

Proceedings of a Workshop

IN BRIEF

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America's Future in Civil Space

Proceedings of a Workshop—in Brief

Since the National Research Council released the report *America's Future in Space: Aligning the Civil Space Program with National Needs* in 2009,¹ numerous changes have occurred in the civil space arena. In May 2017, the National Academies of Sciences, Engineering, and Medicine convened a workshop on *America's Future in Civil Space* with several objectives:

- Review the history of U.S. space policy and how it might form a broad policy basis for twenty-first century leadership in space.
- Examine the balance and interfaces between fundamental scientific research in space, human space exploration, robotic exploration, earth observations, and applications of space technology and civil space systems for societal benefits.
- Discuss the value, purpose, and goals of international cooperation in space.
- Discuss the role that the evolving commercial space sector could play in fulfilling national space goals and the role of the government in facilitating the further evolution and success of new actors and new modes of working with the commercial sector.
- Highlight the challenges in maintaining the sustainability of outer space activities (including the role of space traffic management).
- Highlight options for government attention to address and potentially resolve problems that might prevent achieving key national goals.

The workshop participants sought to capture what has changed, determine how to harness new opportunities, and decisively inform and encourage bold and timely implementation. To start these discussions, four speakers—Dan Mote, Alan Epstein, Fiona Harrison, and Robert Lightfoot—gave preliminary remarks. The president of the National Academy of Engineering, Dan Mote, welcomed the participants and recounted the history of the Academies providing the National Aeronautics and Space Administration (NASA) and other government agencies with advice in the space arena—a history going back to 1958. He noted that this event was being held as part of the 2017 50th anniversary of the Aeronautics and Space Engineering Board (ASEB) and as a precursor to the 2018 60th anniversary of the Space Studies Board (SSB). He thanked NASA for the close relationship with, and support of, the ASEB and SSB. The chair of the ASEB, Alan Epstein noted that we are in the most exciting period of space since the Apollo era, when the ASEB was established, owing to the breadth and depth of activity in space. Fiona Harrison, chair of the SSB, noted the unprecedented

¹ National Research Council, 2009, *America's Future in Space: Aligning the Civil Space Program with National Needs*, The National Academies Press, Washington, D.C., <https://doi.org/10.17226/12701>. See also: National Research Council, 2014, *Pathways to Exploration: Rationales and Approaches for a U.S. Program of Human Space Exploration*, The National Academies Press, Washington, D.C., <https://doi.org/10.17226/18801>.

opportunities in the space sciences when we are exploring our solar system, peering back to the earliest moments of our universe, and discovering worlds around other stars. Robert Lightfoot, acting NASA administrator, noted that the agency still refers to the 2009 report—for instance, in the preparation for the recent political transition. He noted the “N” in NASA is key—with the agency providing a national capability and leadership in space and space exploration. Lightfoot stated that over the years, NASA has been able to push forward with a constancy of purpose—in fostering new discoveries and science with robotic and human exploration, pursuing global engagement and diplomacy, supporting the nation’s economic security and industrial base, addressing societal challenges (including science, technology, engineering, and mathematics [STEM] workforce development and technology transfer to human challenges on Earth), and providing leadership and inspiration for the nation as a symbol of American leadership. The symposium participants then turned their attention to discussing the following three themes: space in support of national and international challenges, the future of exploration and discovery, and public-private partnerships in pursuit of national space priorities.

SPACE IN SUPPORT OF NATIONAL AND INTERNATIONAL CHALLENGES

General Lester Lyles, former ASEP chair, began the dialogue and discussion by recounting the main findings and recommendations of the 2009 report, a study he chaired. He outlined the recommendations from the report as follows:

- Space program capabilities should be aligned with high-priority national imperatives.
- NASA and the National Oceanic and Atmospheric Administration (NOAA) should lead the formation of an international satellite-observing architecture capable of monitoring global climate change and its consequences.
- NASA, in cooperation with other agencies and international partners, should continue to lead a program of scientific exploration and discovery.
- NASA should revolutionize its advanced technology development program.
- The government should pursue international cooperation in space as a means to advance U.S. strategic leadership and meet national and mutual international goals.
- NASA should be on the leading edge of actively pursuing human spaceflight.

Next, Michael Lopez-Alegria, of MLA Space and a former astronaut, gave a personal assessment of what has changed in the space arena since 2009. For example, the space shuttle has retired after being instrumental in the assembly of the International Space Station (ISS). He noted that in 2009 the James Webb Space Telescope (JWST) was in preliminary design review. There was no competitive commercial launch sector as it currently exists, and on the whole space was the domain of nation-states. Lopez-Alegria stated that notwithstanding all these changes, the priorities in the 2009 report remain valid, and many of the 2009 impediments remain in place. He called out several impediments listed in the 2009 report that he said he expected to be at the core of the symposium discussions:

- Loss of focus on national imperatives;
- Constrained resources;
- Inadequate coordination across government;
- Missed opportunities to transition roles from government to private sector-provided services;
- Obstacles to international cooperation;
- Weakened institutional partnerships; and
- Lack of emphasis on technology development programs.

Marion Blakey, of Rolls-Royce, North America, then recounted what she referred to as “the gritty FAA days,” when the United States was trying to develop a more commercial approach to space launch. The first Federal Aviation Administration (FAA)-licensed commercial launch was in March 1989. Blakey noted that there have now been over 300 licensed launches. Blakey stated that she believed we have made tremendous progress in the government’s role in enabling industry’s enormous contributions, such as launch vehicle reusability, to civil space—something she thinks the government did not fully understand when the commercial space transformation began. She also stressed the importance of international collaboration in spaceflight, which evolved from an earlier era of competition. Last, she stated that an ambitious vision for space will require more launches, increased safety, and enhanced capabilities, and that the govern-

ment's role will continue to be an enabler for space endeavors as we work to achieve that exciting future.

Jean-Yves LeGall, of the International Astronautical Federation and Centre National d'Études Spatiales (CNES), the French space agency, spoke about space from a European perspective. He said that he believes that there are three main priorities going forward: innovation—to meet the needs of diverse “user communities”; climate—many climate variables can be observed only from space; and exploration. He said that in the last decade there had been two big changes: around 60 space agencies from around the world are active in space, and private companies in the United States, China, and India are active in spaceflight. He said that the traditional space players are being challenged by this new paradigm, but spaceflight overall is benefiting.

Jonathan Lunine, from Cornell University, asked, how did we get here, is there life elsewhere in the cosmos, what is our destiny as a species and society, and how can we influence that destiny to maximize the quality of human existence on Earth? For him, he said, the progress in these areas has been enormous and the pace of discovery has been increasing, including our understanding of Earth and its climate. Lunine explained that scientific discovery is transformational—it changes the state of reality. He recalled co-chairing a recent National Academies study—resulting in the *Pathways* report on human spaceflight—and his resulting and continuing frustration over our inability to move forward with plans to move beyond low Earth orbit. He concluded by saying that the exploration of the cosmos, for him, is one, if not the primary, reason for going into space.

Mark Lewis, an ASEP member, moderated the discussion that followed. Tom Cremins, from NASA, a symposium participant, noted that the themes of sustainability and affordability resonate strongly with NASA today. He mentioned that recent change has included evolution in acquisition, meaning how NASA acquires goods and services such as space station resupply. Today, NASA's focus has shifted from being destination-based to being focused on creating a permanent human presence in space. He also emphasized the importance of international collaboration in terms of commercial or economic benefits as well as creating exploration opportunities. An audience participant noted that international collaboration has been important and wondered if competition or collaboration will be the way forward. The panelists observed that space has become more and more global and that we will have both competition and collaboration in the future. Innovation, climate, and exploration are all global issues; the United States cannot afford to go it alone; and there is also an inherent national pride in space exploration that we should recognize. There are now entirely new partners thanks to institutions like the United Nations. The panelists stated that international cooperation will drive space policies, and there is the possibility to use science as an impetus for greater cooperation. The Committee on Space Research of the International Council for Science (COSPAR), Lunine noted, will continue to be a promoter of international collaboration in science regardless of any political tensions.

In response to a question from a participant about getting humans to Mars and whether it is too hard to imagine that boots on Mars will happen any time soon, panelists recognized the great challenges that might call into question whether humans will land on Mars in the near term. These include developing reliable and long-duration life support systems, overcoming the effects of radiation and the weightless environment on the human body, and politically justifying such an expensive mission. Lunine stated that what we really want is the infrastructure to support deep-space exploration, with putting people on Mars as the horizon goal. However, Blakey offered an alternative perspective, saying that we should beware of modest ambitions. She stated that there is sufficient opportunity now for the entrepreneur. When asked if we are ready to move beyond ISS, which is currently planned to operate until 2024, but reaches lifetime limits by 2028, Lunine recalled from the *Pathways* report that ISS is essential, but we need to begin planning now for an achievable program to go beyond low Earth orbit. We are already late. LeGall noted that ISS is a great example of international collaboration. The panelists supported the need for this cooperation to continue, and Lopez-Alegria noted that the 2024 deadline of ISS retirement is approaching, so somebody needs to hand off the baton (perhaps to commercial industry); otherwise, we will lose the operational and scientific capabilities we had with ISS. Finally, when confronted with the idea from a participant that “culture eats strategy for breakfast” and the fact that NASA was created as a political tool during a Cold War era of fear, the panel commented that the extant culture in NASA is strong but that there can be a fundamental cultural shift within the agency. Change will come through the approach of the younger generation at NASA, which loves to work in teams, works differently, and is no longer concerned with the Cold War.

THE FUTURE OF EXPLORATION AND DISCOVERY

Jonathan Lunine, of Cornell University, opened the session with a short introductory presentation on some of what he labeled as the tremendous advances in space science—using examples from the exploration of our Solar System. He

added that the more we learn, the more we want to follow up—characterized in planetary science by sequencing flyby, orbiter, and landing missions. This approach has been successful, but Lunine asked if we will need new paradigms for ever more daring ways to explore. These could include lower launch costs, faster trip times, novel human/robotic synergies, novel approaches to the execution of science, novel commercial arrangements, and greater acceptance of risk. Indeed, he added, by the time we are ready to go to Mars the capabilities of robots will be beyond what we might expect, and so we have to be ready to couple intimately robotic and human exploration.

Former SSB chair David Spergel moderated a panel discussion following Lunine's opening talk. The panel consisted of Vint Cerf, of Google; John Grotzinger, of Caltech; and retired astronaut Pamela Melroy, formerly of the Defense Advanced Research Projects Agency (DARPA).

Vint Cerf stressed that today is the most timely and vital opportunity for NASA to create new infrastructure that will support new human and robotic exploration. He emphasized how the Deep Space Network has supported many diverse missions. He noted how the communication protocols that have supported many missions, including the Spirit and Opportunity missions on Mars, are the same used by the Internet, and so there is an opportunity to accrete an expanded communications network for future exploration by leveraging off existing assets. Recalling the development of the Internet on Earth, he noted that an investment now might take decades to transform the way NASA does business in the future.

John Grotzinger noted that sometimes the time scales for scientific discovery can be very long, at times decades to a century—often because we do not have the right instruments or the right experiment. On Mars, we do not yet know what the right rock is to find to provide the evidence of life.

Pamela Melroy noted that the ratio of government investment versus industry in technology research and development is dropping. As a result NASA is unlikely to be able to afford the technology it needs. She asked: How can NASA decide how to make the right investments, either with industry or by itself, in areas that are developing so fast, such as biology, machine learning, artificial intelligence, and robotics and autonomy? Melroy noted that human spaceflight is logistics intensive but that this challenge provides an opportunity to partner with industry to build a robotics infrastructure that can reduce some of the logistics burden. Revolutionary technologies developed for ground applications such as machine vision for autonomous path planning and adaptive compliance control for safety are only trickling into space applications, but will be critical elements in the exploration infrastructure.

Opening the discussion to the audience, Thomas Zurbuchen, associate administrator for NASA's Science Mission Directorate, noted that the agency is interested in getting more science per dollar. Looking at talent and technology, he stated that these are often thought of as being two different things, but this is not the case: talented people make technological developments possible, and a lack of talent will hinder the development of new technology. The space program of the future will be determined by the practice of the talent being educated today.

Bill Gerstenmaier, NASA's associate administrator for the Human Exploration and Operations Mission Directorate, then commented on infrastructure. He said that NASA will need to think strategically about where to place infrastructure. We also need to think carefully about resilience. For instance, repurposing of items like the upper stages of spacecraft could be a huge benefit in the future. Additionally, he emphasized that standards for elements like optical communications need to be put into place. If the correct infrastructure and basic standards are in place, then it is easier for NASA to take a step back and allow the private sector to step in and run fast. Summarizing, he said this is a different vision for NASA, one based on looking at infrastructure, resilience, and standards that create an environment that enables new generations of entrepreneurs to do great things.

Responding, Cerf noted the astonishing resilience of NASA robotics and asked how we should balance the need for new technologies—such as those being demonstrated in autonomous robotics on Earth—against the need for resilience in harsh environments in space and on other planetary surfaces. Melroy noted that recent robotic demonstrators need too much intervention to be deployed in space but they show us the path forward. Cerf noted that the ability to operate autonomously is one goal, the ability to stay operational is another, and perhaps the latter needs more attention.

Responding to a comment from a participant on the importance of sharing of information, Cerf said that one of the big challenges society is going to face is the ability to preserve digital information. We need to plan an infrastructure that will prevent us falling into a digital dark age where important information is not saved or properly archived. Lunine noted that with the way we do space science, there seems to be a cost to engineering in flexibility and we need to break that connection to get as capable a spacecraft as possible at lower costs. Grotzinger noted that we are in a deductive mode of doing science on Mars, which he thinks compels us to have humans nearer to the planet. Europa and

Titan are the new Mars in some ways. We need a system of modes of exploration that allow us to cover space remotely but with added complexity. Melroy noted that one possible solution is a distributed architecture of more simple individual spacecraft. She also asked if decadal surveys are moving fast enough to incorporate the faster rate of change in technology. Cerf also suggested that it may be possible in the future to field recursive neural networks in a spacecraft, and then we could imagine doing Earth-based training, which then could be uploaded to a spacecraft to do better science—again an opportunity provided by a more enabled infrastructure.

In response to a participant comment about advances in simulation, Melroy observed that data visualization technology has improved to the point of being able to exploit near-topological visualizations of data, allowing new ways of making discoveries. In response to comments from participants about the political and policy contexts for space exploration, Melroy noted that if you have to show technical progress in a single political cycle, an environment is created where results must be accomplished within a shorter period, and this argues for a more focused, project-based approach that can be reassessed more frequently. Spergel noted that when we look at the mission selection process, we tend to focus on risk minimization and tend to deemphasize approaches with longer-term benefits. Cerf noted that this is called a “conflict of aspiration,” but that we might be able to use better low-cost missions to develop the technology and move it into bigger missions. Jim Green, from NASA, noted that an upcoming mission will carry a technology demonstrator for optical communication while maintaining capabilities for scientific success. A participant noted that we should not discount that NASA does take risks—for instance, the sky-crane system for landing the Curiosity mission on Mars. Spergel noted that notwithstanding these examples, NASA leadership needs to push the community to take the risks.

PUBLIC-PRIVATE PARTNERSHIPS IN PURSUIT OF NATIONAL SPACE PRIORITIES

Mary Lynne Dittmar, SSB member, introduced the theme of the session by noting that public-private partnerships have been in use in the United States since the earliest days of the nation and have been used to advance space-related goals for decades. They have helped to drive industry forward, inject innovation, remake or open markets, and drive down costs. They are not a panacea, however, and their success depends on balancing government and industry roles and balancing discretion and risk, she said—a balance that evolves. Dittmar then moderated a panel discussion that consisted of Roger Launius, former chief historian for NASA and also formerly at the National Air and Space Museum; John Donahue, of Harvard University; Dan Dumbacher, of Purdue University and formerly of NASA; and Alan Epstein, of Pratt & Whitney and ASEP chair.

Roger Launius gave an introductory presentation and spoke about several case studies of public-private partnerships that can be used as analogies for partnerships in the space program. These include the transcontinental railroad, the incentivized development of commercial aviation, and the evolution of the nascent National Park Service. He noted that in the 1920s in the aviation sector, the government could have decided to establish a national government-run airline for postal and passenger delivery, but instead Congress created a favorable climate for private investment that included a subsidy system that persisted for 40 years. Launius noted that commercial aviation stumbled early on but that Congress wanted to disperse aeronautics research across the nation and to commercialize the aviation sector. He asked the question, how can the lessons of these analogies inform how we apply these partnerships to advance public goals in low Earth orbit, lunar, and deep-space destinations? Thanking Launius, Dittmar identified a set of common pertinent issues associated with the analogies he discussed—such as the assigning of rights to real and intellectual property, the use of government loans and subsidies, and the use of public assets.

John Donahue defined this kind of partnership between government and industry as a construct of rules, procedures, and incentives meant to induce private actors to advance public goals. Donahue said, however, that he questioned use of the term “public-private partnership,” characterizing it as overused and that it “has gone from obscurity to meaninglessness without passing through a period of coherence.” The United States has a long history with such partnerships—such as the Lewis and Clark expedition, which was an example of one of the earliest American public-private partnerships. Donahue also mentioned the transcontinental railroad, noting that it was an expensive and not perfect example, but adding that it has been postulated that it significantly raised the rate of growth of the U.S. economy in the decades that followed. Donahue also noted that there have been a number of major failures in public-private partnerships that have left the government cleaning up the resulting problems—for example, the savings and loan crisis of the late 1980s. He said that at the most fundamental level, one needs to have well-defined rules, procedures, and incentives to induce private actors to do something in the national interest—including pursuing the public good in space—but he added that, in addition, being successful with these partnerships is often correlated with having the best people—“the A team”—on hand.

Dan Dumbacher discussed some historical examples and some lessons learned from past vehicle development programs where NASA partnered with private industry. He said that for the DC-XA program in the early and mid-1990s, regulations regarding NASA cooperation with industry had not been established. But by the time the X-33 program came around in the later 1990s, the regulations were in place—which led to the adoption of a fixed-price contract approach. He said lessons were learned from these and other programs, which led to the development more recently of an acquisition approach for the successful provision of “commercial cargo” services to ISS. Dumbacher said that in his experience at the agency, NASA officials were always asking themselves what was the value for government and for private industry in any proposed partnership, and what was the risk factor. So now, a lot of the mechanics we learned along the way in these programs have led to a larger conversation about public-private partnerships and an “interesting future” for space exploration.

Alan Epstein spoke about what might be learned from public-private partnerships in aviation. He explained that after World War II, the Army, Navy, and industry tried to get the National Advisory Committee for Aeronautics (NACA) shut down. They failed, but some ambivalence to NASA’s role in aeronautics continues, he commented. But historically NASA and aviation evolved together into a symbiotic relationship. Epstein said that while the aviation industry invests far more than NASA in research and development, the value NASA provides has been to push new ideas, ideas whose gestation period is longer than the attention span of industrial investors. Epstein explained that there has been tremendous advancement since the days of the Boeing 707, such as an 80 percent improvement in fuel burn for large aircraft, a result of NASA research. The history of commercial aviation in the United States shows that industry and government work well together over time. Epstein added that today everything in industry is happening much faster, creating challenges when establishing partnerships. He also noted that he has observed that NASA is learning how to work at this new pace of innovation. NASA is, Epstein said, the sparkplug for new ideas from universities and industry and that the current NASA X-plane program is the most exciting thing to happen in aeronautics in decades and may be the only way to get a future commercial aircraft that does not look like a Boeing 707.

Opening the discussion with the audience, Bill Gerstenmaier said that no matter how difficult public-private partnerships may be, they are also necessary. He said that we are “doomed to failure” if we don’t pursue them and that NASA is currently trying to move in the direction of having more public-private partnerships. However, he noted that it is a challenge culturally for NASA to make this shift because the agency has to recognize that partners outside the agency can be the source of innovation. Now what we need, he said, is the “how to” part of getting NASA to better incorporate private operators into NASA goals, which he hoped this symposium would discuss. Vint Cerf noted that the government has constantly reinvented the way that it does public-private partnerships and stimulates private industry and so the challenge now is to figure out how to do that for our future goals in space. Alan Epstein noted that the new entrants in the aerospace industry have a much higher tolerance for risk, and NASA may have to tolerate more risk and have the political cover to do so in order to succeed. Dumbacher noted that market disruption—such as the emergence of cell phones displacing plans for expanding satellite communications—can be painful and necessitate a change of programmatic direction. Donahue noted that a natural evolution has a role in the development of the right approaches to partnership, although more actively thinking through the options is likely required.

One participant noted that private industry is good at finding the value proposition for its own activities, and so we should not expect NASA to find it. He added that undertaking public-private partnerships has to be viewed more broadly as important—just as “heroic” as NASA’s role in developing Apollo. Dumbacher mentioned that NASA is on that path but that it needs to evolve further. Donahue noted that the value proposition for industry may not always be in the long-term public interest—that is the hard part. In response to participant comments Epstein noted that the hard part for space is identifying where an investment boost needs to be applied to realize a self-sustaining profitable outcome. He asked, how long do you consider subsidizing a program, given how long it can take to establish a new industry? One possibility, he added, is to adopt an approach that is a hybrid of the DARPA model, where you plan for only a short-time investment, and then it is “sink or swim.” A participant wondered if public-private partnerships have become a religion and what the limits are of a meaningful definition in the context of where we want the government-industry partnership in space to go. Another participant noted that NASA recognizes that there is no one-size-fits-all, and Epstein added that perhaps these definitions do not matter as long as all parties have decided the approach is most in their own and the national self-interest. Donahue noted that the detailed craft of partnerships comes in by thinking about selecting partners and incentivizing them—think about what the government’s private partners are going to do in their own interest and how you can leverage them to get them closer to a public purpose. Cerf noted that in past successful cases, there was a business that was a nascent value in the fundamental proposition of the partnership, and some incentive needed to be applied to demonstrate that value before the private sector could fully engage.

So, he noted, the question must be what is the business case—launch to space clearly is one case, and so we have to start looking at what are the other activities that NASA now does that would be of interest for private partners to offer, regardless of the type of intervention. A participant noted that the community is still undecided on the question of whether NASA is the government entity responsible for the role of advancing the public good of growing the economy in space. How this question is answered will be important as we plan future partnerships for the agency. Rounding out a point from an earlier session, a participant noted that perhaps the role for NASA is to provide the infrastructure on which commerce can be built.

LIGHTNING TALKS: TECHNOLOGY TALL POLES AND THE FRONTIERS OF SPACE SCIENCE

Following the three focus sessions, there were two sets of lightning talks—short presentations by different experts in their fields. Sarah Shull, of NASA, spoke about environmental control and life support in space and on a planetary surface. Bobby Braun, of the University of Colorado, Boulder, spoke about entry, descent, and landing on Mars. Dave Murrow, of Lockheed Martin Corporation, spoke about radiation mitigation technologies. Monica Bobra, of Stanford University, discussed machine learning and understanding the Sun. Natalie Batalha, of NASA, discussed the frontiers of exoplanet science. Molly Brown, of the University of Maryland, discussed how Earth observation and mobile software are transforming farming. Candice Hansen, of the Planetary Science Institute, talked about the science frontiers of the outer Solar System. Finally, Rob Ferl, of the University of Florida, talked about human spaceflight and the science of adapting to space. In response, Steve Jurczyk, associate administrator for the NASA Space Technology Mission Directorate, stated that there are what NASA calls “quantifiable capabilities” that need to be present before, for instance, a human mission to Mars can be successful. There is also urgency driven by the fact that testing technologies on ISS is vital. However, there is no test site for landing on Mars—modeling and simulation are key. In addition, he noted that as we develop and learn from technology research, we need to feed the lessons back into the architecture and systems. NASA’s Thomas Zurbuchen stated that the two important questions about promoting the agency’s research are “why?” and “why now?” The reason we do space science research is to improve and safeguard life on Earth, he said. Additionally, in learning new things, we can change the way we think about society as a whole. The “why now” question is answered by looking at the technologies that we now have in order to gather and take advantage of data in new compelling ways, he concluded.

SUMMARY DISCUSSION

During the wrap-up discussion at the end of the symposium, John Olson, from the ASEB, and SSB chair Fiona Harrison identified some of the key themes that they discerned from the day’s discussions. Olson stressed that his and Harrison’s presentation was by no means a consensus view but personal assessments of the days’ key themes and issues. In summary they noted the following:

- The goals for our national civil space efforts from the 2009 America’s Future in Space report are still largely valid today, although the environment in which we pursue those goals has changed.
- We need to consider that participants a number of times asserted that the public knows little of the actual goals of our nation’s space endeavors.
- Nevertheless, NASA remains a symbol of American leadership at home and around the world and can continue to be a tool of international policy, power, and diplomacy.
- Scientific discovery in our space program is transformational because it changes our collective perception of reality.
- The year 2028 is a key date for ISS and will drive decisions and actions now, while there was also a strong message from a number of participants that we need to continue to plan for a NASA program that goes beyond ISS and beyond low Earth orbit.
- Many asked the question about what new paradigms will get us out of low Earth orbit and how can we leverage off ideas like repurposing existing spacecraft to establish an infrastructure (including an Internet-like backbone) on which to build new private and government activities. New paradigms are also likely to benefit from advances in artificial intelligence, robotics, and human-machine teaming as enablers for staging, operations, and sustainment.
- New paradigms will also require the development of a new culture in NASA and the advancement of multi-

generational teams while retaining institutional knowledge and expertise.

- The right motivation for partnering with private industry needs to be identified and then policies and incentives need to be established to bring industry into contributing to the public good at the core of the program under consideration. Nevertheless, one size does not fit all.
- Among what has stayed the same in recent years is that Mars has remained the horizon goal for exploration. What also has not changed is that NASA has too much on its plate and many constraints.
- What has changed includes new international actors in space—including an impressive space program from China. These new entrants and new industry players and new ways of doing business with established industry provide many new opportunities.

In conclusion, Harrison mentioned that many commentators at the symposium noted the need for focus and that making choices is vital for the success of our space program. There is a sense that we need to focus more on the overall objective rather than only on the next step. She noted that participants asked if there is something that will significantly alter the current progress and direction. Perhaps it is reusability that will change the cost model—she noted the symposium heard enthusiasm and skepticism on this idea. Perhaps it is the idea of better integrating humans and robotics to accomplish missions. Perhaps it will be a new policy and program objective from the new administration. Perhaps U.S. civil space will be motivated by international competition (maybe with China) or collaboration (maybe with China and other new and established space-faring nations)?

Olson noted that in addition to the archived webcast of the symposium and the publication of a Proceedings in Brief, the lasting impact of the symposium will be the continuing dialogue on these issues. Watch the recorded webcast at <https://vimeo.com/album/4596049>.

DISCLAIMER: This Proceedings of a Workshop—in Brief has been prepared by Dwayne Day and Michael Moloney as a factual summary of what occurred at the meeting. They were assisted by Madison Borrelli. The committee's role was limited to planning the event. The statements made are those of the individual workshop participants and do not necessarily represent the views of all participants, the planning committee, or the National Academies. This Proceedings of a Workshop—in Brief was reviewed in draft form by John M. Logsdon, George Washington University; Sandra H. Magnus, American Institute of Aeronautics and Astronautics; Celinda Marsh, independent consultant; and David Radzanowski, Equator Corporation, to ensure that it meets institutional standards for quality and objectivity. The review comments and draft manuscript remain confidential to protect the integrity of the process.

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