Why a *New Space* Journal? Why Now?

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The "Twitterverse" was recently packed with messages about the amazing rover Curiosity and the "seven minutes of terror" getting to the surface of Mars. The "Blogosphere" crackles with comments by numerous observers of the efforts of Sir Richard Branson and Virgin Galactic, Elon Musk and SpaceX. It is apparent that the old paradigm of government-only space travel is being replaced by something else—a new business ecosystem composed of novel relationships among the National Aeronautics and Space Administration (NASA), aerospace industry, and academia.

Yet, the literature on these subjects is largely found in social media, marketing blurbs, and conventional reporting in the trade press. Meetings and conferences on the subject of space entrepreneurship seem to be flourishing, but the proceedings of such events are not usually part of academic citation indices. Such a situation immediately conjures the questions, "Where are the independently peer-reviewed articles on the emerging entrepreneurial space sector? How does the growing community judge whether assertions are based in rigorous analysis?"

These questions have convinced me to undertake the duty of editor-in-chief of this *Journal*, in large part thanks to the persistence of Mary Ann Liebert and her staff. *New Space* will serve as the peer-reviewed voice of this exciting and emerging field of space entrepreneurship. The staff at Mary Ann Liebert, Inc., especially the managing editor, Bill Ferguson, my associate editor, Ken Davidian, as well as the Editorial Board, will dedicate themselves to publishing relevant and leading-edge articles of the highest quality. We begin with this editorial, our initial peer-reviewed article detailing the first ever privately funded deep-space mission, and a roundtable of experts answering the critical questions that face a new industry. But still, "Why is this happening now?"

I grew up as a "rocket boy" in a small Kentucky town in the 1950s. While launching backyard missiles and conducting explosive experiments in the basement, I devoured science fiction and wondered if personal space travel would ever be possible. And if so, what would it be like? Now, more than 50 years later, after several careers in space and technology, I believe that the dreams of children and imaginative writers are now within reach.

As an aerospace professional and former NASA executive, I have encountered over the decades many concepts for private space exploration. Until a few years ago, none of these ideas came from colleagues who met the qualifications for what I call the "practical visionary," that is, someone capable of seeing a new future but also solidly grounded in lessons learned. Something was always missing in these early ventures. Either the technical approach required some "unobtanium" technology to be invented, or the advocate had good ideas but no money, or the "build it and they will come" philosophy showed total naiveté in business and marketing.

However, over the last eight years, several major new trends surfaced among government, industry, and academic space organizations. NASA has moved from technical hardware specifications to purchasing services. The Agency has gone "all in" for a Shuttle replacement that depends on Commercial Cargo followed by the Commercial Crew program. The Federal Aviation Administration (FAA), not NASA, will be the regulatory authority for launch approval.

Burt Rutan and Virgin Galactic won the Ansari X-Prize for taking two trips to the edge of space within two weeks. Space tourists paid millions to Roscosmos (the Russian Space Agency) via a new company called Space Adventures to visit the International Space Station (ISS). Companies such as SpaceX and Sierra Nevada are new entrants to the field of space transportation services, a market that has been served by incumbent firms such as United Launch Alliance (a joint venture of Lockheed-Martin plus Boeing) and Orbital Sciences. Suborbital space tourism may well take off next year if Virgin Galactic and XCOR are accurate in their timetables. And even more audacious projects are being suggested, such as privately funded asteroid mining and one-way human trips to Mars.

In a study I conducted with seven Stanford MBA candidates in 2006,[1] we took a critical look at this field of business using not only public documents but also interviews with the full range of associated parties: established aerospace executives, Wall Street investment bankers, leading entrepreneurs, and policy makers such as former Congressman Robert S. Walker. What we found was a dramatic difference from the past. In this new era, individuals of high net worth are spending their own money, hiring experienced aerospace engineers, and carefully studying the potential market.

Making a new space industry requires three things: demand, access, and platform. In the Stanford study, we deliberately limited the investor horizon to 5–8 years. At that time (2006), the only truly new business case that clearly closed for profitability was suborbital tourism. In this arena, the technology has proven itself available, private funding is adequate to build the vehicles, and more than enough wealthy individuals have appeared with the means to pay at least $100,000 for a short excursion to the edge of space. Space tourism is coming.

Elliot Pulham, colleague and CEO of the Space Foundation, has posed the "so what" question. Even with generous assumptions about flight rate, the business generated by suborbital companies will be, at best, a tiny blip in the estimated $200-billion-per-year global space market. The market is now dominated by sectors such as

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communications satellites and traditional government missions.[2] So why do individuals such as myself and Elliot Pulham care? The answer lies in the huge potential for space-based goods and services.

As Brewster Shaw, a former astronaut, once pointed out to my students human space travel is such a powerful personal experience that, "the more people who go, the more who will want to go."[1] Once space becomes accessible to tourists on a regular basis, practical industries will certainly follow. And if historical analogues such as early aviation are any indication, two things are true: the demand is woefully underestimated, as is the final development cost. Clever advertising companies and marketing executives are already exploiting space connections to capture their audience's attention, and it appears to be working.

What about true space travel to at least low earth orbit (LEO)? And where, as Congressman Walker put it in 1989, is the "Sutter's gold," (Houston Chronicle, Sept. 24, 1989) the overwhelmingly compelling prize that will draw a new group of forty-niners to space? Travel to LEO is technologically far more demanding than suborbital trips. Yet the propulsion and thermal protection problems have been solved in the past. What's missing is the market demand that will drive economies of scale in launch and development costs with safety and reliability. As with the airmail routes that helped stimulate early aviation, NASA's commercial programs are now the anchor tenants in the direction of government transfer of routine services to the private sector.

Beginning with the NASA Commercial Orbital Transportation Services competition, and now continuing with the Commercial Resupply Services (CRS) and the Commercial Crew Capabilities (CCiCAP) selection, NASA has "bet the farm" on commercial companies filling the gap. Space X and Orbital Sciences are the two companies that have been selected to provide those CRS services to the International Space Station. The CCiCAP companies (SpaceX with launcher and capsule; Boeing and Sierra Nevada Corporation with ULAs Atlas 5) are in a vigorous competitive struggle to replace the Russian launch and Soyuz spacecraft bringing NASA astronauts to the ISS. I believe it is critical that CRS and CCiCAP succeed. History teaches us that without a trailing edge of commercial exploitation and profitability, space exploration as a large-scale, routine human endeavor will not succeed.

My own speculation about the location of Sutter's gold is with biological experimentation in microgravity. Every living organism that we know of evolved in 1g. Science has never been able to fully examine gravity as a variable. From experiments of a few days to a few weeks in space, there are tantalizing hints of radically different gene expression, unusual lignin (a compound vital to connective tissue) growth in plants, and altered rates of disease infectivity. If extraordinary new breakthrough discoveries will occur, then advanced biotechnologies and future products will arise. For the right entrepreneur, setting up a biology lab on the ISS, or in orbit, is not out of the question. They could find gold in "them thar orbits."

In the end, people make the difference. The new breed of space entrepreneur is not so different from the mavericks who founded the business of aviation. It was a pair of bicycle mechanics rather than Professor Langley who first demonstrated powered flight. Lockheed Martin and Boeing did not emerge as full-blown billion dollar companies. William Boeing first gambled on timber production in 1903 before starting a tiny aircraft company. The Loughead brothers risked $4,000 they borrowed from a cab company in 1913 to create a flying boat; the Model G. Rides were a hefty $10 each. They nearly failed, but at the San Francisco exhibition of 1916, they found their market with the public and went on to found the Loughead (now Lockheed) Aircraft Manufacturing Company in 1916. Each major aviation company started in much the same way. In this new entrepreneurial space world, we have all the ingredients we need. It will happen again.

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Resources in Space

Scott Hubbard

Editor-in-Chief

In Robert Heinlein's 1950 book, *The Man Who Sold the Moon*, science-fiction readers got their first look at the idea of using the resources and economics of another world to propel space exploration. Since the earliest studies of human exploration, the concept of "living off the land," or as NASA terms it, "*in situ* resource utilization," has become a staple feature of essentially all NASA studies of future human exploration of space—especially deep space (i.e., Moon, Mars, and beyond.) In recent years, several start-up ventures have proposed for-profit companies aimed at exploiting these space resources. In this issue of *New Space*, we are devoting our Roundtable Discussion and several Field Reports to this emerging, albeit controversial, space business arena.

Usually *in situ* resource utilization, or ISRU in NASA-ese, is cast as a government invention for the purpose of converting resources such as water ice into oxygen to breathe, water to drink, and hydrogen for rocket fuel. A NASA researcher from the 1990s, K.R. Sridar, has successfully transformed an ISRU fuel cell technology into a growing Silicon Valley business called Bloom Energy.[1]

More ambitious studies have branched out into plant biology, chemical recycling, and even what some term "synthetic biology" for the purpose of growing food and sustaining future explorers. In all these technological research projects, and as is typical for NASA projects the government is the driving force.

Since the Apollo program to the Moon, there have been suggestions that the resources of space could be used for other purposes. One of the best known proposals is from Apollo 17 astronaut and geologist Harrison "Jack" Schmidt, who suggested that an elemental isotope (helium 3) could be used on the Moon for large-scale energy production.[2] However, it was only recently that a series of start-up ventures have proposed that resources on asteroids or the Moon could be utilized in for-profit business ventures.

Deep Space Industries (DSI)[3] and Planetary Resources (PR)[4] have gone public with ambitious plans to mine the resources of near earth objects (NEOs) or asteroids. They claim that they will provide fuel for long-term space exploration and ultimately acquire the metals in such objects for space manufacturing and potential return to Earth. Another company, Shackelton Energy Company (SEC), has a business plan to mine the water ice on the Moon and also to provide rocket fuel, water, and oxygen to explorers.

In the next few years, both PR and DSI are planning to build and deploy small spacecraft that will characterize the asteroids by looking at the spectroscopic signatures of these objects. The Firefly of DSI and Arkyd of PRI will be derived from so-called Cubesats (10 cm cubes), which were used in the past as student-teaching projects. Clearly this is a lower-cost venture than what would be required to accomplish the long-term goals.

As you will see in the Roundtable, there are a variety of points of view that differentiate the entrepreneurs from the established science and engineering community. Of particular interest is the question of how many NEOs are sufficient to underwrite a business case. About 10,000 NEOs have been discovered and, of those, perhaps half have well-known orbits. The total population may be as many as several million NEOs over 30 meters in diameter. Are enough objects in the right orbit and of the right size available to induce investors to provide the capital for such ambitious projects? Is the market demand for deep space exploration robust?

SEC, in particular, asserts that the business case for long-term investment for a speculative payoff has already been addressed by the earthly mining industry. Our Roundtable economist, Ward Hanson, provides a *New Space* perspective by describing how an emerging theory called "real option value" might be used in such long-term speculative ventures.

Prospecting and mineral exploration by the petroleum and precious metals industries is a story with a U.S. history hundreds of years long. I say U.S. because as Ken Davidian notes, the idea of an individual keeping the mineral rights to a discovery is uniquely American.[5] In most other countries, the state retains the mineral rights. This leads to the immediate question of mineral rights in deep space—a subject for the nascent field of space law.

I hope you find our space-resource discussion of interest. I'm certain we will keep visiting this controversial area in the coming years.

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The State of New Space

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In this issue we have focused our roundtable article on the status of the space business enterprise, with particular emphasis on the entrepreneurial sector. During the emergence of any new business, whether it was aviation in the early 20th century or the Internet in the 1990s, there are certain hallmarks of a tipping point in the emergence of a sector, for example, large numbers of new companies, growing investment, disruptive technologies, and enabling legislation. We will be examining these elements from a variety of viewpoints.

In this editorial and in subsequent issues, I plan to give my observations for both the health of and obstacles to the continued growth of an entrepreneurial space community. Let's begin at the high dollar, high visibility end: the health of the Earth-to-orbit industry, specifically NASA's Commercial Cargo and Crew programs. This pair of programs serves the dual purpose of both providing NASA-needed capability since the Shuttle's retirement[1] and stimulating a new commercial space service industry.

The competition to provide cargo (goods and supplies) to the International Space Station (ISS) was won by Space Exploration Technologies (SpaceX) and Orbital Sciences Corporation. The combined value of the two contracts is worth up to $3.5B dollars.

Progress to date in the cargo segment has been substantial by both companies: SpaceX has provided two cargo flights and more are on the manifest. Orbital Sciences has completed a new launch facility at Wallops Island in Maryland and at the end of April successfully conducted the first flight of the Antares launch vehicle. The launch successfully delivered the equivalent mass of a cargo spacecraft, a so-called mass-simulated payload, into Earth's orbit.

The Commercial Crew program that will ferry astronauts to the ISS (and replace the Russian Soyuz spacecraft) is in the midst of an intense three-way competition among SpaceX, Sierra Nevada Corporation, and Boeing. SpaceX is using its own Falcon 9 launch vehicle while the others are planning to use the Atlas V. Each company has its own crew vehicle design.

To make such a dramatic change in NASA's Earth-to-orbit capability is an amazing accomplishment given NASA's history of directly managing all space systems. As a federal agency, NASA also needs support from the tax-paying public and Congress. Yet I have found this shift in approach largely unknown by leaders in the non-space-business community and being ignored or even actively opposed in the usually bipartisan space part of the federal budget cycle.

Here's an example of the former obstacle: having spent almost 40 years in the Silicon Valley area of California and held relatively high positions such as NASA Ames Center director, I often come into contact with CEOs in the area. Over the last two years, since the Shuttle retirement, I have had dozens of interactions with senior industry people who have invariably greeted me with some variation on "Hi Scott, too bad about NASA going out of business. What will they do now?"

In response, I usually give the CEO the following capsule description: "Well, NASA retired the Shuttle because it was aging, high risk, and very expensive to operate. Instead of NASA running its own trucking company, the Agency has decided to purchase services to the Space Station from the private sector." Without exception, these heavy-hitter Valley types say "Wow! That's terrific. I had no idea. Why didn't NASA tell us that?"

Clearly there is a huge wellspring of support, even among conservative business people, for NASA's new approach. I can only assign this lack of knowledge to an ineffective public affairs campaign by NASA and the administration. Community supporters like myself and others are doing all we can to publicize Commercial Cargo and Crew, but the major resources for a broad-based information initiative lie with the government and its contractors. I say to NASA, "Go for it! Tell the people about their new space program!"

The second obstacle, opposition in Congress to full funding for commercial programs, can probably be attributed partly to regional self-interest and the confusion over NASA's deep space ambitions. "Does NASA know what it wants?"

In an era of flat or declining budgets and the dreaded sequester, all budgetary content is treated as a zero sum game. This term means that increasing the budget of one NASA program necessarily requires an equal decrease in other, competing NASA missions. Within NASA's Human Space Flight effort, the competing projects include ISS operations, a new deep space launch vehicle reminiscent of the Saturn V from the 1960s called the Space Launch System (SLS), the Multiple Purpose Crewed Vehicle for deep space (more commonly known as Orion), and the Commercial Crew and Cargo programs for Earth-to-orbit.

Budget priorities are currently highest for the first two programs: ISS because of its many international agreements, and SLS + Orion because it was congressionally directed by Senator Richard C. Shelby and others. This set of priorities creates conflicts that continually squeeze the commercial program funding.

In any budget debate, clear-eyed priorities should be the deciding factor. There is no doubt that the United States does need a deep space capability. However, given the current extraordinary tensions with

[1]Currently NASA is completely dependent on the Russians for crew transport and much of the cargo.

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the Russians, national interest in the form of freeing NASA from dependence on the Soyuz transfer to ISS should trump any other consideration. Commercial Cargo and Crew must be a higher priority than SLS + Orion in any Fiscal 2014 budget considerations.

In the longer term, this new set of priorities must continue to inform our decisions. Over several decades, I have watched NASA programs rise and then collapse from their own "overpromise and underbid" approach. The Constellation program[2] is a recent example. While I have no doubt that NASA and its contractors can create a technically successful SLS + Orion, I do have significant reservations about the cost estimates. On the current path, the SLS would be used only once or twice per year at a cost of several billions of dollars per launch.

Given the past history of cost growth in major NASA (and DoD) flight programs, SLS could be headed for a "go/no go" decision point and cost review within the next few years. If this happens, the Nation needs a "Plan B" for deep space that does not continue to threaten the commercial Earth-to-orbit capability. My suggestion is that we use the Orion crew vehicle, but reexamine the current or near-term heavy lift vehicles such as the Delta IV Heavy or Falcon 9 Heavy along with orbiting refueling depots.

I want to see humans go to Mars, but we need to find the most cost effective way to do it. Continuing to develop Commercial Cargo and Crew for Earth-to-orbit is absolutely the right way to save money and to stimulate the new industrial competitors.

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[2]Constellation was a proposed development of two new launch vehicles and a new deep space crew vehicle along with a Moon base (a lunar lander) and more. The budget required was declared "unsustainable" by a blue-ribbon committee report in 2009.

Space Exploration and Inspiration

Scott Hubbard

Editor-in-Chief

As I write this column, the U.S. government has just emerged from a budget struggle that resembles a cold civil war. Some of the combatants threaten to repeat the debacle three months from now. Among the many casualties could well be NASA's budget. Between the dreaded sequester (5% cut) and the less well-known recission (2% cut), NASA has been forced to continue to maintain its commitments with less and less funding. Some discussion has even surfaced in the blogosphere suggesting that NASA could be defunded with little impact. I regard this type of thinking as detrimental to the very fabric of American culture.

Recently, I was at an event in San Francisco seated next to my long-time friend and colleague Paul Otellini. Paul has recently retired as CEO of Intel Corporation, one of the world's largest high tech companies. During dinner Paul and I discussed the sad state of national budget affairs. He commented to me, "America is a frontier nation. We need inspiration to be at the leading edge." "If it were up to me," he said, "I'd increase NASA's budget because it is one of the few organizations that provides that inspiration."

Although this journal is devoted to emerging space entrepreneurship, the anchor tenant for the Commercial Cargo and Crew program is NASA. Purchasing services from the private sector for all the logistics to the Space Station makes eminently good sense. I speculate that a similar acquisition strategy may work for much of Earth remote sensing. We can't talk about space utilization or exploration without also thinking about NASA and its funding.

In my view, NASA should be at the "pointy end of the spear" when it comes to exploration. I've been in many mission statement exercises where the "design by committee" effort results in 100-word sentences that include everyone's favorite Christmas tree ornament. By contrast, to paraphrase Otellini, if it were up to me I'd make NASA's mission statement three words, "explore deep space." As a very recent example, the inspirational nature of going to Mars is huge. It is estimated that 70 million people watched the landing of Curiosity on Mars.

I recall the struggle between the United States and the Soviet Union during the Cold War of the 1950s. The emergence of NASA and our space program became a source of pride, and the Apollo program was a key element of foreign policy. The United States demonstrated to the world that a democracy could achieve great things and be first to the Moon. The landing of Apollo 11 is still today considered one of the high watermarks of human capability. Many, many young people were inspired to go into science, engineering, and other technical pursuits because of the space program.

I was a NASA employee during the last government shutdown in 1995 and '96. At that point, I was the manager of the Lunar Prospector mission, and we were at a critical point in development. Despite the shutdown and disagreement between the political parties, my mission proceeded because we received a "nonpartisan" special exemption. While I cannot give a quantitative analysis of the inspirational impact of the mission, I can say without hesitation that many school kids participated in our educational programs.

"Bipartisan" and even "nonpartisan" have almost always been the words that characterized the U.S. space program since its inception. Today, however, I regard national politics with such a bitter nature that almost every public act is being seen through the lens of ideology. This was on display during the retirement of the Shuttle and subsequent rollout of the Commercial Cargo and Crew programs. As I would encounter my business friends, I would invariably hear comments like "Well, what will happen now that NASA is out of business?" I would explain that the Shuttle was retired because it was aging, very expensive, and high risk. Furthermore, I would continue, NASA is now going to purchase routine services from the private sector and spend the savings on going to deep space. Almost invariably my friends would respond very positively with something like "Wow, that's great. Why didn't someone tell me?" Clearly either poor information or even disinformation was at work.

And so, this editorial is a plea for the ideologues to understand what is right with this country. During this intense debate about debt, jobs, and the proper role of government, let's pause to look up at the sky and realize that there is room for goals that stretch us and challenge us. We are a frontier nation. We do want to know what's over the next hill, and we do need to be inspired. Space exploration, including NASA, is able to provide that visionary goal.

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CubeSats, Return on Investment, Deep Space, and Physics

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Editor-in-Chief

The concept of a 10 cm cubic structure that contains all the basic functionality of a larger spacecraft has been present in the university arena for more than 20 years. Typically weighing 1 to 10 kg, such a small unit is generically called a "nanosat." Most researchers credit Bob Twiggs, formerly of Stanford University, and Jordi Puig-Suari, California Polytechnic State University (CalPoly) with creating, popularizing, and standardizing a specific 10 cm × 10 cm × 10 cm design known as the CubeSat.

In my recent experience, most every college and university with an aerospace department is using a CubeSat to not only teach spacecraft design but also to conduct experiments in science and technology. Launches of multiple CubeSats from a variety of schools now occur on a reasonably regular basis, although routine access to space remains a hurdle for everyone.

Within the past few years, there has been a significant increase in the utilization of CubeSats in larger combinations* for a range of commercial applications beyond teaching and research. Entrepreneurs have identified a business model using these small spacecraft to perform remote sensing measurements that companies like Skybox and Planet Labs believe will create significant return on investment (ROI).

These Silicon Valley–style startup ventures have created quite a buzz. In a recent *Aviation Week and Space Technology* article, my long-time friend and colleague, Frank Morring, Jr., waxes enthusiastic about a "nest" of 28 nanosats headed to the International Space Station as a demonstration of "New Space cooperation across national borders." [1] Built on the 3U cubesat form factor, the spacecraft built by the startup Planet Labs will be ejected into a "string of pearls" orbit and provide imagery to commercial users.

Reporting from a meeting of the International Academy of Astronautics (IAA), Morring's article goes on to speculate that these small spacecraft "may actually do more near-term to benefit the species than the elaborate manned Mars probes the agency bosses want to build."[1]

Frank's column draws what he believes to be an important distinction between the relatively inexpensive accomplishments of the entrepreneurs such as Planet Labs with the much more costly deep space exploration conducted by NASA, ESA, and other government agencies. Morring concludes his essay by saying, "the trick for…the well meaning space professionals of the IAA will be to find ways to link those national interests to the youthful drive and innovation exemplified by the Planet Labs project."[1]

I've seen this type of rhetoric appear quite often recently. Advocates cite the smallsat as a potential panacea for all manner of cost and schedule problems with large systems and tend to ignore whether the application of a small spacecraft meets the requirements or not. The U.S. Department of Defense studied deconstructing a large "national security" spacecraft into many smaller units, ignoring the cost of multiple launches and the requirement for precision formation flying to achieve proper resolution. In our second issue of *New Space*, we published a field report from Planetary Resources in which they displayed a nanosat that is said to find asteroids for mining, despite its limited field of view.

In my view, Frank and others touting the smallsat revolution at times confuse the opportunity to make a profit by adapting existing technology and the difficulty of visiting deep space for science and human exploration. Often this conflation will also include ignoring the laws of physics and the enormous difference in difficulty of, say, reaching the surface of Mars as compared with going to low Earth orbit (LEO). The "seven minutes of terror" in the landing of *Curiosity* was a degree of difficulty of 10 out of 10. Thanks to the last 50 years of development, launching a CubeSat to LEO is perhaps a 3 or 4 out of 10.

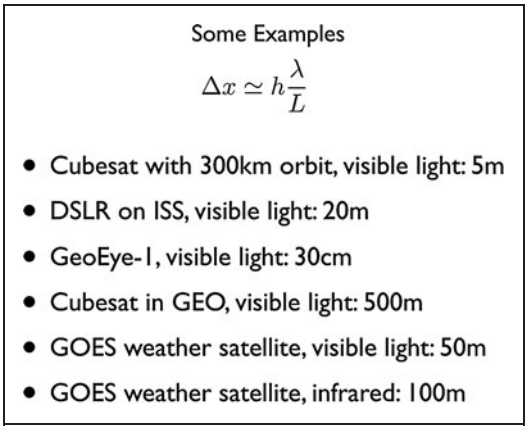

Fig. 1. Diffraction limited resolution as a function of aperture and wavelength for a variety of spacecraft. DSLR, digital single lens reflex (camera); GEO, geosynchronous Earth orbit; GOES, geostationary operational environmental satellite.

*The concept has now been broadened to include configurations of multiple cubes. A simple 10 cm CubeSat is called a 1U. A pair is 2U. A smallsat made of a 2×3 combination is a 6U and so on. Spacecraft systems of up to 12U are routinely discussed in the literature.

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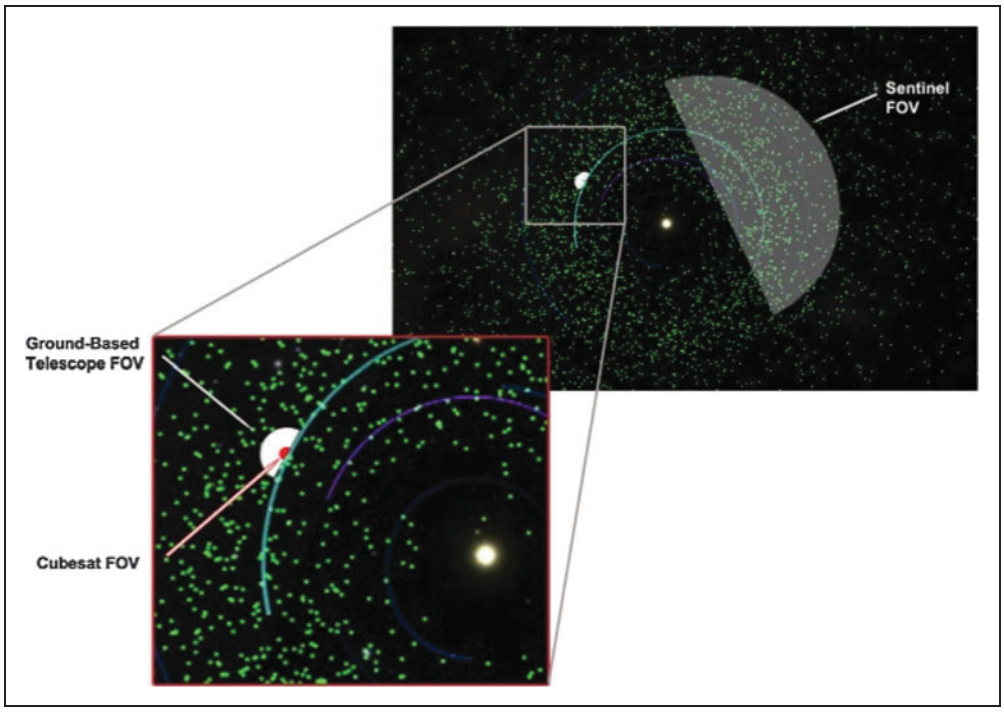

Fig. 2. Field of regard for a deep space 50 cm IR space telescope, a ground based 1 meter telescope and a 10 cm generic CubeSat in Low Earth Orbit. FOV, field of view; IR, infrared.

To further understand how we must objectively view new space claims and innovations, let's examine two examples: First, consider the Planet Labs business case, which is predicated on an assumption of growing need for continuous Earth remote sensing in the 3–5 meter range. Planet Labs is building on the success of companies like DigitalGlobe with their Worldview spacecraft, which can provide visible imaging down to a resolution of 60 cm and less than 2 meters in multispectral bands. The Planet Labs innovation is not in the spacecraft (although using smartphone electronics is clever) or the orbit or even the cost (which may be a trade with the longevity). The innovation is at the system level—coupling all these parts as Apple did with the iPhone—and a bet, yet to be collected, that there's a lot of ROI in 3–5 m remote sensing imagery.

The cost of space-borne optics scales directly with resolution. The physics is called the diffraction limit. If the military needs to count the golf balls on a course in Iran from space, Planet Labs current nanosat won't do it. One of my PhD students, Jonah Zimmerman, made the following set of comparisons in *Figure 1* using basic physics.

For the second example, let us consider the challenge of finding asteroids in the vastness of deep space. Beyond the van Allen belts, beyond the Moon, the radiation background is much more severe; the thermal management, communication, and attitude control are much more complex. To find dark objects such as asteroids one must use the infrared (IR). The optics of a typical cubesat are simply inadequate to the task.

My colleagues at the B612 Foundation prepared this comparison in *Figure 2* of an Earth-based 1 m telescope, a generic LEO cubesat, and the Sentinel observatory, which uses a 50 cm mirror, cooled IR optics, and detectors. It is obvious that in this case, a cubesat solution, as inexpensive as it may be, does not meet the requirements to determine the orbits of a million objects.

Youthful energy and enthusiasm are terrific and absolutely necessary to the future of the worldwide space endeavor. Most people forget that when NASA was in its Apollo heyday, the government employee average age was 32. Today, I am told the NASA average age is over 55. By all means let's recruit the best and brightest for the next adventure.

Innovation is also critical. I want to see the Mars Science Lab "skycrane" used again to take another rover to the red planet. I hope the technology of supersonic retropropulsion is demonstrated by someone so that getting larger payloads to planetary surfaces becomes less complex. And I sincerely hope that the microgravity experiments aboard the ISS yield some extraordinary new insights for deep space exploration as well as new commercial products for Earth.

To achieve the sustainable vision of deep space exploration, I believe we must have a trailing edge of economic development. Skybox and Planet Labs are terrific examples of the latter, as are NASA's Commercial Cargo and Crew programs. However, let us not confuse innovation in a business case that applies existing technology for profit with the degree of difficulty involved in going to Mars and the additional new innovation that will be required to get there. In the end, the laws of physics will trump the marketing department.

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Affording Mars?

Scott Hubbard

Editor-in-Chief

In this issue of *New Space*, we have elected to focus on some of the new initiatives regarding human exploration of the red planet. I commend the roundtable discussion as an exemplar of the debates being stoked among newcomers such as Mars One and Explore Mars with long-time supporters like The Planetary Society.

Mars has long been the most appealing destination for human space travel. Whether the plotline of early science fiction or the result of serious rocket science, the red planet has been beckoning for many years. Werner von Braun wrote his first plan for a human mission to Mars in his spare time. First published in German as *Das Marsprojekt* in 1948, his plan was later translated as Project Mars in 1952.

During my 20 years with NASA, I participated in and reviewed thousands of pages of charts devoted to missions to Mars, both robotic and human. I finally received the chance to translate my scientific interest into reality as NASA's first "Mars Czar" in 2000. My team and I created a long-term program architecture that began with Mars Odyssey and continued through Mars Science Lab/Curiosity.[1]

However, a human mission to Mars has continued to elude both NASA and the rest of the world. The most commonly cited reasons for this disappointment are cost, technical hurdles, and biomedical challenges for the crew. Recently a small group of space experts and aficionados gathered in Washington, DC, to once again assess the status of sending humans to Mars. Perhaps, the organizers hoped, enough things had changed that it was now more nearly possible to send humans to Mars. The results of this workshop are now available and conclude that many of the previous obstacles have been retired or reduced.[2]

I was asked to give the kickoff talk to this invitation-only workshop, entitled, appropriately enough, "Affording Mars." What follows in this editorial is an abstracted and condensed version of my presentation.

My organizing principle was a personal list of why we explore or utilize space—gathered over my 40 years in and around the space enterprise. From an early age I was fascinated with questions like the origin of the universe and where else life might exist. Consequently, I tend to consider major scientific discoveries such as, "Where did we come from?" or "Are we alone?" to be the first among equals for space exploration rationale. Space missions like Kepler have discovered thousands of extrasolar planets, and rovers such as Spirit, Opportunity, and now Curiosity have firmly established the early habitability of Mars. Veteran Mars scientists like Steve Squyres of Cornell, the principal investigator for Spirit and Opportunity, have often given examples from their fieldwork explaining how a human scientist on Mars could explore in a day what a rover may take weeks or even months to accomplish.

However, it is clear that the large sums of funding required to explore space with people are rarely approved by political entities just to satisfy curiosity-driven research. Thus my second (and many would argue the most important) reason for space exploration is national interest or national prestige. The Americans and Soviets squared off in the Cold War space race for just such a contest. In the current world, the European Space Agency (ESA), North Korea, and especially the Chinese, to name a few, regard space missions as a badge of accomplishment on the world stage. As a related comment, many of my space policy colleagues are quick to point out that the historical record suggests that nations that don't explore become stagnant.

Fine and dandy, say my conservative business friends, but what about making money on this space business? Such questions lead to my third rationale: new technology, goods, and services leading to a return on investment. The current world's space enterprise is worth about $300 billion. Almost 70% of that value is generated by commercial space communications, including the ground support and launch services. Not bad for a business that didn't exist until about 50 years ago. NASA retired the Shuttle and created the commercial cargo and crew programs—each of them worth billions of dollars of business to providers. The existence of this *New Space* journal is testament to the surge of interest in other entrepreneurial space enterprises like space tourism and commercial remote sensing. As humanity moves further out of low earth orbit, I believe the only way such exploration is sustainable will be if there is a trailing edge of commercial development.

Despite the recent Russian invasion of the Crimea (shades of 1853!), many observers would cite the International Space Station (ISS) as a shining example of cooperation for peaceful purposes—my fourth reason. Sixteen nations have contributed in one way or another to what is arguably the most significant engineering achievement of the last 50 years. Pundits have even suggested the ISS receive the Nobel Peace Prize or be similarly honored. Such cooperation will be needed for a human expedition to Mars and also for using the ISS to understand long-term exposure to the space environment.

There is another aspect of space exploration that is a bit less well developed but that occurs frequently enough for inclusion: In all my years of speaking to students of varying ages, I've almost always found that among middle school kids there is a fascination with dinosaurs and astronauts. Middle school, most professional educators

[1]See *Exploring Mars: Chronicles from a Decade of Discovery*, University of Arizona Press, 2011.

[2]Thronson, H: Workshop Report: Affordable Missions to Mars. *Space Times*, Jan/Feb 2014. Available at www.astronautical.org/spacetimes

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say, is the time when young people decide (sometimes unconsciously) that they will study science. It is no surprise, then, that space exploration is often seen as a powerful mechanism to stimulate student interest in science, technology, engineering, and mathematics.

And finally, there are those who see space exploration and colonization of Mars as a hedge against future catastrophe or a second home for humanity. This concept has been the stuff of science fiction since H.G. Wells, but the technology to create a livable habitat is now mostly available. As you will see in the current roundtable discussion, the Mars One organization has elected to call a one-way trip "permanent colonization."

So one can ask, "Which of these reasons for exploring or utilizing space are needed to have an affordable humans-to-Mars program?" My answer is "All of them!" By having clarity of purpose, budget, and cost; utilizing existing cooperation and creating new coalitions where there is a convergence of interest; and developing a trailing business ecosystem, I do think the space community can create an affordable humans-to-Mars program.

Scott Hubbard
Editor-in-Chief
New Space

Space Biomedicine: Who Can Travel to the Final Frontier?

Scott Hubbard

Editor-in-Chief

In this issue of *New Space*, we are addressing one of the most frequently cited obstacles to space travel by human beings—the biomedical effects of launching into space and returning safely. So-called "g" forces experienced during launch and reentry can be many times what we experience here on Earth (1 g—the pull of gravity), and the effects of weightlessness can be highly varied. Some trained astronauts have had their careers in space shortened by "space sickness."

One of the important areas of *New Space* research is to determine whether there are biomedical conditions that would disqualify prospective spaceflight participants—the current term of art for what others colloquially call "space tourists." Historically the astronaut corps has been a small subset of applicants—those humans successfully passing through extensive and rigorous physical and mental testing and training. The book and movie *The Right Stuff* documents the extremes that the original Mercury Seven astronauts endured to be America's first astronauts.

Today, several companies are competing to take ordinary citizens to the edge of space for 4 minutes of weightlessness. The question remains, "What if the traveler has an artificial knee joint? What about a pacemaker implanted? What about controlled hypertension?"

To address these and other questions, this issue of *New Space* has been very fortunate to have the collaboration of my good friend and colleague Dr. James Vanderploeg, MD. Vanderploeg has been a flight surgeon working with NASA for many years, and along with his colleagues at the University of Texas Medical Branch in Galveston, Texas, represents the "critical mass" of human space biomedical research in the United States.

Vanderploeg has served as guest editor, soliciting and organizing many of the articles you will see in this issue. In addition, I highly commend the roundtable discussion he led, in which important current and future space biomedical issues are highlighted and debated.

In addition to the review article authored by Vanderploeg, he and Richard Leland (president of the NASTAR Center) collaborated on an article for *New Space* highlighting NASTAR's role in research of this type and the value of their contribution to studies that advance the understanding of human responses to the G profiles encountered during commercial spaceflight.

I hope you enjoy this special issue. The good news for those extreme adventurers in the new space readership is that it appears almost anyone can undertake at least a short ride into space!

Scott Hubbard
Editor-in-Chief
New Space

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The Next Generation of Space Explorers: Those Who Will Carry the Dream Ahead

Scott Hubbard

Editor-in-Chief

Late in 2013, I was asked to give the kickoff talk at a workshop devoted to an updated analysis of whether sending humans to Mars by the 2030s was now an affordable goal. As I was giving my presentation, I noted the amount of gray hair and high average age of the group. A long-time colleague of mine was one of the organizers, and I remarked to him, "We're both in our 60s! Where are all the young people to do the next round of heavy lifting?"

I'll be almost 66 years old when this article appears. One of the most visible and vocal advocates of going to Mars, Apollo Astronaut Buzz Aldrin, is now 84. The average age of the Apollo NASA team (in short-sleeve white shirts and pocket protectors) was 32 in the 1960s!

To be sure that there were older experts providing guidance during that past golden age—Theodore Van Karman, the Hungarian American father of many aerospace principles, was born in 1881 and would have been 81 when Kennedy made his famous speech about going to the Moon. Werner von Braun, the German rocketry expert behind the *Saturn V*, was in his 50s during the Apollo era; Max Faget, the designer of *Mercury* capsule, was in his mid-40s at the same time. Great events almost always have their roots in past accomplishments. Nevertheless, when Gene Krantz told the Apollo 13 ground operations crew in 1970, "Failure is not an option," he was only 37.

In this issue of *New Space*, I decided to give some of the next generation a chance to let their voices be heard and act as "guest editors" providing a wide-range series of articles. One of the two leaders in defining and selecting the space generation material is my recent PhD graduate student from Stanford, Ashley Chandler Karp—now at Jet Propulsion Laboratory. I predict that Ashley will be a leader in our field!

As with previous *New Space* issues, the first major section is our roundtable. Ashley and her colleague Alan Steinberg have selected an outstanding group of participants who cover most of the key student and young professional space groups: Christopher Vasko (cochair, Space Generation Advisory Council [SGAC]/applied physics PhD student), Ryan Kobrick, PhD (executive director, Yuri's Night*/Space Florida), Hannah Kerner (chair, Student Exploration and Development of Space/computer science masters student), Victoria Alonsoperez (cochair SGAC/cofounder IEETECH & CloudStat), and Brad Cheetham (University of Colorado research associate/aerospace engineering PhD student).

Other key articles include "A Perspective on the Space Generation" by my long-time friend and colleague Prof. John Logsdon. John is now an emeritus professor at George Washington University, where he taught space policy in industry and academia to many, many professional staff members now working on Capitol Hill. You will also find descriptions of the Stanford Student Space Initiative as well as commentary on the burgeoning use of social media in space education.

I found editing this special issue to be very encouraging. The dream of exploring deep space is far from dead; these students and young professionals prove it!

Scott Hubbard
Editor-in-Chief
New Space

*Yuri's Night celebrates the first human into space, Yuri Gagarin. Although Yuri was a Soviet citizen and part of the "space race," his groundbreaking flight is now widely acknowledged in events across the world—including the United States.

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Commercial Space for Almost Everyone

Scott Hubbard

Editor-in-Chief

In this issue, we address two commercial industries: one a long-established "money maker" that touches many millions of people, and one on the horizon that might follow soon. There are several ongoing assessments of the financial impact of "commercial space." The best-known document is probably the Space Foundation's annual *Space Report*, but there are others as well. One common point of agreement is the dominant role of space telecommunications in a global space economic enterprise. What began as a demonstration Comsat, Telstar, in 1962 has flourished into a nearly $200B industry.* To be certain, this number includes the distribution networks as well as the cost of satellites and launchers, but however one slices the pie, it is a lot of money—accounting for ~70% of the worldwide space community.

In addition, the communications industry is as pure a commercial effort as can be. The only government roles are to license the launch and transmission frequencies. Companies such as Space Systems Loral (SSL) and others routinely contract for the development and launch of such satellites on a firm fixed-price basis. Satellite operators like SES have made bandwidth essentially a commodity, available on demand. Satellite-based television (the so-called direct-broadcast satellite [DBS]) touches perhaps billions of people worldwide. In his Economist's Corner, Dr. Ward Hanson provides a thought-provoking and insightful analysis of the direct and indirect effect of satellite communications in its competition with cable and the Internet. One of the goals of *New Space* has been to create an interdisciplinary intersection of the science, engineering, business, and entrepreneurship. Ward's column demonstrates we are getting there!

On the horizon is remote sensing that may touch nearly as many people. About 10 years after Telstar, what was to eventually become Landsat was launched with the first Earth Resources Satellite in 1972. Over the years, responsibility for the Landsat series of Earth remote sensing satellites moved from NASA to NOAA and a substantial effort was expended in trying to make such imaging "commercial." Unfortunately, the technology of the time and the business case significantly limited any commercial success. Paying a considerable fee and then waiting weeks for hard-copy pictures didn't work. It wasn't until Landsat provided images for free and posted them on the Internet that companies such as Google Earth began to create a commercial business through searchable data supported by advertising. Companies such as Digital Globe have managed to create a specialized remote sensing niche by developing their own spacecraft such as Worldview and selling the high-resolution imaging. However, the primary customer remains the government even though the transaction is a "commercial" contract.

In this issue of *New Space*, my associate editor Ken Davidian and I decided to highlight a nascent entrepreneurial remote sensing industry by incorporating the regular roundtable discussion with an Emerging Industry Space Leaders (ESIL) conference. In attendance were representatives of Urthecast, Loral, Skybox, and Dauria Aerospace. I think you will find the discussion of what these entrepreneurs are planning and already doing to be fascinating and energizing.

Many readers will know that one of these startups—Skybox, a company proposing to create a fleet of small spacecraft selling imaging in the 1-meter range—has just been purchased by Google for $500M. Another competitor, Planet Labs, has a major venture capital investor in Steve Jurvetson of Draper Fisher Jurvetson. Planet Labs has created a constellation of very small spacecraft that will provide imaging in the 3-meter range with high repeat coverage.

While the new ventures are quite understandably holding their business cases "close to the vest," it is not hard to speculate that a very wide range of citizens and companies such as farmers, land use planners, transportation companies, and even big box stores with large parking lots could use this data. With high repeat coverage, perhaps as short as hours, this imaging could assist economies around the globe.

A companion discussion examining the economics of commercial remote sensing with Greg Autry, Ward Hanson, and Bruce Pittman rounds out the analysis of what may well be an explosion of space data available to nearly everyone. Sixty-five years ago we could not guess where the transistor would lead. Thirty years ago we had no idea where the Internet would take us. A constant feed of imaging from space may have a similar impact.

**Space Report*, 2014.

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We *Can* Send Humans to Mars Safely and Affordably

Scott Hubbard

Editor-in-Chief

The dream of humans on Mars has been part of science fiction for well over a century. Engineering such an undertaking was described a little over 60 years ago by Werner von Braun, first in German and then in English.[1] Von Braun's calculations and overall approach have held up rather well over the years—in part due to the rocket scientist's brilliance and in part due to the fundamental physics of launch requirements. A human mission to Mars was proposed by von Braun and NASA as the logical follow-on to Apollo, but cost considerations and the politics of the Nixon post–Vietnam War era put an end to the dream. As my friend and colleague Prof. John Logsdon has chronicled,[2] it is extremely unlikely that we will once again experience a "Kennedy moment" where NASA receives 4% of the federal budget for a crash program built on an international "space race."*

So, another approach that is pragmatic, affordable, and executable must be found if as a nation we want to explore the red planet in person. One such approach is contained in this issue of *New Space*. An original article by Price, Baker, and Naderi of JPL describes a long-term, cost-constrained program that utilizes as much existing technology as possible and yields a human mission to orbit Mars in 2033. A landed mission then follows in 2039. To create such a program though, a number of boundary conditions had to be satisfied and a series of constraints understood.

Over the past 40 years, I've given many presentations on space science, technology, and exploration. Invariably, someone will ask, "What is the possibility of humans traveling to Mars?" My answer for many years was typically threefold: (1) major engineering developments are required in propulsion, life support, and the like; (2) the costs must fit a plausible NASA budget; and (3) the effects of the space environment, such as prolonged weightlessness and exposure to radiation, must be understood and mitigated. I would usually put particular emphasis on item (3) given the previously unknown character of space radiation effects.

Over the past 5–10 years a number of these constraints have changed dramatically. The so-called *Space Launch System*, a *Saturn V* equivalent, and the new *Orion* crew capsule are under development by NASA. NASA is also poised to save money as they transfer low-Earth-orbit cargo and crew services to the private sector via fixed-price contracts. A detailed analysis of cost estimates for humans to Mars that were conducted between 1989 and 1998 shows that these assessments are now either irrelevant due to new data or were erroneous to begin with. New cost estimates conducted by the Aerospace Corp. for the Price *et al.* article show a budget profile that fits within reasonable future NASA allocations. Astronaut experience aboard the International Space Station (ISS) for stays of 6 months has demonstrated that there are effective countermeasures for prolonged weightlessness. Finally, a recent presentation on radiation effects by NASA's Chief Medical Officer Rich Williams, MD, states quite clearly that "There are no crew mission health risks at this time that are considered 'mission stoppers' for a mission to Mars."†

With all of these previous technical and fiscal issues addressed, we can again believe that the dream of sending people to Mars is alive. The next step is to build a broad consensus around the goal and *strategy* for a long-term program to send humans to Mars.

I have attended scores of workshops and conferences on exploring Mars. The number of viewgraphs I've seen easily numbers in the thousands. One thing I have learned is that clear goals are necessary, but not sufficient. A critical piece of consensus building is for NASA to embrace a notional set of plans, launch dates, and costs that will provide the framework for international partners and commercial providers to participate. Such a plan by NASA would also go a long way toward easing the concerns of many stakeholders that NASA is adrift with no clear purpose. As part of these plans, handing off the expense of the ISS in 2024 or 2028 will be required in order to provide necessary future funding.

I believe that the space exploration community is at a critical point. There is new public interest in exploring Mars with humans. Long-standing organizations like The Planetary Society (TPS) with 50,000 members have recently gone on the record to endorse an affordable approach for such human exploration, something TPS has not done since the late 1980s.

*Since the end of Apollo, NASA's budget has hovered in the 0.5% realm.

†Presentation to NASA Advisory Council, January 14, 2015.

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New entities such as Explore Mars, Inc., Inspiration Mars, and Mars One have garnered large-scale interest. While the engineering and business case of Mars One have drawn a great deal of criticism, the claimed registration of more than 200,000 people for a putative 1-way trip to Mars is not easy to dismiss.

Hollywood has also entered the fray. Two major motion pictures are underway: One, *The Martian*, based on the best-selling book by Andy Weir and directed by Ridley Scott, will debut November 25, 2015. The other movie, tentatively titled *Out of This World*, has signed *Ender's Game* star Asa Butterfield to portray the first child born on Mars. Art imitates life and vice versa.

I think we can build a consensus around a long-term Humans to Mars program provided that we acknowledge cost constraints and act accordingly by limiting our appetite for new technology and by pacing the missions to meet our budget. This editorial and the Price *et al.*'s article are intended to stimulate debate on such value propositions and see if we all agree. The alternative is to concede the human exploration space frontier to others.

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Space is a Global Enterprise—$300B per year!

Scott Hubbard

Editor-in-Chief

A few weeks ago, I was asked to speak at a Global Innovation Conference sponsored by the International Astronautical Federation (IAF) and held at a grand old palace in downtown Munich, Germany. I learned that some of the organizers were concerned about attendance. Would Europeans feel the same space entrepreneurship energy that emerged in the United States—leading to SpaceX, Skybox, OneWeb, and others? The IAF leadership need not have worried. Five hundred people crowded the hall and for two days listened to both American and EU experts discuss innovation and the wave of new space business that is appearing all over the world. My own takeaway from the conference was that there is a drive and indeed even a hunger to see space industry and innovation flourish globally.

In this issue, *New Space* acknowledges the global nature of space, both on the cover and in the content. We have collected an excellent portfolio of articles that discuss emerging space issues in a variety of countries such as Italy, Canada, and India. In addition, this issue has articlles that address capabilities and initiatives that have or might cause a global impact.

Satellites that provide us all with positioning and navigation are a hotly debated national enterprise—every country seems to want its own constellation—but can these services be considered a "public good" as one article argues? In addition, the Economist's Corner addresses a new phenomenon known as OneWeb—one of several ambitious initiatives to launch hundreds of low Earth orbit (LEO) satellites and thereby provide internet service to the four billion residents of planet Earth who currently are not connected to the net. Our economist, Dr. Ward Hanson, provides some cogent analysis of what these trends might mean for the future.

As my friend Elliot Pulham, the CEO of the Space Foundation, has noted in speeches many times, the non-U.S. worldwide space budgets are now comparable to the United States. And of course commercial space dominates the global space enterprise at >75% of the total value for 2013. Unlike the dawn of the Cold War "space race," many countries and many multinational companies are now investing in space. Developing nations like India and China have made space exploration a priority both as a "badge of accomplishment" as well as for practical benefit. How will they respond to the entrepreneurs who are appearing elsewhere and the ubiquitous cubesats that every aerospace student is building? How will closed societies respond to space-based internet where a ground station serving many citizens might be acquired for as little as $250?

Finally, no discussion of entrepreneurship and innovation would be complete without considering the next generation. I'm pleased to announce that Mary Ann Liebert has established a prize for the best paper by a young researcher. My colleague and associate editor, Ken Davidian, has extensive experience in the prize world, having managed prize programs for NASA a number of years ago. To those younger readers: Please study the guidelines that Ken has drafted in the following article and submit a paper!

Having been a young boy in a small town in Kentucky in the late 1940s and early 1950s, I've seen the transition from telephone "party lines" and no TV to today's media-and communication-saturated environment. Some of the collateral effects have been bothersome. It is difficult to disconnect from a constant bombardment of messaging and have a contemplative moment. On the other hand, widespread data, knowledge, and perhaps even understanding are flowing from the pervasive presence of smart phones, computers, and the Internet. There is no longer only a "priesthood" of men in white shirts and skinny black ties operating mainframe systems. Two billion people are connected in some way or another. We cannot predict where all this effort will end, but I, for one, feel energized to know that spaceborne capabilities may be the enabling tool to bring the world together.

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What Do We Do with the Moon?

Scott Hubbard
Editor-in-Chief

Is it economically possible to include the Moon on NASA's Journey to Mars? Is there a low-cost lunar outpost that might fit within a plausible NASA budget or an international consortia capability? Are there commercial and entrepreneurial opportunities? That is the theme of many of the papers in this issue of *New Space*. The articles are the result of a workshop suggested and hosted by Silicon Valley venture capitalist Steve Jurvetson. The event was chartered to ask whether a human lunar exploration program might be possible for a few billion dollars rather than the 10's of billions or more regularly cited. As my long time colleague, planetary explorer Chris McKay put it to me in a meeting more than a year ago, "Wouldn't there be much less argument over Moon versus Mars if the lunar exploration piece was much cheaper?" It was on the basis of that discussion that we agreed to devote most of this issue to peer-reviewed articles emerging from a low-cost lunar exploration workshop.

I believe that the nation can afford one robust human spaceflight program, but not two. *New Space* recently published a novel approach to human exploration[1] in which the authors outlined a mission to Mars program that was independently costed by the Aerospace Corporation. That study indicated that sending humans to Mars orbit and then to the surface could only be accomplished by ending NASA's contribution to the International Space Station in 2024 or at the latest 2028. In a collateral fashion, while the article employed some lunar or cis-lunar demonstrations on the path to Mars, there was no extensive Moon program included.

NASA's previous human spaceflight program, known as Constellation, envisioned a significant lunar base as well as the launcher and landers that would be required. In a review in 2009 led by Norm Augustine, a blue-ribbon presidential commission concluded that the human spaceflight program was on an unsustainable trajectory.[2] As a consequence, Constellation was cancelled and the commercial cargo and crew initiatives emerged. Along the way, the Moon as a prime destination was displaced by the Journey to Mars.[3]

Those readers who are in their late 50s or older very likely remember John F. Kennedy's speech to Congress in May 1961 (and later at Rice University) in which he boldly stated, *"… that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the moon and returning him safely to the Earth."* Thus began what is often termed "the space race," which of course, originated with the Soviet launched Sputnik in 1957.

During the Mercury, Gemini and Apollo era, NASA enjoyed a National Security priority status—essentially a wartime equivalent footing—and as a consequence almost any budget request was fulfilled. Between John F. Kennedy's speech in 1961 and the last Apollo landing (Apollo 17 in 1972), the program consumed ~$150B in today's dollars (peaking at 4% of the federal budget) and changed the course of human history. That special confluence of international competition, presidential directive, and necessary funding is very unlikely to be repeated in our lifetime.

Nevertheless, more than 50 years later, the debate still rages about whether the Moon is a key destination for human exploration. For NASA and the United States, the horizon goal is Mars, as reflected in the latest planning documents. Conversely, the new director general of the European Space Agency (ESA), Professor Johann-Dietrich Woerner, has stated his desire to build a village on the far side of the Moon. Russia and China have also announced that a human presence on the Moon is a key part of their strategic space goals. Clearly, countries that have never had "boots on the Moon" wish to do so.

By publishing this issue with a major emphasis on low-cost lunar exploration, we at *New Space* hope to highlight new and perhaps entrepreneurial methods of exploring our nearest planetary neighbor while also affordably continuing on to Mars.

One more item to highlight: In this issue, I have begun a new feature called "Voices from the New Space Generation." The underlying concept is to provide undergraduate or even high school age space enthusiasts with a forum to describe their future visions for space exploration. The articles will still be peer-reviewed, albeit with the understanding that the authors are not yet working professionals.

I hope you enjoy both the low-cost Moon exploration articles as well as the "Voices" segment.

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The Elephant in the New Space Room: Risk Identification, Management, and Mitigation

Scott Hubbard
Editor-in-Chief

Although the new space landscape is often filled with discussions of cost-saving technology, mission architectures, or novel business plans, one of the most fundamental topics is risk—how it is identified, how it is managed, and (especially for crewed missions) how it is mitigated. The commercial or entrepreneurial space launch companies all have the goal of substantially lowering the cost per pound to orbit while simultaneously improving the reliability of the launch vehicles. This is a tall order.

At the recent Space Symposium in Colorado Springs, Jeff Bezos gave a rare public talk about his space company, Blue Origin. In that discussion, Mr. Bezos outlined the critical role that he thought repeated suborbital launches using identical engines would play in gaining experience and therefore knowledge of performance. That knowledge, he argued, would lead to improved reliability for suborbital tourism and then orbital launches in the future.

To become routine, space travel must eventually become as safe as aviation, where the chance of a fatality on any given flight is about 1 in 30 million. In the first 50 years of aviation, more than a million aircraft were built—many used multiple times. In the first 50 years of space exploration there were only 4500 launches. Today's NASA commercial crew requirements are for a safety factor (accident rate) of 1 in 270. Clearly, the space launch industry has a lot of experience and knowledge to gain before reaching the aviation safety levels of use and reuse.

Currently, legacy companies like ULA responsible for launch vehicles such as the *Atlas V* point to the very extensive test, analysis, and certification paperwork that accompanies national security launches. That effort, it is argued, is necessary in order to guarantee mission success. It is inescapable that all the work also makes the price per launch much higher than a competitor such as the *Falcon 9*. The question all entrepreneurs who hope to transport people or high-value cargo must answer is, "Can the price and risk both be low"?

This issue of *New Space* features 4 articles that deal with the issue of risk—each article addressing the area from a different perspective. The first article, a perspective, deals with the complex issue of informed consent. Recently, NASA altered the human risk posture for deep space missions (i.e., well beyond low Earth orbit). By accepting higher risk of mortality from exposure to dangers like interplanetary radiation, NASA's chief medical officer can now say that there are no biomedical "showstoppers" for a human mission to Mars. However, does informed consent sufficiently cover all the unknowns of such a major undertaking as the journey to Mars?

Three peer-reviewed articles address risk from an academic framework, a governance view, and finally space insurance. Ocampo and Klaus consider in detail the concept of safety. What does it mean and when is it "safe enough"? Then Langston writes about the ethics and governance of commercial human spaceflight, and finally Gubby et al. consider an oft-neglected topic: space insurance. Most commercial launches (nongovernmental) are covered by insurance. That can be expensive—in some cases up to 20% of the value of the vehicle and payload. Over time, will improved reliability lead to much lower insurance rates? What should an insurer (or reinsurer) plan for in their "rainy day" fund?

The staff of *New Space* and I hope you will find these four articles on the critical topic of risk both informative and thought provoking.

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The Next Wave of Internet: Global Connectivity

Scott Hubbard
Editor-in-Chief

I am often asked, "What are the attributes of entrepreneurial space efforts? How would I know it if I saw it? Is "X (fill in the blank) new space?" Usually this question is provoked by some highly publicized space event, such as the recent arrival at Jupiter of the Juno spacecraft. My answer to the inquiries is that new space initiatives are almost always the intersection of a novel business case, entrepreneurship, and innovative science/technology/engineering. Although I fully expect Juno to yield fundamental insights into the composition of Jupiter and the origin of the solar system, the mission was a product of NASA funding and has no proposed monetary return on investment. Thus Juno is not "new space" in my lexicon.

In contrast, there is a growing competition among some deep-pocketed companies that believe that there is a huge untapped business to be found by providing the 4–5 billion people who do not currently have Internet connectivity with that access. Given that fully 70% of the worldwide space business enterprise of >$300B consists of satellite communications, it is not difficult to imagine that doubling the population reached by the Internet could yield substantial income.

The technology to make this global access goal feasible is very large constellations of small spacecraft in low Earth orbit capable of seamlessly handling (and handing off) billions of bits of data as they rapidly circumnavigate the globe. Such engineering is a challenge in electronics, avionics, navigation, and space communications. In my view, this combination of high business risk, global entrepreneurship, and leading edge technology clearly qualifies as *new space,* and if successful, has the potential to change the world.

To evaluate this emerging endeavor, our journal has invited Stanford economist Dr. Ward Hanson* to prepare an original overview article that analyzes the business case, the technology, and the possible impact of what many call "One Web.†" In the course of discussing the guidelines for this article, it became clear that any analysis of a new effort to cover the Earth with electronic communication would not be complete without comparison with past investments such as the Iridium satellite phone attempt. In a bit of serendipity, a new book by John Bloom called "Eccentric Orbits" provides an in-depth look at the rise and fall of the Iridium venture. Ward Hanson has folded this volume into his article along with some very insightful analysis of what the implications for a "One Web" world might be.

In addition to Dr. Hanson's invited article, the journal is conducting a bit of an experiment in providing insight and information on new space efforts by publishing an edited filing by one of the companies attempting worldwide Internet service. Dr. Hanson obtained the publicly available document that WorldVu Satellites company was required to file with the Federal Communications Commission (FCC). Ward then edited down the document to a manageable 20 pages (from 100) and provided some plain language explanations of the practitioner jargon often contained in required government documents. It is my assertion that providing the type of information contained in the WorldVu document adds needed insight for the new space community. Coupling this background with Ward's original review article seems to be an excellent combination.

As I noted when we began the journal more than 4 years ago, much of the written record on emerging entrepreneurial space is in the form of blogs, newspaper accounts, and advertising by the companies themselves. New Space took on the challenge of being the home for scholarly, peer-reviewed articles that could stand the test of time and provide much greater insight into the details often missing in op-ed or publicity pieces. I invite our readers to read Dr. Hanson's excellent overview as well as the editing FCC filing and see for themselves if this type of approach is informative for emerging entrepreneurial space endeavors.

*Many regular readers of New Space will recognize Dr. Hanson as the author of our periodic "Economist's Corner" commentaries. I urge those who have not read Ward's opinion pieces to refer to previous issues of the journal.

†To be clear: One Web is the common name of one of the competitors (WorldVu Satellites LLC). We use the "One Web" term to be generic and cover the multiple approaches to providing global Internet access.

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India Rising: The Evolution of the Indian Space Enterprise

Scott Hubbard, Editor-in-Chief

Until recently, India—the world's largest democracy and second most populous nation—has followed a relatively traditional path in the development of its space program. Government investment and support has led the way. The Indian Space Research Organization (ISRO) along with industry has created the satellites and launch vehicles that supported their scientific and national security objectives. Now, however, India is beginning to take those critical steps to foster and encourage a nascent entrepreneurial space enterprise. In this issue of *New Space*, we feature two papers that outline the prospects for private space ventures: the obstacles and future promise.

A bit of background: India has produced many excellent space scientists and engineers over the last 50 or more years, although the lack of the appropriate indigenous facilities and infrastructure required many of those individuals to practice their skills in other countries. Space exploration and utilization is one of those endeavors that historically places a heavy burden on the need for specialized capabilities. Building complex satellites and developing launch vehicles is a very capital-intensive business that not long ago was solely the province of government investment. However, modest investments by India led to the launch in 1975 of the first satellite built solely with national capabilities. As of the date of this issue, India has now built and launched 86 satellites.

While many countries have successfully built satellites, the number of countries capable of a national launch capability is much more limited. Nevertheless, India has also persisted in this very daunting enterprise, and in 1980 successfully produced the SLV-3, the first fully indigenous rocket capable of orbiting a satellite. This vehicle enterprise has continued to progress until today, when India is offering launch to orbit as a commercially available service.

Such space exploration by India was largely limited to remote sensing, communications, and national security. When one considers the vast expanse of the Indian subcontinent and the enormous challenges of providing food and clean water for 1.3 billion people as well as the often-contentious political relationship with its neighbors, the choice for a limited budget of investment in a selected set of categories makes good sense. However, this focus has begun to change. In 2009, I had the opportunity to give a lecture at the Rome Science Festival. At the same conference was a representative of ISRO, who described not only the expected earth science missions, but also provided a vision for advanced astrophysics space instrumentation and even a fully Indian robotic mission to Mars. Having been NASA's "Mars Czar," and knowing the huge leap in difficulty represented by a deep space planetary mission, I was at the time a bit skeptical about the latter claim. Thus, it was a surprise to the world when, in 2013, Indian launched the so-called Mars Orbiter Mission that in 2014 arrived at the Red Planet and has been operating successfully ever since.

As documented in the last 4 years of *New Space*, U.S. government space investment has now begun to exist in parallel and collaboration with significant private work. Such trends are now appearing elsewhere. As I noted at the beginning of this issue, India has now begun to embrace and explore methods to stimulate the space entrepreneur. The papers by Rao, Murthi, and others argue that in India, "Space-based services have created a huge and growing user base—which is a unique opportunity for developing space industry and creating high technology jobs. Changing policy environment in India—favoring deregulation; investments and privatization; impetus to manufacturing; intensive co-operation etc. are generating a strong market drive for space activities in India."

The papers suggest that India must "…adopt organizational models that will ensure economic efficiency and position a vibrant private sector." The articles proceed to outline the results of studies and a workshop by the National Institute of Advanced Studies to determine a future Indian Space Policy. Articles such as these clearly demonstrate the international appeal of entrepreneurial space endeavors.

The other articles in this issue include a novel analysis of a "space bank" and our own Associate Editor Ken Davidian's cogent take on what actually constitutes "commercial space." I hope you find those thoughts and the ongoing international flavor as typified by the focus on India to be not only rewarding reading, but also significant contributions to the archival literature.

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New Space and New Developments for the New Administration?

Scott Hubbard
Editor-in-Chief

As I write this editorial, the new administration has only been in office a few weeks, and as is generally the case, NASA and the civil space program are not yet a topic of detailed discussion. Largely because NASA is not a Cabinet-level office, the appointment of a new administrator is often delayed for several months following the inauguration of a new president. After such a transition, past administrators have been nominated in March, April, or even May. So stay tuned—it may be a while before there is permanent new leadership at NASA.

On the New Space regulatory side, where the governing body is the Federal Aviation Administration within the Department of Transportation (DOT), a new DOT Secretary, Elaine Chao, has been confirmed, and the FAA administrator has a five-year term of office that lasts until 2018. The Associate Administrator for Commercial Space Transportation, George Nield, is a member of the Senior Executive Service and thus not a political appointee. So, there's reason to hope that the FAA process for approving commercial launches, including payloads for NASA, will continue smoothly.*

Nevertheless, there are indications of a serious internal administration discussion about New Space versus Old Space. Various news reports suggest there might be some sort of competition in the near future between differing approaches. One suggestion is a "humans to/orbiting the Moon by 2020" initiative. If such a concept were to be pursued, it might pit an entrepreneurial company or private business coalition against NASA. The major questions here of course are, first, would this really advance the cause of deep-space exploration or be considered a stunt? Those of us who remember Apollo 8 circumnavigating the Moon in 1968 might wonder about the value of repeating the mission.

The next question is where the funding for such an initiative would be appropriated. As a practical matter, it is difficult to believe that NASA's Space Launch System (SLS) and Orion crew vehicle would be sidelined. The Republican Senator from Alabama, Shelby, who is currently the Chair of Appropriations, is known a fierce protector of the Marshall Space Flight Center, where much of the SLS work is located. Other influential individuals and organizations also support the SLS, including the Commercial Spaceflight Federation. Is it conceivable that there might be some budget increase for NASA, or are the New Space proponents assuming much lower costs than NASA—much as has been demonstrated by the development of the Commercial Cargo Program?

Finally, and perhaps most importantly, what risk posture would be tolerated? NASA has not had astronauts venture into deep space since the Apollo era, and several New Space providers for Commercial Cargo (SpaceX and Orbital) have had very visible accidents. Both SpaceX and Boeing have moved the first flight of the Commercial Crew Program to 2018 as a result of development delays. The Aerospace Safety Advisory Panel has publicly stated their concerns about the SpaceX "load and go" procedure for fueling the Falcon 9 with astronauts on board, and the Government Accountability Office has made known their worries about the SpaceX Falcon 9 engine turbine blade cracking.

Given this background, will a new administration be willing to accept more risk than has been policy since Apollo? Recall that Mercury-Gemini-Apollo was established as a national security imperative—the equivalent of a wartime footing. Money was (almost) no object, and in order to save time, lower-level tests were often eliminated in favor of a full-up system test. That was a calculated risk that is not standard procedure in today's space program. Three astronauts died in the Apollo I fire, but the program returned to development almost immediately, unlike the years-long hiatus after the Challenger and Columbia Shuttle tragedies. Where will the nation and its leadership stand if there is to be a rapid program to return humans to cis-Lunar space? I will note that the return to flight after the Falcon 9 mishaps have been much shorter than for NASA failures—but of course those missions were for cargo, not human beings.

Let me finish with some notable New Space accomplishments and future proposals. We have portrayed four items on the cover. Starting in the lower left corner is the BEAM—Bigelow Expandable Activity Module—attached to the International Space Station. Bob Bigelow, a Las Vegas entrepreneur (in real estate), has successfully used designs that

*One caveat: as the launch frequency increases, the tiny FAA office responsible for commercial space will need to grow accordingly.

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originally came from NASA and SpaceHab to create the first ever habitat that can be expanded with air pressure. This unit could serve as a model for future deep space or planetary surface living and working quarters. This module was attached with the full help and cooperation of NASA. This is quite an accomplishment for Bigelow Aerospace.

Next up on the cover is the remarkable image of the SpaceX Falcon 9 first stage being successfully and autonomously landed on a barge hundreds of miles east of Cape Canaveral out in the Atlantic. The first step toward reusability of a launch system has been reached. Just watching the online video of this remarkable engineering feat is extremely impressive. Clearly, the SpaceX staff have many reasons to be enthusiastic and optimistic.

The third image depicts a current design for a leading entrant in the Google Lunar X-Prize, Moon Express. If this privately funded effort is successful in meeting the requirements and claims the $20m prize, such an achievement would set the stage for entrepreneurs to provide robotic access for lunar exploration and science at a fraction of the previous cost. Small countries and even individuals could plan on sending payloads to the Moon.

Finally, we included a very forward-looking New Space–type concept by Lockheed Martin called Mars Base Camp. The notion depicted here claims to be able to get a crew of astronauts to Mars by 2028, in orbit around the Red Planet. While no costs were given, the information accompanying the LMCO concept pushes the schedule and advances thinking about how near the exploration of Mars may be.

There is quite a future for space exploration. I hope that the nation's best and brightest join the journey.

A Surprise Commentary Plus Advanced Life Support: Don't Leave Earth Without It

Scott Hubbard

This issue is a two-fer bonus! As regular readers are aware, *New Space* was the first journal to publish the "Minimal Architecture for Human Journeys to Mars" study by the JPL staff.[1] In this issue, Elon Musk has submitted a written version of the SpaceX "Making Humans a Multi-Planetary Species" that he presented at the last International Astronautical Congress in 2016. In my view, publishing this paper not only provides an opportunity for the spacefaring community to read the SpaceX vision in print with all the charts in context, but also serves as a valuable archival reference for future studies and planning. My goal is to make New Space *the* forum for publication of novel exploration concepts—particularly those that suggest an entrepreneurial path for humans traveling to deep space.

I've studied and implemented space exploration concepts and programs for more than 40 years. With that experience, I can say without hesitation that an absolute prerequisite for any viable human space exploration program is a set of procedures, materials, and devices that will provide for the support of life. The natural public focus of space projects is the fire, sound, and excitement of a launch. Indeed, the reliability and cost of the rocket system and spacecraft is fundamental to sustainable exploration. However, once people are involved, the next most important (and often overlooked) systems are the devices that provide air to breathe, water and food (if the trip is long enough), and also protect our fragile bodies from the extraordinarily harsh environment of space.

In addition to the constraints cited above, which are also encountered in aviation and underwater ventures, space has the very special environmental effects associated with prolonged exposure to weightlessness and the ionizing radiation present outside the protection of Earth's magnetic fields. Whether the exploration approach is more traditional and governmental or entrepreneurial, all human mission designers must address life support and how it mitigates the risk inherent in an endeavor such as space exploration.

For flights of any substantive duration (i.e., more than a few hours), life-support systems must perform a variety of tasks in as efficient a manner as possible. So-called Environmental Control Life Support Systems (ECLSS) must scrub CO_2 from the cabin air, recycle liquid wastes to drinkable water, and package solid waste for disposal, among other requirements. The "holy grail" of ECLSS, which has not yet been achieved, is a 100% closed-loop system—in other words, full recyclability. On a voyage of 7 months or more, for example to Mars, taking additional resources such as air, water, and food to make up for losses represents a cost and additional risk burden to the project.

One critical element of the entire life-support system is the "space suit." Protective clothing has routinely been developed for the launch in case of sudden depressurization, as well as for the "spacewalks" that have become a regular part of space travel. The experience of the International Space Station has clearly demonstrated the utility of in-space repair, maintenance, and upgrades to a very complex facility. Future deep-space exploration or establishing a Moon or Mars base will not be any different.

I recall a NASA exploration planning meeting perhaps 20 years ago where our team was fortunate to have several Apollo astronauts in attendance, including Buzz Aldrin. When asked about future needs, Buzz didn't hesitate: "Give us a much better space-suit glove," he responded, and, he continued, "Find a way to clean off the (Moon) dust…." Those of us who are Earth bound fail to realize that even with the low pressures typical of a space suit (4.3 psi), a glove in a vacuum will be extremely stiff and difficult to manipulate. Similarly, the exit and entrance from the Apollo module was complicated by the ubiquitous presence of the surface dust. Mars—the dusty Red Planet—may well be as problematic.

In this issue, we decided to address the complex issues of ECLSS, space-suit design, and the like from a commercial or entrepreneurial view. To that end, we have invited a set of papers from individuals and organizations that have taken on the substantial challenge of future life-support designs. I hope you find this material thought provoking in an area that is critical, but often underrepresented, in the general space-exploration publications.

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The Encouraging Diversity and Vector of New Space Entrepreneurship

Scott Hubbard

For every issue of *New Space*, I have the task and privilege of writing an editorial. Sometimes the topic suggests itself: a change of administration or a new emerging technology such as the space elevator or an entrepreneurial achievement such as reuse of a launch vehicle. Occasionally though, the topic is more elusive. Such was the case for this issue until my colleagues, Ken Davidian and Karen Cloud-Hansen, and I reviewed the amazing array of papers being published. From innovative material processing to several legal and economic analyses to a business case for Mars settlement, this issue is rich in diverse *New Space* topics.

The review of this issue, especially when compared to our first issue almost 5 years ago, also highlights one of the encouraging features of the entrepreneurial space business enterprise. The vector of worthy peer-reviewed publications in our journal is not only positive but also trending toward greater quality. This issue in particular is comprised solely of original articles—those that demonstrate solid scholarship, depth of research, along with the ability to respond to and pass peer review.

As my associate editor, Ken Davidian commented that this collection of papers shows that the innovators are using a variety disciplines and pushing toward novel space business cases, rather than those external disciplines having to "pull" space into them. When we began *New Space*, the goal was to create a peer-reviewed home for the best ideas. That goal appears to be coming a reality and, to me, seems a welcome companion to the welter of press releases and claims in the popular press.

Looking at some specific papers in this issue, I am reminded of a "bumper sticker" thought by one of the visionaries of the early space entrepreneurial enterprise, Jim Benson. Jim founded SpaceDev, now part of Sierra Nevada Corporation, with the idea that "to pay for space, space must pay." I think that Jim's notion was that a purely government-funded space enterprise was unsustainable and that there had to be a "killer app," a space service or product that would be uniquely tied to a presence in space.

Thus far, communications, exploration, and transportation are the leading commercial enterprises. Communication satellites of course dominate the worldwide space business and have for many years. Of the $300b+ space enterprise, fully 75% of the revenue comes from the Comsat business and associated distribution networks. However, with the advent of NASA's Commercial Cargo and Crew Programs, space transportation companies have adapted or been created to supply NASA's exploration goals. Those programs are worth billions to the companies and represent a substantial new space type of economic development. The long-term future of those businesses depends on utilization of the International Space Station, even after NASA steps away. If countries or individuals find utility in low Earth orbit research, then support for the space station or perhaps Bigelow's BEAM habitat will continue to require space transportation such as Commercial Cargo and Crew.

However, the idea that a product manufactured in space would have unique properties is one that has been around since the days of Skylab. In this issue of *New Space*, I point to the Cozmuta and Rasky paper as perhaps an indication of where such a space product might appear. I would not expect there to be an instantaneous transition to large-scale space manufacturing, but if there are very special optical fibers and glasses made in space that have properties unavailable anywhere else, I can foresee this seed growing into a much more substantial plant (pun intended).

My final comment concerns the papers that deal with the legal and regulatory frameworks for space entrepreneurship. Unlike some, I do not subscribe to the idea that the world community needs to reopen the Outer Space Treaty (OST) of 1967. According to space law experts, that Treaty was put into place primarily to exclude nuclear weapons from space. In the current world environment, who knows what would happen if the treaty were renegotiated? The risk is simply too great in order to achieve some hoped for improvement in the commercial space aspects of the OST.

I do believe that U.S. law and regulation can be revised and improved to assist the growth of the commercial space industry. One area that can clearly be addressed is the so-called regulatory gap that exists where no agency has the charter to "authorize and supervise" commercial space activities beyond launch and re-entry. My personal choice is to ask the FAA Office of Commercial Space Transportation to shoulder this duty (with augmented resources if needed.) In any event, I see a growth in the need for space lawyers—a terrifying thought to some, I'm sure.

To our readers: keep sending in those papers. Issue 5.4 promises to be just as rich as this one.

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Keeping the Focus on Mars

Scott Hubbard

My purpose in this editorial is to explain as clearly as I can why I think human exploration as well as robotic science and the space entrepreneur must maintain a focus on the exploration of Mars.

In my lifetime, I have heard four Administrations present a major space exploration initiative. Vice President Pence's recent statements are the latest. To date, the only promise that has become reality was President Kennedy's speech in 1961, where he committed the nation to sending a man to the Moon before the end of the decade and returning him safely.[1,2] It is well worth noting that to achieve JFK's vision required about $200 billion (in today's money) and a budget profile that peaked at 4% of the Federal budget.*

Then there came George H.W. Bush in 1989 and his Space Exploration Initiative (SEI) that promised a return to the Moon (with human astronauts) and then on to Mars. After a now infamous 90-day study, Bush 41's plan was pronounced dead on arrival at the Congress due to a rumored (but never published) ~$500 billion price tag.

George W. Bush made a Kennedy-like proclamation with his talk at NASA headquarters in 2004 that unveiled the so-called Constellation program that would, yes, return U.S. astronauts to the Moon and then on to Mars. (I was in the room as a NASA Center Director for that talk. When a group of us senior folks took a look at the budget assumptions, we were dumbfounded by the math. The plan did not look executable even in 2004.)

Constellation was reviewed by a blue-ribbon committee in 2009, which found the program would require multi-year increases adding about $3B to NASA's annual budget.[3] That path was declared unsustainable and replaced by a much more modest NASA in-house program (Space Launch System plus the Orion capsule) and the beginning of what became the Commercial Cargo and Crew Programs.

President Obama tried his hand at a presidential space statement in 2010 in a speech at the Kennedy Space Center. (I was also present for that talk but now as a Stanford faculty member.) This time the Administration avoided the Moon and proclaimed that U.S. astronauts would dock with an asteroid and then eventually go on to Mars. Obama's speech caused NASA to produce two outcomes: one was the ill-fated Asteroid Redirect Mission (ARM) that never enjoyed the support of Congress, the science community, or even NASA's own Advisory Council.[4] The other result was a NASA Journey to Mars that was constructed in a series of phases that would retire risk and eventually get humans to Mars in the 2030s. The most recent Journey to Mars approach adopted an approach to orbit Mars with humans first, then land in a subsequent mission. That plan was championed by a paper published in this journal[5] and a workshop I co-chaired.[6] While NASA's Journey was not highly detailed, most of us in the Mars community thought it built on a reasonable set of assumptions and might be contained within a plausible budget if appetites were limited.

Very recently, in October 2017, the new Administration, through Vice President Pence, has announced both to the resurrected Space Council and in an Op-Ed that NASA should study a plan for "human missions to the moon" as a "stepping-stone" for later human missions to Mars.[7,8] Pence also called for a "full review" of commercial space regulations to identify areas that can be streamlined.

In the narrative thus far, you should have noticed a trend: these human space-flight initiatives ultimately required large amounts of funding to be successful, but except for Apollo, that funding never appeared and the program was canceled. So, we must ask, what are the risks and rewards of Pence's proposed path?

During the Augustine review, one of the "budget busters" of the Constellation plan was the cost of developing a full human-rated lunar landing system plus infrastructure in addition to new launch vehicles.† Clearly, a major cost risk in Pence's plan will be the same. By adding human surface lunar missions, one of two things will likely happen: the new costs will push back the Journey to Mars to some date much further in the future than 2033 *or* some other part of NASA will be cut to make up the difference.

There may be other ways to mitigate the cost risk: adding international partners, adopting a minimum lunar plan such as the minimum Mars approach, or perhaps using some acquisition strategy such as the Commercial Cargo Program. Pence's statements did not explicitly suggest these possibilities, although a subsequent message from Acting Administrator Lightfoot clarifies: "Specifically, NASA has been directed to

*Logsdon has argued rather convincingly that the set of circumstances in the JFK era will not be repeated again.

†The other major budget issues identified in the report were that NASA could not afford to continue the Shuttle Program and sustain the Space Station indefinitely.

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develop a plan for an innovative and sustainable program of exploration with commercial and international partners to enable human expansion across the solar system, returning humans to the Moon for long-term exploration and utilization, followed by human missions to Mars and other destinations."[9] In my opinion, asking for a realistic cost assessment of this new plan should be clearly demanded by all stakeholders, including the public.

What are the benefits of making lunar surface exploration part of the future NASA plan? In my view, the only unambiguous value is perceived U.S. leadership. The European Space Agency (ESA), as articulated by Jan Woener, the Director of ESA, has for several years been calling for a "Moon Village."[10] The Chinese have publicized plans to send humans to the Moon and have already landed a robotic mission in 2013. I can imagine a politically sensitive Administration desiring to counter the claims of the Chinese, even at the expense of delaying the real prize—exploring Mars.

The Moon is scientifically much less diverse and interesting than Mars. For example, no one claims that life could have originated on the Moon—unlike Mars. The technologies needed for landing and living on an airless body like the Moon are quite different from Mars. Lunar technologies will have limited benefit to future Mars exploration. Finally, some claim that the Moon's resources, especially water ice, can be exploited for future exploration. In general, the Moon is extremely dry. There are data from previous missions to suggest that there may be more abundant water ice trapped at the poles of the Moon, but getting there and mining in temperatures nearing absolute zero will prove very challenging and expensive. By comparison, Mars has water in much greater concentrations distributed more broadly across the planet.

In the meantime, NASA's science organization is moving ahead with planning for what some have long considered the Holy Grail of planetary science: a Mars Sample Return mission. The first leg of the Mars Sample Return campaign is well into development: the Mars 2020 mission with its sample caching hardware. The other two elements of the return—collecting the sample tubes and sending them back to Earth—are now being openly discussed.[11] These carefully selected samples hold the promise of giving us an answer to whether life ever emerged on Mars. This is a truly profound question.

As described above, there are now the beginnings of some well thought out affordable humans to Mars plans. And last but certainly not least, the door appears open for commercial and entrepreneurial entities to engage in the deep space program. Elon Musk's vision for going to Mars first stated in 2016 and recently updated[12,13] holds out the potential for drastically reducing the cost of transport to Mars. This issue of *New Space* contains the details of how Lockheed Martin Corporation (LMCO) would create a Mars Base Camp.

I strongly advocate completing the Mars Sample Return. That initiative alone will show continued U.S. leadership and perhaps provide answers to the most fundamental questions humans ask: "Are we alone?" I also believe that any future human exploration plan must keep moving toward Mars for all the reasons described earlier. And if even part of the SpaceX or LMCO Mars plans are executable, these innovators can play a critical role as well.

To end up where I began: from almost any perspective, Mars is the goal for human and scientific exploration. As taxpayers and citizens, we must challenge this Administration to demonstrate how including a human lunar surface program and in parallel continuing the Journey to Mars will be affordable and sustainable. These are very exciting times for space exploration and must not be derailed by an abrupt shift in direction.

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An Embarrassment of Riches

Scott Hubbard

This editorial will be brief. Our first publication of 2018 is not only a special issue devoted to the research of the Center of Excellence for Commercial Space Transportation (COE CST), but also leads with Elon Musk's *Making Life Multiplanetary* presentation from the International Astronautical Congress held in Adelaide Australia, September 29, 2017.

The genesis of the COE CST special issue began long ago during conversations with my associate editor, Ken Davidian. Ken serves as the Director of Research for the FAA's office of Commercial Space Transportation and as such plays a critical role in guiding the efforts of the principal investigators at the various universities that comprise the COE CST. I was fortunate enough to be the director of the Stanford COE CST for the first five years of its existence. *New Space* was designated as the official journal of the COE CST some time ago, and while individual research work has been published, there has never been the opportunity to showcase the full range of work until now. Ken's overview right after Elon's article does an admirable job of putting the last eight years of the COE's existence into focus.

Elon Musk's visionary presentation from 2016, *Making Humans a Multiplanetary Species*, which was published in *New Space* issue 5.2, has been downloaded an astonishing **499,969** times! Subsequent to the initial presentation, ongoing engineering and design work led Mr. Musk and the SpaceX team to revisit the Mars architecture and vehicle design. That re-engineering led to an update at an international space meeting in September. As with the original presentation, *New Space* is presenting the SpaceX material with accompanying graphics. We at *New Space* hope you find the Perspective and the COE CST special issue a valuable addition to the literature.

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Mr. Bridenstine's "To Do" List

Scott Hubbard

In a recent, party-line 50–49 vote, the U.S. Senate confirmed James Frederick "Jim" Bridenstine's nomination to be the NASA Administrator. This was a historically close vote. Since NASA was created in 1958, the space agency has been considered not only bipartisan but, perhaps, nonpartisan. The extraordinary contributions of NASA to the nation's worldwide prestige, technology, high-tech jobs, scientific discovery, and public inspiration have been countless and usually engage both sides of the aisle.

In the current environment though, where science is under attack in many quarters, Bridenstine's prior comments that questioned anthropocentric climate change nearly torpedoed the nomination. Although Bridenstine has since recanted and now acknowledges human contributions to climate change, another widely circulated criticism was Bridenstine's lack of technical knowledge or experience in the space realm. These concerns and others led to confirmation by a whisker.

All of these factors suggest to me that Mr. Bridenstine has a substantial task ahead of him in leading the agency in the U.S. Government with arguably the most technical mission of any. Here's my personal "to do" list for the Administrator.

First, Mr. Bridenstine must establish the mutual respect for and necessary cooperation with the approximately 20,000 civil servants and 60,000 contractors that are directly employed by NASA.

NASA is not a monolithic organization. There are 10 NASA centers: some that focus on human space flight and launch capability, some largely devoted to science and scientific missions, and a few that mostly conduct advanced research. While NASA's origins in the cold war and roots in military aeronautics provide some culture of top-down command and control, there is also a questioning attitude that is part of what makes NASA special. Famously, a previous NASA official who came from the military was known to have stated that only in NASA was a direct order considered an invitation to a debate…

Jim Bridenstine might remind the employees that he has been deeply interested in the future of the nation's space program before he was nominated. In the American Space Renaissance Act document presented at the Space Symposium in 2016, Bridenstine described his thoughts about commercial and civil space in particular. For a Congressman from Oklahoma (not home to a NASA center) to spend that much time on the future of space was quite interesting to me at the time—and represents more than a passing engagement.

And there is no substitute for visiting each center to become personally familiar with the nuance and culture of each. As a former elected official, Mr. Bridenstine must be aware that each institution has a devoted group of Representatives and Senators who jealously guard the jobs and role of the center. An administrator who ignores this political reality will find ongoing resistance when leading the agency.

Second, the new administrator must provide NASA and the rest of the world much more clarity on the brief statement issued by Vice President Pence and the newly revived Space Council that the United States will "lead the return of humans to the Moon." Studies of the future of human space exploration have for decades emphasized that Mars is the target of greatest interest for reasons of science and exploration.[1–4] The last initiative that attempted to include both human landings on the Moon and eventually Mars, the so-called Constellation program, collapsed from its own budgetary (over) weight.

Using international collaboration, commercial providers, and some clever operations in the lunar space, it may be possible to lead the return of humans to the Moon and also keep the Mars goal in clear focus. Cost control, rigorous execution, and careful program management are paramount. I also implore Mr. Bridenstine to avoid the politicization that seemingly appears everywhere. The Moon is not a Republican and Mars is not a Democrat! These are space exploration destinations for the good of all humanity.

Third, Mr. Bridenstine must realize the value and strength of the U.S. science community. Over the past 50+ years, the scientists, technologists, and engineers who create and support NASA programs have devised a mechanism to provide the Agency with sound advice on the future strategic directions for science missions. Through the National Academies of Science, Engineering and Medicine, the so-called Decadal Surveys have defined the gold standard for planetary science, astronomy and astrophysics, Earth science, and heliophysics. By committing to support the recommendations of these Surveys, the new administrator will send a strong signal that he understands the scientific process and is committed to the best possible programs for each discipline.

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Of course, such missions must be constrained by cost realism. In this vein, I applaud Thomas Zurbuchen of the Science Mission Directorate for proposing the "lean" Mars Sample Return (MSR). MSR has been a Holy Grail of planetary science for more than 40 years and is currently the top strategic priority of the Planetary Science Decadal Survey. Supporting fiscally and scientifically sound initiatives such as the lean MSR will garner much support for Bridenstine. Similarly, an even-handed treatment for Earth science, ongoing funding for heliophysics, and seeing a successful launch for the Webb Space Telescope for astrophysics will underscore support for a major element of NASA's portfolio.

Finally, Mr. Bridenstine should study the previous, nontechnical administrators. Two such examples come to mind: James Webb and Sean O'Keefe. Webb was a lawyer who knew well the processes of Washington and Capitol Hill. Webb provided powerful leadership during the Apollo era, and history indicates he was crucial in ensuring the success of the United States in the "Space Race" of the 1960s. However, Webb was sufficiently astute to have two deputies who were world-class engineers: Bob Seamans and Hugh Dryden.

My own experience as a Center Director was with Sean O'Keefe who came from the Office of Management and Budget and was known as a financial management expert. Sean selected an astronaut as his deputy and was known to ask his staff to read *Powering Apollo*, the story of James Webb's experience. O'Keefe appointed me to be the Center Director of NASA Ames and, when the Columbia Shuttle accident occurred, asked me to serve as the sole NASA representative on the 13-person failure review group. The recommendations that emerged from the Columbia Accident Investigation Board (CAIB) were partly very technical fixes and also a critique of management failures in a high-risk environment. To his credit, Sean embraced the entire CAIB report and set about implementing each recommendation. As far as I could tell, any political considerations about the findings were set aside in the interest of fixing the problem and getting back to flight.

Mr. Bridenstine should surround himself with the most highly qualified individuals he can find who understand both the ambition and risk that is inherent in NASA's visionary mission. Every space professional I know wants NASA to succeed at returning humans to deep space and successfully executing the scientific and aeronautics goals of the agency. It is my fervent hope that Mr. Bridenstine will fully embrace a bipartisan leadership role, engage the emerging space entrepreneurs, and provide international leadership for the crown jewel of U.S. exploration capability.

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Pivot to the Moon: Apollo 2.0 or a Lunar Business Case?

Scott Hubbard

Announcements from the Administration about a shift in space policy toward the Moon as the next deep space destination for humans began with a Space Policy Directive on December 11, 2017.[1] While the notice emphasized the incorporation of commercial and international partnerships, details were scant.

In subsequent presentations by NASA, schedules were shown that indicate NASA plans to partner with companies to fly small robotic landers carrying scientific instruments to the Moon, possibly as soon as next year. This step would initiate public–private partnerships that aim to help companies develop increasingly capable landers presumably faster and at lower cost than NASA could on its own. Reports indicate a medium-size lander could fly a demonstration mission as soon as 2022, helping to inform the design of a larger human-class lander.[2] This approach sounds appealing, but what business model will enable this approach? Can the so-called COTS (Commercial Orbital Transportations Services) competition using a Space Act Agreement that kicked off the Commercial Cargo Program be utilized where at present there is no customer base other than governments? Will entrepreneurs and legacy companies be amenable to fixed-price contracts for ferrying cargo and perhaps ultimately crews to the lunar surface?

Other news reports indicate that rather than the so-called flags-and-footprints model of lunar exploration with short-term stays, the United States now hopes to establish a long-term presence on and around the Moon. The centerpiece of the new system will be what NASA calls the Lunar Orbital Platform-Gateway—essentially a space station in lunar orbit.[3] Such a Gateway has been in the planning stages for a number of years but does not address the major expense associated with human-rated landers. In the previous Constellation program, the development cost of the lander was easily in the many billions of dollars and contributed to the cancellation of Constellation.

All of this early information still raises the question of NASA's ultimate goals and budgetary exposure. The head of the European Space Agency (ESA), Jan Werner, has promoted the idea of a Moon Village where many countries could participate in the development and operations of a long-term lunar base. But what investment does ESA plan to make? Will they take on the cost of a lunar lander or major element of a Moon base? And would ESA provide this hardware via some innovative industry arrangement?

It is instructive to review a bit of history, since those who do not learn from it are doomed to repeat it, says the philosopher Santayana. A recent article in this journal by Kim[4] documents quite thoroughly the extraordinary expenditure that was required to make the Mercury-Gemini-Apollo program a success. A peak spending of 4% of the Federal budget was needed in order to complete the race to the Moon by 1969. Eventually the cost, combined with waning enthusiasm, led Richard Nixon in 1975 to remove NASA's national priority and reduce the budget to <1% where it has remained ever since.

In my view, an Apollo 2.0 effort by NASA alone would be unsustainable. If attempted, the resource requirements would guarantee that exploring Mars—the real prize—would be put off for another generation. Some have suggested that if NASA is stuck on the Moon, others might step into the breach. Much in the same way that the United States responded to Sputnik with Apollo, might some other country with substantial resources such as China or even SpaceX with the "Big Falcon Rocket (BFR)"[5] leapfrog NASA and its partners?

So, where does that leave us? While I was part of a team in 1999 that developed the stepping-stone concept of near-Earth, then deep space, Moon then Mars, I have become skeptical of the argument. There are significant differences between the Moon and Mars: atmosphere, gravity, light travel time, resources (regolith* and water ice), temperature range, radiation environment, science value, and so on. These very dramatic distinctions make me doubt that there are many lunar resources, technologies, or mission architectures that will provide significant benefit to the human journey to Mars. Realistically, I think that each destination will largely need its own development and tools. As a minimum, a non-advocate study is required.

What would be a reasonable argument to proceed with some focus on the Moon? I can think of only two: geopolitical cooperation and gaining greater experience living and working in deep space. Of those, the incorporation of the Moon Village would provide a worldwide basis for further

*Regolith defined as rocks and dirt near the surface.

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human exploration, somewhat analogous to the geopolitics that was the context for developing the International Space Station (ISS). Arguing that humans need more experience operating further from Earth has been put forward before, but was never constrained by a time limit. Let's set some schedules and define a *minimum* lunar architecture as has been suggested for Mars.[6] Keep the 2033 goal for a human mission to Mars.

Here's what I propose for NASA and the world space community: let's create an interdependent coalition (as was done for the ISS) for deep space human exploration, but make the participation contingent on collaboration on both the Moon *and* Mars. Set out a schedule with milestones that clearly show that the progress to be made with a minimum lunar architecture that could plausibly, in a brief time, enable continuing the journey to Mars. Invite all spacefaring nations, including China.

Create a COTS-like competition with Space Act agreements for key transportation and habitats to the Moon and Mars that would allow entrepreneurs to propose and bid to provide goods and services for exploration. Ask ESA and other nations to do something equivalent.

In the end, I want to argue for keeping our eyes on the science prize: understanding whether life ever formed or is still present on Mars. A positive answer to this question would be perhaps the most profound discovery in the history of humanity. As I write this column, a peer-reviewed paper in the prestigious journal *Science* has just appeared that provides the first ever data showing a 20 km pool of stable liquid water about 1.5 km below the south pole layered deposits.[7] This measurement using a radar instrument on board the European Mars Express mission presents the very real possibility that if life formed on Mars, it might still be present in a pool of water. The paper goes on to speculate that other such pools may exist.

However, 1.5 km drilling is out of the current technology capability for autonomous robotic systems—but maybe not human-tended systems. Along with others, I have argued that a human presence on Mars will advance our understanding of fundamental questions much more rapidly than robots alone. Let's use the Moon as needed to advance exploration, but get human scientists to Mars as soon as we can!

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Living off the Land: A Business Opportunity for the Moon and Mars

Scott Hubbard

As noted in the previous issue of New Space,[1] the current Administration is pursuing a human space flight policy of returning to the Moon with commercial and international partners. Then, so goes the stated plan, technologies and mission architectures developed for lunar exploration will facilitate the human journey to Mars.

There are profound differences between the environment of the Moon and Mars. Those differences (atmosphere, gravity, distance, surface composition, and so on) severely constrain any claim of broad applicability. Nevertheless, a group of advocates for the human exploration of Mars gathered in August 2018 in Washington, DC, to discuss the potential for lunar exploration to "feed forward" for the journey to Mars.[2]

The workshop, dubbed Achieving Mars workshop number 6 (AM VI), was attended by 70 self-selected members of the human spaceflight community with a smattering of planetary scientists, related technologists, and some industrial/commercial providers. Many of the participants were from NASA, a not-unexpected outcome, since the domain of human exploration has traditionally been almost exclusively NASA and other governments. In addition to technical issues, there is almost always an economic subtext to this type of meeting. Having participated in many such conferences over the past 40+ years, I can say without hesitation that NASA staff are fully aware that any redirection of NASA's ~$8 billion/year human spaceflight programs involves thousands of jobs and huge amounts of funding. If you work for NASA or the industry, it is in your best interests to attend such a workshop—and attempt to influence the outcome.

As a consequence of the underlying factors described above, one cannot regard the AM VI recommendations as free of bias or self-interest. However, as a participant in both the workshop and subsequent report writing, I can say that in general the attendees and conference leadership made a sincere effort to achieve balance and consensus. The outcome of the efforts resulted in a document that identifies a relatively small number of technologies and engineering developments that if utilized for the Moon may assist in the future human exploration of Mars.[3]

From the recommendations put forward, one, in my view, stands out as absolutely critical to creating a sustainable future of human exploration on the Moon or Mars: that technology is, in the inimitable parlance of NASA, *in situ* resource utilization or ISRU. In simple terms, ISRU means living off the land. There is no believable mission architecture that plans for astronauts to take all possible supplies with them for exploration lasting months or years. Using regolith (soil), atmosphere (if one exists), and all-important water ice deposits to create water, oxygen, building materials, and rocket fuel is a critical element of long-term exploration and settlement.

The latest novel by Andy Weir (of *The Martian* fame), *Artemis*, speculates on the business case that might emerge if a private lunar settlement were to be established. Oxygen production would be pivotal (and very lucrative) in any such enterprise. Without being a spoiler, let's say that key plot elements hinge on who controls the ISRU of the Moon.

Science fiction aside, in recognition of the long-term importance of ISRU, AM VI called for a National Academy of Science (NAS) study of ISRU for the Moon and Mars. Beyond the fundamental importance of living off the land for sustainability, there are several reasons why I believe such a study is required:

1. NAS studies are the gold standard for advice to the nation. Exquisite care is given to selecting a panel with the correct expertise, balancing perspectives, and achieving consensus.
2. Sufficient time (usually three to five multi-day meetings, plus months of writing and editing) is devoted to hearing from advocates/experts in a public setting, as well as opportunities for deliberation and (often) intense debate internal to the panel.
3. An ISRU study would serve as a practical bridge between the robotic science and human spaceflight (HSF) communities—a collaboration that has long been sought by some, including me. The science community would learn about the special constraints that accompany human exploration, and the HSF groups would be confronted with what scientists and mission data say (and do not say) about the composition of the Moon and Mars.

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4. Finally, all consensus reports of the NAS go through a peer-review process by a completely separate panel of experts, just as is done for top-quality journal articles.

To highlight reason (3) above, let me cite one example. Administration officials have recently touted water on the Moon as the exciting finding that would lead to long-term lunar exploration.[4] While the paper cited does indicate there may be some water ice deposits where the water ice mass fraction approaches 30%[1] (as opposed to a few percent), all the inferences were drawn from remote-sensing measurements by previous missions such as the U.S. built M3 (Moon Mineralogical Mapper) aboard the Indian Chandrayyan-1 spacecraft. To date, there has been no *in situ* confirmation that such deposits exist or a dispassionate evaluation of the difficulty of mining in a shadowed region where the temperature is near absolute zero (40 K).

By comparison, the near-surface water ice on Mars with a mass fraction up to 80% at the poles has not only been detected by remote-sensing instruments on multiple spacecraft but also validated by the landed Phoenix mission. Buried glaciers the size of New Mexico have been identified on Mars, and recently there was the announcement of the detection of a "lake" perhaps half a mile beneath the surface.[5] Add to these data the existence of an atmosphere on Mars (unlike the airless Moon) plus surface soil that can be processed, and it is clear that we currently have better ISRU data on the Red Planet than the Moon.

To me, that one example of science-based analysis with significant engineering implications is more than enough reason to ask the Academy to evaluate ISRU. But if the outcome is a positive one, the potential for some entrepreneur to step in and process the lunar and Martian resources for future explorers (or settlers) represents the promise of *New Space*. The basic premise of Andy Weir's latest book may not be so fantastical after all.

[1]For comparison, the samples returned by Apollo show an extremely dry surface. Other missions such as Lunar Prospector and Lunar Reconnaissance Orbiter indicate water ice in shadowed regions of 4%.

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