactic, storing a deceased crewmate in the coldest part of the station. "I would probably store them in there until a ship was going home," astronaut Hadfield said. "If someone died while on an EVA, I would bring them inside the airlock first ... [and] keep them inside their pressurized suit," he adds. That would make a tidy, if temporary, solution.

In deep space, bodies will need to be stored long term or disposed of in some way. Inspired by seafarers again, one option might be to commit a body to the deep, essentially ditch them overboard. "There's no international law that says you couldn't ... give somebody a burial like Spock at the end of *Star Trek II*," said Newman. Still, some countries may oppose free-floating cadavers, which could worsen the space debris problem, especially if jettisoned near Earth. Care would be needed on trans-lunar or trans-Mars trajectories, lest the body encounter another (far larger) celestial body. Astronaut remains survived the disintegration of space shuttle Columbia (STS 107), so it is by no means certain that a space-suited corpse would be entirely incinerated on atmospheric reentry.

Death on the Moon or Mars would offer more options. It is unlikely anyone would be interred in a spacesuit that surviving astronauts could reuse, so a body bag or shroud would be needed. "It would be some sort of sealed [container]," observed Newman. "Some metal foil blankets or things like that." In a pinch, an improvised shroud could be made from space-resistant material such as metal foil or thermal blankets used on spacecraft. The latter consists of a transparent layer of amber-colored material on top of reflective aluminized fabric for long-term durability and thermal protection—ideal for safeguarding the newly departed.

The Moon's south pole features long shadows and cold-trap craters, which is an ideal spot for a gravesite. Burial, or "inhumation," in a mostly shadowed region would deep-freeze the corpse long term. "Much better in the cold ... away from the settlement rather than [near] actual living quarters," agrees Newman. On Earth, natural cold storage is a great preserver. Dozens of bodies litter Mount Everest and other tall peaks in a fair state of preservation. Similarly, corpses from the ill-fated Franklin expedition have been preserved in the artic permafrost for centuries. A shallow grave might need to suffice because digging and drilling are notoriously difficult on the Moon, as the Apollo astronauts discovered. Fortunately, NASA has evaluated special regolith-digging robots that could be drafted for grave digging. A nearby lunar cave or lava tube would offer an alternative for the newly deceased to go gently into the good night, but either way, the polar lunar environment would help preserve the body. Elon Musk has warned that the first people to journey to Mars should be "prepared to die," but Mars is a long way from home, making an interplanetary funeral unlikely. "I would expect that if a crew member died while on Mars, we would bury them there rather than bring the body all the way home,"

Hadfield observes. The Red Planet is cold and dry, and permafrost covers the surface in the high latitudes. Natural preservatives like perchlorate lace the soil. In such a place, a corpse would be desiccated, irradiated, and mummified in no time.

However, disposal of human remains on Mars is fraught with planetary protection questions, since an interred body could biologically contaminate the planet. It is not a problem on the lifeless Moon, but Mars is a different matter. Professor Newman suggests creating "some sort of biological zoning" or "environmental exclusion areas ... we just stay out of ... if we suspect there might be life." Catherine Conley, the former head of NASA's Office of Planetary Protection, proposes cremation instead. "Regarding the disposal of organic material (including bodies) on Mars, we impose no restrictions so long as all Earth microbes have been killed ... so cremation would be necessary," she explains. Incineration would certainly be a premium way to go since it would require precious oxygen and an accelerant to stoke the flames. Being resource intensive, however, it might be a non-starter on the airless Moon or Mars, and flames in an oxygen-rich environment are always a risk. Homeric funeral pyres are probably out. Certainly, technical solutions will emerge over time for the storage and disposal of human remains in space. There is work ongoing "regarding the removal of water from humans ... and creating ... a much smaller 'package' that is more manageable," explains Newman. In 2005, NASA commissioned a study from a Swedish "eco-burial" company for an innovative technique to freeze-dry a cadaver and shake whatever is left into tiny bits. Called "promession," the process uses liquid nitrogen, but in space a robotic arm could suspend a bagged body in the freezing void until brittle then vibrate it into dust. Promesserizing a human body, which is around 75 percent water, would turn a 200-pound astronaut into a 50-pound, backpack-sized package.

From a purely utilitarian view, of course, human bodies are composed of very useful water and compounds, not to mention specific elements. "They have a lot of material that would actually be quite useful to a colony," notes Newman. That raises the issue of human recycling. Today, people on Earth donate their organs or have their ashes sprinkled over greenery, a recycling of sorts. The exigencies of the Moon or Mars would make salvaging or reprocessing corpses even more critical. "You are still in an organic form, which means you ... are still food for the soil, and if you spread it around you will be food for birds, or fish, or whatever," says Susanne Wiigh-Mäsak, one of the inventors of promession. Ending one's days as a bag of fertilizer is certainly a utilitarian option and would surely attract the altruists among us. "I'd be quite happy if you wanted to use my remains to fertilize things," pledges Newman.

In the end, space settlement will inevitably raise knotty social issues including governance and dealing with unavoidable deaths. Practices may differ and evolve over time, but rest assured that both will be high on the list since death and taxes are, of course, eternal. ■

The plains of Mars will one day be the final resting place for people who die due to an accident or just old age.
Credit: NASA

NEW LEASE ON LIFE FROM SPACE

MELISSA SILVA

Marvel's Deadpool superhero has a regenerative healing factor, which quickly heals even the most serious injuries—like being decapitated—rendering him effectively immortal. It's a neat trick, and one that would transform modern medicine. But currently, according to the Health Resources and Service Administration, 106,803 women, men, and children are on the national transplant waiting list, and 17 people die each day waiting for a life-saving organ transplant. Comic book legends aren't going to help them.

Technological advancements in this field can impact the lives of thousands of patients worldwide who suffer from terminal organ failure, however, and looking ahead, some are likely to have their roots in spaceflight. Space is not a welcoming place for people, and decades of human space travel have yielded a wealth of evidence for why that's the case. Microgravity causes bones to deteriorate and muscles to atrophy, as well as issues with vision. Extended exposure to radiation can cause permanent damage to organs. Simply put, we're not built for space; consequently, research is ongoing regarding the responses of human bodies to microgravity.

Astronaut Peggy Whitson with a plant growth experiment aboard the ISS
Credit: NASA

To that end, NASA's Vascular Tissue Challenge offered a $500,000 prize to the first three teams that could successfully create "thick, metabolically-functional human vascularized organ tissue in a controlled laboratory environment." The objective of the challenge, which was announced in 2016, is to produce technology capable of creating tissues that can be used as organ analogs to study the effects of deep space and how to minimize damage to healthy cells. The tissue will advance research on human physiology and space biology and medicine, which will help address little-understood areas like risks related to traumatic bodily injury in space and how to improve general crew health and performance.

Two teams from the Wake Forest Institute for Regenerative Medicine (WFIRM) in Winston-Salem, North Carolina—Team Winston and Team WFIRM—won first and second place. WFIRM scientists and doctors were the first in the world to engineer laboratory-grown tissues that were successfully implanted into humans. Team Winston, which won first place and $300,000, will have an opportunity to continue its research aboard the International Space Station (ISS). The team, led by James Yoo, M.D., Ph.D., used technology called bioprinting to create their tissue sample, which will be sent to the ISS to test the effects of microgravity on vascular tissue.

"Vascularized tissue, in the simplest term, is tissue that has blood vessels and the reality is all the tissues in our body are comprised of many, many blood vessels. So, if we want to better understand how the human body is functioning, we want to develop vascularized tissues outside of the body that also contain engineered blood vessels," explained Dr. Arun Sharma, a research fellow at Cedars-Sinai Medical Center in Los Angeles, during a NASA Live broadcast. Muscular tissue, for example, is vascular, while cartilage is avascular, containing no blood vessels. "Nature is the best engineer, and we're trying to replicate what nature can do."

The winning team's tissue sample had to meet several requirements; first, the tissue had to be at least a centimeter thick in each direction, retain at least 85 percent of the required parenchymal cells throughout a 30 calendar day period, and maintain metabolic functionality. The teams had to demonstrate three successful trials with at least a 75 percent success rate to be eligible to win the award. "Meeting one of those criteria would be an accomplishment, but to meet all three criteria is absolutely tremendous," says Dr. Sharma.

Team Winston employed a "gyroid shape," which Kelsey Willson, a graduate student who led the team, describes as "a series of interconnecting wave-like tubes." Gyroid shapes have been studied as a means of turning two dimensional materials into three dimensional structures that are low in density yet high in tensile strength, which has a wide range of applications. In this case, a gyroid shape was determined by Willson's team as "the best for getting fluid flow all the way through the samples and for getting nutrients in and out."

The team's next step was finding a way for the cells within the sample to grow, expand, and communicate. In the human body, cells communicate with chemical signals carried by receptors that travel through extracellular fluid and cytoplasm. The Winston Team used modified gelatin, "sort of similar to what you might make Jell-O out of at home in your kitchen," as the foundation for the sample's circulation system.

Creating engineered vascular tissue is a massive breakthrough in biomedicine, as researchers will better understand how human tissue, in all varieties, actually functions. This will transform the study of diseases, which all intersect with the blood vessel network. This technology and new scientific discoveries could also translate into clinical therapies. "For example, after folks have a heart attack ... a lot of the cells in your heart are lost and ideally, you want to be able to replace those lost cells with an adequate cell type that's going to replace the function of those dead cells, and vascularized tissue can provide a way to actually restore the proper function of the heart," explains Dr. Sharma.

Understanding the nuances of vascularized tissue and being able to create it is invaluable to human spaceflight and the development of space settlements. Prolonged spaceflight will require novel approaches to ensuring that astronauts maintain their health. Currently, astronaut crews aboard the ISS work out six days a week for two and a half hours each day to combat muscle atrophy and the deterioration of bone density. Additional research is being conducted on possible supplements and different kinds of exercise, like whole body vibration, that could benefit from the use of lab-grown vascularized tissue for testing.

NASA's Rad-X experiment flew aboard a high altitude balloon to measure radiation doses over time. Credit: NASA

Such tissue will also help scientists study exactly how microgravity affects organs. In 2016, NASA astronaut Kate Rubins conducted research on the effects of microgravity on engineered heart tissues. The heart exerts an opposite force to gravity on Earth and being in zero gravity is known to cause abnormalities, both molecular and structural, in heart cells and tissues that can eventually lead to disease. Spaceflight has also been demonstrated to change gene expression in this kind of tissue when exposed to altered gravity in space. In fact, researchers found that the human cardiovascular response to microgravity is similar to heart disease. Rubins' research could help identify new components of heart disease, and possibly new treatments.

Rubins was also the first person to sequence DNA in microgravity, a major achievement with long-term implications. NASA's Biomolecule Sequencer experiment sought out to prove whether DNA sequencing was possible in an orbiting spacecraft like the ISS. The ability to sequence DNA in space, which Rubins proved, means that astronauts can diagnose an illness or identify microbes there. Looking forward, this technology could help protect astronauts' health during long journeys or identify DNA-based life beyond Earth.

Such technology will surely be used in conjunction with engineered tissue, and researchers can examine changes in genetic material or gene expression while in orbit, rather than returning the samples to Earth for testing. This will become more important the further human beings travel from Earth, where resupply missions and opportunities to physically send things back will become extremely

limited. Investigations into how microgravity affects human tissue and how this translates genetically can also provide new understanding of similar issues on Earth.

The dream for scientists studying regenerative medicine is to be able to one day replace damaged or injured tissues. This would not only positively benefit the lives of millions worldwide, but could revolutionize space medicine, especially as people embark on longer and longer missions. As space settlement becomes a reality, the space medicine field will need to be equipped with the knowledge of how to treat a variety of ailments and injuries in extreme environments. This includes devising methods for doing surgery and handling other medical emergencies, not just during space travel, but also in a habitat on the Moon, Mars, or in free space.

Astronauts have already performed a few minor surgical procedures in space on rats, and their experiences have led to new innovations and ideas for how to address problems like floating intestines—everything floats in microgravity, including intestines during surgery, which obstructs the view of the surgeon. Scientists have also theorized that blood could stick to surgical instruments on Mars because of surface tension. Ideally, by the time people settle on Mars, the Moon, or elsewhere in the solar system, we'll have the technology to send surgical robots, 3D printers to create instruments, and trauma pods along with the voyagers.

For now, Team Winston's vascularized tissue sample will be received at the International Space Station for further research. Crew members aboard the ISS have said that research on commercial regenerative tissue could play a key role in the station's future. Not included in the statistics for those on the organ transplant waiting list are those that are ill, but don't qualify for a transplant; regenerative medicine could potentially enable physicians to treat sick organs with 3D printed tissue patches. For applications in settlements, the ISS will continue to be at the center of research for the challenges people will face when they establish a long-term presence in space. ■

Astronaut Reid Wiseman exercising aboard the ISS
Credit: NASA

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DEFENDING EARTH

THE LONG, CHALLENGING JOURNEY OF THE DOUBLE ASTEROID REDIRECTION TEST

In the 1998 film *Armageddon*, oil drillers head to an asteroid the size of Texas to rig and detonate a nuclear device to save everyone on Earth as the exploded remains pass by harmlessly. The thriller *Deep Impact*, made the same year, concerns a similar scenario in which a nuclear warhead is dispatched to a comet heading toward the planet. Both movies were successful, but neither was particularly accurate in its portrayal of protecting people from dangerous deep space objects.

Specifically, nuclear warheads aren't regarded as the best tool for staving off such an event—it's also against international law to use nuclear weapons, or any devices of mass destruction, in space. Given this, how could humanity prevent a cataclysmic disaster like the one that caused the extinction-level event that killed off the dinosaurs 66 million years ago? This year, a project developed by NASA's Planetary Defense Coordination Office and Johns Hopkins University's Applied Physics Laboratory will test one option, the diverting of an asteroid's trajectory.

In late 2022, the Double Asteroid Redirection Test (DART) will slam into a near-Earth object (NEO) in an attempt to nudge it off its original trajectory. The asteroid and its moonlet are the ideal candidates for this initial planetary defense experiment, though they aren't on a path to collide with Earth anytime soon.

JORDAN STRICKLER

Illustration of the DART spacecraft under final acceleration toward a fatal meeting with Dimorphos
Credit: NASA

The twin asteroid Didymos (Greek for "twin") is in the crosshairs. The larger of the two bodies has a diameter of a half-mile (780 meters). A smaller moonlet asteroid, Dimorphos, which is 525 feet (160 mters) across, is the actual target of the DART spacecraft, and orbits the larger asteroid.

So why aim for the asteroid's moonlet and not the asteroid itself? "If you visit a binary asteroid and hit the moonlet, measuring the speed change of that impact is much easier," said Andy Rivkin, DART Investigation Team Lead with the Johns Hopkins University Applied Physics Laboratory.

The Didymos system is an eclipsing binary as viewed from Earth, which means that Dimorphos passes in front of and behind Didymos as it orbits the larger asteroid. Since there is no second craft to assess the impact (the European Space Agency had planned one, but the program was ultimately cancelled), measurements must be taken from Earth-bound telescopes looking at the variation in brightness as the moon orbits its host.

The measurements will reveal the change in the orbit of Dimorphos by comparison to measurements made prior to impact. The timing of DART's impact was chosen to minimize the distance between Earth and Didymos in order to facilitate the highest quality telescopic observations. Didymos will be roughly 6.8 million miles (11 million

While DART has a mass of only about 1300 pounds (590 kilograms), it should be enough to cause a shift in Dimorphos' orbit
Credit: NASA

kilometers) from Earth at the time of impact, and telescopes across the globe will be able to contribute to the global international observing campaign to determine the effect of DART's impact.

Near the end of its journey, the DART spacecraft will achieve the kinetic impact deflection by pancaking itself into the moonlet at a speed of 15,000 miles per hour (24,140 kilometers per hour), with the resulting impact energy of three tons of TNT. If all goes as planned, the collision will alter the velocity of the moonlet in its orbit around the main body by a fraction of one percent, changing the orbital period by several minutes.

Observations from Earth will help researchers assess the kinetic impactor strategy of asteroid deflection. While DART's impact will only have a small effect on the orbit of Dimorphos, larger impactors deployed while an asteroid is sufficiently far away from the planet could impart enough deflection to avert disaster in the future.

DART is small by satellite standards, about a yard (0.9 meters) across and 40 feet (12.2 meters) across after its two solar arrays are deployed. The ROSA (Roll Out Solar Arrays) solar panels provide power for DART's electric propulsion, the NASA Evolutionary Xenon Thruster-Commercial (NEXT-C) solar electric propulsion system, which features improved performance and fuel efficiency compared to its predecessors. Although NEXT-C is not the primary propulsion system on DART, its inclusion on the mission will allow for in-flight testing and demonstrate the potential for application to future deep-space missions.

However, the main show will be the impact into Dimorphos. "People have been wanting to test an impact technique for 20 years," said Rivkin. "With the Didymos system, we've got that perfect opportunity. There's thousands and thousands of near-Earth objects, but how many of them are binaries? How many of them have this line of sight where we can view the measurements we perform? How many of them have moons that are small enough that we can evaluate the speed change with the spacecraft we have? When we take all of those things into account, the Didymos system is really the only choice."

For final-stage guidance, navigation, and control, DART's creators developed algorithms called SMART Nav (Small-body Maneuvering Autonomous Real Time Navigation). This autonomous optical navigation system will identify and distinguish between the two bodies, and then direct the spacecraft toward the smaller Dimorphos during its final hour of flight. SMART Nav borrows from decades of missile guidance algorithms developed at Johns Hopkins University's Applied Physics Laboratory, and uses older technology—

its microprocessor is about the same vintage as a Playstation from 20 years ago. As it turns out, older (and larger) microprocessors are more radiation-resistant than newer, smaller ones, and are that much better suited to spaceflight in radiation-rich environments. SMART Nav will guide DART autonomously during final approach.

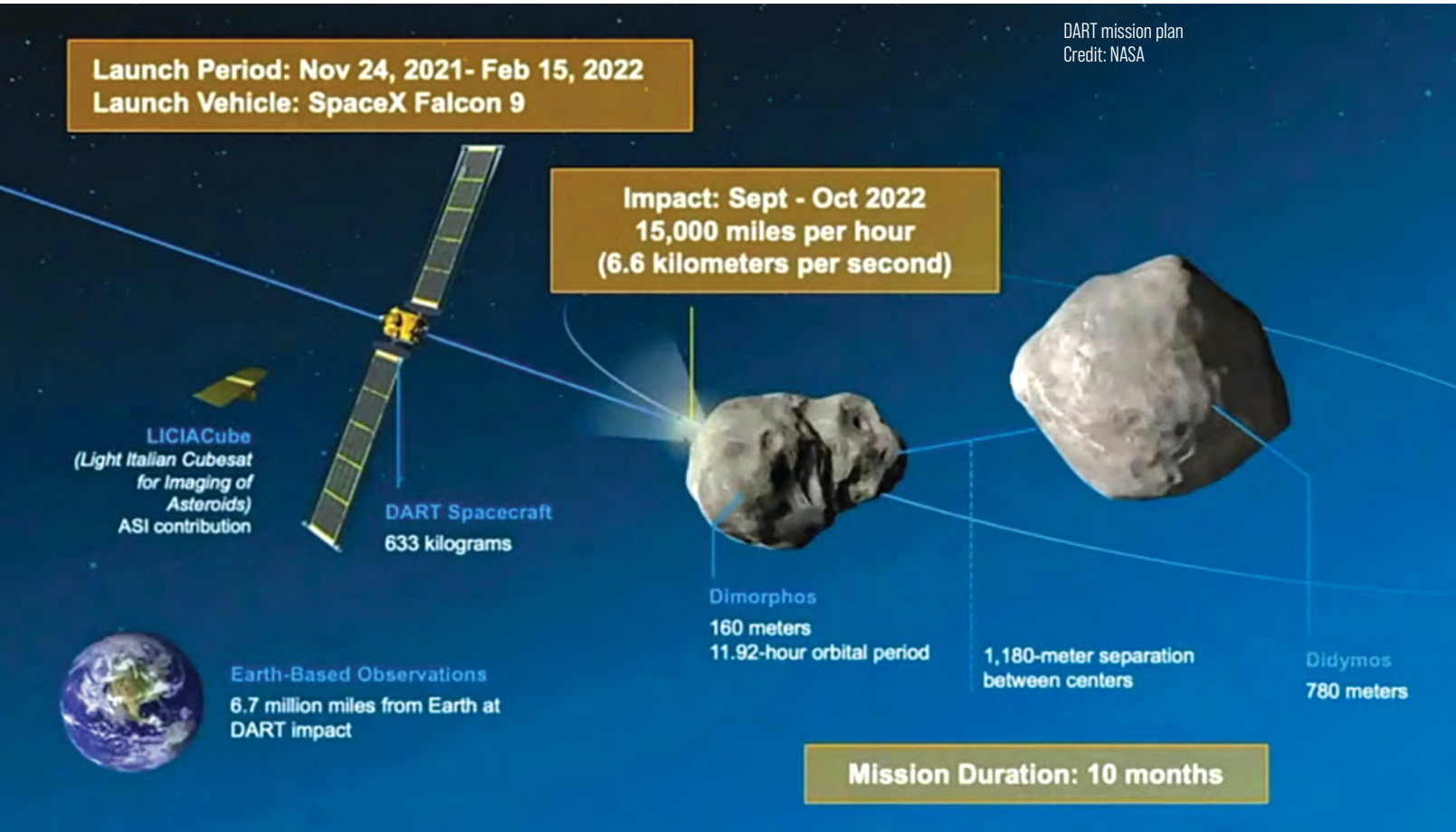
The probe's only instrument is a high-resolution camera (coined DRACO or Didymos Reconnaissance and Asteroid Camera for OpNav) based on camera systems used in both the New Horizons and Dawn missions.

Also along for the ride is the LICIACube (Light Italian CubeSat for Imaging of Asteroids) from the Italian Space Agency, which will be released from its mother craft roughly a week to 10 days prior to the impact to capture images of DART's final moments. Ejected particles and other aftereffects of the impact will be documented. LICIACube is comprised of two instruments: LEIA (LICIACube Explorer Imaging for Asteroids), a narrow field panchromatic camera to acquire images from long distance with a high spatial resolution, and LUKE (LICIACube Unit Key Explorer), a wide field Red Green Blue (RGB) camera, allowing a multicolor analysis.

DART has been developed in cooperation with the European Space Agency (ESA) in a project called the Asteroid Impact and Deflection Assessment. ESA's original contribution would have been called the Asteroid Impact Mission (AIM) and would have provided high-resolution visual, thermal, and radar mapping of Dimorphos in advance of DART's approach. AIM would have contributed detailed maps of the asteroids and an analysis of their physical properties. Unfortunately, the mission was cancelled in 2016 due to budgetary constraints when Germany ended up funding a project called ExoMars instead.

All real-time effects of the DART impact will now be monitored from ground-based telescopes and radar. While they'll be late to the party, ESA will still have a spacecraft headed for Didymos and its moonlet five years after DART's impact. Called Hera after the Greek goddess of marriage, the mission is expected to launch in 2024 and will see whether the impactor mission worked as planned from close-up. Hera will also investigate the asteroid's internal properties while simultaneously measuring the outcome of DART using high-resolution visual, laser, and radio science mapping.

"[Hera will] make measurements that DART will not be able to make because our business is so short," Rivkin said. "It will be able to investigate the crater that that DART makes in much more detail and deploy landers along with being able to make compositional measurements that DART will not. Both missions are independently doing a lot of great stuff. Together they're going to provide a really complete picture of the whole system. Not just



DART mission plan
Credit: NASA

validating the kinetic impact techniques, but also looking at the science of the system as a whole."

Hera will demonstrate several new technologies, including autonomous navigation around the asteroid, and will gather scientific data to help researchers and future mission planners better understand asteroid compositions and structures. It will also carry two CubeSats that will utilize radar to explore the interior of the moonlet as well as imaging and mass spectrometers to analyze its mineralogical and elemental makeup.

So, what happens to Dimorphos after the impact? A research team led by the University of Maryland's Harrison Agrusa created some models to find out, and the results were surprising. "It could start tumbling and enter a chaotic state," Agrusa told the *MIT Technology Review*. "This was really quite a big surprise," and the impact could create more tumbling than originally thought. This would complicate things for the Hera craft. The impact could send thousands of pieces of debris out into space, and other changes could occur a few days after the impact according to Agrusa's models.

Soon after impact, Dimorphos may begin to wobble. This shimmying may develop further until the momentum of the blast throws the rotation of Dimorphos off kilter. The moon then may start to spin along its long axis. Within a few days, the once stable satellite could start to swing wildly back and forth. Within weeks, Dimorphos could rotate so much that it begins a slow tumble. In some of the more extreme (and unlikely) results from the modeling, the tidal lock with its parent could separate completely. All of this chaos could create headaches for Hera's engineers when the probe arrives. Instead of landing on Dimorphos, the landers could end up facing a very challenging navigational problem. "Landing on such a small body is hard anyway," Patrick Michel told the *Technological Review*. Michel, from the French National Centre for Scientific Research, is one of the mission leads and a coauthor on Agrusa's paper. "But [this] doesn't make it easier."

This all points to the value of real-world experimentation in space—models are just mathematical assertions, and the actual results of the DART test could be less dramatic. "There could be an extra wobble put into Dimorphos' motion, but measuring that ... would provide opportunities for Hera to take data about the interior structure of Dimorphos that would be otherwise unavailable," comments Rivkin.

Some have theorized that punching Dimorphos could cause repercussions impacting Earth, but Rivkin doesn't think so. "Models don't show that," he said about the lack of a meteor maelstrom. "The prediction is that we might get one or two extra meteors years after the impact. So, while I think it would be cool to be able to look up in the sky and say 'yeah, we did that,' and there might be a slight rain of particles over the decades, it isn't actually going to be anything that is dangerous."

Dart is powered by NASA's NEXT ion-electric thruster
Credit: NASA

While asteroid surveys suggest that no bodies larger than 450 feet (137 meters) have a significant chance to hit Earth for the next 100 years, less than half of the estimated 25,000 near-Earth objects have to date been charted by NASA; more motivation for programs like DART to proceed with all due haste. ■

Astronaut Al Travels to the Moon

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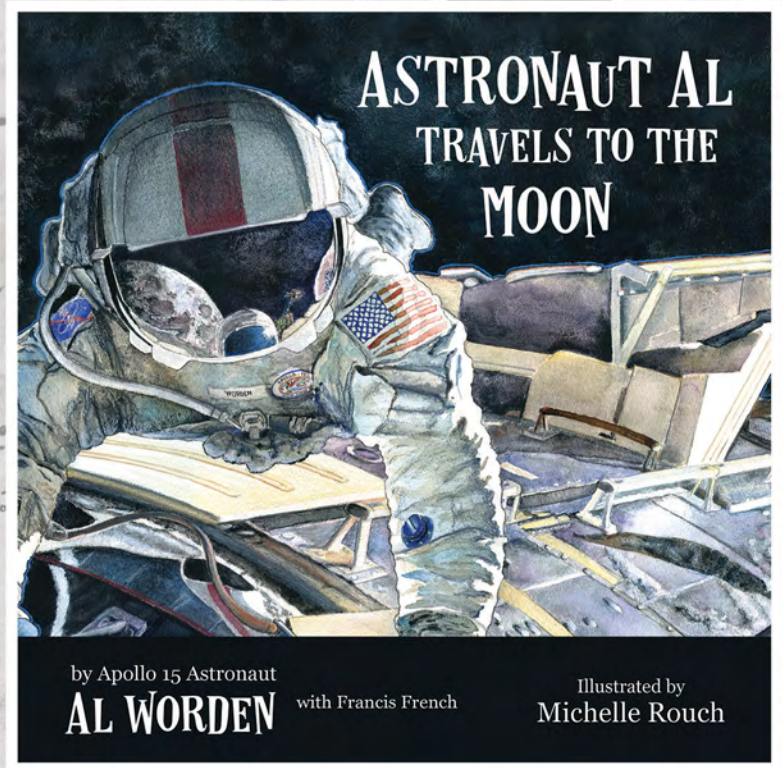

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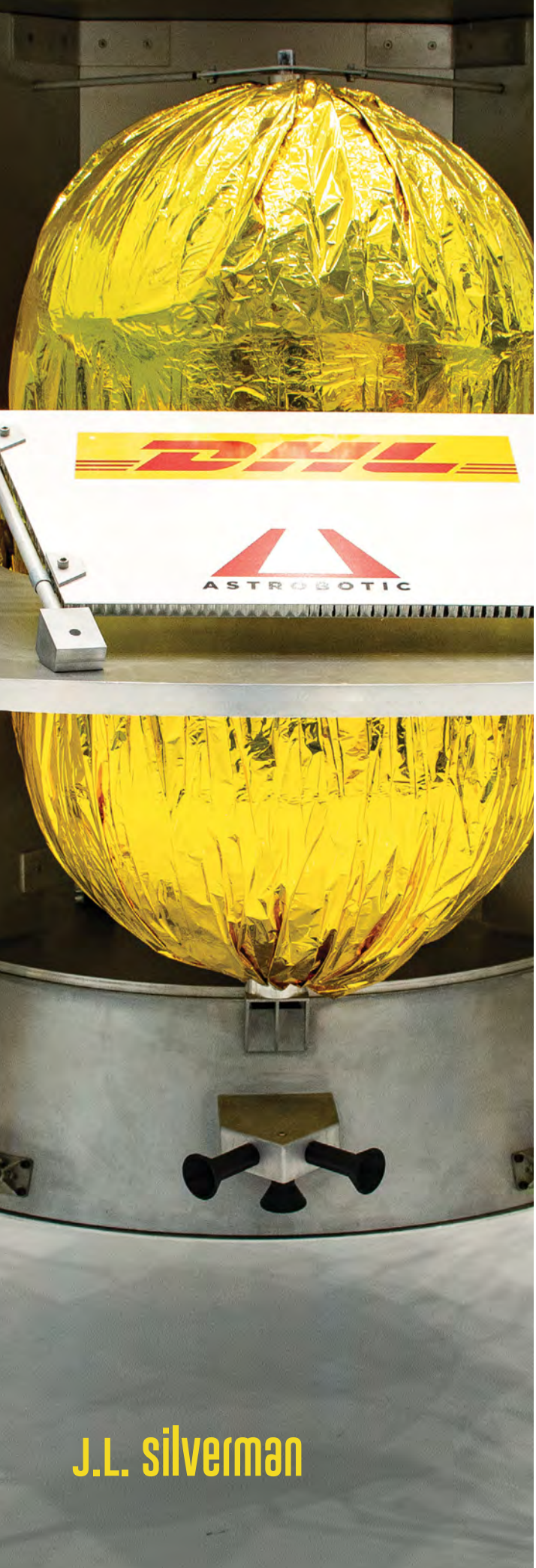

Astrobotic's Peregrine lunar lander
Credit: Astrobotic

J.L. Silverman

When you last sent a package, international options may have seemed the farthest destinations your service offered. But more distant options may soon be available, as NASA hopes to create marketable commercial services to a previously unlikely goal, the Moon, and the private company Astrobotic Technology is leading the way.

Thirteen years ago, a lunar delivery market didn't even exist. John Thornton, the company's CEO, refers to Astrobotic as a "13-year overnight success" inspired by a challenge issued from Carnegie Mellon University professor Red Whittaker In 2007, when Whittaker founded a team to compete in the inaugural Google Lunar XPrize competition. The prize would go to the first commercial team to land a craft on the Moon, drive 1,640 feet (500 meters) across the surface, and send back still images and video to Earth. The prize remains unclaimed, but the competition spawned the now-thriving Astrobotic Technology, which has grown to occupy a 47,000 square foot (4,366.4 square meter) facility in Pittsburgh, the largest private lunar logistics facility to date.

A turning point was reached upon NASA's selection of Astrobotic Technology in May 2019 to deliver payloads to the Moon with a contract of $79.5 million. The following year, NASA purchased a $200-million-package for lunar surface deliveries under the Commercial Lunar Payload Services (CLPS) program. Astrobotic Technology had prior contracts with both NASA and commercial technology companies, but this would be the first time since the Apollo missions that American payloads aimed to reach the lunar surface. The company's lunar lander, Peregrine, will perform the delivery.

The uncrewed Peregrine is being assembled entirely in-house. Five main engines execute the major maneuvers of the spacecraft, and four landing legs absorb the shock of touchdown on the rocky lunar surface. A technology demonstration of a new

Astrobotic's Cube Rover, a tiny machine that could easily travel to the Moon aboard the Peregrine lander
Credit: Astrobotic

imaging-based terrain navigation system, called OPAL (Optical Precision Autonomous Landing), will be tested on the first mission. The OPAL system, designed by an Astobotic-led team including Moog Space and Defense, NASA's Jet Propulsion Laboratory, and NASA's Johnson Space Center, aims to dramatically improve landing accuracy using techniques similar to the critical event data collected by NASA's Perseverance rover as it maneuvered to a safe Martian landing in 2020. Future missions will use this technology to target landing ellipses based on a client's desired landing site.

The first Peregrine is planned to launch aboard a United Launch Alliance Vulcan rocket in 2020. As the launch phase enters a highly elliptical Earth orbit, Peregrine will separate from the vehicle and start the cruise phase toward the Moon. Just over a month later, it will enter lunar orbit, deploy its orbital payloads, and touch down on the lunar surface.

Potential customer interests include Earth observation, monitoring space weather in real-time, examining the Apollo spacecraft to determine the long-term effects of the lunar environment on materials, lunar settlement research, and other activities and experiments. The company intends to make the Moon accessible to the world, and invites private companies, universities, or anyone interested in investing in space exploration the opportunity to use their lunar delivery service.

The first mission of Astrobotic Technology will deliver and operate science instruments for NASA, but other payloads from non-NASA customers from around the world are also tagging along. Mexico will field a lunar payload for the first time, and other lunar rookies are in the queue. Thornton says the goal of the company is to make the Moon accessible in a way that ushers in a new era of exploration and science, flying on routine schedules and at affordable prices. The first landing will carry smaller private payloads from advertising companies and private clients. For future payloads, the Astrobotic website advertises "MoonBoxes" in which clients can send items specific to categories indicated, such as brand promotion, arts and education, data, and even personal keepsakes. The Moonbox is made in partnership with the traditional delivery company DHL, and contains 28 capsules that have already been filled for the 2022 landing.

Moonbox customers will have access to end-to-end tracking similar to what DHL offers for terrestrial deliveries but through telecommands transmitted from the lander to Astrobotic Technology's Mission Control Center. Astrobotic Technology customers will receive comprehensive support from contract signature to mission completion, receiving updates as the mission progresses through launch, spacecraft deployment, lunar orbit insertion, and landing.

After the first commercial mission lands on the Lacus Mortis basaltic plain, a regular cadence of routine deliveries to the Moon will prime larger infrastructure on the Moon. Thornton has recognized the Moon as "the place where we'll learn to extract fuel, and grow food, and do all the basic things that help us break the tether of reliance on Earth." He believes that learning to live on a planetary body other than Earth begins with the Moon.

First, however, Astrobotic Technology will work to reduce the cost of delivering lunar cargo through a private-public partnership with NASA. When the space agency created the Commercial Lunar Payload Services program, it inspired competition between private companies, and the contractors, not NASA, are expected to provide what is needed to safely integrate and transport NASA payloads. All the resources are the responsibility of the contractors, who also assume the risk. It's a new way of doing business in spaceflight.

When the Peregrine lander settles on the lunar surface—hopefully in 2022—a new era of space payload delivery will have begun, and where Astrobotic Technology goes, others will likely follow. Innovative new experiments and observations will become routine occurrences. Precursor activities for benefiting human habitations off-Earth may thrive, and the use of valuable technologies could be a return investment for life back home. The lunar gold rush is on. ■

Astrobotic's Peregrine lander is expected to arrive at the Moon in late 2022
Credit: NASA

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MY QUEST TO TRANSFORM NASA AND LAUNCH A NEW SPACE AGE

EXCERPT FROM CHAPTER ONE: GAME CHANGER, PROVIDED FOR PUBLICATION IN *AD ASTRA* MAGAZINE, IN ADVANCE OF JUNE 7, 2022 PUBLICATION DATE

lori garver

I was a straight-A student in high school, and aptitude tests predicted engineering and science careers for me. There were six of us in my grade who had completed all the math available before our senior year of high school. When we returned from summer break, I discovered that the school administrators had registered the other five—all boys—in a calculus class at the local university. I hadn't been contacted about taking the course with them, and when my parents asked why, they were told it hadn't occurred to them that a girl would want to take calculus. My mom was particularly upset about this, but I was just as happy to add another elective to my schedule and was relieved I wouldn't have to commute to take the class with the geeky boys. But not taking calculus in high school channeled me into the social sciences in college, and like many girls my age, I didn't take much of a direct interest in space until NASA sent an astronaut there who looked like me.

That was the year, 1983, when I graduated from Colorado College and started my first full-time job working on John Glenn's presidential campaign. It is often assumed that I came to Washington, DC, to work for John Glenn because he was an astronaut. I haven't always corrected that assumption as I am aware that it fits into a nice narrative for my own mythology. The reality of my first post-college job was more pragmatic. I was disillusioned with the current national political leadership and wanted to help someone get elected who I thought would be better. More than a year before the election, as I was making post-graduation plans, John Glenn was the only Democrat in the field running ahead of President Reagan in the polls.

Not only is politics in my blood, but I've been campaigning since before I could walk. In addition to farming, my grandfather and uncle, both Republicans, had been in the Michigan state legislature for a combined forty years. My sister and me were featured on campaign brochures, and when I was a baby, my grandpa carried me while shaking hands in local parades. When the state legislature was in session, my grandpa let me join him on the House floor during school visits to the Capitol, and the experience left an indelible positive memory. My formative role models were public servants dedicated to helping their neighbors. Doing something similar became my aspirational goal.

By '83, I'd worked on a lot of political campaigns but never anything like a national election, and I found the experience invigorating. I eventually worked my way up to become a scheduler and spent long hours in a bullpen of desks adorned with overflowing ashtrays and large, constantly ringing phones with long, spiral cords attached to the receivers. I fell in love with the campaign and with my soon-to-be husband Dave Brandt, a recent Kent State graduate who worked in Glenn's press office.

John Glenn was the first astronaut to leave NASA, less than two years after his solo flight, and avoided serving on space-related committees as a senator. He wanted to be known for more than his three-orbit, five-hour spaceflight. But when *The Right Stuff*, the film based on Tom Wolfe's book—was released in theaters during the campaign, he agreed to exploit his spaceflight as a differentiator. It didn't pan out as he planned. Glenn was portrayed as a do-good outsider among the other Mercury astronauts, and some thought the movie did more harm than good.

When Super Tuesday results came in from thirteen states in March of 1984, after outspending the others, Senator Glenn didn't win a single state. A political cartoon ran the following day that caricatured Gary Hart saying, "I'm New," Walter Mondale saying, "I'm Ready," and John Glenn saying, "I'm History."

I hadn't gotten to know the Senator extremely well, but he was a politician, so he always pretended to remember me when he called or visited the office. My career led me to work with him several more times, both at NASA and advising other presidential candidates. My early campaign association with him provided a positive foundation for our continued professional relationship, even though his policy views were more traditional than my own.

With the campaign abruptly ending, senior staff looked out for more junior employees and helped me get an entry-level job at a nonprofit membership organization called the National Space Institute. Wernher von Braun, known as the father of the Moon program, founded the association with aerospace industry funding in 1974, frustrated by the lack of public and political support for NASA after Apollo. Von Braun had died in 1977, but my new boss, Executive Director Dr. Glen Wilson, had known him

Garver meets with Elon Musk
Credit: Lori Garver

since his career began as a legislative clerk for Senator Lyndon Johnson. Dr. Wilson planned to retire soon and spent his mornings reading the newspaper and his afternoons sharing stories about his memories of von Braun and the early days of the space program, including what led to NASA's formation.

Before Dr. Wilson's retirement, the National Space Institute merged with another space advocacy organization, the L5 Society, and changed its name to the National Space Society. In stark contrast to NSI's topdown, industry-supported beginnings, the L5 Society was founded by a group of followers of Gerard O'Neill, a physics professor at Princeton University who had, among other things, developed a concept of free-floating, self-sustaining space colonies. The society's name came from Lagrangian points in the Earth-Moon system proposed as locations for the huge rotating space habitats that O'Neill envisioned.

NSI had focused on advocating for whatever programs NASA put forward, but the L5ers were activists who wanted to move the program toward more sustainable space development. The shorthand version is that von Braunians are explorers, drawn to space activities for the daring challenge, and O'Neillians are exploiters, drawn to space for economic expansion and human settlement. In addition to differences in what they supported, they differed on how they went about doing it. NSI had a top-down traditional approach, while the L5ers were activists willing to challenge the status quo. This was my first introduction to the group I refer to here as space pirates.

Similar to pirates on the high seas, space pirates have been depicted as both heroes and villains. The recurring villains in the 1930s Buck Rogers comic strip were called space pirates, but early science fiction authors used the term to refer to heroes mining asteroids and collecting other bounty on space trade routes of the future. More familiar references include *Star Wars*' Han Solo as well as Mark Watney, the character in the book and subsequent film *The Martian* by Andy Weir, who refers to himself as the first space pirate as he takes possession of a spaceship parked on Mars in "international waters," without permission of NASA, to survive on Mars. In 2019, after Senator Ted Cruz justified the Trump administration's new Space Force by claiming that just as pirates threaten the open seas, the same thing is possible in space, Elon Musk tweeted a picture of the pirate's signature flag with skull and crossbones.

As with any group, the space pirates are unique individuals who share some common characteristics and views. Many of them have spent decades working to create a spacefaring civilization at great personal cost. They have advanced important policies and legislation, kept the United States from signing treaties that would have blocked space development

Garver watches SpaceX Falcon 9 rocket launch in 2013 from Kennedy Space Center
Credit: NASA/Bill Ingalls

started new companies and organizations, lobbied members of Congress, antagonized senior aerospace industry leaders, and often been ignored and marginalized by the established space community. These are the people who raised me—my original space family.

When the Space Shuttle program was announced in 1972, President Nixon said it would be "an entirely new type of space transportation system designed to help transform the space frontier of the 1970s into familiar territory, easily accessible for human endeavor in the 1980s and '90s." He said, "It will revolutionize transportation into near space, by routinizing it. It will take the astronomical costs out of astronautics." NASA's initial estimated $6 billion development cost quadrupled and by the mid-1980s it was obvious to anyone paying attention that it was never going to deliver on its stated promise.

The space pirates saw early that the biggest obstacle to space development was the lack of affordable, reliable access to space. They believed the Space Shuttle was impeding progress. To some this made the space pirates heroes and to others villains. One of the initial ways they advanced their objective was to devise the 1984 Commercial Space Launch Incentives Act, which was enacted to support acquiring more innovative equipment and services offered by the private sector. I viewed this as an extremely logical concept, without questioning why it was left to a small nonprofit advocacy organization to champion instead of the nation's space agency. I didn't yet realize what the space pirates already

I didn't yet realize what the space pirates already knew, that the traditional aerospace community cared more about increasing the size of their slice of NASA's budget pie than lowering costs to create a sustainable program.

Like most others, I still held NASA on a pedestal. My National Space Society office was across the street from NASA's DC Headquarters. My colleagues and I frequented the local bar, where we got to know astronauts and agency leaders. I immersed myself in all things NASA and even played on their softball team. The Shuttle program succeeded in exciting the public initially, and as I got to know astronauts who weren't all white men from the military, I sensed we were nearing a new space age. NSS developed membership tours and public education activities focused on the popular new space plane, and I jumped at the chance to be involved.

I was leading a tour in Florida when Columbia launched mission 61-C on January 12, 1986. This was the mission's fifth launch attempt, and I had been corralling tour groups for all four delays, starting the previous December. Technical and weather issues had been plaguing the program, and after five years, this was only its 24th mission. NASA was anxious to prove they could increase the launch rate as advertised, and in an attempt to demonstrate the system was safe and routine, had begun flying non-professional astronauts on the Shuttle. As part of that effort, Florida Congressman Bill Nelson was a member of the crew that morning, along with rookie pilot Charlie Bolden. Never in my wildest imagination could I have envisioned how the bond they developed on that flight would impact the space program and my own career. As an indicator of NASA's intent to pick up the pace, a second shuttle— the Challenger—was already sitting on the adjacent launchpad. As Columbia finally lit the candle, the next mission was scheduled to launch two weeks later.

I was thrilled to be back in the Florida sunshine leading another launch tour for the Challenger mission, set to take off on January 27. I waited with my tour group at the viewing site four miles away, answering their questions about NASA and the Shuttle program as morning turned into afternoon. The technicians closing the hatch had trouble removing the handle from the vehicle's door, and after trying to unstick the handle manually for a while, they requested power tools to help with the removal. Pad technicians went to retrieve battery-operated drills and cutting blades, only to find them drained of power once they got to the top of the gantry. Next, they decided to cut the handle with a hacksaw, and they called for another delivery. Again, a maintenance worker ran from the service building and took the elevator up to the gantry where the team finally just sawed off the handle. By now, a weather front had blown in and the winds exceeded the launch threshold. The hours long comedy of errors left no time for the storm to blow through, so the launch window expired, and the seven astronauts were escorted out of the vehicle.

Garver poses with her offical portrait, 2014
Credit: NASA

Increasing public interest and proving the Shuttle was safe and routine wasn't just about flying members of congress; NASA started a program to fly average citizens, beginning with the Teacher in Space. The first teacher—Christa McAuliffe—was a member of the Challenger crew, which made the day's troubles even more publicly embarrassing. I had met Christa and several other crew members at events in Washington and imagined they were as frustrated as anyone by the confounding delay.

As we were leaving the viewing site, I asked the NASA volunteer assigned to our bus whether or not he thought they would try to launch the next day. The twenty-something-engineer casually responded that the weather forecast indicated it would be too cold for a launch the following morning. With that information, I took a late flight back to DC. I was in my apartment getting ready to head into the office when I saw the countdown had begun for another launch attempt.

A cold front had indeed rolled into Cape Canaveral overnight and cameras were showing photos of ice on the vehicle and tank throughout the fuel's loading. It didn't appear to be a problem, since they proceeded with the countdown. I was disappointed to miss what was always a thrilling experience in person and a bit irritated at being told bad information about a potential weather problem. Disappointment turned to disbelief when the Shuttle's contrail exploded into a fireball 73 seconds into the flight.

NASA Administrator Charlie Bolden and Deputy Administrator Lori Garver at their Senate confirmation hearing in July 2009
Credit: NASA/Bill Ingalls

The Challenger broke apart as the astronauts' families and loved ones attending the launch searched the empty Florida sky and millions of school children watched on television. NASA's first in-flight astronaut fatalities were on a vehicle that had promised cheap, routine space transportation and was deemed to be safe and reliable.

Later, when Sally Ride and others zeroed in on the temperature being the problem that caused the hot gasses to escape from the solid rocket motor, the world learned that NASA managers and contractors who were in charge had overridden vehement objections from engineering and waived the established temperature rules. Like many others, I was astonished and disheartened that NASA and industry leaders had been so reckless with the nation's precious assets—the lives of the crew and the future of human spaceflight.

The Challenger accident was a determinative event for space development. In order to justify the government's large investment in the program, US policy had directed nearly all its satellites to be launched by the Shuttle, which had extinguished the competition. The disaster not only killed seven astronauts, it grounded scores of national security, civil and commercial satellites. The accident led to a new policy that directed the Shuttle be used exclusively for missions that required the presence of astronauts and the government started transitioning ownership of the existing expendable rockets to the private sector. After nearly a three-year hiatus, the Shuttle returned to flight with a more insular mission.

President Reagan had initiated a program called Space Station Freedom in 1984, designed to be NASA's central purpose for the Space Shuttle. It was billed as "The Next Logical Step." Without a destination, the Shuttle limited human spaceflight to week-long missions, so developing a station was critical to learning how to live and work in space for longer periods of time. Not coincidentally, having a space station helped justify continued operations of the Shuttle. There wasn't much of a debate about whether to continue with the Shuttle after Challenger, but without a space station program on the drawing board, that might have been a different story.

The Space Station's goals—outlined by President Reagan's introductory speech for the program—were for scientific advancement and commerce. Reagan predicted the "space station will permit quantum leaps in our research in science, communications, and in metals and lifesaving medicines which could be manufactured only in space." He said, "Just as the oceans opened up a new world for clipper ships and Yankee traders, space holds enormous potential for commerce today." By the time I returned to work at NASA twenty-five years and more than $100 billion later, achieving these goals had remained elusive.

The 1986 Shuttle accident was also determinative in my own career. Like it did with others, the tragedy caused me to question what NASA was doing and to what end. NSS was one of the few non-government space organizations in those days, and we were called upon to provide expertise and to field media requests. I was immediately thrown into the deep end of the pool, appearing as a guest on DC's local NPR station theevening of the accident. When I didn't drown, I received more requests to serve as a public space analyst and spokesperson.

I enjoyed highlighting the many innovative industries and unique scientific information that had been gained from our space endeavors. There was a general appreciation for how NASA's

early investments helped drive instantaneous global communications, the miniaturization of electronics, aeronautical advances, and knowledge about our own planet that couldn't be obtained from the ground. Questions about what NASA had been doing since Apollo, revealed a disconnect with the public over the purpose of government spending for human spaceflight. Public concerns centered on what we'd achieved since beating the Soviets to the Moon and at what cost.

I did my best to defend the program, espousing the usual rationales of international prestige and inspiration, but after the accident those justifications were wearing thin. I learned from my early experiences that defending the government's funding of human spaceflight in media interviews often required deftly avoiding landmines. I was determined to give honest and meaningful answers to what I was being asked, and dug more deeply into the issues.

NASA's justification of ancillary products referred to as "spin-offs," often seemed specious. If the government wanted to seed innovations like memory foam or cordless power tools, there were better ways to go about it then spending billions of tax dollars sending astronauts to space. The economic argument was also a bit deceptive, since direct funding of government jobs slows rather than stimulates the economy if it doesn't stimulate new markets.

In my view, the primary long-term rationale is simple. Humanity's only chance for survival as a species is to expand beyond the confines of Earth. This is a multigenerational goal and isn't NASA's sole responsibility. But the space pirates were already coming up with ways to utilize resources in space that could help people both on and off Earth.

I was fascinated by a book by Frank White called *The Overview Effect* that described how astronauts' view from space transformed their perspective about Earth's environment and humanity's ability to live and work together on our home planet. Every astronaut I'd met had shared how seeing the thin line of the atmosphere and land masses without borders changed their world outlook. This was certainly special, but I recognized it wouldn't make much of a difference until it was experienced by many more people, from all backgrounds.

For me, the value of human spaceflight is in its ability to transform humanity and society. One of my favorite examples of this power is the photograph called Earthrise, taken by the Apollo 8 astronauts from behind the Moon. The photo is one of the most famous of all time and is widely credited with starting the environmental movement. Robotic spacecraft had taken photos of Earth from space before, but it took a person to see the beauty of that unique perspective. Knowing it was the first time humans had seen the view with their own eyes gave the photograph more meaning to the rest of us.

I developed a reputation as a thoughtful and clear communicator about the space program and began to realize there might be a consequential role for me in the field. Assuring future space activities fulfilled their full potential

Garver addressing an audience at Seattle's Museum of Flight in 2011
Credit: Lori Garver

to make a positive impact on society became my mission. I'd been planning to go to grad school to get an MBA or law degree, but I decided instead to pursue an advanced degree more directly aligned with my newfound goal and passion.

George Washington University offered a Master's program in International Science and Technology Policy, with a focus on space policy, and I attended night school while continuing to work full-time. The curriculum focused on history, and I enjoyed learning how lessons from the past could be adjusted to advance more effective policies and capitalize on the vantage of space. It sometimes bothered me that what drew me to the space program was different from what attracted nearly everyone else in the aerospace world. Instead of allowing myself to feel like a square peg in a round hole, I tried to think of ways I could connect the gears. I wanted to fill a missing piece of the puzzle to help the brilliant engineers and scientists solve the mysteries of the universe and advance civilization.

The Challenger accident was a game-changer that shook everyone involved in the space program to their core. NASA's ill-fated decisions exposed both poor management and technical failures that had been ignored by its renowned safety and engineering leadership. Less obvious at the time was how that cold day began the shift toward policies that would eventually allow the private sector to enter the arena in more significant ways. Whether it was fate or failure that kept me from taking calculus and pursuing engineering, as it turned out, studying policy and economics gave me a unique perspective that underpinned my career for the next thirty-five years. ■

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SPACE PLACES_
A NEW HOME FOR SPACEFLIGHT
Vandenberg Space Force Base
Mark Armstrong

A Delta IV Heavy departs Vandenberg
Credit: United Launch Alliance

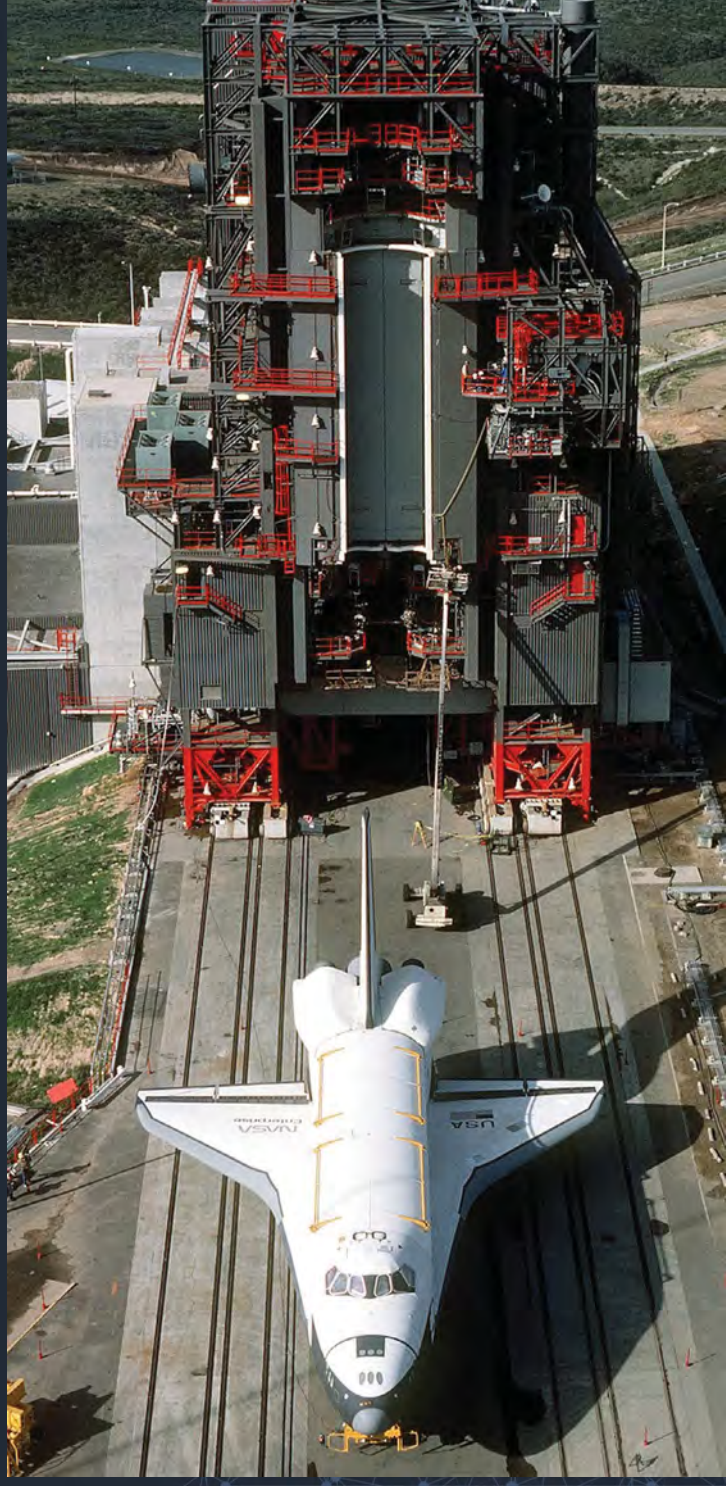
Visitors to Vandenberg Space Force Base on the central California coast see the new signs long before they turn off coastal Highway 1 and enter on the Avenue of the Flags, passing the flying banners of the allied spacefaring nations and the 50 state flags, before encountering a ballistic missile on display and the greeting: Welcome to Space Country.

Along the way, they may pass deer, coyotes, and other reminders of the untamed nature surrounding the base. Spanning 99,000 acres, about 1,000 of which are devoted to housing and support operations like the commissary, the post office, and other support facilities, the launch complexes are widely scattered and remote, some along rocky ridges decorated centuries ago by Chumash Indian petroglyphs. Security forces patrol the far reaches and canyons of the base on horseback or with ATVs.

Vandenberg Space Force Base is a destination for space tourists. The post exchange has a steady of stream of visitors picking up T-shirts and sweaters with the Space Force insignia, some adorned with the motto Semper Supra or displaying the caption "Eat–Sleep–Launch–Repeat." Wine glasses and beer steins with the Space Force emblem sell briskly. The local newspaper, the *Lompoc Record*, recently displayed a large photo of SpaceX's NROL-87 launch along with one of a young couple toasting the launch with champagne. Successful launches are routine and a source of great local pride, as seen in the space-themed murals in the nearby city of Lompoc. Launches are often visible up and down the California coast for hundreds of miles.

The base's coastline stretches over 20 miles (32.2 kilometers), encompassing the boat ramp where barges bring some of the rocket boosters to shore, and extends north toward the Reagan Memorial Viewing Site and the ICBM launching facilities near Point Sal, not far from Santa Maria.

The property was destined to be the west coast training ground for troops during World War II and the Korean War, and later the site of vital national security launches, both orbital and ballistic. The Army originally identified the site in 1941, citing the area's undeveloped mesa and rolling landscape as desired characteristics. It was initially named Camp Cook in honor of the Civil War-era officer who stayed loyal to the Union and led the first military expedition west to California. During World War II, seven armor and infantry divisions and over 400 other units trained there before heading overseas. In June 1943, the post hosted over 35,000 troops, and other units were based there during the Korean War. In 1956, as the Space Age approached, the U.S. government considered numerous sites for strategic missile testing and rocket launch. Camp Cook stood out once again for its unique geography and location—it could launch missiles west across the Pacific, and also due south into polar or sun-synchronous orbits, without threatening populated areas.



The shuttle test item Enterprise at Vandenberg. The shuttle program was intended to launch military payloads from the base.
Credit: USAF

This combination has made Vandenberg Space Force Base what it is today, a vital facility for U.S. national security and other programs, like those of the National Oceanographic and Atmospheric Administration (NOAA), that rely on polar orbiting spacecraft to carry out their missions.

The facility took on this new role in 1957, when it was transferred to the Air Force and the Navy for missile testing, and was soon re-named in honor of Air Force General Hoyt Vandenberg. A rapid succession of firsts accrued as the Cold War and the Space Race provided urgency to the base's

operations. America's first successful ballistic missile test occurred on December 16, 1958; the first U.S. satellite to enter a polar orbit launched on February 28, 1959; and the first launch of a GPS satellite was on February 22, 1978.

Between 1958 and 1966, Vandenberg Space Force Base was the site of more than 650 launches. The list of ballistic missile tests includes the Thor, Titan, and Minuteman missiles, and finally the Peacekeeper ICBM, which was retired in 2004. The base's first orbital launch, Discoverer 1, occurred in 1959, and led to the first space payload returned to Earth when it was recovered from the Pacific. Just a few days later, another first was achieved when a returning payload was snared in midair. In 1995, the CIA was ordered to declassify information that revealed Discoverer was actually a cover story for CORONA, the first satellite photography reconnaissance program, which successfully captured images revealing the U.S.S.R.'s nuclear missile launch sites.

Although orbital operations continued through the years with successful launches of weather satellites, national security missions, and remote sensing payloads atop Atlas, Delta, and other boosters, two high profile missions undertaken at the base were ultimately cancelled. In 1965, President Lyndon Johnson announced the Air Force Manned Orbital Laboratory (MOL) program, which envisioned a payload combining a Gemini capsule with an orbital lab crewed by two Air Force astronauts for a 30-day mission, after which the crew would return to Earth in the capsule. As the program study continued, additional land was purchased at the south end of the base, and construction of a new complex was initiated. Behind the scenes, military planners selected the launch site so a polar orbit could be used, enabling overflight of the Soviet Union. The project, competing with increasingly sophisticated robotic spy satellites, was continuously starved of funding and cancelled in 1969.

The critical importance of Vandenberg Space Force Base's launch angle was highlighted again during the Reagan administration. Billions of dollars were authorized to prepare for the space shuttle to launch and land at the base to accommodate national security missions in polar orbits. The SLC-6 launch pad underwent extensive improvements; including a massive vehicle assembly building that would accommodate assembly of the shuttle on the launch pad, and then retract. The base's runway was also extended and strengthened to support shuttle landings, and roads and bridges were improved as necessary for transporting the shuttle and its booster elements. These efforts were halted after the loss of the shuttle Challenger in 1986,and the Western Range shuttle launch facility project was officially cancelled in 1989.

Today, SLC-6 is the site for launches of Delta and Atlas rockets by United Launch Alliance. Missions supporting the National Reconnaissance Office

A United Launch Alliance Delta IV Heavy inside the servicing structure
Credit: ULA

Titan ICBMs were routinely tested at Vandenberg during the Cold War.
Credit: USAF

Unwrapping the name change to Vandenberg Space Force Base
Credit: USAF

and the NOAA have continued successfully there since 2006. In late 2021, the newly-rechristened Vandenberg Space Force Base marked the successful launch of Landsat-9 with a celebration at the Pacific Coast Club of the 2,000th successful launch in the base's history.

SpaceX has its own history at the base, having begun preparations to launch from there in 2011. The first launch of a Falcon 9 rocket took place at SLC-4E in September 2013, with its payload, the Canadian CASSIOPE satellite, successfully placed in a polar orbit. SpaceX has also succeeded in returning numerous first stages of the Falcon 9 to a landing pad near SLC-4E. The resulting double sonic boom as the booster descends is a rare experience not heard since the space shuttle era. SpaceX continues an aggressive schedule of Starlink and other launches with a half dozen or more planned for 2022.

Vandenberg Space Force Base's resident commands and units are a good example of how confusing the U.S. military space effort can appear. The Department of Defense is divided into military departments and combatant commands. The Space Force was created in 2019 as a part of the Department of the Air Force, in the same way the Marines are a part of the Navy. Each of the departments—Army, Navy, and Air Force—provide trained personnel, units, and expertise to the combatant commands, each of which have different areas of responsibility. In this case, Space Force elements support the operations of U.S. Space Command (SPACECOM). The base is home to Space Force units like Space Launch Delta 30, which oversees all launch activities there, as well as the headquarters of Combined Forces Space Component Command, which oversees military space operations around the world. It can be a tangled org chart to decipher.

Among the subordinate units are those who ensure the safety of human space flight and monitor threats of potential collision to every payload in orbit. While Congress has planned for the Department of Commerce's Office of Space Traffic Management to eventually take responsibility for commercial space traffic safety, in the meantime the mission is quietly carried out here. The orbital data they collect is posted to space-track.org, and warnings of potential collisions are sent to every nation or commercial operator whose payload may be threatened.

As a result of the many units and missions supported by the base, the personnel there sport a wide variety of unit patches, featuring orbiting deltas, meteors, and eagles. Some conspicuously feature a tiger, harkening back to the 30th's roots as the 14th Air Force in World War II, the Flying Tigers of the China/Burma/India theater of operations. At the headquarters, a vintage P-40 fighter aircraft sits on a pedestal across from a statue honoring the service of 14th Air Force veterans.

Vandenberg Space Force Base is a unique location with a feel all to itself; one day basking in warm California sunshine, and the next buffeted by frigid winds. You may see a heron stalking squirrels or a coyote prowling for house cats. The days roll by in routine shift work, until thunder rolls across the mesas as another spacecraft heads to orbit. ■

For more information on visiting Vandenberg Space Force Base, contact the visitor's center at 805-606-7662, or online at vandenberg.spaceforce.mil.

A SpaceX Falcon 9 rocket prepares to lift off carrying the Iridium NEXT satellite from Space Launch Complex-4 at Vandenberg Air Force Base January 13, 2017
Credit: SpaceX

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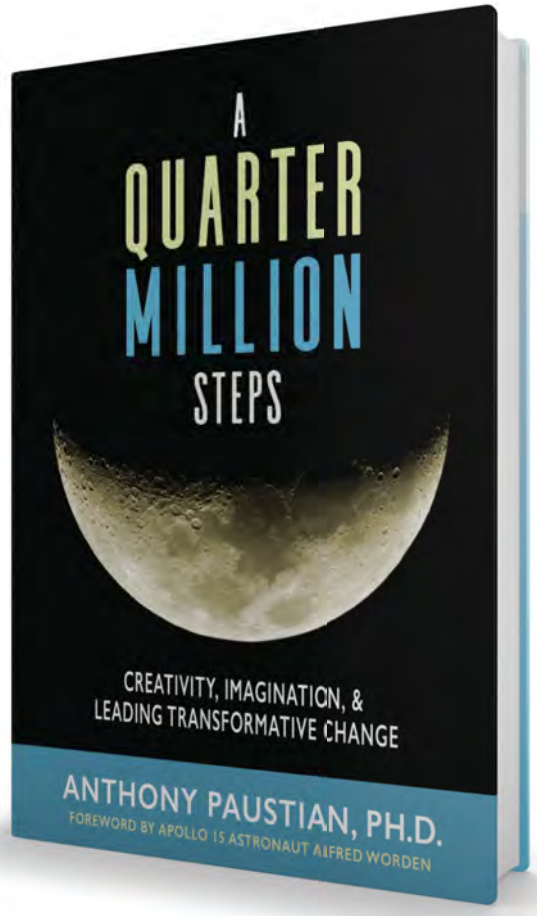

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PATHWAYS TO SPACE CAREERS FOR WOMEN

MELISSA SILVA

Valentina Tereshkova
Credit: RPM

"Hello, my darling," Valentina Tereshkova greeted the Vostok 6 spacecraft that would ultimately take her into orbit every day she encountered it. The Vostok was the Soviet Union's first crewed spacecraft, and Tereshkova was frequently posed next to it, standing tall and proud, a world unto themselves. The first woman in space, she has been succeeded by numerous female scientists and engineers determined to make their own way to the stars, both in space and on the ground in support of spaceflight. Their path, however, hasn't been easy.

Reports published by the United Nations on gender inequality in Science, Technology, Engineering, and Mathematics (STEM) fields reveal that women are still underrepresented in aviation and aerospace, averaging about 20 percent of those in the field, and that has remained largely unchanged for at least 30 years. Further studies reveal that there are significant gaps across the STEM fields themselves; in the United States, for example, a statistic published by the U.S. Bureau of Labor Statistics revealed that more women pursue careers in the biological sciences than mathematical, engineering, or architectural disciplines.

The data is hardly surprising to many. The struggle women face to be seen as equal to their male counterparts has been a recurring theme since the very beginning of human history. Gender stereotypes, male-dominated cultures, underrepresentation, and a lack of role models are oft-cited reasons that fewer women pursue education and careers in STEM fields, particularly aviation and aerospace.

The importance of gender diversity, and talent attraction and retention, has been noted as a point of focus to address the growing workforce shortages challenging the aerospace and defense industry. Successfully engaging young, college-aged women in STEM education has been a focal point for many programs hoping to find students that will join the aerospace workforce. Role models that can potentially serve as mentors have been identified as crucial pillars of these programs, which are often backed by organizations addressing talent retention

in hopes to revitalize the aging aerospace industry. According to some reports, the average employee in this field is aged 45 to 47, significantly higher compared to other fields and career paths. While NewSpace companies like SpaceX and Blue Origin claim to be addressing this challenge, there are reports that would seem to indicate otherwise.

There have been exceptions over the decades—Canadian Elizabeth MacGill is considered the world's first female chief aeronautical engineer. Women were employed by the National Advisory Committee for Aeronautics (NACA), which operated from 1915 until 1958, when it was dissolved and NASA was created, as computers, mathematicians, engineers, and supervisors. In fact, women have been in aviation before they had the right to vote.

Élisabeth Thible, rumored by historical accounts to have been a young opera singer, was the first passenger of a free-flying hot air balloon in 1784, the first flight of an untethered hot air balloon having just occurred a year prior. Thus began a long history of women who found non-traditional ways to enter a field that has been traditionally male dominated.

She was followed in the 19th century by Hélène Dutrieu, an unlikely champion of avionics. Dutrieu made her fame as a world champion track cyclist in Belgium, setting records and winning titles, and was eventually awarded the Cross of St. André for her accomplishments. She later became an automobile race driver and a stuntwoman. In the early 1900s, Dutrieu learned to fly and may have become the first female pilot to fly with a passenger in 1910, setting distance and altitude records early in her aviation career. She was known as the "Girl Hawk" and was celebrated in France for her success.

Lee Ya-Ching was a young girl watching an airshow in Paris when she decided she wanted to become China's first female aviator. She had already made a name for herself as a silent film actress when she relocated to England to continue her education. As she said in a 1943 interview, "When I was a tiny girl, I often listened to fairy tales at my grandmother's knee. One of them ... was the legend of a kind lady who flew through the clouds, helping the poor and the unfortunate ... I was back in China in 1931 after schooling in Europe, and I saw how ruthlessly Japan started her pattern of aggression. Then and there, I decided to do my bit for China ... and began studying the fascinating art of flying. I knew even then that someday I would be able to help my homeland with this knowledge of aviation."

Lee earned her pilot's license in 1933, at a time when women in China weren't allowed to drive automobiles. She attended the Boeing School of Aeronautics in Oakland, California, before returning to China in late 1935, where she had to be given special consideration to receive a pilot's license from the Chinese government. A number of firsts are attributed to Lee—she established

Astronaut Mae Jemison
Credit: NASA

the country's first civilian flying school and became the first Chinese woman to perform an aerobatic routine, which occurred before 15,000 spectators at a celebration of Chiang Kai-shek's 50th birthday in 1937 (Chiang was the president of the Republic of China at the time).

Later that year when the Sino-Japanese War broke out, Lee was grounded for the duration of the war despite her attempts to aid in the war effort as a combat pilot or a courier. Disheartened yet determined, she would conduct a wildly successful goodwill tour to raise funds for Chinese refugees, touring throughout the United States, Canada, the Caribbean, and Central and South America.

In 1963, toward the tail end of Nikita Khrushchev's leadership in the Soviet Union, Valentina Tereshkova became the first woman to fly in space, and the first—and only, to this day—woman to have conducted a solo space mission. Svetlana Savitskaya followed in Tereshkova's footsteps in 1982 and became the second woman in space, and in 1984, a year after Sally Ride became the first American woman in space, Savitskaya became the first woman to not only return to space, but the first to perform a spacewalk.

Valentina Ponomaryova, the second backup for Tereshkova, was trained to be the commander of the first all-women mission, which was canceled due to shifts in the Soviet Union's space program. Female cosmonauts vying for a spot on the mission underwent rigorous academic tests and interviews, and while Ponomaryova reportedly had the best results, when interviewed she asserted that a woman could smoke and still be a decent person. The perturbed interviewers then asked what she wanted from life, and she replied, "I want to take everything it can offer." Tereshkova, on the other hand, replied, "I want to support irrevocably the Komsomol and Communist Party," was not known to be a smoker (which was viewed as unbecoming behavior for women), and was ultimately chosen for the Vostok 6 flight. Denied her spaceflight opportunity, Ponomaryova became a space historian and research scientist.

The 21st century has seen an influx of female talent in the aerospace industry. SpaceX, a giant in the private spaceflight sector, is led by CEO Elon Musk and president and COO Gwynne Shotwell. Jane Poynter, co-CEO of luxury space travel company Space Perspective, was also the co-founder and former CEO of World View Enterprises and one of eight people who participated in the controversial first Biosphere 2 mission, which lasted from September 1991 to September 1993. Poynter's space tourism company, Space Perspective, will ferry travelers to an altitude of 100,000 feet (30,480 meters) on a giant balloon for six hours, allowing passengers to enjoy 360-degree views while sipping champagne.

Another woman in the NewSpace sector is Sirisha Bandla, Vice President of Government Affairs and Research Operations for Virgin Galactic. Bandla flew on the 2021 Virgin Galactic Unity 22 mission, making her

Elsie MacGill
Credit: Libraries and Archives Canada

Li Xiaqing
Credit: RPM

the second India-born woman to go to space. Unity 22, which launched from Spaceport America in New Mexico, was the first fully-crewed Virgin Galactic flight.

Today, women comprise approximately 10 percent of the people who have been to space. The first all-woman spacewalk, scheduled for March 2019, was canceled because the spacesuits didn't fit the astronauts—NASA administrator Ken Bowersox blamed physical differences (and a limited supply of aging spacesuit components) for impeding how well the astronauts could "work the suit." These differences, however, are perhaps what make women the ideal choice for space travel.

On average, women weigh less than men, and body mass is very important when it comes to fuel costs. As women are usually smaller, they also require fewer calories and less oxygen, and therefore produce less waste, saving even more weight. Furthermore, a 2014 NASA publication analyzing data from the ISS finds that women's eyes are possibly not as affected by zero-gravity as their male counterparts, and female astronauts experience fewer complications with intracranial pressure in space, though they may be more susceptible to radiation due to increased risk of ovarian, uterine, and breast cancers. "Depending on when you fly a space mission, a female will fly only 45 to 50 percent of the missions that a male can fly," said Peggy Whitson, the former chief of NASA's Astronaut Corps.

NASA plans to put the first woman on the Moon's surface in 2024 with the Artemis program. It's been a long time coming, but despite making up nearly half of the United States workforce, women account for only about 27 percent of STEM workers, according to census data. Globally, only about 35 percent of STEM students in higher education are women, according to a UNESCO report, even though women tend to outperform men on science test scores on average. Additionally, only about a third of women employed in STEM fields are women of color. Women are also likely to have lower starting wages than their male counterparts, and men are seven times more likely to receive STEM roles in television and film.

Organizations like the Society of Woman Engineers and Women in Aerospace offer scholarships, mentorship programs, and networking opportunities worldwide to young women interested in breaking into STEM. Role models like Sirisha Bandla demonstrate road maps to young women from diverse backgrounds seeking more unconventional and creative paths to careers in STEM.

Science communicators like Emily Calandrelli, an MIT-trained aerospace engineer, serve as examples of how diverse STEM careers can be—besides her work as an engineer, she has been featured in science programming on Netflix and Fox.

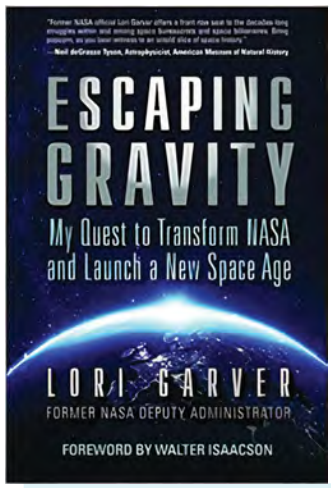
Why are women and girls less interested in STEM careers? Environment plays a huge role in nurturing aspirations for STEM; in the United States, data from a Microsoft study shows that around 74 percent of middle school girls have an interest in STEM subjects. However, this interest drops when those girls reach high school. Cultural challenges, biases, and social norms also gravely influence the education and career decisions women make worldwide.

Interestingly, new studies find that countries where women experience greater inequality tend to produce more women in STEM careers. A study published in *Psychological Science* posits that women in countries with higher gender inequality view STEM professions as paths to financial freedom. Such countries also offer less support for the unemployed, and STEM careers often offer more stability and financial security than the arts, making them more attractive. The study also suggests that countries that empower women indirectly encourage them to pick careers they would enjoy the most; allowing them to not pursue science if their passions don't lie there. Past research published in the *American Journal of Sociology* shows that economically developed countries often experience a greater gender gap in STEM fields, corroborating these findings.

"For people who are younger, I think of what I would tell myself if I could back—and it's patience," advises Sian Proctor, a crewmember of SpaceX's Inspiration4 mission. "We live in a fast society with rapid change and a lot of information, and sometimes you feel like you're behind and that you're not moving at a quick enough pace along with everybody else. But ... you've got to go at your pace." Proctor found her way to space after failing to be selected for NASA's astronaut program—twice—and winning the "prosperity seat" aboard the Inspiration4 flight by making videos about her online art business. She is the first black female pilot of a spacecraft and the first black civilian astronaut.

NASA astronaut Mae Jemison, the first black woman in space, said, "the fact is that space and its resources belong to all of us, not to any one group." Professional mentorship and academic support for young women and girls interested in STEM could transform the landscape of aerospace when the unique qualities and skillsets possessed by this yet untapped talent pool are unlocked. In the words of Valentina Tereshkova, "A bird cannot fly with one wing only. Human space flight cannot develop any further without the active participation of women." ■

Dr. Sian Proctor
Credit: Inspiration4



ESCAPING GRAVITY

BOOK REVIEW

REVIEWED BY:	ROD PYLE
AUTHOR:	LORI GARVER
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Lori Garver begins her NASA tell-all *Escaping Gravity* by by citing a conversation with the presumed presidential nominee Barack Obama in 2008, just prior to her tenure as the NASA Deputy Administrator. Obama asked her if she agreed with the idea of extending the space shuttle program into the next decade and she unreservedly replied, "No." She continued to explain that while the shuttle program had been "the most visible part of NASA," it had never fulfilled its stated purpose—to lower launch costs and assure routine access to space safely and reliably—and it was dated and unreliable technology. When asked what she would advise instead, she told him, and thus began her sometimes tumultuous, but transformative, career as the number two boss at NASA.

Garver's career in the space industry began pleasantly enough, when she worked her way up to the role of executive director of the National Space Society (which publishes this magazine) in the 1980s, after working for then-senator John Glenn from 1983 to 84. Her tenure at the NSS extended through 1998, when she accepted the role of Associate Administrator of the Office of Policy and Plans at NASA—her first inside look at the space agency. Garver has been a pivotal force in modern spaceflight, and the ups and downs of that journey are well related in this no-holds-barred book.

The "space industrial complex," as she unflinchingly calls NASA and its then-cozy cadre of aerospace companies, needed disruption, and she felt it was her responsibility to begin that process. Readers should note that this is not a book that supports warm memories that many still cherish of gleaming rockets and heroic astronauts—it's somewhat of a tell-all that reveals the less appetizing side of a government agency operating past its prime and in need of reinvigoration.Notably, Garver had spent time adjacent to the nascent commercial spaceflight sector (first as president of Capital Space, followed by a role as a senior advisor for space at the Avascent Group, a strategy and management consulting firm), in the early 2000s. She had now seen both sides of the equation and had some profound ideas about how change was needed. Her tenure as the NASA Deputy Administrator was predicated on advising three presidential candidates on space, rounding out her knowledge of government and technology. As she puts it, "I'd spent my 25-year career training to be prepared for such an assignment, and although my background was different from everyone who had been in the position before, I believed that was a positive feature and not a bug." It may have been this feature that allowed her to spot the potential of the emerging newspace industry, in which rising stars such as Elon Musk were just beginning to gain traction. Not everyone agreed with her assessment, however, and the pushback began almost immediately upon her assignment as the second in command at NASA.

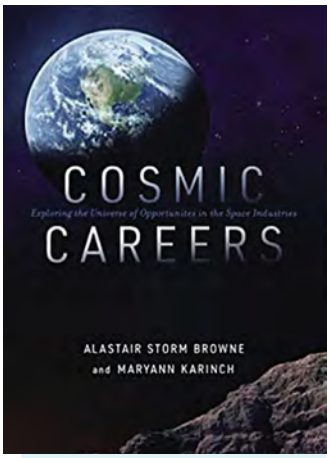
Besides supporting the cancellation of the shuttle, she leveled criticism at the Constellation program, intended to return Americans to the Moon, which was behind schedule and well over budget. But cancelling Constellation would impact powerful aerospace contractors—and their political representatives—across the country. By the time the program was cancelled on her watch, with subsequent recommendations of contracting out routine spaceflight operations to private spaceflight operators, her detractors included such space luminaries as Neil Armstrong and Gene Cernan, the first and last men to walk on the Moon, and people she had idolized. She even butted heads with Charlie Bolden, her boss at NASA, and earned the ire of both sides of the Congressional aisle. Bill Nelson, the current NASA administrator who was then serving in the Senate, said that these choices would be the "death knell for human spaceflight in the United States."

The path to the modernization of NASA would be neither easy nor pretty, but she felt there was no other realistic road ahead if success were to be achieved. The case she was making was particularly challenging due to the fact that the nascent newspace companies that would lead this transformation were yet to hit their stride, and her commitment to the cost-reducing competition they would bring to the table required both faith and vision.

She likens the transformation of NASA and its way of doing business to a scene in the movie *Moneyball*, in which the owner of the Red Sox tells the team manager, "the first guy through the wall ... always gets bloody," and this became her mantra. With that sentiment in mind, she began to engineer a revolution in how the United States does space.

As her changes began to settle in, many detractors let their displeasure be known, loud and clear. Garver pulls few punches in the text, guiding readers through some of these battles. On her side were the individuals she termed the "space pirates"—people like Elon Musk, Jeff Bezos, and a handful of others, who have changed spaceflight in ways many could scarcely have imagined in 2010. The path was not a smooth one. Congress underfunded the initial efforts to commercialize routine space operations for years. But Garver's instincts were correct, and the long game has borne fruit. By NASA's own estimates—depending on what part of SpaceX's launch system you analyze—the new relationship has saved the American public between 50 and 90 percent for the past few years. That amount will only increase over time.

Perhaps the *Moneyball* reference sums up the main theme of this book best. The allegory fits aerospace as well as it does baseball, as the team owner continues, "This is threatening not just a way of doing business ... but in their minds, it's threatening the game. Really what it's threatening is their livelihood, their jobs. It's threatening the way they do things ... and every time that happens, whether it's the government, a way of doing business, whatever, the people who are holding the reins—they have their hands on the switch—they go batshit crazy." Fortunately, the worst of the madness has ebbed, NASA is modernizing, and we can see the benefits echoed throughout America's spaceflight endeavors. This book gives readers an insider's look at how that transformation began.



COSMIC CAREERS

BOOK REVIEW

REVIEWED BY: ROD PYLE
AUTHORS: ALISTAIR STORM BROWNE AND MARYANN KARINCH
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When I was a young man and the Apollo program was still flying to the Moon, if one wanted a career in space, the only real options were to be a scientist, engineer, support person for NASA or the military, or to become an astronaut. The first few were somewhat realistic options if one were academically inclined; the last, unrealistic for all but a very special few. These programs, whether civilian or military, were also entirely at the whim of government funding, and that could be—and is—fickle.

In the new space age, this has changed, and *Cosmic Careers: Exploring the Universe of Opportunities in the Space Industries*, a new book by Alastair Storm Browne, a longtime member of the National Space Society and Maryanne Karinch, a business and space journalist and author, endeavors to tell readers how.

The book begins with a Space Age primer, including why Americans went to the Moon and what happened to civilian spaceflight once that goal was met. The shuttle program and the construction of the International Space Station are explored in detail, and then the authors take a rear-view mirror look at the many follow-on programs that were explored but not attempted: a lunar base, more evolved versions of the shuttle, and even crewed planetary flybys of Mars and Venus. It is noteworthy that all these programs were designed and constructed using traditional cost-plus contracting between NASA, the federal government, and the aerospace industry (and others), possibly one of humanity's most expensive business arrangements—and therein lay doom for NASA's planned post-Apollo efforts.

The book then dives into greater detail about human spaceflight efforts—quite a bit of detail, actually, which primes one to learn what career opportunities may await in the final frontier. NSS members may enjoy the discussion of various aspects of space settlement, including radiation mediation, space agriculture, and biomedical issues, among others. Included is a lengthy discussion of how we might get space settlement to pay for itself using lunar resources, asteroid mining, and other opportunities.

This brings us to the new space age. In the 2010s, we saw the rise of a new arrangement—private industry self-funding some of the design and prototyping (and in the case of SpaceX in particular, self-financed flight), with companies sharing a much larger part of the risk through fixed-price contracts—the same arrangements many who have worked in business are used to.

A reasonably detailed discussion follows of new partnerships between NASA and private space companies, and how these have and will continue to evolve. We're getting to the red meat here, and some case studies are included. A longer conversation about infrastructure related to space industries and the role of governments adjoins this, and it is a welcome one—this is a subject all too rarely encountered in books intended for a general readership. How government funds space development and should do so in the future to reap maximum benefits for its citizens is critical to space settlement.

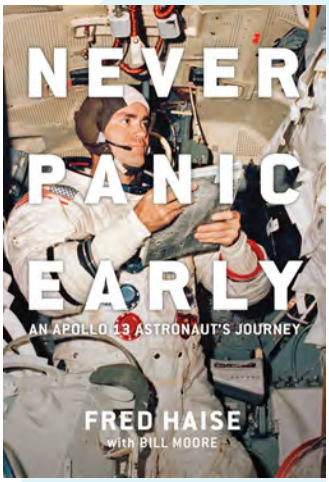
By mid-book, we have a primer on spaceflight technology for the 21st century, reviewing various systems and extending into nuclear propulsion—a welcome look at how we can better cross the vast distances involved in what is to follow: settlement.

One note regarding the text: multiple references are made to "manned spaceflight," an anachronism according to NASA's style guide, which prefers "human" or "crewed" spaceflight as identifying terms, but this in no way detracts from the overall discussion.

The second half of *Cosmic Careers* looks at how people might settle space. Chapters are devoted to free-space settlements, discussing designs most NSS members are familiar with—O'Neill Cylinders, the Stanford Torus, and Bernal Spheres among them. Gravity requirements and radiation shielding are discussed, as is food production. A section on space tourism looks at its role in longer-term settlement.

The authors wrap up with chapters on lunar settlements and human migration to Mars. Curiously, though the book was released in 2021, open-ended discussions of Lockheed Martin's Mars Base Camp and even Mars One are included, with the former currently quiescent and the latter rather discredited.

While the book is light on actual career advice, an overall worthy read.



NEVER PANIC EARLY

BOOK REVIEW

REVIEWED BY:	EMILY CARNEY
AUTHOR:	FRED HAISE WITH BILL MOORE
PUBLISHER:	SMITHSONIAN BOOKS
PUBLISHED:	2022
PAGES:	216
AGE:	ADULT
ISBN:	1588347133
FORMAT:	HARDBACK/KINDLE
PRICE:	$29.95/$17.99

Fred Haise may have experienced more near misses and what-ifs than any other astronaut in spaceflight history. In *Never Panic Early*, the aptly titled and long-awaited autobiography written with spaceflight historian Bill Moore, Haise relates that narrowly missing walking on the Moon was even crueler than it seemed; not only because he missed his chance to walk there, but also felt remorseful that prime command module pilot Ken Mattingly was bumped from the crew due to measles exposure.

While Haise, who was notably the first of his astronaut class to be given a flight assignment, endured subfreezing temperatures and a fever caused by a urinary tract infection he had picked up during the Apollo 13 mission, he would later watch others in his group make jubilant lunar excursions for which he'd so diligently trained. He relates matter-of-factly, "I was the first of the competitive 'Original 19' to be given a flight assignment, but I felt Ed Mitchell [Apollo 14 lunar module pilot] won the competition because, ultimately, he got to walk on the Moon first and I never did."

This isn't to say that Haise's contributions to Apollo weren't noticed by others. His colleague Al Worden wrote in his memoir *The Light of Earth*, "Fred saved Apollo 13. That's my opinion ... I believe he was absolutely the best-prepared guy on the mission. The crew's survival depended on the lunar module. I think that's why Fred was so important; he was the guy who knew the spacecraft best." He continues, "I'm not sure Apollo 13 would have been so successful if Fred had not been on the flight."

As momentous as Apollo 13 was, the story of that mission was only one of the many speed bumps in Haise's career and life that served as a wistful almost. He was slated to command the Apollo 19 mission, but that flight was ultimately scuttled by budget cuts. Instead, his work on Apollo segued almost seamlessly into the next big NASA project: the Space Transportation System, better known as the space shuttle. Haise was involved in the shuttle's inception and design from its very beginnings and during the early 1970s saw it transition from concept art that bordered on science fiction to actual blueprints. But even the space shuttle, as far off in the future as it was, almost didn't happen for him.

Haise became ensnared in his life's biggest near-miss in 1974—even bigger than the one he encountered thousands of miles away from Earth in 1970—when he suffered second- and third-degree burns on over 65 percent of his body after the Vultee B-13 World War Two trainer aircraft he was piloting cartwheeled upon landing.

Haise's vivid story of his rehabilitation—which he describes in the book succinctly as "hell"—is graphic, shocking, and terrifying. This is not Haise trying to be overly morbid or sensational; this is the unvarnished truth of his experience. Here readers learn what 11 weeks in a burn unit is like, first fighting for his very existence, then having his legs saved. It makes Apollo 13 seem almost like a Disney ride in stark comparison.

After this traumatic experience, one might think Haise would have put his helmet bag in the back of a bedroom closet, forgotten it was there, and quit flying. But a week after being released from the hospital and still wearing compression garments to protect his healing wounds, Haise went back to work at NASA. Within 18 months, he was selected to be among the first to fly the shuttle test craft Enterprise. Haise's recollections about how Enterprise came to be and the 1977 Approach and Landing Test (ALT) program are the definitive account of this underrated time in spaceflight history.

After that, he was slated to command one of shuttle Columbia's first missions alongside fellow astronaut Jack Lousma, an ambitious journey to re-boost the ailing Skylab space station into a higher (and more stable) orbit. But this too didn't happen, thwarted both by a shuttle program that wasn't yet flight ready, and the unexpectedly high level of atmospheric drag that brought Skylab down, scattered over the Indian Ocean and parts of Western Australia.

Never Panic Early also discusses Haise's modest Mississippi roots, his pioneering career in flight testing that happened well before he was selected for 1966's astronaut group, and his triumphs and frustrations working in the private aerospace industry post-NASA, when he was attempting to move Space Station Freedom (the ISS's predecessor) from wall poster graphics to reality. His honesty never falters, and if the political pressure that defines the direction of NASA spaceflight was ever in doubt, readers will know it by the end of *Never Panic Early*.

Haise doesn't end the book with the purgatory, as he puts it, of his Space Station Freedom experience. Like many visionaries, he looks forward to what the future will bring and portrays no bitterness about his sometimes tumultuous past. Anchored by his lack of ego and sometimes blunt, often humorous candor, *Never Panic Early* is the consummate story of how one man overcame enough adversity to fill several lifetimes, but ceaselessly kept moving forward.

HIGHER, FASTER, LONGER: WALLY FUNK

BOOK REVIEW

REVIEWED BY:	MELISSA SILVA
AUTHORS:	JANET IVEY-DUENSING AND LORETTA HALL
CATEGORY:	NONFICTION
PUBLISHER:	JANET'S PLANET INC.
DATE:	JANUARY, 2022
PAGES:	204 PAGES
AGE:	YOUTH
ISBN:	978-1087992044
FORMAT:	HARDCOVER
RETAIL PRICE:	$24.99

Mary Wallace Funk, more commonly known as Wally Funk, was one of the Mercury 13, a privately funded program which put that number of women through the same physiological screening tests that NASA astronauts underwent for Project Mercury. The program was started by William Randolph Lovelace II, a physician and former chairman of the NASA Special Advisory Committee on Life Science, who was curious about how women would fare if they underwent the same assessments male prospective astronauts did. While the women were never part of NASA's astronaut program, one of them did eventually fly into space—Wally Funk.

Higher, Faster, Longer: Wally Funk is the latest book by science communicator Janey Ivey-Duensing, who created the award-winning children's television series *Janet's Planet*, and is co-written by Funk's autobiography collaborator, Loretta Hall. The book is part of Ivey's "Unsung Genius" series for children, which celebrates heroic figures in the sciences. The book follows Funk's journey as an aerospace pioneer who showed an interest in flying and aviation at the young age of two, when she saw a plane at the airport.

Peppered with illustrations, photographs, and quizzes for readers, *Higher, Faster, Longer* is an inspiring read. Each chapter starts with a memo from Funk herself, writing directly to her readers to motivate them to follow their dreams and achieve the goals they set for themselves. "Dear Genius You," the letter opening Chapter 11 says, "Always, always keep looking up! Look for the positives, eliminate the negatives, and keep heading in the direction of every dream you can dream!"

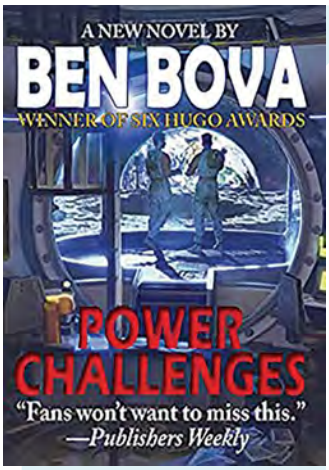
Funk describes her carefree upbringing, filled with bikes and horses, and how her parents encouraged and nurtured her adventurous spirit. She writes that her parents gave her the gift of confidence and fostered her fearlessness. In fact, her first "flight" was when she was five, off the edge of the family's barn, inspiring her to pursue a career in aviation.

She details her struggles with school, which took a turn when her mother suggested to the head of Stephen's College in Missouri that they enroll her in aviation courses. There, Funk found that she not only loved to fly, but enjoyed teaching others how to fly too. She would become the first woman to obtain permission to go to the El Toro Marine Corps Air Station in California to take the Martin-Baker ejection seat test and the high-altitude chamber test.

Her path to the Mercury 13 began with a magazine story about Jerrie Cobb participating in a study where she floated in a water tank without any outside stimulation—a sensory deprivation tank—to see how long she could withstand being deprived of stimuli. Funk would write a letter to Lovelace expressing her interest in participating in the tests. She describes these events in great detail, adding personal anecdotes about her experiences with not only the tests she was subjected to but also the people she met along the way.

Funk has unique tales about the equipment she and the other Mercury 13 learned to use and adapt to during their training. For example, she writes that G-suits were not fashioned or designed with female anatomy in mind and how she altered one with the help of a corset and girdle. Funk even describes how the aerospace industry has changed—we're now in space 2.0—and how she was invited to be Jeff Bezos' honored guest aboard his New Shepherd spacecraft. She shares her experience aboard the history-making flight in detail, including how she indulged her long-held dream of spaceflight by being the first to unbuckle her seatbelt.

This book is an inspiring look at the spaceflight industry, how it's changed, and where it's going. It's a fantastic resource for anyone looking to learn more about Funk's upbringing, her education, and her journey with Blue Origin's New Shepherd. While it may be marketed as a book for young readers, adults will find as much enjoyment and information as younger audiences.



POWER CHALLENGES

BOOK REVIEW

REVIEWED BY:	SUSAN RAIZER
AUTHOR:	BEN BOVA
PUBLISHER:	CAEZIK SF & FANTASY ARC MANOR
PUBLISHED:	2021
PAGES:	236
AGE:	ADULT
ISBN:	978-1-64710-018-6
FORMAT:	HARD COVER
PRICE:	$28.50

Power Challenges, despite being fictional, stands alone as a narrative of how space policy and actions in the space arena are viewed by politicians, the media, and the general public.

Ben Bova was a prolific writer who published more than 125 science fiction and nonfiction science books over his illustrious career. Sadly, he passed away on November 29, 2020, from COVID-19 complications. Bova was a six-time Hugo Award winner, editor of several science fiction magazines, and a past president of the National Space Society and the Science Fiction and Fantasy Writers of America. He had received other awards and served on various science and science fiction committees within the aerospace, science, and science fiction communities.

The book is fast-reading, multi-faceted, and easily plausible. The first half centers on Jake Ross, the president's science advisor, and his pet project to get people back there. The Artemis program aims to send astronauts to the Moon for long-term exploration as a stepping-stone to later missions to Mars. The difference now, compared to the Apollo program in the 1960s and 70s, is that the program will be funded entirely by private investors. Set against the enthusiasm of Ross are openly hostile members of Congress as well as NASA management, who feel they are being left out of the project, coupled with the more immediate needs of people worldwide as they struggle against climate change, economic instability, and growing food insecurity. The protagonist aggressively lobbies all concerned and is successful despite the death of the president. He encourages the former vice president and new president to wholeheartedly support the project. It becomes a reality, and scientists soon begin to live and work on the lunar base. They discover the potential existence of another intelligent life form in the galaxy and send a message, but it will take 50 years to hear back, and not all humanity is ready for interstellar contact, which segues into the second part of the book.

The second focus of the book is more of a classic science fiction battle in space, which is unrelated to the first theme. It's like having two stories that are presented through the eyes of Ross, which in a way mirrors the current politics of space. Once the lunar base is operational, he is introduced to a new concept, a network of geosynchronous satellites which are controlled by space-faring countries through a system of military space stations. The purpose of the satellites is to provide an early warning system if any of the nations become hostile. While there is a great deal of resistance, the president asks his arch-rival in Congress to be his vice president and spearhead the program. Ross succeeds in getting multiple countries to agree to the network and gets the satellites and space stations built. Then, without warning, one of the stations is attacked and several of the astronauts aboard are killed. The commander of the station, J. W. Hazard, is an experienced military man and soon realizes that some of the other stations have gone rogue. Through his leadership, he is able to thwart the coup, which was led by the vice president, who wants to start a nuclear conflagration by destroying all the other stations and pitting the network's members against each other. The plot is thwarted, and an uneasy peace prevails.

I recommend this book to National Space Society members as an easy-to-read story by a past NSS Governor that is very well written and contains timely subject matter. First, the Artemis program will soon take people back to the Moon for exploration and training for long-duration missions to Mars. Second, with the recent escalations in unease caused by the Russian destruction of one of their satellites, which placed the International Space Station in danger of being hit by the debris, the issue of the militarization of space has become a topic of discussion. While a global network of military satellites poised to attack other nations is not a reality at this time, tensions are rising, which could translate to military actions in space. Third, throughout his career, Bova has time and again presaged or predicted actual events and breakthroughs in science through his science fiction stories.

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If you support the exploration and development of space and the creation of a spacefaring civilization, joining the National Space Society (NSS) is a good first step. But what if you want to do more?

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Your first step is to see if there is a chapter that meets your needs already. Chapter contact listings are in every issue of "Ad Astra" and online at space.nss.org/nss-chapters-directory. Then contact the local leaders or check their Chapter websites for upcoming events and activities near you.

Local chapters also often concentrate in special areas (e.g., rocketry, education, original peer-reviewed research on space settlement, etc.) and will generally welcome distant members who share their particular interests.

If there are no existing chapters that meet your needs, you may want to form a new one. Instructions are available on the NSS website at: space.nss.org/community-chapters.

You may also contact Chapters Resources Coordinator Larry Ahearn to get a NSS Chapter Starter Kit emailed or mailed to you. Chapters in good standing with the NSS have access to assistance and resources from both NSS national and other nearby chapters. Resources from both NSS national and other nearby chapters. Resources include promotional materials, educational materials, and membership recruitment rebates. See space.nss.org/resources-for-chapters for more details.

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