Pioneering Space: NASA's Next Steps on the Path to Mars

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Exploration and pioneering have inspired and shaped civilizations since the dawn of human history. Such endeavors are one distinguishing characteristic of an advancing civilization. As nations explore, they discover, innovate, prosper, lead—and become great. This has been the American story thus far and NASA figures prominently in it. NASA missions, both robotic and human, expand our knowledge of the Earth, our solar system and the universe beyond. NASA's discoveries and innovations foster an imaginative and skilled technical workforce and grow our economy. NASA's missions garner national prestige and our collaborations unite nations of the world around a common goal.

Over the past four years, NASA has been implementing the NASA Authorization Act of 2010, enacted with broad bipartisan support and reflecting agreement between the Congress and the Administration on the nation's next steps into space. The Act calls on NASA to develop and evolve the Space Launch System (SLS) rocket and Orion crew vehicle and to expand human exploration beyond low Earth orbit to cis-lunar space destinations, leading eventually to the international exploration of Mars.

Why Mars? From a scientific standpoint, Mars has a history, geology and climate—as well as accessibility—that make it an ideal location on which to study the most pressing questions of solar system origins, including those involving the search for life beyond Earth. From a human exploration and pioneering standpoint, Mars contains resources that could sustain human presence. These include water ice at the poles and close to the surface over much of the planet. Nitrogen, trace concentrations of oxygen, and water vapor in its atmosphere might be used to produce breathable air, propellant for ascent from the surface and nutrients for plant growth. From a technology standpoint, Mars poses challenges for which solutions will find, and already are finding, their way into our economy and society.

Indeed, the pioneering exploration of Mars is already underway. The Mars rovers Curiosity and Opportunity are moving about Mars and have shown it exhibits conditions that could have supported microbial life in the past. Curiosity's sensors measured the radiation environment both in transit to Mars and on the surface. The Mars Reconnaissance Orbiter and Mars Odyssey orbiter are examining the Martian surface and climate in great detail, and their imagery may one day identify the first human landing sites. The MAVEN and InSight missions will study Mars' atmosphere and interior, respectively, allowing us to peer into Mars' past and its future.

Explorers go with the intent of returning to tell their story and point the way for future forays. Pioneers go with the intent to establish a permanent presence. Pioneering space requires we progress from Earth-dependent to Earth-independent. Today and for the last 13 years, humans have continuously lived off Earth on the International Space Station (ISS). While dependent on Earth for resupply and short transit times, ISS is allowing us to learn what we will need to operate at greater distances and longer durations. We will use the proving ground of cis-lunar space to mature technologies on missions such as the capture and redirection of an asteroid so astronauts can visit it and return samples. Missions in this proving ground will get us ready for much more Earth-independent missions to Mars.

No endeavor of exploration and pioneering is without risk. NASA's approach is to build on our robotic emissaries and precursors, leverage our space shuttle heritage and ISS experience, and then proceed in a step-wise manner by first using cis-lunar space as a proving ground for human Mars exploration to gain experience and test capabilities in the Earth-Moon system. As with all pioneering efforts, when we expand the boundaries of human exploration we also introduce an added measure of risk to loss of human life. The benefits associated with these risks must be easily recognizable. This will not deter us from our goal, but using the proving ground to identify and address our risks will inform how we get there and when we will be Mars ready.

NASA will explore and pioneer Mars in good company. Twelve space agencies from nations around the world jointly issued in August 2013 the second edition of a Global Exploration Roadmap, (http://www.nasa.gov/sites/default/files/files/GER-2013_Small.pdf) "that begins with ISS and expands human presence into the solar system, leading to human missions on the surface of Mars." This international roadmap provides a framework for coordination among the agencies, a context for partnership on specific missions, and a basis from which the agencies can discuss plans and investment from stakeholders in their own nations. U.S. commercial firms also are expanding their capabilities to reach and operate in space. As they have followed us into Earth orbit and seek to establish a market there, we anticipate they will join us in ever-deeper forays into space.

Dialog with our stakeholders and partners—the public, Congress, academia, industry and international partners—on space pioneering and exploration priorities and plans is critical to our future. We continuously seek advice and counsel as we chart our path into the solar system. Shortly, NASA will receive a report from the National Research Council on future directions for human spaceflight. This summer and fall, NASA is conducting studies on approaches to a sustained campaign of human Mars exploration. We will articulate a synthesis of these efforts in an update to our Voyages document (http://go.nasa.gov/nasavoyages), released in 2012, around the end of this calendar year. The present interim document provides a status on the strategy and plans to date to implement this next human journey. It is the current state of an iterative effort that will continue to mature as capabilities develop, partnerships mature and evolve, and the ties to national and global priorities and challenges deepen.

Mars is the next new frontier beckoning great nations. Building on our robotic Mars Exploration Program and today's investments in the ISS, the Commercial Crew Program, SLS, the Orion spacecraft, and future technology advances from our Space

Technology Mission Directorate programs, America is well poised to lead the next wave of missions and partnerships to pioneer the space frontier. As stated in our 2014 Strategic Plan, NASA aims to *expand human presence into the solar system and to the surface of Mars*.

Getting to "Mars Ready"

NASA's programmatic approach to deep space and Mars exploration and pioneering includes the principle of **sustainability**. For sustained human presence in deep space and on Mars, the programs, transportation, habitability systems, and partnerships must be sustainable over changes in political and budgetary priorities and evolvable over technology advances and scientific discoveries across timespans of decades.

NASA's development of capabilities for sustainability provides a modular approach for mission options to the Mars system—reusing systems when and where possible, such as advanced solar electric propulsion and deep space habitation, and is also open to international and commercial participation in which partners can leverage and build on our activities to share cost, increase utilization and provide for greater scientific and economic returns to society.

To achieve sustainability in all these dimensions, NASA is discussing with its stakeholders the following principles to guide planning and implementation:

1. Implementable in the ***near-term with the buying power of current budgets*** and in the longer term with budgets commensurate with economic growth*;*
2. Application of ***high Technology Readiness Level*** (TRL) technologies for near term missions, while focusing sustained investments on **technologies and capabilities** to address challenges of future missions;
3. ***Near-term mission opportunities*** with a defined cadence of compelling human and robotic missions providing for an incremental buildup of capabilities for more complex missions over time;
4. Opportunities for ***US commercial business*** to further enhance the experience and business base learned from the ISS logistics and crew market;
5. ***Multi-use, evolvable*** space infrastructure;
6. Substantial ***international and commercial participation***, leveraging current International Space Station partnerships.

Guided by these principles even as they mature, NASA is defining a long-term, flexible and sustainable deep space exploration architecture termed the "**Evolvable Mars Campaign**."

Each word is important. While "*Mars*" is the goal, the Evolvable Mars Campaign recognizes the capabilities of space-faring nations today are not sufficient to safely land and return humans from the surface of Mars, as we know we have gaps in our scientific, engineering and technological knowledge. As a result, the Evolvable Mars

Campaign reflects the use of cis-lunar space (the lunar vicinity) as a staging area to test our systems, technologies and abilities to mount future Mars missions. Further, it addresses the potential exploration and use of Mars' moons Phobos and Deimos as steps toward the Martian surface.

"*Campaign*" signifies the fact that multiple missions, both robotic and human, will be involved in the exploration and pioneering of Mars. This is not a point design for a single mission to reach the Martian surface. Rather it is a methodical approach toward incrementally building technologies and testing capabilities to go beyond low Earth orbit (LEO) with an efficiency of purpose, leading to a sustained campaign of Mars exploration and pioneering. Our Strategic Knowledge Gaps document (http://www.nasa.gov/exploration/library/skg.html#.U4dIvsaiiMV) formally identifies what we don't yet know and it will assist requirements selection for many future robotic precursors. As one example, we need to advance our ability to descend to and ascend from Mars' surface through the planet's very thin atmosphere. The system that successfully landed the Curiosity rover is capable of landing one ton on the surface; human missions could require as much as 10 times that amount using descent systems that are not directly scalable from the Curiosity mission.

"*Evolvable*" recognizes we don't have all the scientific and technical answers now, and will not know all the answers for future missions when we conduct the first ones. While we expect to learn much as we explore, a number of technical trade studies already are underway, with initial results available later this summer and fall. These include the mix of cargo and crewed missions, the orbital trajectories to be employed for each, the relative advantages of Earth-Mars conjunction opportunities, the use of Martian Lagrange points and Martian moons, the potential for in-situ resource utilization to limit logistical dependence on cargo missions from Earth, and many others. While scientific understanding of our solar system is growing every day, we recognize future discoveries can and should guide the first steps in the Martian vicinity. To ensure science considerations are included in human spaceflight planning, the Solar System Exploration Virtual Institute (SSERVI) provides external science and research community insight and guidance into both architecture and international spaceflight plans. Further, the partnerships that conduct these missions are bound to change over time, or political priorities may provide new direction, science may reprioritize our precursor planning and site selections, and technology advances may offer innovative solutions as more nations and more companies become spacefaring partners in the drive toward Mars.

In short, the Evolvable Mars Campaign provides a basis for architecture development and identification and analysis of trade studies with our partners and stakeholders and incorporates the flexibility to adjust to changing priorities across the decades. From this work will emerge the roadmap we will follow through cis-lunar space to pioneer Mars.

Advancing From Earth Reliance To Earth Independence

Fundamentally, extending human presence into the solar system and to the surface of Mars requires advancing from an Earth-reliant to Earth-independent state of technology. Currently, we are Earth-reliant. Today's astronauts on ISS rely on regular logistics resupply flights from Earth and on being able to return from Earth orbit in a matter of hours. Returning to Earth from Mars, either for a planned return or during an emergency, could be one to two years—necessitating full self-sufficiency for safely working, living and ensuring continued safe transportation across deep space. Once landed, these future explorers and pioneers will need to be Earth-independent, living off resources extant in their immediate environment. To progress responsibly from Earth-reliant to Earth-independent, we need to first move beyond low-Earth orbit into the proving ground of cis-lunar space, where return times are days to weeks. This allows us to gain experience with advanced exploration systems, long-duration human health in high radiation environments and more sophisticated deep space operations. Only after we have successfully demonstrated these capabilities are we able to provide the necessary independence that prepares us for the longer journeys across the solar system.

The **International Space Station** (ISS) is the cornerstone of space exploration and pioneering. The ISS is our in-space laboratory for long-duration crew health and performance, habitability, logistics, and explorations systems such as docking, high reliability closed loop life support, advanced extravehicular activity (EVA), and long-term system performance in a microgravity and vacuum environment. Extension of ISS operations to at least 2024 is enabling NASA's Human Research Program to identify and retire or reduce the risks of long-duration spaceflight. This includes decreased gravity affecting bone, muscle, cardiovascular and sensorimotor systems, nutrition, behavior/performance, immunology and the ability to provide remote medical care via telemedicine. For example, the one-year ISS stay by astronaut Scott Kelly and cosmonaut Mikhail Kornienko in 2015 will advance human microgravity knowledge beyond the six-month in-orbit human research mark that is the limit of most of today's data. While we have countermeasures to limit bone and muscle loss during six-month durations, we can investigate if these countermeasures are equally effective for the longer durations expected in Mars missions. The Environmental Control and Life Support System (ECLSS)—the system used to keep the crew alive with fresh air, water and thermal controls—is critical for Mars missions and will be tested on ISS. Additionally, the Commercial Cargo and Commercial Crew Programs foster a thriving U.S. commercial space industry that can operate in low-Earth orbit (LEO) while NASA moves outward. Finally, ISS is a partnership among 15 nations, with some 68 nations conducting research, and serves as a foundation for future partnerships in human exploration and pioneering the solar system.

The **Space Launch System (SLS) and Orion** crew vehicle and associated Exploration Ground Systems are progressing well in development of our initial exploration capabilities. The Exploration Flight Test-1 (EFT-1) of the Orion capsule systems and heat shield is scheduled for late 2014 on a Delta IV launch vehicle. All the major contracts for these systems are in place. Manufacturing tooling for SLS is being installed at the Michoud Assembly Facility, and the launch pad, mobile launch platform, and Vehicle Assembly Building upgrades are underway at the Kennedy Space Center. By the end of 2016, the first SLS core stage will arrive at the Stennis Space Center for hot-fire testing. The Exploration Mission-1 (EM-1) first test launch of SLS with Orion utilizing the Exploration Ground Systems infrastructure is planned for fiscal year 2018. This mission, the first to a Distant Retrograde Orbit (DRO) around the moon, will leverage this cis-lunar proving ground to practice sophisticated DRO trajectory operations, perform system tests in a high radiation environment, and demonstrate operation of human rated vehicles farther from Earth than ever before. The Exploration Mission-2 (EM-2) in 2021-2022 will be the first to carry humans into the cis-lunar proving ground, on a mission duration of about 25 days, testing and demonstrating our ability to live and work independent from Earth. SLS and Orion, in their evolved forms, will be the transportation system that carries humans and supporting cargo to the Martian system. The initial SLS configuration will yield a 70 metric ton (mT) to LEO capability, evolvable to 105 mT and 130 mT via a combination of upper stage and advanced booster additions, to make it both Mars-capable and a valuable launch vehicle asset with the potential to transport other government and NASA science missions. The capabilities of Orion will evolve and be augmented with an in-space human habitat module for long duration stays beyond the moon.

Sustained investments in **new technologies and advance capabilities are essential** to close our knowledge gaps and safely take our first steps beyond low Earth orbit and into deep space and to Mars. While the SLS and Orion programs are well underway to providing transportation beyond LEO, there are several additional (and necessary) technologies in various stages of conceptualization, development, and testing by NASA’s Space Technology Mission Directorate (STMD) and HEOMD’s Advanced Exploration Systems (AES) Division. Both these organizations mature lower Technology Readiness Level (TRL) technologies into flight proven, reliable systems for eventual use by Mars pioneers. STMD manages a portfolio approach, ranging from early-stage technology concepts addressing long-term exploration needs, to high technology readiness level spaceflight demonstrations required for near term exploration missions. STMD focuses on crosscutting technologies and capabilities needed to achieve future robotic and human exploration missions. STMD’s Game Changing Program matures component and subsystem-level technologies, while AES integrates the advanced subsystems technologies developed by STMD to create prototype flight systems for use by HEOMD’s current space flight systems development programs. Focused on mission fusion, STMD also executes in-space demonstrations of critically needed technologies to bridge the gap to successful utilization of crosscutting capabilities spanning customers in NASA Science, Human Exploration and the broader national aerospace community.

Key technology areas include:

- High-efficiency in-space transportation systems based on high power solar electric propulsion (SEP) and cryogenic propellant storage;
- Space optical communications and advanced deep space navigation for efficient high bandwidth data transmission and assured spacecraft position and state vectors;
- Advanced highly reliable and efficient life support and in situ resource utilization to ensure that deep space exploration mission can safely occur independent of earth;
- Mars entry, descent, and landing technologies and systems for masses an order of magnitude greater than the system that landed the Curiosity rover;
- Space robotic systems and automation such as humanoid robots and autonomous rovers to offload astronaut workloads and substantially extend the science and exploration that humans will perform at destinations;
- Lightweight space structures and advanced manufacturing with a focus on large composite structures, composite launch vehicle structures and lightweight habitats;
- Advance surface power generation and storage systems to provide the energy needed at deep space destinations to sustain life and perform science and exploration.

NASA developed (and is updating) its Space Technology Roadmaps and Space Technology Investment Plans to detail the specific technologies NASA may pursue in each area and focus the integrated Agency technology efforts toward most efficiently achieving NASA's strategic goals.

The Path to Mars: Into the Proving Ground of Cis-lunar Space

The path to Mars runs through cis-lunar space and we can exploit the beneficial features of this region in a relatively low-risk environment. We also can benefit from international and commercial partnerships to prepare our hardware and gain experience for human missions beyond and on to Mars. High Earth orbits, the DRO around the Moon to which EM-1 and EM-2 will fly, and the Earth-Moon Lagrange points are all orbital locations in which deep space systems can be tested and operational procedures validated while still close enough to Earth to safely recover systems in the event of problems. Cis-lunar space is ideal for the advancement of deep space systems such as human deep space habitation.

The series of missions NASA is planning in the proving ground of cis-lunar space follow a sustainable approach to developing the capabilities required to get humans to Mars. NASA is refining mission objectives of the Orion/SLS EM-2, and EM-3 to incorporate additional operational testing relevant to the Asteroid Redirect Mission (ARM) in the cis-lunar environment. Systems testing and demonstration and risk reduction for the ARM crewed mission and future missions to Mars moons, Mars orbit and Mars surface will all be important drivers for these missions. Using current candidate asteroids, a mid-2019 launch of the advanced solar electric propulsion (SEP)-based ARM robotic spacecraft and a substantial asteroid mass returned to a stable lunar DRO would allow for astronaut exploration and sampling in the 2024-25 timeframe via SLS and Orion. NASA's plan is for this crewed mission to encompass 26-28 days, including five days in the lunar DRO for Orion rendezvous and docking with the ARM robotic spacecraft and attached asteroid mass to conduct astronauts' extravehicular activities (EVAs) to obtain select samples.

One other benefit afforded by the cis-lunar environment is the 'low energy' transfer of spacecraft between the Mars environment and our moon—avoiding the need for large propulsion systems to escape or descend into the Earth's strong gravity. While low speed and best for non-perishable items, cargo can be efficiently transited among Mars-lunar locations, allowing for optimization of human missions and durations and possibly increased economy with the re-use of key systems and spacecraft. For example, with an existing cis-lunar spacecraft and docking capability, samples from the lunar or Martian surfaces can be transported via robotic spacecraft to a DRO around the moon for accessing, study and retrieval by astronauts via Orion and SLS. Human missions to Mars will be preceded by cargo pre-emplaced robotically; transfer vehicles propelled by solar electric power systems can very efficiently shuttle cargo well in advance of crew arrival, thus decoupling crew and cargo missions, easing orbital mechanics launch constraints and opening up architectures to more cost-efficient solutions.

The **Asteroid Redirect Mission (ARM)** leverages and integrates existing programs in NASA's Science, Space Technology and HEO Mission Directorates to provide a moderately low marginal cost opportunity to exercise our emerging deep space exploration capabilities on the path to Mars. SMD's Near Earth Object Observation program will identify and characterize candidate targets. A robotic mission using advanced solar electric propulsion will encounter and redirect the selected near-Earth asteroid (or boulder from the surface of a larger asteroid) into a lunar DRO, where it can be visited by a crewed Orion mission that will return samples to Earth for detailed analysis. ARM will test the transport of large objects using advanced SEP, automated rendezvous and docking, deep space navigation, integrated robotic and crewed vehicle stack operations in a deep space environment, and extra-vehicular activities (EVAs) outside of Orion that will be needed for future cis-lunar space and Mars missions. NASA's strategy is that the ARM SEP module and spacecraft bus would be used for the first cargo missions to Mars and its moons. We might do so by procuring these systems commercially to lower cost and for reproducibility. Another option is to repurpose the ARM vehicle after its first mission, as a lowest cost option to transport or *in situ* resource utilization (ISRU) payload to Mars' moon Phobos and back to lunar DRO. Coupled with a new entry, descent and landing capability, a science or ISRU payload could be placed on the Martian surface. In any case, the reuse of space infrastructure such as the ARM spacecraft is a key principal of sustainable space exploration. A second mission for the ARM spacecraft could provide information essential to selecting the path to Mars and significantly reduce the risks facing human explorers—such as understanding our ability to leverage

Phobos resources, and characterizing the surface and microgravity environments. These are among the options being studied this year.

Mars-class missions will require crew life support for many hundreds of days at a minimum; a **deep space habitation capability (hab)** is critical for mission success. It is essential that the hab design receive thorough testing in a relevant deep space microgravity and high radiation environment—well before a final design and committing a crew on a Mars mission. The first deep space hab could be provided by a commercial or international partner, and could provide additional resources including power, EVA suits, stowage, science instruments, and advanced life support testing for Mars class missions as well as extend the in-space time of crewed Orion missions. The hab element also could facilitate additional docking ports to open the cis-lunar space to commercial and international missions in concert with or in addition to the Orion flights. In keeping with our space infrastructure reuse principle, a deep space hab also could provide a dual purpose, in addition to proving systems for Mars missions, by potentially serving as a staging point for lunar surface robotic science or human missions sought by our international partners. Based on the early results of orbital mechanics studies, the cis-lunar proving ground is a favorable location to test and develop the Mars class spacecraft systems prior to sending humans to pioneer Mars.

Our **moon** is of great interest to countries that worked with NASA to develop the Global Exploration Roadmap (GER). NASA is interested in operations in various lunar orbits for the reasons cited above, and in samples returned from the South Pole – Aiken Basin region. Various international partners are interested in both robotic and human missions to the lunar surface, and NASA will likely go with them in some way. U.S. commercial entities also have interest in robotic lunar missions through NASA's Lunar CATALYST program, which aims at enabling commercial provision of lunar landing services. NASA exploring the possibility of utilizing one of these commercial landers to place a Regolith and Environment Science and Oxygen and Lunar Volatile Extraction (RESOLVE) payload onto the lunar surface later this decade, an early test of ISRU with lunar regolith. Consistent with the GER, a web of international, NASA and commercial partnerships will yield both robotic and crewed spacecraft around and on the Moon. Additionally, many of our international partners want to send humans to the lunar surface. NASA may participate at some level, as the lunar surface affords some benefit in partial Earth-gravity operations. But NASA's human spaceflight focus is on advancing technologies and operational experience in long-duration missions in the cis-lunar proving ground, using DRO missions, on the path that leads to Mars.

The **moons of Mars**, Phobos and Deimos—themselves likely captured asteroids—may contain material accrued from the Martian surface as well as resources useful for expeditions to the Martian surface. Orbital locations around Mars, including its two moons, provide potential staging areas for transit habitats and cargo assets for human expeditions to the Martian system. Cargo shuttled by SEP-propelled spacecraft between orbits around Earth's moon and orbits around Mars and its moons may figure prominently in the human pioneering of Mars.

Building Toward Earth-Independent Exploration

NASA and its partners already are exploring **Mars' surface**, with humans working through our robotic spacecraft to prepare the way for future human pioneers. Current Mars exploration is showing us amazing features of the Red Planet—it once had a denser atmosphere and liquid water on its surface—but it underwent dramatic change that may hold lessons for understanding our own changing planet. Even so, today Mars has nitrogen, trace oxygen and water vapor in its atmosphere, along with water ice at its poles and close its surface over much of the planet. These valuable elements can be harvested to provide nutrients for plants, fuel for propulsion systems and breathable air for future human pioneers. Understanding the viability of ISRU early in concept planning can dramatically alter our plans for pioneering the Martian surface. Building off of the successful radiation monitor already operating on the Curiosity rover, the next Mars rover is planned for launch in 2020. Just as these rovers help us answer the question if life ever existed on Mars in the past, we want to know how to successfully put human life on Mars in the future.

Further, the Mars 2020 rover will cache samples for possible return to Earth by future missions. Excited by the long and continuing history of learning from lunar samples returned by the Apollo missions, scientists regard the return of samples from Mars as one of the top priorities for planetary science and a potential boon for preparation of future human missions to Mars. The Mars Reconnaissance Orbiter is scanning the climate and surface of Mars and identifying the best possible landing sites for Mars 2020 and future missions.

On Mars, humans and machines will explore together. Robotic craft are first into new and hazardous environments, but they cannot interact with their environment with the speed, intuitive ease, and efficiency of a human. Designed to operate on the Martian surface for three months, the Opportunity rover has survived for more than ten years and explored more than 22 miles of the Martian surface. When the Apollo 17 crew landed on the Moon in 1972, they equaled that distance in just three days on the lunar surface. Putting human geologists and astrobiologists on Mars will accelerate the pace of discovery and thus the safety and productivity of the pioneers to follow.

Achieving Earth-independent exploration and pioneering capability is a substantial undertaking. We have identified key areas under the broad categories of space transportation, staying healthy in space, and working in space and planetary environments in order to guide our technology and future mission planning.

The Next Steps: Mission Plans for the Coming Decade

NASA's next steps are steps toward extending human presence into the solar system and to the surface of Mars.

ISS: The United States has announced plans to extend ISS operations and utilization to at least 2024, and we anticipate codification via Congressional authorization. In 2015, the ISS partners will conduct a one-year mission with an astronaut and a cosmonaut to accelerate our understanding of needs and means to enable long-duration space flight.

Commercial Crew Transportation Capability: NASA and its commercial partners are working toward the first commercially provided transportation of crews to and from the ISS by the end of 2017. Later this year, NASA will select from among the proposing partners that shall proceed into the development and certification phase.

Exploration Flight Test-1 (EFT-1): In December 2014, the first Orion vehicle will launch aboard a Delta IV rocket with the aim of returning back through the Earth's atmosphere at the velocities that will be experienced by deep space crewed missions. This will be a test of the Orion heat shield and other critical systems, leading to the final design of the first crewed Orion vehicle.

EDL Capability: Aerodynamic decelerators are identified as key technologies needed to enable many future planetary exploration missions for NASA, which cannot be accomplished today. Included in those missions are scientific missions focused on exploring the Southern Highlands of Mars and eventually delivering the large mass payloads required for human exploration to the surface of Mars. STMD investments are exploring multiple classes of aerodynamic decelerators such as hypersonic inflatables, supersonic inflatables, mechanically deployables and supersonic parachutes. The key technology advancements needed to realize the benefits of inflatable decelerators are being established within the Low Density Supersonic Decelerator (LDSD) project and the Hypersonic Inflatable Atmospheric Decelerators (HIAD) project. The LDSD project is currently demonstrating both inflatable decelerator and advanced parachutes at supersonic speeds from a solid rocket propelled vehicle dropped from a high-altitude balloon, with a first test planned for June 2014 of the world's largest supersonic parachute. The HIAD Project is orchestrating a series of ground and flight tests in the next few years to demonstrate the viability of thermal resilient materials manufactured in robust configurations to withstand the extreme structural and thermal environments experienced during atmospheric entry. STMD also is investigating mechanically deployable hypersonic aerodynamic decelerators and the use of supersonic retro propulsion technology as an alternative aerodynamic deceleration. It also is engaging with SpaceX to utilize the company's first stage return engine data to help understand supersonic thruster atmospheric interaction.

2014 Discovery Announcement: Working with STMD and HEOMD, SMD's Planetary Science Division (PSD) held a Technology Day for Discovery mission proposers to showcase technologies under development that could support Discovery proposals in response to this year's Announcement of Opportunities (AO). HEO and STMD presented several technologies that have been under development to support human exploration activities that could have direct applicability to a Discovery mission. PSD hopes that in working together to share technologies across our robotic and human missions, we can expand the user base and experience for these new technologies. Specific technologies have been identified in the Discovery AO for incentives to the proposal team including NEXT solar electric propulsion system, a new heat shield technology (HEEET), optical communications and atomic clock. All of these can be applicable to future human mission. In addition, we introduced Advance Landing and Hazard Avoidance Technology, Advanced Solar Arrays, and Green propulsion technologies to the Discovery proposers as advanced technologies that were ready for proposals.

Exploration Mission-1 (EM-1): In Fiscal Year 2018, NASA will conduct the first integrated flight test of Orion and SLS. The rocket will launch Orion into a distant retrograde orbit around the Moon—the orbit that figures so prominently in our future human Mars exploration plans. EM-1 and subsequent missions will include the deployment of secondary payloads to accomplish a variety of exploration, technology and science test objectives. EM-1 also will use a Service Module provided by the European Space Agency, leading off the international human deep space exploration partnership.

Asteroid Redirect Mission: In about 2019, NASA will launch a robotic mission to rendezvous with a near Earth asteroid and redirect it (or a boulder extracted from a larger asteroid) into a stable orbit around the moon to exercise systems and operational techniques critical to future missions to Mars and its moons. The choice of mission option will be made by the end of this year in preparation for Mission Confirmation Review in early calendar year 2015. Candidate target identification and characterization is underway through NASA's Near Earth Object Observation Program, with at least one viable target already identified for each mission option. ARM will fully demonstrate a 50 kilowatt (kW)-class high power SEP tug that could later extend to provide a highly efficient cargo and logistics transportation system for a Mars campaign

Mars 2020: In 2020, NASA will launch a new rover to Mars that will seek signs of past life on the Martian surface. The Mars 2020 heat shield will be instrumented to provide additional data on the performance of the shield during descent through the Martian atmosphere, thus informing design of entry, descent and landing systems for future human missions. The Mars 2020 rover also will carry science and exploration technology investigations that advance the state of knowledge needed to prepare for future human and robotic pioneers on Mars.

Exploration Mission-2 (EM-2): In 2021-22, NASA will launch the first crewed mission of Orion and SLS. This will be the first mission to demonstrate crewed flight beyond low Earth orbit; carrying a crew of up to four farther into space than humans have ever traveled.

Exploration Upper Stage: NASA is working toward development of a new upper stage in time for EM-3, and sooner if possible, which would advance SLS to a greater than 105mT capability.

Asteroid Redirect Crewed Mission: NASA plans to conduct the Asteroid Redirect Crewed Mission (ARCM), once the asteroid is in a stable orbit around the moon. The timing of this mission depends on the orbital attributes of the asteroid chosen. ACRM will demonstrate EVA out of Orion and other critical operations needed for future deep space exploration.

Exploration Augmentation Module Partnership: NASA is investigating concepts for deep space habitation module systems development. The deep space habitation module itself is likely to be provided by a commercial or international partner—or some hybrid of these.

Beyond the early Exploration Missions above, NASA plans to achieve a regular, more frequent cadence of missions, to include both crewed missions with Orion and uncrewed missions of SLS carrying exploration cargo or future science missions to deep space. Thus current SLS development efforts provide pathways for evolution in lift capability and focus on affordability of production and launch operations.

Summary

We already have taken the first steps on the path to Mars and our future course is being charted in accordance with continuing stakeholder dialog, founded on the principles, architecture studies and capabilities in development for the Evolvable Mars Campaign. Many of the building blocks, such as SLS, Orion, ARM and various technologies already are in development or formulation. The studies under the rubric of the Evolvable Mars Campaign will continue through this summer and we will engage our stakeholders throughout the process to further refine our roadmap to Mars. We plan to issue a revision to the Voyages document—with a more detailed roadmap to Mars—by the end of this calendar year, after more rounds of discussion with our partners and stakeholders. We also are laying the foundation for partnerships with both other nations and the US commercial sector. This will be an evolving roadmap; we will fill in more detail—and some major pieces—in the months and years to come as options and partnerships materialize and mature. We will shape and proceed along the path to Mars at the pace fiscal and technological conditions allow, as explorers and pioneers always have. And like those who have gone before, we have our eyes on the frontier, and on a better future for the nation and for humankind.