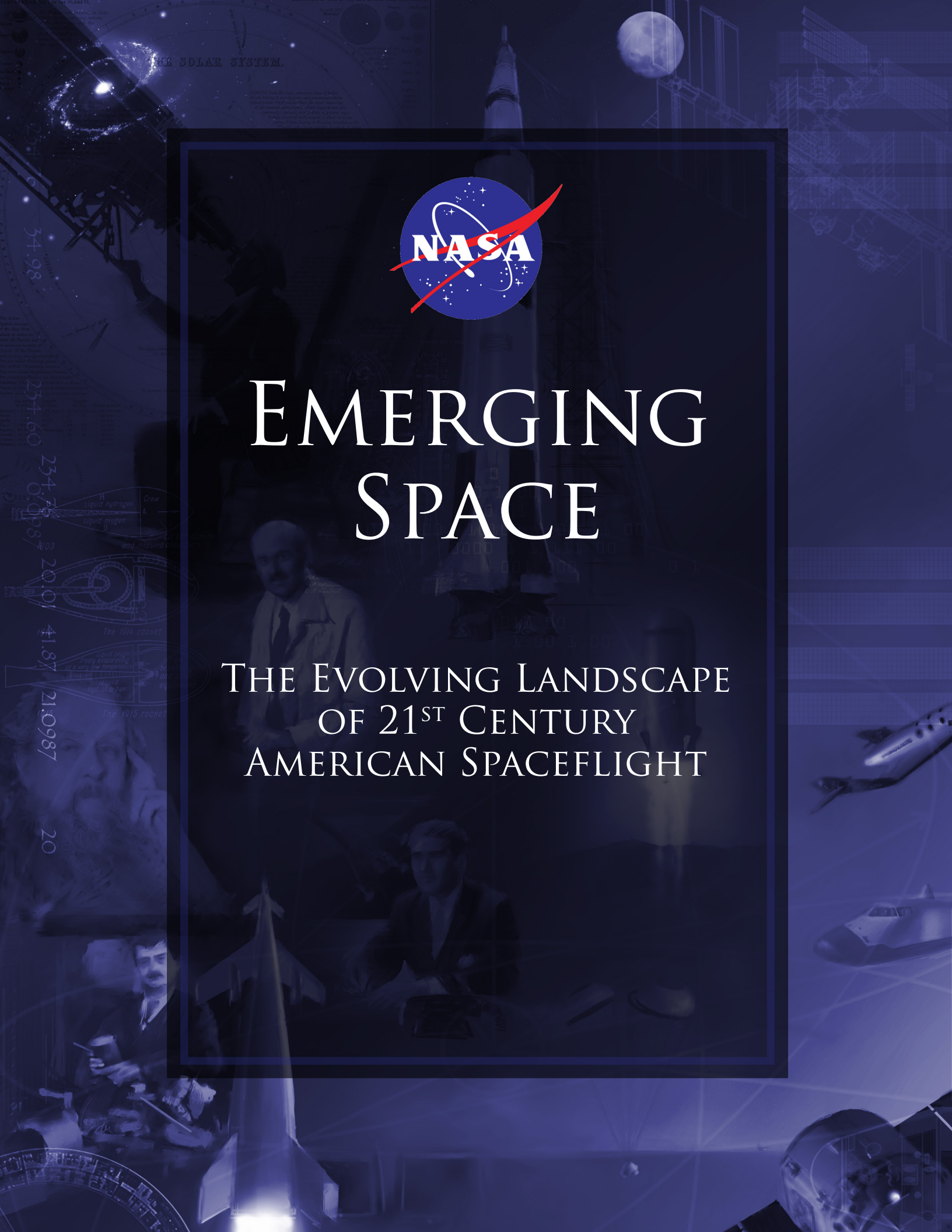
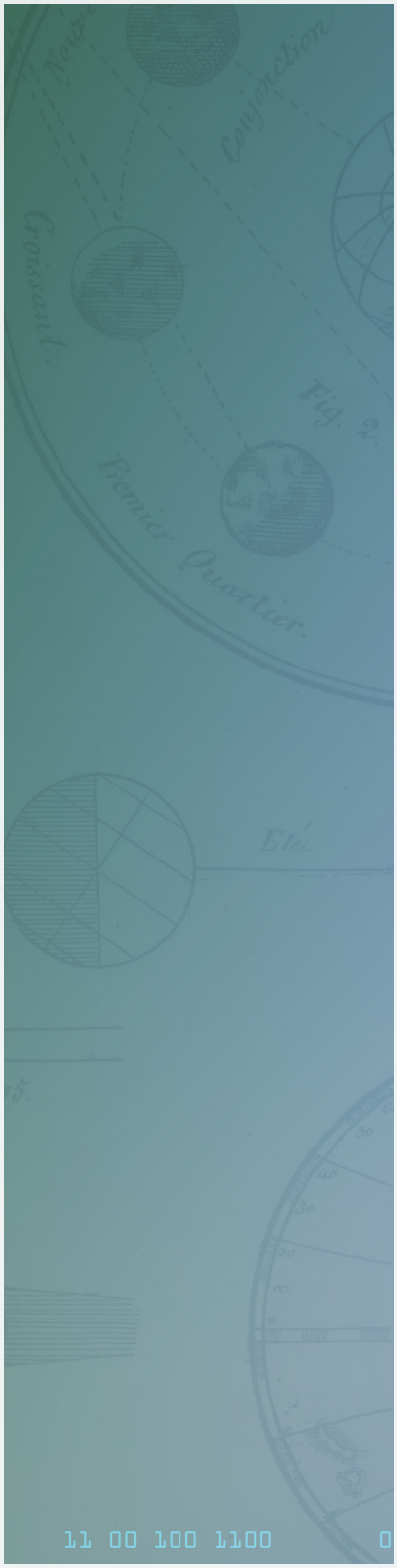


Emerging Space

The Evolving Landscape of 21st Century American Spaceflight

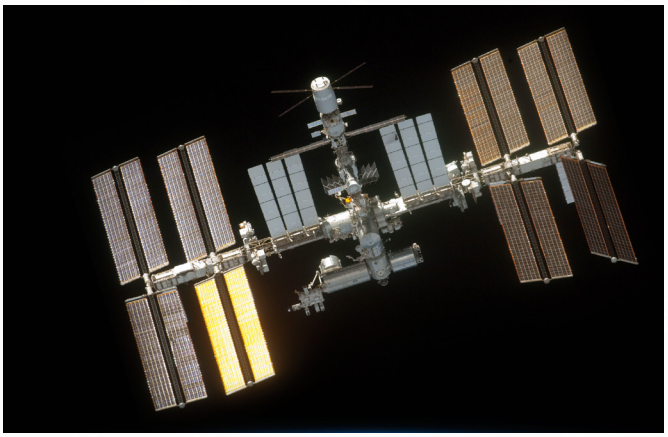

THE SOLAR SYSTEM
Liquid hydrogen
Liquid oxygen
Crew
Carbon-dioxide and miasma absorbers
1903
The 1914 rocket
Liquid oxygen freely evaporating at a very low temperature
Liquid hydrocarbon
Crew, breathing and other equipment
The 1915 rocket
NATIONAL AERONAUTICS AN
U.S.

Contents

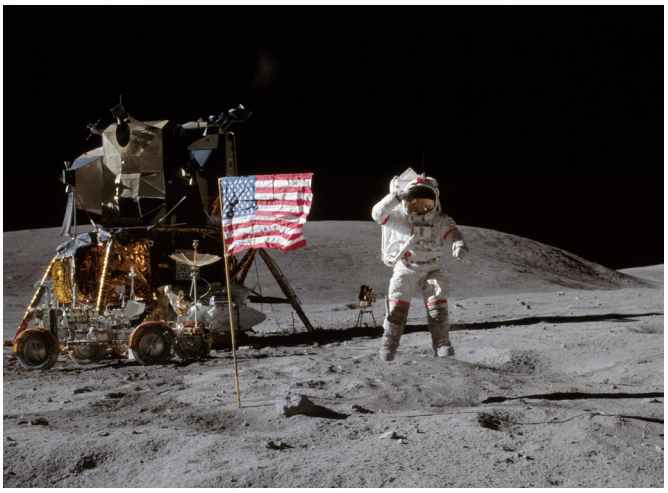


This report is intended for informational purposes only, and does not indicate a commitment or intention, implied or otherwise, by the government to engage in any activity or to enter into any agreement, contract or other obligation. The inclusion of information in this report does not constitute endorsement of any entity, or any products, services, technologies or activities.

Introduction:
The Evolving Landscape of 21st Century American Spaceflight



The International Space Stattion (ISS), the most complex international endeavor ever undertaken, orbits the Earth.



Astronaut John Young salutes the flag on Apollo 16.

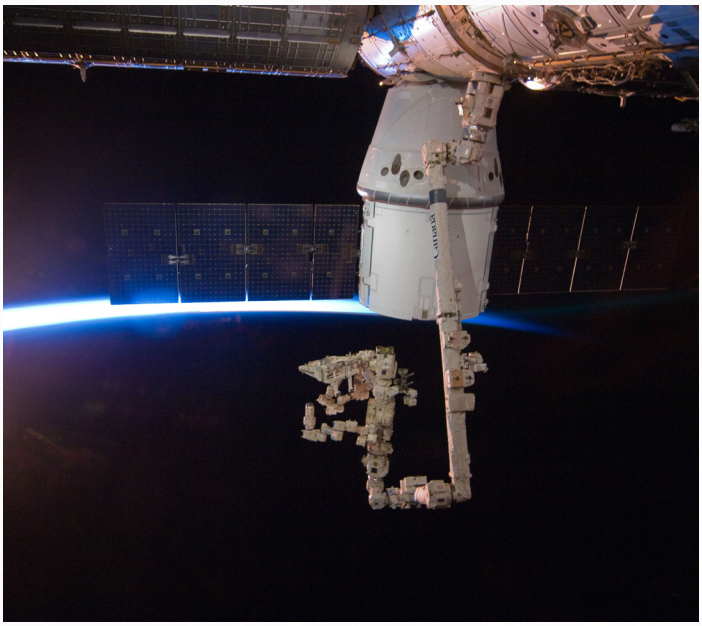
NASA's Curiosity rover, which landed on Mars in 2012, explorers the surface of the Red Planet.

America stands today at the opening of a second Space Age. Innovative NASA programs and American entrepreneurs together are transforming the space industry. These initiatives—both at NASA and in the private sector—are expanding the nation's opportunities for exploration and for the economic development of the solar system.

Today's space economy extends some 36,000 kilometers (22,369 miles) from the surface of the Earth and includes an array of critical technologies—satellite communications, global positioning satellites, and imaging satellites—on which our economy depends. These technologies are now an integral part of our economy, and they would not exist if not for the over 50 years of research, development, and investment in the enabling technologies by NASA and other government agencies that seeded these efforts and allowed them to bloom. As we expand our activities in the solar system over the next decades, NASA programs and investments will provide the seed and soil that encourage economic development increasingly farther from Earth. The first signs of this are already visible.

The next era of space exploration will see governments pushing technological development and the American private sector using these technologies as they expand their economic activities to new worlds. NASA's next objectives for exploration—visits to asteroids and Mars—are more complex than any previous space mission attempted. They will happen in the context of relatively smaller NASA budgets and an expanding commercial space economy. Teaming with private sector partners to develop keystone markets like low Earth orbit (LEO) transportation and technological capabilities like asteroid mining will help NASA achieve its mission goals, help the space economy evolve to embrace new ambitions, and provide large economic returns to the taxpayer through the stimulation and growth of new businesses and 21st century American jobs.

Motivated by an intrinsic desire to explore space, successful American entrepreneurs have pledged and spent hundreds of millions of dollars to develop technologies aimed at fundamentally improving space access. Since 2003, commercial human spaceflight has received $2.5 billion in private investment.[1] At the same time, a new generation of space enthusiasts are engaging directly though small-scale projects. Through cubesats, suborbital and orbital adventures, and citizen science opportunities, the United States is transitioning from a spacefaring nation to a nation of spacefarers.



Commercial space companies SpaceX (left) and Orbital Sciences Corp. (right) currently provide cargo transportation services to the ISS.

In addition to executing its scientific and human spaceflight programs, NASA also has a legislated responsibility to "encourage, to the maximum extent possible, the fullest commercial use of space." As part of fulfilling this responsibility, this report examines how NASA has collaborated with American private-sector individuals and companies investing in space exploration, collectively known as "emerging space." Today, more than fifty years after the creation of NASA, our goal is no longer just to reach a destination. Our goal is to develop the capabilities that will allow the American people to explore and expand our economic sphere into the solar system. Although when NASA was founded only a government program could undertake a voyage from the Earth to the Moon, this may not be true in the future. By taking full advantage of the combined talents of government and the American private sector, our next journeys beyond Earth will come sooner and we will catalyze new industries and economic growth in the process.

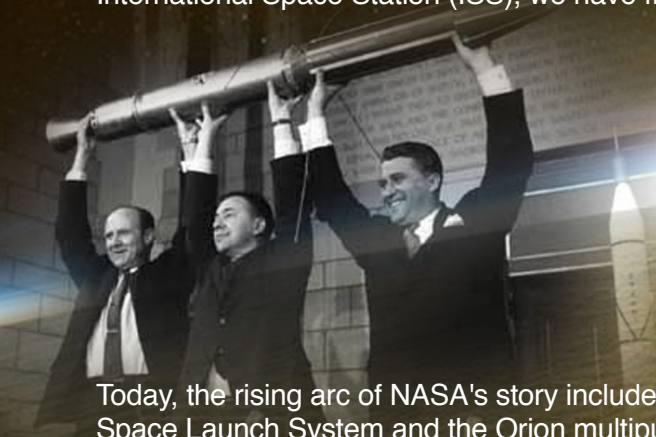
The launch of NASA's Lunar Atmosphere and Dust Environment Explorer (LADEE) on September 6, 2013 as seen from New York City.

When NASA was founded, only a government program could undertake a voyage from the Earth to the Moon. This may not be true in the future

NASA Engages with Emerging Space:

Forging the New Space Economy

Humans have been traveling into space for more than half a century. Prior to that first flight, however, American citizens had been thinking about and working towards spaceflight for over a hundred years. The story of the continuing American journey in space has been an epic one, and NASA is proud to have been one of the central characters of that story. Over the decades NASA's role has been to steadily build humanity's capability to function away from our home planet on behalf of the American public. The Mercury Program showed us that we could go into space and return safely, the Gemini Program taught us essential lessons in operating in space, and the Apollo Program demonstrated that our drive to explore could bring about the once unimaginable feat of a human on the Moon. From there, the Space Shuttle taught us how to return to space on a continuous basis, and with the International Space Station (ISS), we have finally achieved a permanent home in space.



Today, the rising arc of NASA's story includes the development of new rockets and spaceships—such as the Space Launch System and the Orion multipurpose crew vehicle—that will enable us to go beyond the Earth's environs, to operate in the vicinity of the Moon, and eventually to move out further into the solar system.

Sustaining the expansion of our frontiers will also require fresh ideas and new approaches. An emerging space industry sparked by the initiative of private entrepreneurs and dedicated to creating new markets for goods and services will be integral to helping NASA continue to explore space and help the nation expand the space economy to sustain that exploration. NASA has embraced the emerging space industry, both because of our legislative responsibility to encourage the fullest commercial use of space and because we recognize kindred explorer spirits in these nascent private-sector American spaceflight projects. NASA has taken steps to foster the emerging space industry in a deliberate effort to build capability and seed an expansion of economic activity. Through competition for cargo and ultimately crew transportation to the ISS, NASA is helping to develop commercial capabilities that can enable new markets and increased American competitiveness in existing ones. NASA has also partnered with these new companies to transfer technological know-how, while at the same time encouraging competition between them. Perhaps the most salient area of this competition is in access to low Earth orbit. By leveraging NASA's modest support with their own resources, American companies are lowering the cost of launching cargo into space. As lower launch costs transform economic decision-making, new markets for services that once were cost-prohibitive

are becoming increasingly realistic, to the point where serious people are now contemplating ideas that once seemed fanciful, such as asteroid mining and privately-run missions to Mars.

Although it is not NASA's responsibility to ensure the success of these independent private-sector ventures, as the U.S. federal agency responsible for advancing American civil space technologies and civil spaceflight capabilities, NASA has a robust suite of programs that are helping to advance, purchase services from, and transfer technologies to emerging U.S. private-sector space projects. By helping to develop a number of different aspects of the emerging commercial space ecosystem in tandem, NASA is helping to facilitate the emergence of a new approach to American spaceflight. Future exploration activities such as NASA's Asteroid Redirect Mission will take us farther away from our home planet than we have ever been before and we will need a robust, innovative, and energetic American space economy to support and build off of it. The following section highlights just some of NASA's efforts to work with the emerging space community on the International Space Station; the ISS commercial crew and cargo; space technology; as well as emerging space companies seeking out NASA's expertise and facilities. It also shows how NASA and its ten centers around the country have already helped to expand and embed the American space experience as a part of every state's economy as we work to extend the nation's reach into the solar system.

"A robust and competitive commercial space sector is vital to continued progress in space. The United States is committed to encouraging and facilitating the growth of a U.S. commercial space sector that supports U.S. needs, is globally competitive, and advances U.S. leadership in the generation of new markets and innovation-driven entrepreneurship."

National Space Policy of the United States of America, 2010

NASA Engages with Emerging Space:

Economic Development and the ISS

The ISS is the most complex international scientific and engineering project in history and the largest structure humans have operated in space. It is also the core of our human economy in space with six people living within it. The ISS is a partnership between the United States, Russia, Europe, Japan, and Canada, with 15 nations coming together to design, assemble, occupy, and conduct research inside and out. For the last 10 years, research has been primarily conducted by the government and public sector. For the next decade, NASA is actively welcoming a broader array of partners and is pursuing the continued economic development of our home in orbit.

NASA seeks and encourages the utilization of the ISS for scientific research by commercial firms, universities, non-profits, and other organizations, offering access to its high-quality microgravity facility for research in life and physical sciences. The microgravity environment holds promise for private-sector research in pharmaceuticals, biotechnology, physical sciences, and life sciences, as it allows cells and crystals to grow larger, and alloys and materials to form with fewer impurities, than they can under gravity. The ISS was designated a National Laboratory in 2005, and NASA helped create the Center for Advancement of Science in Space (CASIS) to manage the use of the station for scientific research. The ISS is also our first international human economic ecosystem in space and we are learning how to foster economic development in space through its utilization and further development.

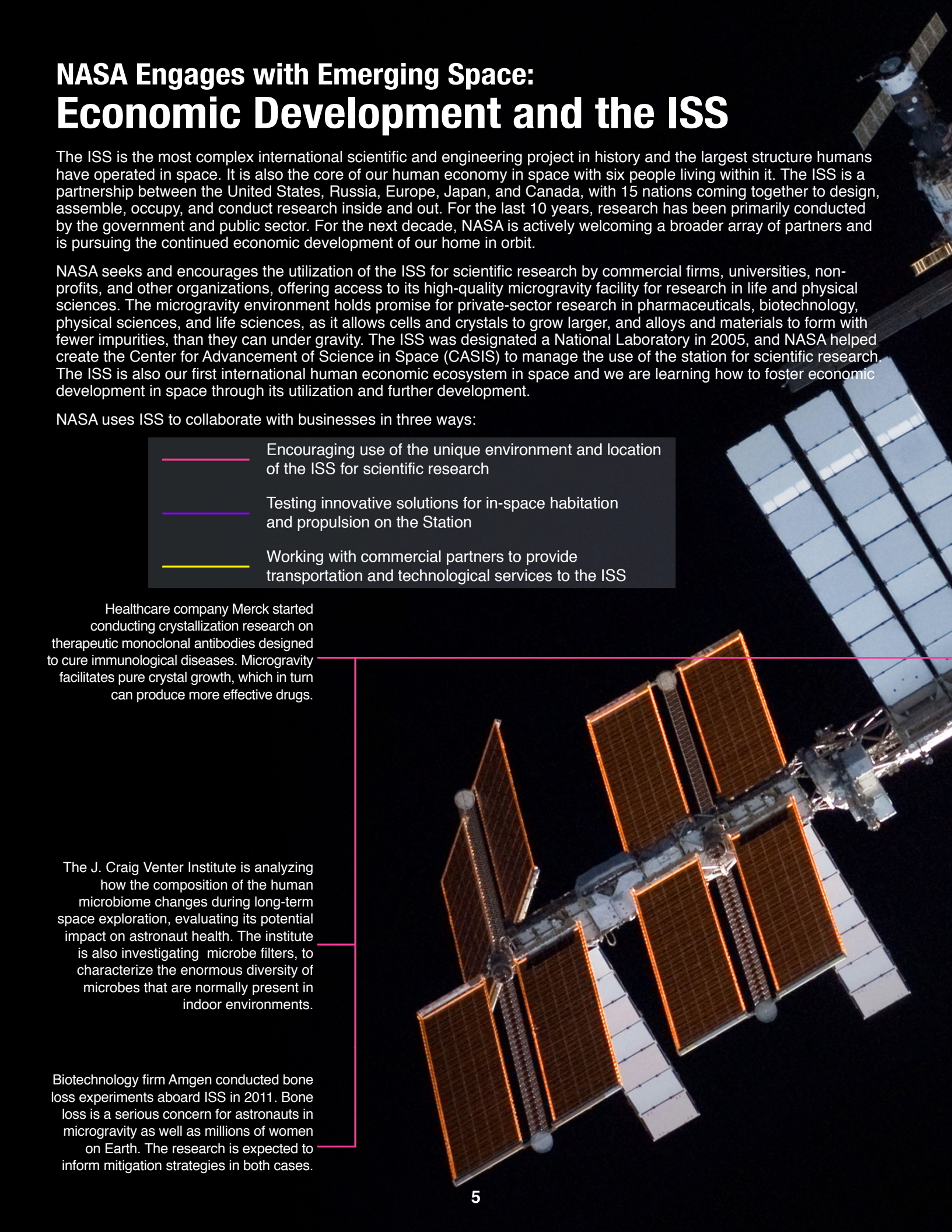
NASA uses ISS to collaborate with businesses in three ways:

- Encouraging use of the unique environment and location of the ISS for scientific research
- Testing innovative solutions for in-space habitation and propulsion on the Station
- Working with commercial partners to provide transportation and technological services to the ISS

Healthcare company Merck started conducting crystallization research on therapeutic monoclonal antibodies designed to cure immunological diseases. Microgravity facilitates pure crystal growth, which in turn can produce more effective drugs.

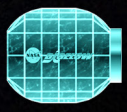
The J. Craig Venter Institute is analyzing how the composition of the human microbiome changes during long-term space exploration, evaluating its potential impact on astronaut health. The institute is also investigating microbe filters, to characterize the enormous diversity of microbes that are normally present in indoor environments.

Biotechnology firm Amgen conducted bone loss experiments aboard ISS in 2011. Bone loss is a serious concern for astronauts in microgravity as well as millions of women on Earth. The research is expected to inform mitigation strategies in both cases.



The ISS is becoming a frontier industrial and development hub for the nation

Hamilton Sundstrand is selling NASA the water produced by the Sabatier Reactor System. NASA did not buy the hardware, but instead will purchase the water as a service. If the system does not work, NASA will not pay for it.



NASA awarded Bigelow Aerospace a $17.8M contract to test an inflatable structure on the ISS. The company aims to develop larger inflatable modules for use as habitats in orbit and on the Moon. The ISS provides a unique opportunity to test these products in a real world environment.

Innovative Space Propulsion Systems (ISPS) plans to test its NOFBX green propellant thruster on the ISS within the next few years. Replacing toxic fuels now in use would simplify spacecraft ground operations. It may also be ideal for use as a storable propellant in orbital fuel depots and Earth departure stages because it doesn't boil-off or degrade containers.

NanoRacks lowers the barriers to space by providing a standard platform for companies, universities, schools, and individuals to help maximize the use of ISS. The company's modular research systems are located in the Japanese Kibo module.

NASA purchases cargo delivery services to ISS from Orbital Sciences Corp. and SpaceX. Orbital provides the expendable Cygnus (left) and SpaceX provides the retrievable Dragon (right). A shortfall in ISS logistics needs after retirement of the Shuttle provided an opportunity for NASA to stimulate a commercial space cargo transportation capability that has the potential to open up the ISS to greater private-sector utilization than ever before.

NASA Engages with Emerging Space:
Enabling Commercial Crew and Cargo

Commercial companies developing vehicles under commercial cargo or commercial crew contracts with NASA include (top to bottom) SpaceX for its Dragon vehicle, Orbital Sciences Corporation for the Cygnus, Boeing for the CST-100, and Sierra Nevada Corporation (SNC) for Dream Chaser.

NASA has initiated several innovative new programs that partner with commercial firms to reduce the cost of transportation to and from orbit and help foster a commercial market for space transportation independent of NASA activities. The Commercial Crew and Cargo Program purchases flight services to the ISS, a departure from the previous model of NASA owning and operating its own vehicles. NASA is currently working with Orbital Sciences Corp. and SpaceX to carry cargo and experiments to and from the ISS. To date, NASA has invested over $5.7 billion in commercial partners located throughout the United States as part of the agency's commitment to develop the nation's emerging space industries (see Table 1). A 2011 NASA study showed that NASA's decision to stimulate the development of commercial capabilities instead of using a traditional cost-based contract to develop similar capabilities resulted in significant savings for NASA.[2] Not only did NASA save a significant amount of money, but the United States now has a commercial launch vehicle that is competing with Europe and Russia for commercial telecommunication launches. By the beginning of 2014, SpaceX had completed two cargo flights to the ISS and had a backlog of 28 missions for non-NASA customers.

In addition to financial investments, the program also helps its commercial partners by sharing the knowledge NASA has matured through over 50 years of space flight. NASA has received nearly 1,000 requests for documents, drawings, test plans, and test results from its commercial crew partners (see Figure 1). More than half of these requests concern information regarding the Space Shuttle, but requests also include data from Apollo. NASA's partners use these data products to accelerate their crew transportation system development efforts. These agreements allow NASA's partners to access unique expertise, goods, and services without incurring extra costs to NASA.

Because all space activity requires transportation to space, NASA’s Commercial Crew and Cargo Program is the critical enabler for further American space economic development—the equivalent to roads, railroads, canals, and other national investments that expanded our frontiers.

Through competition, NASA is encouraging development of commercial crew and cargo access to low Earth orbit and beyond

Agreement or Contract	Investment to Date	Partners	Scope
Commercial Orbital Transportation Services	$891M	Orbital and SpaceX	Cargo transportation system technologies and concepts
Commercial Resupply Services	$3.4B	Orbital and SpaceX	Cargo resupply services to the ISS
Commercial Crew Development Round 1	$50M	Blue Origin, Boeing, Paragon, Sierra Nevada, and ULA	Crew transportation system technologies and concepts
Commercial Crew Development Round 2	$315M	Blue Origin, Boeing, Sierra Nevada, and SpaceX	Elements of a crew transportation system
Commercial Crew Integrated Capability	$1.1B	Boeing, Sierra Nevada, and SpaceX	Integrated crew transportation systems
Certification Products Contract	$29.6M	Boeing, Sierra Nevada, and SpaceX	Early certification products

Table 1. NASA has distributed more than $5.7B in contracts and Space Act Agreements for commercial crew and cargo.

Commercial Applications for Commercial Crew and Cargo

SpaceX's Dragon capsule, designed to address ISS cargo and crew requirements, is also being marketed as a free-flying platform for in-space technology demonstrations and scientific instrument testing. SpaceX is currently manifesting fully commercial, non-ISS Dragon flights under the name "DragonLab." SpaceX has also partnered with Bigelow Aerospace to conduct a joint marketing effort focused on international customers. The two companies plan to offer rides on SpaceX's Dragon spacecraft to carry passengers to the anticipated Bigelow habitats orbiting the earth.

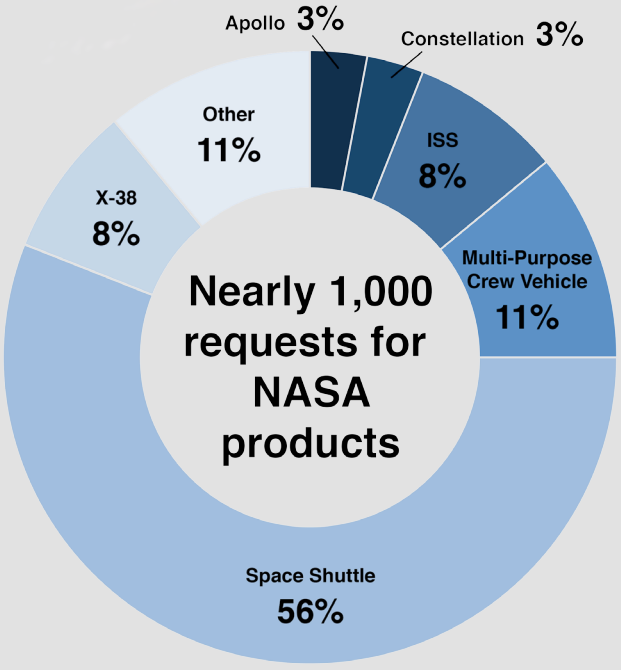


Figure 1. Partner data requests by program.

NASA Engages with Emerging Space:
Advancing Space Technology

Extraordinary endeavors, like moving asteroids or supporting people on voyages to Mars, require extraordinary technologies. NASA's community of innovators includes the NASA workforce, small businesses, and established and emerging space companies. This is a community that regularly develops, tests, and implements cutting-edge research, and which yields potentially transformative solutions that can accelerate timelines, slash costs, or multiply science return. NASA makes progress in essential space technologies daily, enabling more capable and far-reaching future space activities for our nation.

NASA's Space Technology portfolio includes critical technologies for expanding American activities in the solar system as well as technologies that will benefit the public and our economy

Solar Electric Propulsion

Using advanced Solar Electric Propulsion (SEP) technologies is an essential part of future missions into deep space with larger payloads. NASA's SEP Project will develop and mature technologies for its asteroid redirect mission and ultimately human and robotic exploration of Mars and beyond. SEP systems can reduce the mass of a satellite, which could offer significant cost savings for government and commercial satellites. Solar electric propulsion enables the efficient transport of heavy payloads from low Earth orbit to higher orbits. It could significantly benefit the U.S. satellite industry, and already a number of U.S. satellite manufacturers have developed or are developing solar electric satellite buses. Commercial missions could use solar electric propulsion tugs to place, service, resupply, reposition and salvage space assets.

Cryogenic Propellant Storage and Transfer

Cryogenic Propellant Storage and Transfer will allow a new generation of spacecraft to operate deeper and longer in space because the spacecraft will be able to refuel along the way. Cryogenic propellants provide high-energy propulsion solutions critical to future, long-term human exploration missions beyond LEO. NASA is currently developing the Cryogenic Propellant Storage and Transfer Project to explore a means of storing and transferring these propellants in space for long durations, and preventing temperature fluctuations that contribute to fuel losses due to boil-off. The technologies may lead to the development of propellant depots—space gas stations—that will be important as traffic volumes in the solar system increase.

Laser Communications

Laser communication between space assets can provide 10 to 100 times higher data rates than radio, and enable communication across tens of millions of kilometers. NASA recently successfully tested laser communications on its LADEE lunar mission. NASA has developed the hardware and documentation to also transfer this technology over to commercial developers. This capability could revolutionize the way data is transmitted and received, dramatically improving communications between satellites, probes, and spacecraft deployed throughout the solar system.

Early Stage Innovations

NASA’s early stage space innovations address high priority technical needs that America's space program must master to enable future missions. This program reaches out to American innovators through NASA's Innovative Advanced Concepts (NIAC) program, which encourages potentially transformative engineering concepts that could enable entirely new missions or breakthroughs in future aerospace capabilities. It involves universities, through its Space Technology Research Fellowships, to select technology research that is a dramatic improvement over existing capabilities. NASA has over 450 activities in early stage innovation, and is working to include more of America's top universities to address NASA's technical needs.

Flight Opportunities Program

The Flight Opportunities Program provides opportunities to test and demonstrate spacecraft technologies and payloads that could help revolutionize future space missions. In June 2013, NASA announced it is also considering funding flights of astronaut researchers aboard some vehicles as opportunities present themselves. Seven companies are providing flight opportunities for payloads.

Small Satellite Programs

NASA is pursuing development of new subsystem technologies to enhance or expand the capabilities of small spacecraft; support flight demonstrations of new technologies, capabilities and applications for small spacecraft; and use small spacecraft as platforms for testing and demonstrating technologies and capabilities that might have more general applications in larger-scale spacecraft and systems. A recent example is NASA's Fast, Affordable, Science and Technology Satellite (FASTSAT) mission, which successfully demonstrated a capability to build, deploy and operate a science and technology flight mission at lower costs than previously possible.

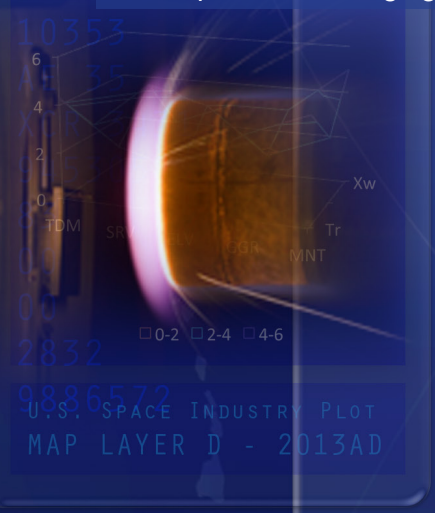
NASA Engages with Emerging Space:

NASA Facilities and Expertise Advance Space Development

NASA's infrastructure and expertise are valuable resources for emerging space companies. The agency's investments in facilities and capabilities began with the acquisition of research centers managed by the National Advisory Committee for Aeronautics established in 1915 and Army missile expertise acquired shortly after NASA was established. NASA's centers bring almost a century of heritage and expertise to assisting with the development of American spaceflight capabilities.

As the agency's priorities and missions evolve, so too do its needs in terms of facilities and expertise. The retirement of the Space Shuttle means that valuable infrastructure and experience can now be made available to the emerging space industry. These assets, otherwise latent, provide emerging space companies with capabilities they could otherwise not afford. The benefit to NASA is that it can leverage advancements made by these companies to help execute and assist agency programs. The benefit to the American taxpayer is that high value resources are continually reused, rather than abandoned or removed. Use of these publicly funded assets means that the U.S. space industrial base can remain vigorous and competitive.

This map describes only a few examples of how NASA facilities and expertise are being used to encourage the development of emerging space capabilities that may in turn help further NASA's goals.



Ames Research Center (ARC) provides support in wind tunnel testing, risk analysis, test beds for human space flight, and thermal protective system (TPS) testing and analysis. ARC used its expertise and facilities to help SpaceX develop the PICA-X ablative material used on the company's Dragon capsule. The Center has been working with Paragon to evaluate the company's TPS being designed for a mission sponsored by the Inspiration Mars Foundation. ARC has also provided support to Blue Origin, Boeing, and SNC.

The **Armstrong Flight Research Center** (AFRC) was able to help SNC perform Dream Chaser ejection seat and structural design testing.

The **Jet Propulsion Laboratory** (JPL) is working with Masten Space Systems to develop a flight control algorithm called Fuel Optimal Large Divert Guidance (G-FOLD), designed to enable pinpoint landing using Masten's XA-0.1B "Xombie" vehicle. JPL has also been supporting SpaceX on acoustic and ablative shield testing for Dragon.

Johnson Space Center (JSC) is supporting companies like Blue Origin, Boeing, SNC, and SpaceX in the development of commercial crew and cargo with engineering support and testing. For example, JSC supported SNC in the technical development of, and operations support for, the Dream Chaser Space System.

Over 30 non-NASA customers have processed and qualified their flight hardware through **Goddard Space Flight Center's** (GSFC) Rapid Spacecraft Development program since it's inception in 1997. Over 140 successful environmental tests in the past 12 years.

Glenn Research Center's (GRC) unique Plum Brook facilities feature the world's largest space environment simulation chamber; the world's only test facility capable of handling rocket engine firings; a cryogenic test facility; and a hypersonic wind tunnel. These facilities have been used for tests by many emerging and traditional space companies including SNC and SpaceX.

Wallops Flight Facility (WFF) has substantially collaborated with or supported more than 35 different commercial space companies over the last two decades. Support has included activities associated with the launch range, integration and testing and engineering expertise.

Marshall Space Flight Center (MSFC) has over 200 ongoing collaborative agreements that leverage its unique experience in propulsion, space systems, science, and operations capabilities. It has agreements for support with all the commercial crew and cargo partners, as well as with many other companies including Virgin Galactic.

Langley Research Center (LaRC) has provided support for commercial companies in the testing of guidance, navigation and control systems; analysis of aerodynamic and aerothermodynamic structures; and wind tunnel testing. Boeing, SNC, and SpaceX have all used LaRC's expertise.

Kennedy Space Center (KSC) operates some of the largest and most sophisticated testing and processing facilities in the country and can offer unique access to laboratories and experts, as well as use of the Shuttle Landing Facility and hangars. KSC is actively working with commercial crew and cargo companies, suborbital companies like XCOR and Masten, as well as safety aviation companies like BRS Aerospace.

Stennis Space Center (SSC) is the home of the nation's largest and primary rocket propulsion testing ground. For over 40 years it has provided propulsion test services for NASA and the Department of Defense, as well as the private sector. Blue Origin tested its BE-3 engine at SSC in 2012.

NASA's facilities and expertise represent opportunities for emerging space companies to build upon a legacy of success

NASA Engages with Emerging Space:
The NASA Era Space Economy

MAP KEY

- NASA Centers
- FAA-Licensed Launch and Reentry Sites
- Military Space Installations (procurement, control, launch)
- Major Space Businesses and Facilities
- NASA Space Grant Consortium (city of location)

The U.S. space economy grew substantially following the establishment of NASA. NASA played an integral role in the development of satellite communications and remote sensing, a contribution that ultimately led to the emergence of the largest space-based market consisting of commercial television, telephone, data, and remote sensing services. An impressive space industrial infrastructure formed within a relatively short time to support the agency's Apollo and Space Shuttle programs, as well as scientific missions that have been launched since 1958. Combined with military space activities, the U.S. space industry employed over 240,000 people by 2011 across thousands of companies. The agency also set up the NASA Space Grant Consortium spanning all 50 states, the District of Columbia, and Puerto Rico to support students pursuing careers in science, mathematics, engineering and technology. NASA has transformed the pursuit of spaceflight from the private domain of a few to a national endeavor, creating a vibrant American space industry in the process. This map captures only the tip of the iceberg of America's space enterprise, including NASA centers, the top two tiers of space manufacturers, major space legacy companies, major satellite operators, emerging space companies, space-related military installations, and NASA Space Grant Consortium centers.

The formation of NASA as a federal agency expanded spaceflight activities to the whole of the nation

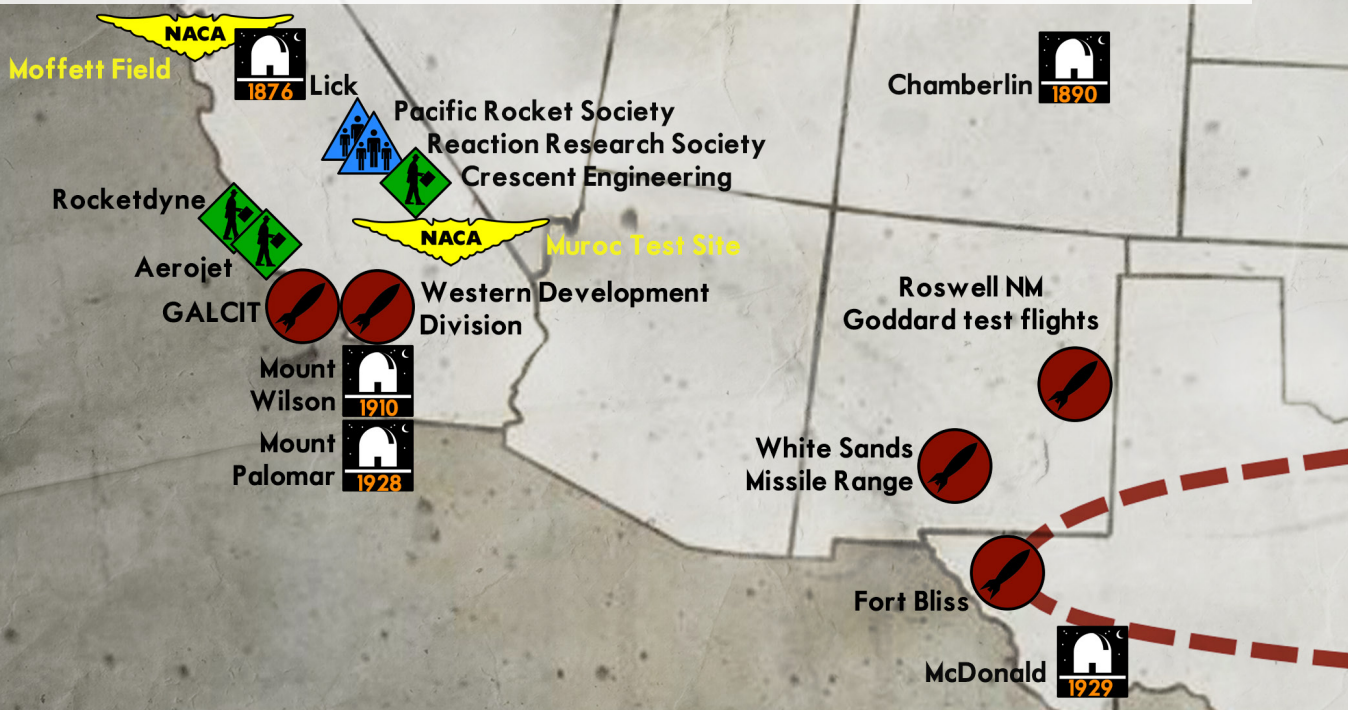
NASA Engages with Emerging Space:

The Pre-NASA Space Economy

Prior to NASA's formation Americans were already working to explore space—both through astronomical observatories and through the private-sector development of liquid-fuel rocketry. By 1958, private investments in over 40 U.S. observatories totalled about $8 billion in 2012 dollars, and nationwide rocket clubs and test sites laid the first foundations of the American space community.[3] Rocket engine companies were also established during this time, and these helped form the basis for a space industry to come. Prior to NASA's formation, the U.S. was already a global hub for the development of astronomy, spaceflight technology, and grand ambitions for the exploration of space.

When NASA was formed in 1958, its core centers came from the National Advisory Committee for Aeronautics (NACA), founded in 1915 to investigate aeronautical problems and conduct research that would be of overall benefit to the U.S. aerospace industry and the national interest. Rocket engineers like Frank Malina and James Wyld were already contributing to the field of rocketry, with their efforts pursued at the privately endowed GALCIT, later the Jet Propulsion Laboratory and Reaction Motors, Inc. After the war, the newly formed Air Force pursued development of the Atlas and Thor missiles at the Western Development Division in California, commanded by Brigadier General Bernard Schriever. In 1945, the German rocket team behind the V-2, led by Werner Von Braun, arrived in America, adding their technological expertise, culture, and spaceflight vision to the mix.

This map identifies some early observatories and aerospace research and development sites, NACA facilities, major rocket clubs and space advocacy associations, Robert Goddard's test sites, and the journey of German rocket engineers to the United States. It shows the variety of public and private initiatives around which NASA and the American space program of the Cold War would form.



Map Key

- Major rocket and missile development sites
- Major astronomical observatories with year established (1874)
- Major rocket groups and associations
- Rocket engine companies
- NACA — National Advisory Committee for Aeronautics
- PROJECT PAPERCLIP journey of German rocket engineers


Even before the formation of NASA, American citizens were working, organizing, and investing in order to make spaceflight a reality
Goddard launch of liquid fueled rocket from Auburn
Dudley 1854
MIT Rocket Society
Warner 1880
Vassar 1865
1889
Yale
Yale Rocket Club
1842
West Point
American Rocket Society
Detroit Rocket Society
Washburn 1876
Detroit 1852
Lewis
NACA
Reaction Motors Inc
Yerkes 1895
United States Rocket Society
Chicago Rocket Society
Cleveland Rocket Society
Allegheny 1862
US Naval Observatory
1842
Georgetown 1844
American Rocketry Association
Peoria Rocket Association
1843
Cincinnati
Morrison 1874
NACA
Langley
McCormick 1881
Morehead 1831
1950
Redstone Arsenal
1945
Cape Canaveral Missile Annex
ALASKA
Bonham AFB
HAWAII

New Landscape of Space Exploration:
Private Investors and Entrepreneurs

Participation by individuals is characteristic of how space exploration in the United States began. It was private capital from successful entrepreneurs that contributed to the construction of America's first ground-based astronomical observatories during the early part of the 19th century. Shortly after the dawn of the 20th century, investments from philanthropists like Daniel Guggenheim, the dedication of inventors like Robert Goddard, and research conducted by amateur rocket societies combined to advance the development of American spaceflight technology. Adjusting for inflation, these early investments in astronomical observatories and liquid-fuel rocketry were similar in scale to the commitments of the current generation of entrepreneurs in commercial space. Individual Americans investing in and advancing the exploration of space is not a new phenomenon.

Today's commercial spaceflight industry, which focuses on pushing the technological boundaries to enable routine access to space for humans, represents the leading edge of rocket development. This industry generated almost $770 million in revenues in 2012, a number that is projected to grow as new vehicles come on line before 2020.[4] The majority of revenue has been generated by the development and operations of new launch vehicles powered by new engines capable of carrying humans into orbit. Because it represents a technological leading edge, the commercial spaceflight industry represents only a small fraction of the overall worldwide space economy, which was estimated to be about $320 billion in 2013.[5]

The underlying current of individual investment and dedicated genius, which began almost two centuries ago, is what energizes the continuing evolution of space exploration. NASA was a major boost to American space efforts when it was established in 1958, tapping this current of innovation and merging substantial expertise and funding in a way that placed men on the Moon and a research installation in Earth orbit. Today, teams big and small, from government to garages, continue to pursue the challenge of spaceflight, leveraging a legacy that is almost as old as the nation itself.

A sampling of U.S. companies pursuing innovative plans for space development follow. Each builds upon and depends on the vast industrial base that has formed since the end of World War II.

Andrew Carnegie (1835-1919): Steel tycoon, contributed more than $1.4M (about $630M today) to the Mount Wilson Solar Observatory, the first astronomical observatory established by a major philanthropic foundation.[6]

James Lick (1796-1876): Considered one of the earliest American patrons of science, dedicated $700,000 (about $1.2B today) to the construction of The Lick Observatory on Mount Hamilton, California.[6]

Daniel Guggenheim (1856-1930): Industrialist, philanthropist, and aviation enthusiast, started a grant for Robert Goddard's rocket experiments that the Guggenheim family continued for 11 years, totalling $188,500 (about $36M today).[6]

Robert Bigelow, a hotel entrepreneur and founder of Bigelow Aerospace, has spent $250M, and pledged over $500M, on the development of inflatable habitation modules for living and working in space.[7] In 2013, Bigelow Aerospace was awarded a contract by NASA to install a small inflatable technology demonstration module on ISS in 2015.

Microsoft co-founder **Paul Allen** invested about $26M in the development of Scaled Composites' SpaceShipOne, the demonstration vehicle that won the $10M Ansari X PRIZE in 2004. This vehicle served as the basis for the development of SpaceShipTwo, a much more capable vehicle announced to begin operations in 2014. Sir Richard Branson, founder of Virgin Group, invested $100M in Virgin Galactic to provide suborbital flights for private individuals using a fleet of SpaceShipTwo vehicles.[8] By 2013, about 625 people had reserved tickets at a price of $200,000-$250,000.

Amazon CEO **Jeff Bezos** established Blue Origin in 2000, a venture dedicated to providing low-cost suborbital and orbital transportation services, using his own fortune. In 2013, his team successfully test fired the company's BE-3 engine, the most powerful liquid hydrogen-liquid oxygen rocket engine developed in the U.S. since the introduction of Pratt & Whitney Rocketdyne's (now Aerojet Rocketdyne) RS-68 a decade ago.

SpaceX, founded by entrepreneur **Elon Musk**, has invested about $500 million to build vehicles to access LEO and beyond.[9] He hired Thomas Mueller, an engineer who was designing and building rocket engines in his garage, to manage development of the Falcon 9 launch vehicle. In 2012, SpaceX became the first company to provide commercial cargo services to the ISS.

Entrepreneurs and philanthropists, past and present, have played a critical role in advancing and investing in our nation's space exploration capabilities

New Landscape of Space Exploration:
Emerging Space Companies

Today's space companies aim to develop viable businesses to provide services such as human space travel and habitation—currently the domain of government agencies. The re-emergence of private investment in space, coupled with ongoing government investment, combines for a promising future in space exploration.

A belief in space exploration and economic development drives the current wave of space entrepreneurs, who seek revolutionary change in our relationship with space, and are motivated by their mission. They do not necessarily view exploration as movement towards one singular accomplishment (such as a moon landing), but as the development of sustainable and diverse economic activities in space. This requires new capabilities enabled by new technologies, but also existing capabilities (like access to space) available at lower costs and prices. By developing these products and services, they aim to open new markets for space experiences and industrial activity.

The following is an overview of emerging space companies and their visions of space exploration. Many of these companies are entrepreneurial, but several (Sierra Nevada, Boeing, and ULA) are accomplished aerospace firms seeking to drive new markets. In addition, there are many other emerging space companies in supplier, component, and services segments. This is a dynamic industry with frequent changes and the listing here is only a sample of the diverse efforts under way. This is not an exhaustive list and several of these companies plan to provide more than one type of service; for example, in addition to providing orbital launch services, SpaceX also intends to provide crew and cargo launch services to Mars sometime in the 2030s.

	Company	Vehicle(s) or Spacecraft	Services
Space Access	Blue Origin	New Shepard, Biconic Spacecraft	Suborbital and orbital launch services including human spaceflight
	Masten Space Systems	Xaero, Xogdor	Suborbital launches of small payloads
	Virgin Galactic	SpaceShipTwo, LauncherOne	Suborbital launches of small payloads, suborbital human spaceflight, and air-launched nanosatellite launches
	XCOR Aerospace	Lynx	Suborbital launches of small payloads, suborbital human spaceflight, and nanosatellite launches
	Orbital Sciences Corporation	Pegasus, Tauris, Antares, Cygnus	Orbital launches of satellites and ISS cargo
	SpaceX	Falcon 9, Falcon Heavy, Dragon	Orbital launches of satellites and ISS cargo, with orbital human spaceflight planned by 2017
	Stratolaunch Systems	Stratolauncher	Air-launched orbital launch services
	United Launch Alliance	Atlas V, Delta IV	Orbital launch services
Remote Sensing	Planet Labs	Dove, Flock 1	Frequent imaging of the Earth and open access to acquired data via website
	Skybox Imaging	SkySat	Frequent imaging and HD video of the Earth, data analysis, and open access to acquired data via website
LEO Human Spaceflight	Bigelow Aerospace	BA 330	Inflatable habitats for use in orbit or on the Moon
	Boeing	CST-100	Crewed LEO transportation
	Sierra Nevada Corporation	Dream Chaser	Crewed LEO transportation
	Space Adventures	Soyuz	Crewed LEO and lunar expeditions
Beyond LEO	B612 Foundation	Sentinel	Detection and characterization of potentially hazardous asteroids
	Inspiration Mars Foundation	Inspiration Mars	Crewed Mars flyby expedition
	Moon Express	Moon Express	Prospecting and mining lunar resources
	Planetary Resources	Arkyd 100, Arkyd 200, Arkyd 300	Prospecting and mining asteroid resources

Table 2. List of emerging space companies, grouped by destination.

Blue Origin

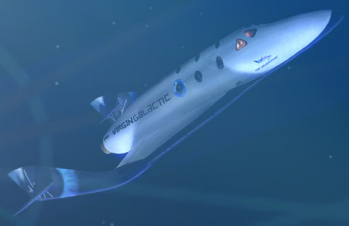
Blue Origin's goal is to lower the cost of spaceflight to enable markets for exploration. Blue Origin is outwardly ambitious and outspoken about its long-term commitment to spaceflight. In 2011, Blue Origin conducted a test-flight of a vehicle prototype for safely sending and returning three passengers into suborbital space.

Masten Space Systems

Masten Space Systems designs and builds reusable launch vehicles intended to serve a niche for low-cost flight experiences. The company's development approach emphasizes frequent flights and rapid validation of data. Masten leadership have invested several million dollars in the company, which has also received $1,150,000 in prize money from NASA Centennial Challenges for developing a terrestrial test-bed for low-cost lunar lander technologies.

Virgin Galactic

Virgin Galactic's goal is to bring spaceflight experiences to consumers. The company's vehicle, SpaceShipTwo, will travel on a suborbital trajectory that provides several minutes in space at a cost of $200,000-$250,000 per passenger. More than 550 people have signed up for Virgin's suborbital flights as of April 2013. Virgin plans to provide orbital services in the future. A reported investment of about $100 million from The Virgin Group and $390 million from Aabar Investments fund development.[10]



XCOR

XCOR Aerospace is developing the Lynx series of suborbital vehicles to transport customers and payloads past the threshold of space at a ticket price of $95,000. By late 2013, about 250 customers had placed deposits for future flights.[11] Investors provided $5M to XCOR in 2012 and $14.2M in financing was contributed by Space Expedition Corporation (SXC) of The Netherlands in 2014.[12]

Orbital Sciences Corporation

Orbital was founded in 1982 with the intention of reducing the costs of launch and is now diversified among launch, satellite, and defense markets. The company is providing commercial resupply services to the ISS after developing the new launch vehicle Antares and orbital vehicle Cygnus through both the COTS and CRS programs. Orbital intends to use Antares for non-ISS commercial launches as well.

SpaceX

SpaceX's goal is to reduce the cost of spaceflight and ultimately, make humanity a space-faring civilization. About $500 million has been invested in the company; about $100 million of that from Elon Musk personally.[13] SpaceX's Dragon capsule is demonstrating resupply missions to the ISS and returning cargo to Earth. SpaceX is competing to be one of three companies to resupply the ISS with crew and successfully offers its vehicles in the commercial satellite launch market. SpaceX is also the first private organization in history to bring back cargo from space. Elon Musk often speaks publicly about enabling missions to Mars.

Stratolaunch Systems

Stratolaunch's goal is to reduce the cost of access to space with air-launched rockets at a scale previously deemed impossible. The custom carrier will have the longest wingspan of any aircraft ever built. The company has estimated investment in development of the vehicle will be about $300 million.[14]

United Launch Alliance

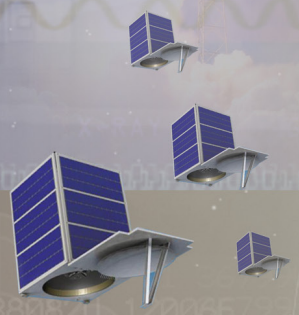
United Launch Alliance (ULA), a joint venture between Boeing and Lockheed Martin, manufactures Atlas V and Delta IV vehicles and only provides launch services to the U.S. Government. ULA has invested its own resources under a Space Act Agreement with NASA to human rate the Atlas V, which may be used to launch crewed spacecraft for Boeing, Sierra Nevada, and Bigelow.

Planet Labs

U.S.-based Planet Labs is a new satellite remote sensing company that operates a constellation of up to 100 small satellites to provide on-demand imagery products. In 2013, it raised about $65 million in funding from Draper Fisher Jurvetson, Industry Ventures, Felicis Ventures, Lux Capital, and Ray Rothrock.[15] The first 28 satellites of its constellation were successfully deployed in early 2014, and the company expects to deploy the remaining satellites by 2015.

Skybox Imaging

Skybox Imaging is designing and building its own fleet of small satellites, each weighing about 100 kilograms. Its objective is to use computers to analyze huge amounts of imagery data that can be turned into useful, near real-time products, including video, for customers. The company has raised almost $91 million, and its first satellite, SkySat-1 was launched in 2013 aboard a Russian vehicle.[16] In 2014, it signed a launch contract with Orbital Sciences Corp. to launch six satellites in 2015.



Bigelow Aerospace

Bigelow Aerospace plans to provide affordable options for people to live and work in space, using an orbital platform it developed based on NASA's inflatable transit habitation technology. Bigelow, who has committed $500 million to the project, announced recently that for $26 to $36 million, clients will be able to spend up to 60 days on the Bigelow Alpha Station, composed of BA 330 modules.[17] Prior to the launch of BA 330 modules, Bigelow Aerospace will test an inflatable platform on the ISS, starting in 2015.

Boeing

Boeing is developing a crewed capsule, the CST-100, in collaboration with Bigelow Aerospace. Boeing has invested corporate resources in the vehicle, which it is also developing through several commercial-style NASA programs. The capsule will address markets for ISS transportation and beyond.

Sierra Nevada

Sierra Nevada is building the Dream Chaser, an orbital vehicle designed to carry seven people and spend months at a time in orbit. The company plans to make the Dream Chaser inexpensive to manufacture and able to land at most airports. The vehicle is a lifting body, originally based on a NASA design, the HL-20, and has been built with support from NASA and internal SNC investment.

Space Adventures

Space Adventure's vision is to open up the space frontier to private citizens and provide access to space resources. Since 2001, the company has flown eight missions to the ISS and remains the only company to contract with private citizens for spaceflight. Space Adventures offers lunar flyby missions, the first of which is planned in 2017 carrying two paying customers.

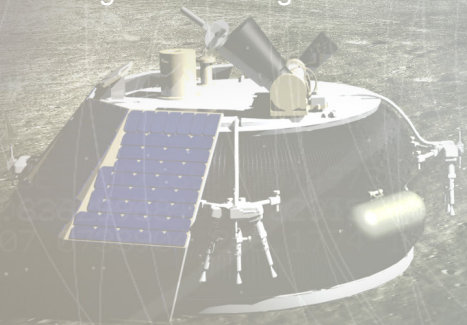
B612 Foundation

B612 Foundation is a non-profit organization that intends to discover and catalog asteroids in the Earth's region of the solar system by launching infrared telescopes (estimated to cost $450 million) into a Venus-like orbit around the sun in 2017 or 2018. The mission will result in the first comprehensive, dynamic map of the inner solar system, to protect the Earth against asteroid strikes.

Inspiration Mars

Inspiration Mars is a non-profit organization that advocates for a low-cost human Mars flyby mission in 2018 or 2021. Dennis Tito, the first private astronaut, has publicly stated that he is willing to spend as much as $100 million on the venture.[18] The greater goals of the organization are to generate knowledge, experience, and momentum for the next great era of space exploration.

Moon Express



Moon Express' long-term goal is to enable commercial mining on the Moon. The company has received funding from former-NASA-employee-turned-millionaire-entrepreneur Barney Pell and is competing to win the Google Lunar X PRIZE.

Planetary Resources

In 2012, Planetary Resources announced plans to mine a near-Earth asteroid (NEA) for raw materials. Supported by billionaires like Google's Larry Page and Eric E. Schmidt, the company is beginning by developing a network of orbital telescopes to prospect for potentially valuable NEAs.

Spacefaring Nation to Nation of Spacefarers

Citizen Astronauts

Since 2001, seven individuals have purchased eight orbital flights (one passenger flew twice) for approximately $20 to $35 million per flight. More and more individuals want, and now are able, to go into space themselves, be it on a suborbital flight, high altitude balloon, or an orbital flight.

Three companies are developing suborbital vehicles to carry humans to the edge of space, Blue Origin, Virgin Galactic, and XCOR. Virgin Galactic and XCOR have announced that they have over 850 existing reservations for trips into suborbital space, which means over the next several years, private suborbital flight providers might almost double the number of humans flown in space (currently just over 500). Their clientele includes wealthy individuals, sponsored researchers, celebrities, and space enthusiasts who have spent a substantial fraction of their wealth to realize long-held dreams of spaceflight. More than 10 celebrities hope to be one of the first to fly; those who have purchased tickets include Angelina Jolie, Lady Gaga, Brad Pitt, and Tom Hanks. The first paying customers are expected to be flying by the end of 2014. Since suborbital vehicles are funded by private companies rather than governments, the companies are seeking out public relations and advertising opportunities to help their business case. NBC television is working with Virgin Galactic to produce a reality television show on contestants for a suborbital flight. XCOR sold 22 flights for a men's cologne campaign that includes advertising and contests to win a flight.

In a survey of ultra-wealthy individuals, seeing the curvature of the Earth from space was cited as the number one reason for wanting to go on a space flight. Paragon Space Development Corporation along with other companies are developing ultra-high altitude balloons that will allow individuals to see the curvature of the earth, a view previously only seen by astronauts and pilots flying at very high altitudes. The Federal Aviation Administration (FAA) has given a preliminary classification approval to World View that the balloon's capsule will qualify as a space launch vehicle under its guidelines. Those guidelines govern suborbital rockets and launch vehicles. The possibility of space as a place for sports and adventure came a little closer in 2012 when

Image: MarsScientific.com & Clay Center Observatory

Scaled Composites conducted two successful powered test flights of SpaceShipTwo in 2013.

On October 14, 2013, Felix Baumgartner broke the world records for the highest altitude of a manned balloon flight, parachute jump from the highest altitude, and greatest free fall velocity.

U.S. company World View Experience, a subsidiary of Paragon, aims to provide high-altitude balloon flights for customers paying $75,000 per ticket. Test flights are planned in 2014.

Felix Baumgartner broke the sound barrier, traveling at a speed of 1,358 kilometers per hour (844 miles per hour) during his jump from a balloon over 39,000 meters (125,000 feet) above sea level. The jump dubbed "Mission to the Edge of Space" made national and international news.

Currently five companies are building vehicles to carry humans to low Earth orbit and beyond. Only one company is building the vehicles strictly for NASA use. Four of the companies are expecting that many of their passengers will not be NASA astronauts, but other paying customers.

In 2013, NASA chose 8 applicants out of 6,300 applications for its astronaut corps. By comparison, about 850 citizens have purchased tickets for a suborbital flight with Virgin Galactic and XCOR. There is demand in the American public for direct access and use of space greater than what any single organization alone can provide—and that demand is growing. The great interest in the space experience and the emergence of private spaceflight capabilities suggest that someday the United States may have more than one astronaut corps, perhaps from the private sector as well as in the government.

As people learn more about space, and as new capabilities emerge, enabling participation in space exploration and development, demand and enthusiasm for direct access to orbit and beyond grows

New Landscape of Space Exploration:

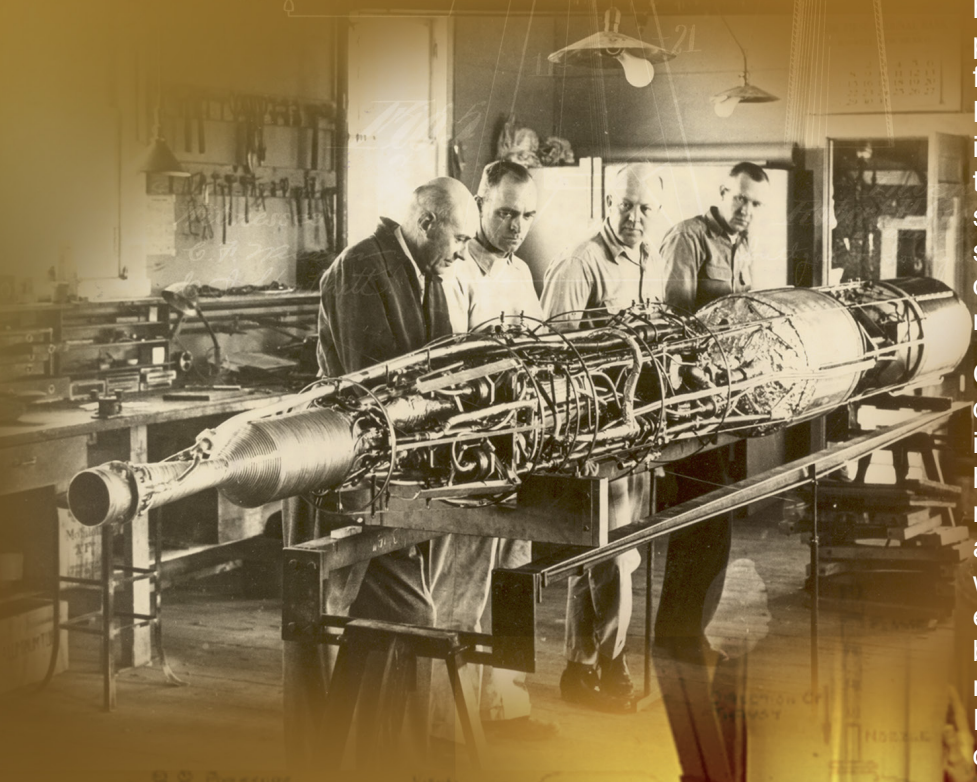
Garage Inventors

Although much of the funding for launch vehicle development ultimately came from military sources during World War II, and later during the Cold War, the earliest American spaceflight pioneers were backed by private investment. In 1914, driven by a desire to personally explore space, Robert Goddard conceived of and patented the components for a liquid-fueled, staged rocket for sending objects to space. Using his own funds, and a grant from his university, Goddard flew the world's first liquid-fuel rocket on his aunt's farm outside Auburn, Massachusetts in 1926. In terms of rocketry, Goddard was America's first garage inventor. His work attracted the support of the Guggenheim family who would provide him with today's equivalent of over $36 million in funding. Other engineers pursued rocketry in a similar way, like Goddard's contemporary Frank Malina. Malina conducted research at the Guggenheim Aeronautical Laboratory at the California Institute of Technology (GALCIT), and in 1942 co-founded the Aerojet Corporation (now Aerojet Rocketdyne, the largest rocket engine company in the U.S.)

The garage inventor—also called a hacker, maker, or hobbyist—is a do-it-yourself creator. "Makershops" or "Hackerspaces" (communal high-tech workplaces) exist now for space garage inventors, such as the Mojave Makers group. Citizens in Space, a private non-profit group held a "Space Hacker Workshop" in 2013. The suborbital reusable vehicle industry features several garage inventors, with small teams working with limited resources to develop rockets and spaceplanes capable of temporarily sending small payloads into space.

In recent years, garage inventors have started to work on satellites. These satellites tend to be based on standardized kits derived from the Cubesat developed in the 1990s for university projects. Since 2009, NASA has selected 115 of these Cubesat projects, from across 29 different states, for launch into space through its Cubesat Launch Initiative. Building on this rapid-iteration ecosystem, individuals, small teams, high schools, universities, and small companies have expanded on the kit standard to produce a wide variety of low-cost satellites capable of everything from remote sensing to communications.

Garage inventors add greater engineering diversity and innovation to the space industrial base. Using affordable, high quality materials, equipment, manufacturing processes, and kits, citizens around the country have been busy working to improve space systems, or even invent new ones. Sometimes, what begins in a garage ends up becoming a multi-million dollar company—the company Planet Labs first got started in the garage of a house in Cupertino, California.



Robert Goddard (left) and his team working on a Series P rocket; Frank Malina (right) standing next to a WAC Corporal rocket.

The stories about Goddard and his spaceflight technology inspired dozens of people to volunteer to fly his rockets to space, even though the highest altitude his rockets ever flew was only 2.7 kilometers. By 1929, the American Interplanetary Society (AIS) formed in New York—the first of roughly a dozen societies and associations nationwide to advocate for the development of spaceflight and conduct some of the country's earliest experiments in rocketry. The AIS soon became the American Rocket Society (ARS) and ultimately the American Institute for Aeronautics and Astronautics (AIAA). On the West Coast, the Pacific Rocket Society helped found the International Astronautical Federation in 1951 and began conducting flight tests on land that would later become part of the Mojave Air and Space Port. The Reaction Research Society (RRS), established in 1943 as the Southern California Rocket Society near Los Angeles, is the oldest continuously operating amateur experimental rocket group in the United States.

Sixty years later, RRS member Thomas Mueller, a TRW executive, was experimenting with liquid rocket engines in what amounted to an expansive garage. He would affix the engines to test stands and airframes in the Mojave Desert, following in the footsteps of earlier rocket pioneers. In 2002, he moved his work to a warehouse where he developed an engine capable of producing 58 kiloNewtons (13,000 pounds) of thrust. That same year, Elon Musk approached Mueller, offering him the opportunity to manage a team to design and build what ultimately becomes the Falcon 9. The Falcon 9, a 68-meter (224-foot) rocket powered by nine first-stage engines producing a combined 5,885 kiloNewtons (1.3 million pounds) of thrust, has launched successfully nine times since 2010.

The legacy and capability of ingenious, independent inventors and tinkerers contributing to the advancement of American space capabilities is as strong today as it was in the days of Robert Goddard. NASA recognizes this, and is working to unleash the genius of independent American innovation through a number of programs—including its Prizes and Challenges efforts.

SpaceX's Tom Mueller stands next to Merlin engines.

Once an area of research and development for a few, now space is becoming an area where dedicated garage inventors across the country contribute to the nation's knowledge and industrial base

Challenges and Prizes

Garage inventors and small companies are often inspired by grand challenges and open competition. Challenges and prizes have been offered since the 1700s to spur innovation, including the first airplane. NASA uses prizes and challenges to help solve problems and advance technology by opening participation to the entire country. Since 2007, more than 5,000 individuals and 117 corporate teams have participated in NASA challenges, and NASA has awarded over $6 million to 16 winning teams.

NASA's Centennial Challenges program, established in 2005 and managed by the Space Technology Mission Directorate, seeks to drive progress in aerospace technology, encourage participation in aerospace research and development, and find the most innovative solutions to technical challenges through competition and cooperation. Seven challenges have been initiated during the past eight years, with objectives including lunar lander demonstration missions, power beaming, and improved astronaut gloves.

Not all challenges are federally funded. In 1995, the X PRIZE Foundation was founded to stimulate dynamic shifts in the public's expectations for private-sector spaceflight. The award of the $10-million Ansari X PRIZE to Scaled Composites for the successful flights of the SpaceShipOne in 2004 was a major milestone in the development of private spaceflight capabilities. The Google Lunar X PRIZE is a major purse of $40 million to a private team able to land safely on the Moon, travel 500 meters above, below, or on the lunar surface, and send back two "Mooncasts" to Earth. The prize expires on December 31, 2015.

Challenges and prizes provide incentives for innovation, a relatively low-cost investment than can yield high returns for the nation's space industry

Crowd Sourcing

NASA has also engaged the nation's innovation community through crowdsourcing technical solutions using online innovation platforms. For example, NASA has partnered with Harvard University, TopCoder, and other vendors to form the NASA Tournament Lab (NTL). The NTL leverages a community of coders to create low-cost software and application development, analytics, and algorithm solutions for specific, real world challenges faced by NASA. Also, through the NASA Innovation Pavilion, NASA has partnered with Innocentive to crowdsource solutions to additional types of problems NASA faces ranging from identifying non-invasive intracranial pressure techniques to methods for measuring strain on Kevlar and Vectran strap webbing.

In a 2012 recent report to Congress on the use of prize competitions in government, the White House Office of Science and Technology Policy noted the particular value and importance of NASA's prize and crowdsourcing programs to the government as a whole, stating "From the Centennial Challenges Program, to the NASA Open Innovation Pavilion, to the NTL, NASA leads the public sector in the breadth and depth of experience and experimentation with prizes and challenges…"

NASA Administrator Charlie Bolden (far left) along with NASA officials Doug Comstock and Andy Petro, acknowledging winners and organizers of NASA's 2009 Centennial Challenges.

NASA prize checks awarded to Masten Space Systems and Armadillo Aerospace for their accomplishments during the Lunar Lander Challenge in 2009.

New Landscape of Space Exploration:
Citizen Scientists and Crowdfunding

Citizen Scientists

NASA's team extends beyond the agency's professional cadre of employees and contractors. American citizens of all ages can play an important role in contributing scientific research that enhances NASA's exploration objectives. The benefits are mutual: NASA receives much needed help to sort through huge volumes of data and citizen scientists receive valuable education and experience. Participation is particularly critical for young people because they learn about science, technology, engineering, and mathematics through hands-on exploration. This experience, in turn, can inspire pursuit of a STEM career, ensuring that NASA has a pool of qualified recruits in the generations to come.

Crowdsourcing science is a way to have citizens participate with NASA in a way never before possible. Through science crowdsourcing, large numbers of people can contribute services, ideas, or content with an aim toward advancing the agency's mission. It represents an opportunity for Americans from all walks of life to be an integral part of NASA's team. It also represents a new mechanism that NASA employees can leverage to find innovative solutions to some of NASA's science challenges.

NASA provides a number of resources for people willing to contribute as citizen scientists. All are available online, meaning all you need is access to the Internet. Software tools are also provided. Table 3 provides a sampling of these resources and the number of citizen scientist participants.

Anyone can log on to NASA's "Be a Martian" website to help NASA tag the thousands of images downloaded from the *Spirit*, *Opportunity*, and *Curiosity* rovers. Tagging helps NASA scientists by saving research time.

Project	Citizen Scientist Role	Participants
Be a Martian	Tag rover images and map craters from satellite pictures	1,230,000
HiTranslate	Help translate NASA's HiRISE project captions into different languages	1,021 new in 2012
International Space Apps Challenge	Develop mobile applications, software, hardware, data visualization, and platforms to address current challenges relevant to space exploration and social need	2,083 from 17 countries in 2012
Lunar Impacts	Independent observers can monitor the rates and sizes of large meteoroids striking the far side of the Moon	26 impact candidates
Rock Around the World	Help Mars scientists better understand the red planet by sending rocks to NASA for analysis	12,461 rocks received
Stardust at Home	Search for the first samples of solid matter from outside the solar system	30,649 from 2006 to 2012
Target Asteroids!	Observe asteroids, to help scientists refine orbits and determine the composition of near-Earth objects (NEOs) in support of the OSIRIS-Rex mission	104 registered users from 23 countries

Table 3. More than 1.2 million people from 80 countries have participated in NASA's citizen science projects. This table captures just a few of them.

Crowdfunding

Crowdfunding is a method for individual citizens to pool their resources, usually via the Internet, to support efforts initiated by other people or organizations. Crowdfunding campaigns can finance any type of effort, from startup companies, to movies, and disaster relief and a number of groups are using it to fund private-sector space projects too.

Crowdfunding offers space organizations avenues for fundraising outside traditional institutional methods. Sites like Kickstarter.com, Rockethub.com, and Indiegogo.com allow space companies to tap the financial resources of private citizens interested in space exploration. In addition to providing crucial funds for the companies, crowd funding allows citizens to directly engage in space exploration by funding the projects that interest them. The number of these projects continues to grow. Table 4 provides a few prominent examples known at the time of printing.

ISEE-3, a NASA probe launched in 1978, became the first spacecraft in deep space to be operated by a private-sector organization thanks in part to a crowd funding campaign.

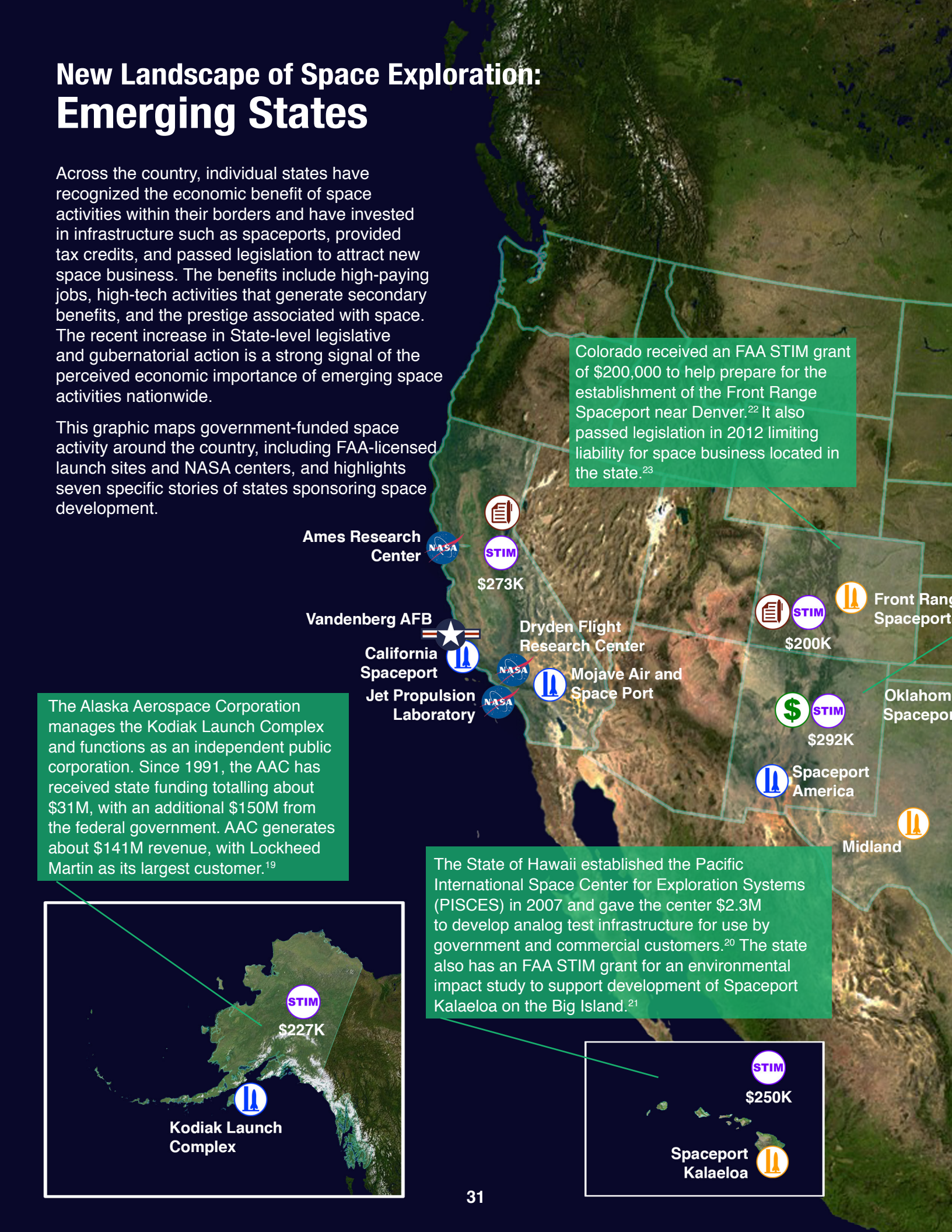
Year	Company	Description	Funding Goal	Funding Raised	Backers	Platform
2011	KickSat	Develop spacecraft the size of two postage stamps	$30,000	~$75,000	> 300	Kickstarter
2012	ArduSat	Launch the ArduSat (Arduino satellite) and allow the public to design and run space-based applications, games, and experiments and take pictures on demand	$35,000	$103,330	676	Kickstarter
2012	Uwingu	Help create “The Uwingu Fund” for space research and education	$75,000	~$80,000	> 800	Indiegogo
2012	STAR Systems	Develop a full-size rocket motor for the Hermes spacecraft	$20,000	$20,843	> 300	Kickstarter
2012	LiftPort Group	Space elevator research and demonstration	$8,000	> $110,000	3,468	Kickstarter
2012	Hyper-V	Demonstrate a prototype electric pulsed plasma jet thruster	$69,000	~$73,000	1,101	Kickstarter
2013	Aerospace Industries Association	Run a 30 second trailer about the space program before the new Star Trek movie	$33,000	> $50,000	> 1,600	Indiegogo
2013	Lunar Orbiter Image Recovery Project	Identify changes in the lunar surface over time using photos from NASA’s Lunar Orbiter program	$75,000	$62,585	549	Rockethub
2013	Planetary Resources	Development and launch of an asteroid-hunting telescope by 2015	$1M	$1.5M	17,614	Kickstarter
2014	Skycorp/SpaceRef/ Space College	Regaining control of ISEE-3, which NASA launched in 1978	$125K	$160K	2,238	RocketHub

Table 4. Thousands of people have directly contributed to developing space projects by donating funds.

New Landscape of Space Exploration:
Emerging States

Across the country, individual states have recognized the economic benefit of space activities within their borders and have invested in infrastructure such as spaceports, provided tax credits, and passed legislation to attract new space business. The benefits include high-paying jobs, high-tech activities that generate secondary benefits, and the prestige associated with space. The recent increase in State-level legislative and gubernatorial action is a strong signal of the perceived economic importance of emerging space activities nationwide.

This graphic maps government-funded space activity around the country, including FAA-licensed launch sites and NASA centers, and highlights seven specific stories of states sponsoring space development.



States have recognized the economic benefits of space and have become involved at the state level

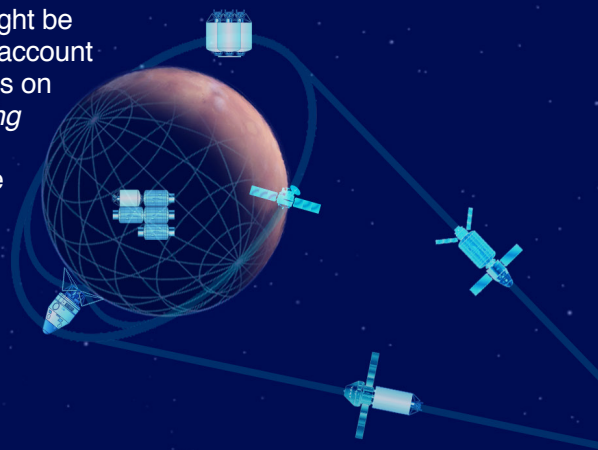
Building a Future Economy:
Emerging Space in 2044

Where are all of these diverse and energetic emerging space activities leading us to in the future?

The President has directed that by the mid-2030s NASA's human exploration wavefront will have reached Mars with a human mission to an asteroid as a stepping-stone. Private sector entities and other nations are presently planning new stations, missions to the Moon, and even Mars. Robotic missions will continue throughout the solar system, featuring a mix of large, complex spacecraft and small but sophisticated micro-satellites and probes. We stand today at the beginning of a grand sequence of voyages into the cosmos.

NASA is on a path of exploration and pioneering in the inner solar system, opening new opportunities and challenges for future generations and driving the American economic expansion into space. Although the specific shape and rate of this economic expansion depends as much on the actions of the individuals, corporations, and foundations involved as it does on NASA, the following descriptions present one view of the future in 2044 as it could be as NASA catalyzes an expansion of American space activities through its programs and partnerships.

The following is a vision of our next steps out into the solar system as they might be recalled by someone looking back over the previous decades from 2044 - an account of one possible future, and how we might have gotten there. This outline builds on the framework and philosophy described in the NASA report *Voyages: Charting the Course for Sustainable Human Space Exploration*.[30] Although the order of presentation represents present prioritization, all three sets of destinations are expected to be critical parts of space development in the decades to come and we should expect them to take different levels of prioritization at different times depending on political, economic, and technological circumstances.



NEAR-EARTH ASTEROIDS

NASA's near-earth asteroid explorations paved the way for regular government and private-sector activity involving near-earth asteroids. With the support of NASA partnerships, companies began extracting water ice, metals and rock from NEAs identified as viable candidates for mining, beginning the process of providing materials and propellant for the expanding interplanetary transportation system and economy. As on the Moon, activities relating to mining necessitated the development of more robust reusable systems capable of routinely operating in harsh environments. NASA's human exploration of NEAs contributed insights valuable both to governments and private-sector actors regarding NEA characteristics, proximity operations, extraction techniques, and options for planetary defense from the threat of asteroid impact.

MARS

Human exploration of Mars began in the 2030s, featuring cooperative partnerships between governments and private entities. As the greatest challenge of American space exploration of the age, the American private-sector mustered significant expenditure and investment in order to advance the date of this achievement in partnership with NASA and enabled long-term habitation following NASA's initial missions. Martian surface asset emplacement activities occurred periodically to test systems and deliver cargo for the upcoming landing, include supplemental private sector activities. Prior to the first human steps on Mars, NASA and privately financed expeditions traveled to Mars orbit and visited Phobos to validate systems in preparation for the historic expedition to the Martian surface.

EARTH and MOON

The ISS continued to serve as a venerable space research and development institution into the 2020s when the first commercial modular stations began to be deployed for microgravity applications and private-sector expeditions. Reductions in launch costs, the emergence of low-cost satellite development kits, and the introduction of commercial spaceflight opportunities allowed more people than ever before to have direct access to space—inspiring and training a resurgent generation of aerospace engineers, scientists, and technologists in the process. Space traffic management and active debris removal and mitigation were developed to address the greater amount of orbital activity. Propellant depots and spacecraft servicing systems located in GEO and Lagrangian Libration Points provided support for the growing interplanetary transportation system. Some of these facilities were established by governments as independent authorities that could operate independently and could raise their own funds and issue their own bonds, as do seaports on Earth. These served as gateways to points beyond as cargo and crew spacecraft launched from Earth prepared for journeys to the Moon, asteroids, and Mars.

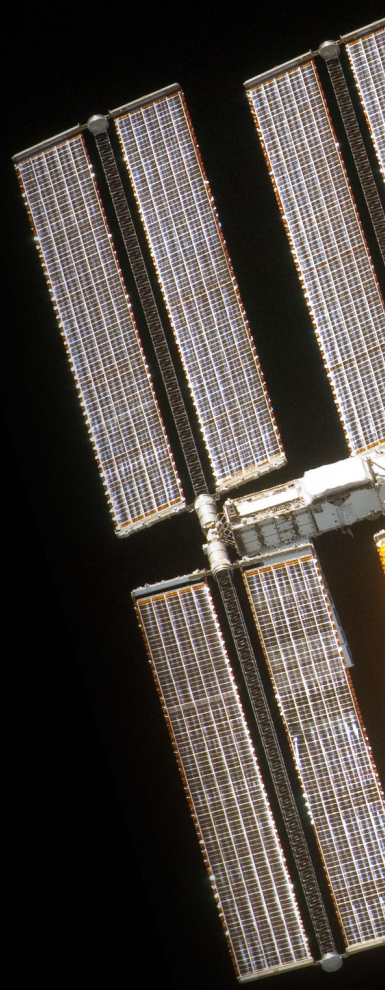
The Moon and cis-lunar environment became a primary proving-ground for exploration systems and technology development, particularly for the development of robotic planetary surface systems. Surface operations were supported by a modest station, communications satellites, navigation satellites, and remote sensing satellites in lunar orbit. Prospecting, extraction, and processing of lunar volatiles and metals began to scale up to support activities on the Moon as well as to sell propellant for in-space transportation. The costs of working on the Moon fell due to the investments in space transportation infrastructure and local production. Exploration of the lunar surface was supplemented by privately financed expeditions with NASA partnerships enabling renewed American activities on the lunar surface.

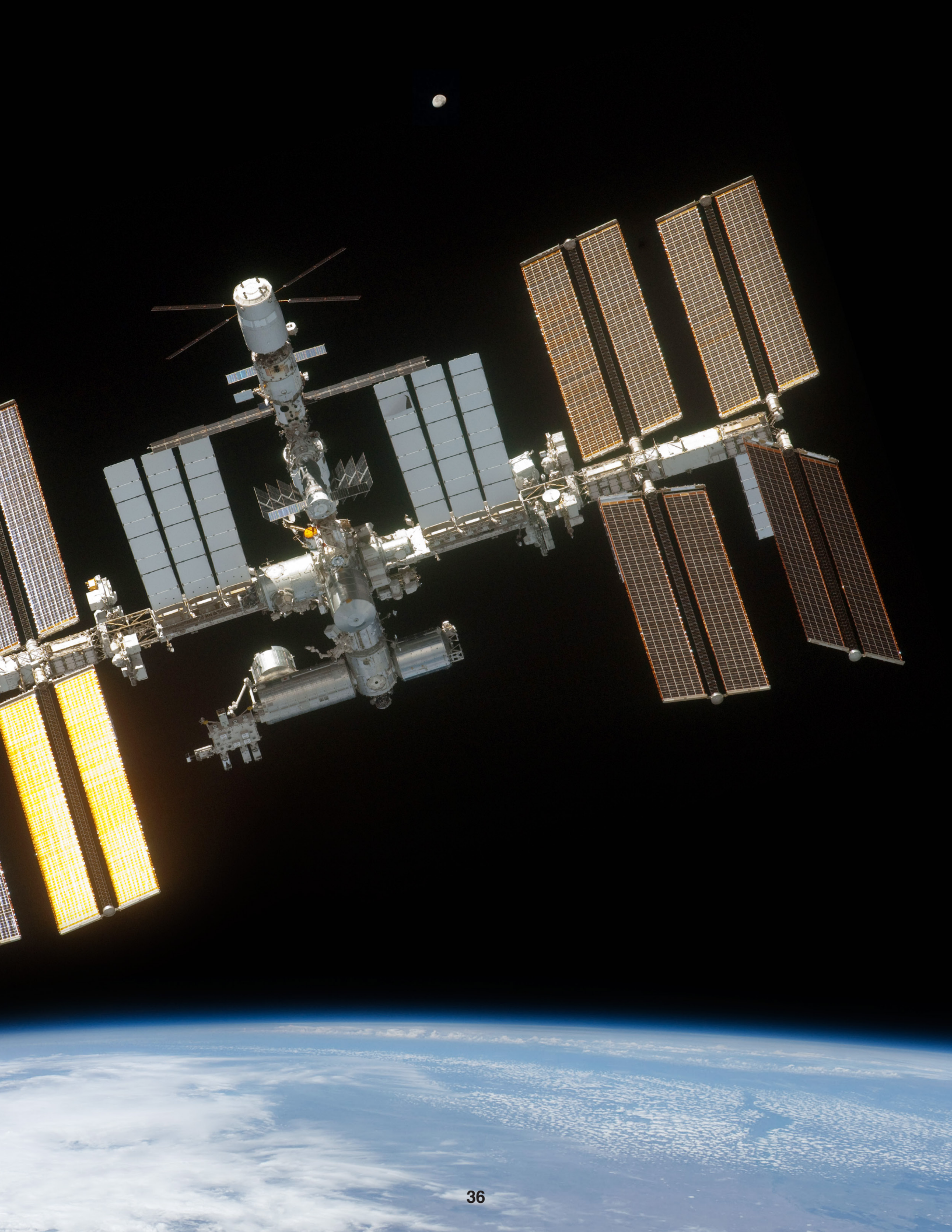
NASA and private industry will together expand the American economic sphere into the solar system

Conclusion:
Exploring Space Forever

Fifty years after the creation of NASA, our goal is no longer just to reach a destination. Our goal is to develop the capabilities that will allow the American people to explore, pioneer, and expand our economic sphere into the solar system. To do this we will build on our long-standing relationships with American industry by embracing new and diverse forms of partnerships. Private-sector leadership in space exploration was the normal state of affairs in America before the foundation of NASA. Today, we have recognized the advantages of that earlier model in terms of private-sector energy and initiative, combined it with NASA's legacy of technical expertise and programmatic accomplishment, and have helped give rise to the birth of a 'Second Space Age'. The space economy of the future will come about through the combined efforts of government, private industry, scientists, students and citizens, each playing their own unique and essential role. Together, we will create a new economic ecosystem in space that will hasten our journey into the cosmos.

NASA is proud to recognize that American spaceflight—after sparking, nurturing, and carrying its flame for over half a century—is not just about us anymore. This economic and cultural transition in the American space industry and in American spaceflight culture is an exciting one and it will further NASA's mission of advancing exploration and discovery. Our continued national leadership in spaceflight relies on the ability to adapt our habits and strategies for success when needed. NASA will continue to be the world leader in space exploration. It is that role of leadership that is expected of NASA by American citizens and by the world. It is exciting to consider that as we move farther into the 21st century that leadership will be expressed as much by the American private-sector space activities that NASA supports and enables as it is by our own missions. Realizing this broader role of leadership is a significant part of the challenge—and the adventure—that lies before us.





Acknowledgments

Report by:

NASA Office of the Chief Technologist, 2014

Point of Contact:

Alexander MacDonald
alexander.c.macdonald@nasa.gov

REFERENCES

[1] 2013 Commercial Spaceflight Industry Indicators, Commercial Spaceflight Federation.

[2] "Falcon 9 Launch Vehicle NAFCOM Cost Estimates," August 2011 (http://www.nasa.gov/pdf/586023main_8-3-11_NAFCOM.pdf)

[3] MacDonald, Alexander, "The Long Space Age: An Economic Perspective on the History of American Space Exploration," (PhD dissertation, University of Oxford, 2012).

[4] 2013 Commercial Spaceflight Industry Indicators, Commercial Spaceflight Federation.

[5] *The Space Report*, Space Foundation (2013). Also see "State of the Satellite Industry Report," Satellite Industry Association, May 2014.

[6] MacDonald, Alexander, "The Long Space Age: An Economic Perspective on the History of American Space Exploration," (PhD dissertation, University of Oxford, 2012).

[7] Chang, Kenneth, "For Space Station, a Pod That Folds Like a Shirt and Inflates Like a Balloon," *New York Times*, January 16, 2013.

[8] Schreck, Adam, "Abu Dhabi partners with Virgin Galactic spaceship firm," *ABC News*, July 28, 2009.

[9] Paszator, Andy, "SpaceX Has Invested $500 Million," *Wall Street Journal*, October 27, 2011.

[10] Messier, Doug, "Branson: Virgin Plans Reusable Replacement for SS2 Hybrid Engine," *Parabolic Arc*, November 24, 2013.

[11] Druce-McFadden, Colin, "XCOR Lynx space plane to begin flight tests soon," *Dvice.com*, September 17, 2013.

[12] "XCOR Aerospace Closes $5 Million Round of Investment Capital," XCOR press release, February 27, 2012 and "CFIUS Approval Clears XCOR Aerospace's First Close of Series B Financing," XCOR press release, May 27, 2014.

[13] Gross, Daniel, "Elon's Élan," Slate, April 30, 2014.

[14] Boyle, Alan, "Billionaire plans world's biggest plane for orbital launches," MSNBC, December 13, 2011.

[15] Lawler, Ryan, "Planet Labs Raises $52 Million From Yuri Milner To Build The Biggest (Little) Flock Of Satellites," *TechCrunch.com*, December 18, 2013.

[16] Vance, Ashlee, "Satellite Imaging Startups Skybox, Planet Labs Race to Cover Earth," *Bloomberg Business Week*, February 13, 2014.

[17] McGarry, Brendan, "Las Vegas UFO Aficionado Bets $500 Million on Space Hotel," *Bloomberg News*, January 28, 2013.

[18] Koebler, Jason, "Expert: Dennis Tito's Mars Flyby Has '1-in-3' Chance of Succeeding," *US News and World Report*, March 1, 2013.

[19] Alaska Aerospace Corporation Annual Report (2012).

[20] Jensen, Chelsea, "PISCES space program gets $2.3M boost," Hawaii Tribune Herald, November 14, 2012.

[21] FAA AST Annual Compendium of Commercial Space Transportation (February 2013).

[22] http://www.colorado.gov/cs/Satellite?c=Page&childpagename=GovHickenlooper%2FCBONLayout&cid=1251621416275&pagename=CBONWrapper (accessed July 2013).

[23] Hoover, Tim, "Colorado Senate bill would limit spaceflight companies' liability," *Denver Post*, February 7, 2012.

[24] http://spaceportamerica.com/newsletters/ (accessed July 2013).

[25] http://leg1.state.va.us/cgi-bin/legp504.exe?071+ful+HB3184H2 (accessed July 2013).

[26] http://leg1.state.va.us/cgi-bin/legp504.exe?081+sum+SB286 (accessed July 2013).

[27] http://rescommunis.wordpress.com/2011/05/11/texas-space-liability-act/ (accessed July 2013).

[28] http://www.flsenate.gov/Session/Bill/2011/0652 (accessed July 2013).

[29] Klotz, Irene, "NASA Efforts To Revamp KSC Get $20 Million Boost from Florida," Space News, May 23, 2013.

[30] http://www.nasa.gov/exploration/whyweexplore/voyages-report.html#.U7yUlqgoyxo (accessed July 2014).

PHOTO CREDITS

All images are credited to NASA except when noted below.
Cover: Phil Smith
Pages ii-iii: Phil Smith
Page 2 (upper left): NASA/SpaceX
Page 2 (upper right): NASA/Orbital Sciences Corp.
Page 2 (lower right): Ben Cooper
Page 7 (top left): NASA/SpaceX
Page 7 (top center left): NASA/Orbital Sciences Corp.
Page 7 (bottom center left): NASA/Boeing
Page 7 (bottom left): NASA/Sierra Nevada Corp.
Page 8: NASA/SpaceX
Page 17 (Guggenheim): Library of Congress
Page 17 (Carnegie): Library of Congress
Page 17 (Lick): University of California Observatories
Page 18 (BA 330): Bigelow Aerospace
Page 18 (SpaceShipOne): Phil Smith
Page 18 (BE-3): NASA/Blue Origin
Page 14 (NASA/SpaceX mission logos): NASA/SpaceX
Page 20 (PM-2): Phil Smith
Page 20 (Xaero): Masten Space Systems
Page 20 (SpaceShipTwo): Phil Smith
Page 20 (Lynx): Phil Smith
Page 20 (Antares): NASA/Orbital Sciences Corp.
Page 21 (Falcon 9): NASA/SpaceX
Page 21 (Stratolauncher): Stratolaunch Systems
Page 21 (Atlas V): ULA
Page 21 (Dove): Planet Labs
Page 21 (SkySat): Skybox Imaging
Page 21 (BA 330 complex): Phil Smith
Page 22 (CST-100): Boeing
Page 22 (Dream Chaser): Phil Smith
Page 22 (Soyuz): NASA/Roscosmos
Page 22 (Sentinel): B612 Foundation
Page 22 (Inspiration Mars): Inspiration Mars Foundation
Page 22 (Moon Express): Moon Express

Page 22 (Arkyd): Planetary Resources
Page 23 (SpaceShipTwo): MarsScientific.com & Clay Center Observatory
Page 24 (Felix Baumgartner): © Red Bull GmbH
Page 24 (balloon): World View Enterprises
Page 25 (Goddard): Library of Congress
Page 25 (Malina): Library of Congress
Page 26 (Mueller): SpaceX/Tom Mueller

ACRONYMS

AAC	Alaska Aerospace Corporation
AIAA	American Institute of Aeronautics and Astronautics
AIS	American Interplanetary Society
ARC	Ames Research Center
ARS	American Rocket Society
BEAM	Bigelow Expandable Activity Module
CASIS	Center for Advancement of Science in Space
CCDev	Commercial Crew Development
CCP	Commercial Crew Program
CEO	Chief Executive Officer
COTS	Commercial Orbital Transportation Services
CRS	Commercial Resupply Services
CST	Crew Space Transportation
ELaNa	Educational Launch of Nanosatellites
ESO	Emerging Space Office
FAA	Federal Aviation Administration
FOP	Flight Opportunities Program
G-FOLD	Fuel Optimal Large Divert Guidance
GALCIT	Guggenheim Aeronautical Laboratory at the California Institute of Technology
GEO	Geosynchronous Earth Orbit
GPS	Global Positioning System
ISPS	Innovative Space Propulsion Systems
ISS	International Space Station
LaRC	Langley Research Center
LEO	Low Earth Orbit
LLC	Limited Liability Corporation
MARS	Mid-Atlantic Regional Spaceport
MEO	Medium Earth Orbit
NACA	National Advisory Committee for Aeronautics
NASA	National Aeronautics and Space Administration
NASTAR	National Aerospace Training and Research Center
NEA	Near-Earth Asteroid
NIAC	NASA Innovative Advanced Concepts
NOAA	National Oceanic and Atmospheric Administration
NSI	National Space Institute
NSS	National Space Society
NTL	NASA Tournament Lab
OCT	Office of the Chief Technologist
PISCES	Pacific International Space Center for Exploration Systems
RMI	Reaction Motors Incorporated
SEP	Solar-Electric Propulsion
SLS	Space Launch System
SNC	Sierra Nevada Corporation
SpaceX	Space Exploration Technologies Corporation
STEM	Science, Technology, Education, and Mathematics
STIM	Space Transportation Infrastructure Matching grants
TPS	Thermal Protection System
ULA	United Launch Alliance
VASIMR	Variable Specific Impulse Magnetoplasma Rocket
WIA	Women in Aerospace

National Aeronautics and Space Administration

NASA Headquarters
300 E Street Southwest
Washington, DC 20546

www.nasa.gov