Abstract

CySat, Iowa State University's CubeSat program, is seeking a review of the educational and scientific merit of the CySat I mission. The review is for the purpose of applying to NASA's CubeSat Launch Initiative. This review will address the quality and benefits of the CySat I mission and it's relevance to NASA's Strategic Plan and Education Strategic Coordination Framework.

Contents

1 Introduction

CySat is designing a nanosatellite platform in accordance with the CubeSat standard set forth by California Polytechnic University and Stanford University. The CubeSat program offers educational institutions, like Iowa State, the opportunity to design a space worthy satellite for a relatively low cost. The primary educational objective of CySat is the establishment of a small satellite program at Iowa State that allows the opportunity for students to apply their knowledge and coursework to a real astronautics project. CySat pulls students from a number of the Engineering Departments to foster an interdisciplinary environment within the College of Engineering and accomplish complex missions requiring multiple areas of expertise. Students have the opportunity to design a system and mission for a small satellite from concept to flight. CySat teaches it's members how to function within a multidisciplinary engineering team and gives them access to established industry and NASA contacts. CySat provides a unique educational experience which helps prepare students for working in the space industry.

1.1 Project Overview

CySat falls under the umbrella of Iowa State's College of Engineering Make to Innovate organization (M:2:I). M:2:I is devoted to giving students the opportunity to submit proposals for engineering projects and supplying resources to help students independently fulfill those goals. Students in M:2:I receive academic credit for their contributions to their projects. CySat is an ongoing M:2:I project that has a strong history of support and backing from the department. CySat adheres to M:2:I's goals of providing further hands on educational experience for undergraduates outside of classes.
CySat is provided a faculty academic advisor by M:2:I and has acquired the assistance of three technical advisors, one at NASA's Johnson Space Center and two at Boeing. CySat is student run and composed of six individual teams that each focus on a specific subsystem of the satellite. CySat has developed this project structure to increase the efficiency of the teams design process and provide members with an authentic representation of space missions in industry.

1.1.1 Project Goals

The overall goals for CySat have been the driving force behind all design considerations and operational plans. The following were developed jointly between CySat and the team's academic advisors.

1. Serve as a catalyst for the small satellite program at Iowa State University

2. Develop a baseline, modular design for future CubeSat missions
3. Demonstrate the functionality of CubeSat's for asteroid surveying

1.1.2 Project Structure

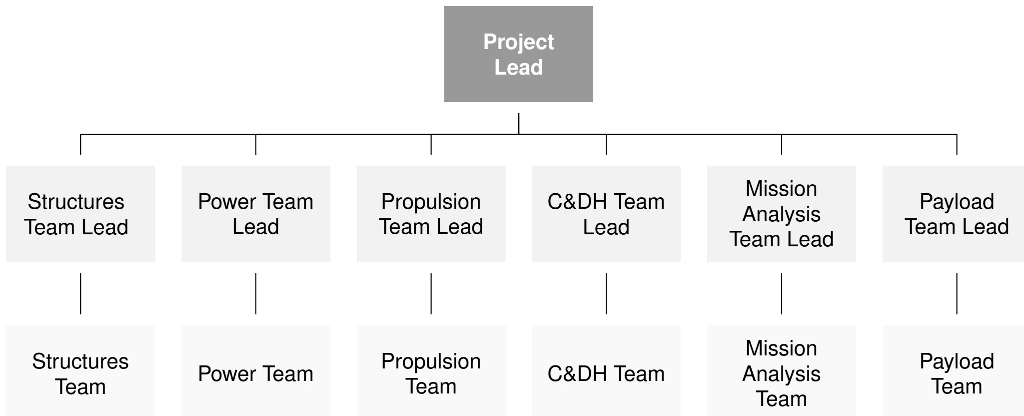


Figure 1. CySat Team Hierarchy

1.1.2.1 Teams **Structures Team:**

The Structures Team is responsible for the structural design of the satellite. The team is working with computer aided design (CAD) software in order to model the satellite's configurations. Structures is designing mechanical testing procedures and will oversee the satellite's integration in order to ensure it is compliant with the structural design.

Power Team:

The Power Team controls power generation, storage, and management for the satellite. The Power Team is currently finalizing the design of the solar arrays, and assisting the Propulsion Team in the implementation of stabilization.

Propulsion Team:

The Propulsion Team is currently performing research to find the ideal propulsion system to use for future asteroid missions. With current information, the team is focusing on electric engines and cold gas thrusters. Propulsion is also assisting Power in the implementation of stabilization.

Communications & Data Handling Team (C&DH):

The C&DH team's focus is on the terrestrial and vehicle infrastructure and software. The team is designing and fabricating the flight computer and creating a robust, automated ground station and a beta mission control application. C&DH is preparing for the finalization of the onboard radio band, mode and hardware along with data serialization format and telemetry processing.

Mission Analysis Team:
Mission Analysis is responsible for application of orbital mechanics to practical problems concerning the motion the satellite. Additionally, the team is responsible for designing the mission architecture and assessing the feasibility of comprehensive mission designs.

Payload Team:
The Payload Team will lead the scientific justification, acquisition and development of mission specific instrumentation. The Payload Team is working on the development of an asteroid-surveying payload, which will detect valuable resources within an asteroid and provide estimates of the location and quantity of the material.

1.2 Mission Objectives

CySat's current primary scientific objective is to demonstrate that CubeSats can be used as effective tools for the asteroid mining industry. CySat is developing a payload for asteroid surveying. CySat's first mission, CySat I, will be a proof-of-concept flown in Low Earth Orbit (LEO). CySat I will demonstrate the state-of-the-art communications and radar payload, the functionality of the satellite platform, and CySat's operational readiness. CySat I's payload will map the target's density and collect absorption spectrum's to determine the target's composition. CySat's CubeSat platform has been designed to be adaptable for different payload configurations, this will allow CySat to repurpose the platform for future missions.

2 Design Factors

Because of the recent surge in private industry support for CubeSats, CySat has been able to capitalize on recent commercial off-the-shelf (COTS) components to minimize design time and risk. The design team focused on COTS components due to several factors: flight heritage, short development time, and out of box functionality. Key components will be purchased commercially to decrease risk while some electronics will be developed in-house to increase efficiency. This system has allowed CySat to develop complex mission specific components in-house due to the increased flexibility of the commercial systems.

2.1 Satellite Component Evaluation Criteria

Mass: Pursuant to CubeSat specifications, special considerations were made to select and design components that would keep the system under the 4.0 Kg mass requirement.

Volume: Ensuring that components would not consume too much of the 10 x 10 x 30 cm cube, and building in allowances for a diverse range of mission specific payloads.

Cost: Due to the current fiscal situations of most state funded institutions, some high dollar amount components will be fabricated in house.

Flight Heritage: Knowing that components had successfully worked in the space environment was of great importance. This can be seen with the selection of COTS components.

2.2 Design Restrictions

The CubeSat team developed several design restrictions to guide and optimize the design early on. Since the payload will require substantial resources from the spacecraft, the design goal was to provide a robust platform with enough features to allow the spacecraft to operate beyond LEO. This strategy has produced a satellite platform which can be easily adapted for future collaborations with small businesses and other universities.

1. The spacecraft shall conform to the 3U CubeSat standard
2. Spacecraft subsystems should be as simplistic as possible to reduce failure points
3. Non-deployable solar arrays will be manufactured in house due to design needs and cost restrictions
4. COTS components will be used when possible to limit risk. Custom, mission optimized, electronics will be designed to increase efficiency

3 Science Implementation

To accomplish the scientific mission objectives, CySat has developed a state of the art communications and radar payload. CySat is actively collaborating with the Caterpillar & Iowa State Space Mining Operations team (CISSMO) to identify the relevant information which can be gained from prospecting an asteroid. CySat I's scientific payload will be based upon an integrated software defined radar for density and spatial mapping and an infrared spectrometer for collecting composition data. CySat I will fly the block I version of the payload which will serve as a risk-reduction pathfinder build of the software radio architecture designed for the mapping and prospecting of asteroids.

3.1 Radar

3.1.1 Science Justification

The CySat Mapping Radar (CMR) will serve as the primary scientific instrument and provide both a geodetic datum to correlate other instrumentation to, as well as returning data on the density and geological features of the target. Leveraging the flexibility of the software defined radio (SDR), the radar system is designed to provide spatial and density mapping by interrogating with different bands of radio energy as required. The application of reconfigurable hardware makes for an efficient and upgradeable platform to run radar across the spectrum as needed. By mapping data from all instruments aboard the satellite to a master spatial/density map, a total sense of the asteroid's composition and excavation viability can be assessed.

3.1.2 Principles of Operation

Underpinning the system is a SDR. By moving components of a traditional radio signal pipeline out of the hardware domain and into digital signal processing (DSP), a lighter and more flexible radio system can be created. All these desirable characteristic not only reduce energy and space usage on board the satellite, but also enable the SDR to function as the primary communications system, as well an integral component of the instrumentation payload.

Once in orbit of the target, the radar will operate as a synthetic aperture radar (SAR) where the relative motion of the satellite acts to increase apparent size of the antenna. This effect allows for successive passes of the target to act in place of a well matched antenna to regain lost accuracy and permits the selection of an antenna better suited for the chassis of the satellite.

3.1.3 Implementation

The CySat I mission will fly the CMR Block I. To accomplish this goal, the CMR is a synthetic aperture radar capable software defined radio for planetary radio imaging. The benefits of SDR for this experimental platform such as the flexibility in application (utilization for communications as well as radio navigation and radar mapping in multiple RF bands), reduction in system complexity (over having separate radio instruments for each function), and ease of manufacture by the reduced component count were key in selecting this approach. The intrinsic reprogrammability of the system will enable the CySat Payload Development Team to undertake progressive radar experiments with the CMR Block I until the satellite reaches end-of-life, including missions developed during flight with data from initial check-out.

3.2 Spectrometer

3.2.1 Science Justification

Infrared spectroscopy is used for determining the chemical composition of molecules. Infrared spectrometers have been used in many applications such as atmospheric observation, forensic analysis, and analysis of solid samples. CySat will use this technique to determine the chemical composition of an asteroid and search for minerals, metals and ices, which would be valuable resources for mining.

3.2.2 Principles of Operation

Infrared spectroscopy is the study of the interaction of electromagnetic radiation and matter, in the infrared range. Infrared spectroscopy provides access to quantifiable chemical information about the target. An infrared spectrometer is used to detect the light reflected by the target. When compared to the light emitted, a spectrum of the light absorbed can be produced. An infrared spectrum is a plot of the absorbance or transmittance of infrared light as a function of its wavelength or frequency. Different wavelengths of light are absorbed by different types of bonds and correspond to vibrations unique to the molecule. This allows the molecular structure and chemical composition of the target to be determined based on the infrared spectrum.

3.2.3 Implementation

CySat I will be flying the CySat Infrared Spectrometer Block I, which will consist of a COTS infrared spectrometer, the Argus 1000. The Argus 1000 is a miniature infrared spectrometer, designed for nanosatellites, with a proven flight heritage on multiple CubeSats. The Argus 1000, developed by researchers at York University, is currently commercially available and is the primary option CySat is considering for the surveying payload. The Argus 1000 was flown on the CanX-2 CubeSat, a mission by UTIAS/SFL (University of Toronto, Institute for Aerospace Studies/Space Flight Laboratory), and was designed to collect atmospheric spectra. The Argus 1000 has also been flown successfully on SRMSAT of Sri Ramaswamy Memorial University in Chennai. SRMSATs primary mission was a demonstration of the satellite platform and secondary was the operation of the Argus 1000 spectrometer for monitoring greenhouse gasses in the atmosphere. Both of these missions will serve as models for CySat's implementation of the Argus 1000 as the CySat Infrared Spectrometer Block I. The Argus 1000's small form factor, will fit easily within the volume allocated for the payload. The CySat Infrared Spectrometer Block I will provide the necessary operational experience for the team to develop a Block 2 Spectrometer that can reach the spectral ranges required to detect minerals, heavy metals, and ices.

4 Schedule

CySat is currently aiming for a completed satellite by May 2018. To support this, the following schedule has been developed.

Table 1. CySat I Development Schedule

Task	Semester(s)	Dates
Design Finalization	Fall 2016 - Spring 2017	August 22nd - May 6th
Fabrication	Spring - Fall 2017	January 9th - December 16th
Testing	Spring 2018	January 8th - May 5th
Delivery	Summer 2018	May 15th

5 Budget

5.1 Funding Sources

CySat has been able to work with many organizations over the last year to secure sources of monetary funding and in-kind donations. The main suppliers of funding have been Iowa Space Grant Consortium, NASA JSC, Boeing, Rockwell Collins, and Iowa State University's Electrical Engineering and Aerospace Engineering departments. Through continued dialogue, funding has been guaranteed to continue through the next two years until satellite completion. CySat is also in the process of obtaining in-kind donations to minimize cost for testing the satellite structure and acquiring the Argus 1000 Spectrometer. The following budget has been developed as a conservative estimate of the total project cost.

5.2 Budget Component Breakdown

Table 2. Budget Component Breakdown

Subsystem	Item(s)	Cost ($)
Structures	Manufacturing	1,000
	Mounting hardware	500
Power	Electronic power system	9,000
	Solar array side panels	15,000
	Deployable solar array	28,000
Stabilization	Active stabilization	15,000
	Passive stabilization	7,000
C&DH	Flight Computer	1,050
	Radio board	8,600
Payload	CMR block I	2,500
	Argus 1000 spectrometer	50,000
	Payload antenna	800
		Total: 138,450

6 Relevance to NASA

CySat's educational and mission objectives align with multiple NASA Strategic Goals (Appendix B) and Education Outcome Objectives (Appendix A) which have been identified in the sections below.

6.1 Strategic Goals

6.1.1 Objective 2.3

Strategic Objective 2.3:
Optimize Agency technology investments, foster open innovation, and facilitate technology infusion, ensuring the greatest national benefit.

CySat has a history of collaboration and technology transfer and all of CySat's Designs will be made publicly available after successful completion of the mission. CySat is currently collaborating with other projects at Iowa Sate such as the M:2:I High Altitude Balloon Experiments in Technology team (HABET), to perform high altitude balloon tests for payload components, and with the Caterpillar & Iowa State Space Mining Operation (CISSMO), a project which could realistically benefit from CySat's asteroid surveying mission. In the past, CySat has collaborated with Softronics Ltd. and the

University of North Dakota on two different past projects. CySat completed the design of a 1U CubeSat platform which was adapted for the two different outsourced payloads. Neither satellite flew as neither payload was completed. CySat plans to return to this collaborative mission model after completing the 3U CubeSat platform and acquiring flight heritage. CySat hopes to encourage involvement in the space industry by providing a robust and adaptable space vehicle platform for scientific payloads developed by small business and universities.

CySat has focused on delivering the following benefits to encourage involvement and innovation in the space industry and facilitate technology transfer:

1. Developing relationships and fostering collaborations in industry and academia
2. Sharing research, designs, and information with the public to benefit the scientific and small satellite communities
3. Development of an adaptable 3U CubSat platform for providing space vehicle services for innovative outsourced missions
4. Completion of an asteroid surveying payload to help support space mining efforts and advance the developments of software defined radar for space applications

6.1.2 Objective 2.4

Strategic Objective 2.4:

Advance the Nation's STEM education and workforce pipeline by working collaboratively with other agencies to engage students, teachers, and faculty in NASA's missions and unique assets.

As described in section 6.1.1, CySat has a long history of collaboration. CySat and it's advisors meet on a biweekly basis to evaluate the state of the project. This provides members with direct contact and input from CySat's technical advisor at NASA JSC, Lee Graham. CySat hopes to continue developing this relationship and fly NASA payloads on future missions. These collaborations not only provide beneficial information and resources for the project they also teach the student members how to manage professional relationships and facilitate direct contact with professionals in industry. CySat's mission has been designed not only to benefit private space mining efforts but also to align with NASA's goals. As stated in NASA's Strategic Plan, NASA's has a bold new initiative to capture and explore an asteroid and is currently undertaking detailed examination of NEA's (Appendix B: NASA's Strategic Plan). CySat's asteroid surveying payload would provide valuable information for any asteroid exploration mission. CySat's primary option for acquiring a launch vehicle is through the NASA CubeSat Launch Initiative (CSLI). CySat's CubeSat platform has been designed to NASA's specifications to ensure the projects ability to take advantage of this initiative and use NASA's unique launch assets. CySat provides an opportunity for students to receive credit while directly collaborating with NASA and designing systems directly related to NASA's missions and goals.

CySat has identified the following benefits which provide students with access to industry and enables them to engage in NASA's missions while receiving an education:

1. Developing relationships and fostering collaborations in industry and academia
2. Direct collaboration with a technical advisor at NASA
3. Development of an asteroid surveying payload with direct benefits to NASA's ambitious goals regarding the exploration of asteroids
4. All systems must be designed to NASA's specifications to benefit from NASA's launch initiatives

6.2 Education Outcome Objectives

Educational Outcome Objective 1.3: Student Involvement, Higher Education (Educate)
Provide opportunities for groups of post-secondary students to engage in authentic NASA-related mission-based research and development activities.

Educational Outcome Objective 1.4: Course Development (Educate)
Develop NASA-related course resources for integration into STEM disciplines.

Educational Outcome Objective 1.5 Targeted Institution Research and Academic Infrastructure (Employ)
Improve the ability of targeted institutions to compete for NASA research and development work.

As stated in section 6.1.2, CySat's mission and systems are directly related to NASA's missions. CySat is working closely with NASA and is dependent on NASA resources to accomplish it's missions. Since CySat is a part of the M:2:I organization, students receive credit towards graduation for their contributions. CySat provides a course option at Iowa State which is fundamentally related to NASA. CySat is preparing to take part in NASA's Cube Quest Challenge to secure a launch for CySat 2, the planned asteroid or lunar surveying mission which will begin after completion of CySat I. By applying for these initiatives and challenges, CySat's members gain experience delivering work which meets NASA's high standards of technical excellence. Acquiring successful flight heritage with CySat I will greatly improve CySat's likelihood of securing launch vehicles for future missions. By giving members access to NASA employees and other industry contacts, CySat enables students to build and expand their professional networks. CySat's project structure has been designed to give students an authentic industry experience by working on a project consisting of multidisciplinary teams and collaborating with NASA, private companies and other educational institutions. The unique experience members of CySat gain helps better prepare them for working in industry or with NASA.

CySat has identified the following benefits which enable students to receive an education through NASA related coursework and prepare students for employment:

1. Train engineering team in planning, proposing, design, building, testing, launch, and operation of a satellite
2. Provide students with direct access to NASA employees and resources through collaborating with CySat's technical advisor at NASA JSC
3. Gives students academic credit for NASA-related projects towards their degrees
4. Gives students experience preparing technical and scientific reports for NASA research and development
5. Expose students to collaborative mission models and teach them to manage professional relationships
6. Foster an interdisciplinary environment within the College of Engineering at Iowa State University which gives students an authentic representation of space missions in industry

7 Conclusion

CySat plans to launch the first student built CubeSat from Iowa. CySat is working to establish a robust and modular platform for building low cost, low risk satellites on a short development timeline. The objective of CySat I's mission is a technology demonstration of the state-of-the-art communications and radar payload, the functionality of the satellite platform, and the satellite's operational capabilities. CySat's mission will showcase the diverse range of applications for low-cost small satellites and demonstrate their usefulness for surveying asteroids. In addition to readying students for work in the space industry, CySat is also working to further scientific study by increasing access to small satellites for small businesses in Iowa and student organizations. Through collaborations, this project would allow any interested group to test their space bound equipment using CySat's CubeSat platform, before investing resources in a full sized satellite. By completing CySat I's mission, the CySat team will obtain valuable flight heritage for the CySat I Platform and demonstrate that novel space missions are within scope of small businesses and universities.

8 Review Rubric

CySat is asking for a review of merit for the NASA-CSLI proposal. In the review, the goals and objectives of the proposed investigation must be assessed to determine the scientific and educational quality of the investigation. The review must assess the overall alignment of the proposed investigation in addressing the objectives identified in the NASA Strategic Plan. The following questions have been drafted to help guide your analysis.

- ◦ Is CySat providing students with opportunities to learn authentic NASA-related skills?
- ◦ Is CySat demonstrating its ability to design and implement novel space missions?
- ◦ Has CySat developed a robust asteroid surveying payload which will fulfill the missions objectives?
- ◦ Does the CySat I mission have scientific merit?
- ◦ Does the CySat I mission have educational merit?
- ◦ Is the CySat I mission relevant to NASA's Strategic Plan?
- ◦ Based on the scientific and educational merit of the mission, would you recommend that NASA provide a launch vehicle for CySat I?

Appendix A

NASA Education Strategic Coordination Framework: Education Outcome and Objective Hierarchy

NASA Education Outcome and Objective Hierarchy

Outcome 1
Higher Education – Employ and Educate: Contribute to the development of the STEM (Science, Technology, Engineering, Mathematics) workforce in disciplines needed to achieve NASA's strategic goals, through a portfolio of investments.

Objective 1.1 Faculty and Research Support (Employ)
Provide NASA competency-building education and research opportunities for faculty, researchers, and post-doctoral fellows.
Objective 1.2 Student Support (Educate)
Provide NASA competency-building education and research opportunities to individuals to develop qualified undergraduate and graduate students who are prepared for employment in STEM disciplines at NASA, industry, and higher education.
Objective 1.3 Student Involvement, Higher Education (Educate)
Provide opportunities for groups of post-secondary students to engage in authentic NASA-related mission-based research and development activities.
Objective 1.4 Course Development (Educate)
Develop NASA-related course resources for integration into STEM disciplines.
Objective 1.5 Targeted Institution Research and Academic Infrastructure (Employ) Improve the ability of targeted institutions to compete for NASA research and development work.

Outcome 2
Elementary and Secondary Education – Educate and Engage: Attract and retain students in STEM disciplines through a progression of educational opportunities for students, teachers and faculty.

Objective 2.1 Educator Professional Development – Short Duration (Engage)
Provide short duration professional development and training opportunities to educators, equipping them with the skills and knowledge to attract and retain students in STEM disciplines.
Objective 2.2 Educator Professional Development – Long Duration (Educate)
Provide long-duration and/or sustained professional development training opportunities to educators that result in deeper content understanding and/or competence and confidence in teaching STEM disciplines.
Objective 2.3 Curricular Support Resources (Educate and Engage)
Provide curricular support resources that use NASA themes and content to a) enhance student skills and proficiency in STEM disciplines; b) inform students about STEM career opportunities; and c) communicate information about NASA's mission activities.
Objective 2.4 Student Involvement, K-12 (Engage

Provide K-12 students with authentic first-hand opportunities to participate in NASA mission activities, thus inspiring interest in STEM disciplines and careers, as well as provide opportunities for family involvement in K-12 student learning in STEM areas.

Outcome 3
Informal Education – Engage and Inspire: Build strategic partnerships and linkages with STEM formal and informal education providers that promote STEM literacy and awareness of NASA's mission.

Objective 3.1 Resources (Engage and Inspire) Provide informal education resources or tools that use NASA's unique content to connect NASA's missions to self-directed learners or to attract or retain individuals to STEM careers.

Objective 3.2 Professional Development for Information Education Providers (Engage) Provide informal education that improves competency to embed NASA expertise, content, or STEM career development among those professionals and individuals who create or offer local, regional or national NASA-themed educational activities or exhibits.

Appendix B

NASA Strategic Plan

Achieving Our Vision and Mission

The United States is a world leader in the pursuit of new frontiers, discoveries, and knowledge. NASA performs a unique role in America's leadership in space. We have landed people on the Moon, sent spacecraft to the Sun and almost every planet in the solar system, and launched robotic explorers to travel beyond it. All the work NASA does benefits Americans and people around the world. NASA's budget is spent on Earth, supporting a strong economy and creating spinoffs that improve the quality of life.

Since 1958, NASA has amassed a rich history of unique scientific and technological achievements in human space flight, aeronautics, science, and space applications, including the International Space Station (ISS), improved aircraft safety, and dozens of robotic interplanetary probes, including the first man-made object to reach interstellar space, Voyager 1. These achievements are based on the guiding principles, which are in NASA's authorizing legislation, the National Aeronautics and Space Act (the "Space Act," found at 51 U.S.C. sec. 20101 et seq.). The Space Act directs us to:

- Plan, direct, and conduct aeronautical and space activities;
- Arrange for participation by the scientific community in planning scientific measurements and observations to be made through use of aeronautical and space vehicles, and conduct or arrange for the conduct of such measurements and observations;
- Provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof;
- Seek and encourage, to the maximum extent possible, the fullest commercial use of space;
- Engage in a program of international cooperation; and
- Encourage and provide for Federal Government use of commercially provided space services and hardware, consistent with the requirements of the Federal Government.

Our future success and global leadership will be determined largely by the investments and innovations we make today in scientific research, technology, and our workforce. NASA's focus has always been, and will always be, to discover, invent, and demonstrate new technologies, tools, and techniques that will allow our Nation to explore space while improving life on Earth. This is our passion, our purpose, and what drives our Vision and Mission.

Our Vision

We reach for new heights and reveal the unknown for the benefit of humankind.

Our Mission

Drive advances in science, technology, aeronautics, and space exploration to enhance knowledge, education, innovation, economic vitality, and stewardship of Earth.

NASA's Vision and Mission statements remind us of our purpose and our path. NASA's Vision leads to a future with an American-made launch capability supporting cutting-edge science, technology, and human exploration with strong technology and aeronautics programs. We will continue to push the frontier of space. We will develop new technologies for use in air, space, and on the ground. We will be a part of a strong, high-tech economy, and we will continue to partner with other nations to create a better world. We will increase our understanding of the universe and our place in it.

Our Mission statement outlines our fundamental purpose and role in bringing that Vision to life. As the Nation's leading organization for research and development in aeronautics and space, we are explorers and innovators who create and use our unique tools and capabilities for the benefit of the Nation and the world.

Foundations for Our Strategic Plan

Strategic planning at NASA begins with our Vision and Mission, shared core values, and broad overarching approach. NASA's core values of safety, integrity, teamwork, and excellence guide individual and organizational behavior. NASA's overarching approach consists of practices that each organization within NASA employs in developing and executing their plans to achieve our strategic goals. Each of these values guide our leadership in making decisions that optimize performance and stewardship in the current environment. Constant attention to these core values leads to mission success.

Core Values

Safety

NASA's constant attention to safety is the cornerstone upon which we build mission success. We are committed, individually and as a team, to protecting the safety and health of the public, our team members, and those assets that the Nation entrusts to us.

Integrity

NASA is committed to maintaining an environment of trust, built upon honesty, ethical behavior, respect, and candor. Our leaders encourage this virtue in the NASA workforce by fostering an open flow of communication on issues among all employees without fear of reprisal. At NASA, we regard and reward employees for demonstrating integrity. Building trust through ethical conduct as individuals and as an organization is a necessary component of mission success.

Teamwork

NASA's most powerful asset for achieving mission success is a multi-disciplinary team of diverse, competent people across NASA Centers. Our approach to teamwork is based on a philosophy that each team member brings unique experience and important expertise to project issues. Recognition of and openness to that insight improves the likelihood of identifying and resolving challenges to safety and mission success. We are committed to creating an environment that fosters teamwork and processes that support equal opportunity, collaboration, continuous learning, and openness to innovation and new ideas.

Excellence

To achieve the highest standards in engineering, research, operations, and management in support of mission success, NASA is committed to nurturing an organizational culture in which individuals make full use of their time, talent, and opportunities to pursue excellence in both the ordinary and the extraordinary.

Overarching Approach

- **Invest** in next-generation technologies and approaches to spur innovation;
- **Inspire** students to be our future scientists, engineers, explorers, and educators through interactions with NASA's people, missions, research, and facilities;
- **Expand** partnerships with international, intergovernmental, academic, industrial, and entrepreneurial communities, recognizing them as important contributors of skill and creativity to our missions and for the propagation of our results;
- **Commit** to environmental stewardship through Earth observation and science, and the development and use of green technologies and capabilities in NASA missions and facilities; and
- **Safeguard** the public trust through transparency and accountability in our programmatic and financial management, procurement, and reporting practices.

Our strategic direction reflects and aligns NASA's full spectrum of activities to accomplish national priorities in civil aeronautics research, space exploration, science, and advanced research and development. Building on our progress in fostering openness and transparency in Government, we consulted both internal and external stakeholders, including Congress, to identify challenges and opportunities NASA faces in the coming years as we execute this strategic plan. Understanding and mitigating these challenges, while taking advantage of the opportunities, allows us to plan more effectively and ensures that we can accomplish our goals.

For example, other nations are building space programs and may become competitors. But they may also become partners. Opportunities for cooperation can expand our potential and add to our collective accomplishments. Cooperation on the ISS taught us the benefits and intricacies of collaboration in space. Collaborating with more international partners in our endeavors enhances capabilities and enables missions that would otherwise not be possible, but also increases the complexity of planning each mission.

NASA is working on new ways to do business, investing in new technology, and increasing the sustainability, accountability, and transparency in our operations.

- **Finding new ways to do business**

  We are leveraging more public-private partnerships and harnessing the ingenuity of the American people to accomplish our work. We have spent nearly 50 years mastering the science and art of getting to low Earth orbit. We have proven the technologies and put the infrastructure in place. Now, we are ready to employ the capabilities of emerging U.S. commercial partners who can provide cargo and crew services. Transferring low Earth orbit access to commercial providers allows us to focus our resources on pursuing the next frontier: mastering access to deep space. In addition, we are expanding our partnerships outside the traditional aerospace industry to share knowledge and expertise in areas such as manufacturing, information technology, and resource management. Also, recognizing the value of the American public as a strategic partner in addressing some of the country's most pressing challenges, NASA relies on the expertise, ingenuity, and creativity of the American public by enabling, accelerating, and scaling the use of open innovation methods including prizes, challenges, crowdsourcing, and citizen science across NASA.

- **Investing in cutting-edge technologies**

  As we prepare for the proposed missions to an asteroid and then to Mars, and for the doubling of the global commercial aviation fleet in 20 years, we are entering an exciting time in which we will push the very boundaries of research and technology development. We are implementing a new space technology development and test program with partners from industry, academia, and other nations. This program will facilitate our objectives of building, flying, and testing new technologies that have the potential to increase capabilities, decrease costs, and expand opportunities for future space activities. As the enabler for safe, efficient, and affordable modern air travel, our research and technologies have formed the DNA of all modern aircraft. Through cutting-edge aeronautics research to solve technical challenges driven by global demands for mobility and mitigation of environment impact due to aviation, we will bring transformative innovations to usher National and global air transportation systems into the 21st Century.

- **Increasing sustainability, accountability, and transparency**

  We must invest wisely to ensure sustainable and reliable support for NASA's missions. This means careful management of our infrastructure and workforce. It may also require accepting higher risk on some mission activities. While we strive for sustainability, we must maintain our commitment to the American public to be responsible stewards of the resources entrusted to us. We are sharing our data, our successes, and our setbacks with the public at an unprecedented level. Through our transparency, we want the Nation to understand both why and how our challenging work will create a brighter future.

In the words of visionary computer scientist, Alan C. Kay, "The best way to predict the future is to invent it." NASA is working to invent the future through new technologies and new ways of doing business, and our strategic plan reflects this approach.

Our Strategic Plan and Priorities

This plan outlines the strategic direction, goals, and priorities we will pursue to make our Vision of the future a reality. We have identified three strategic goals that will strengthen NASA's ability to accomplish its Mission and contribute to U.S. preeminence in science and technology, improve life on Earth, and help protect Earth, while also benefiting the American economy. Each strategic goal is discussed in detail in the next section of this plan. Our strategic goals are each supported by several strategic objectives. The first strategic goal focuses on expanding knowledge, capability, and opportunity in space. The second strategic goal focuses on our work to improve the understanding of and life on Earth. Finally, the third strategic goal focuses on major management priorities and challenges.

Strategic Goals

Expand the frontiers of knowledge, capability, and opportunity in space.

Advance understanding of Earth and develop technologies to improve the quality of life on our home planet.

Serve the American public and accomplish our Mission by effectively managing our people, technical capabilities, and infrastructure.

Strategic Objectives

Understand the Sun and its interactions with Earth and the solar system, including space weather.

Discover how the universe works, explore how it began and evolved, and search for life on planets around other stars.

Ascertain the content, origin, and evolution of the solar system and the potential for life elsewhere.

Transform NASA missions and advance the Nation's capabilities by maturing crosscutting and innovative space technologies.

Advance knowledge of Earth as a system to meet the challenges of environmental change, and to improve life on our planet.

Optimize Agency technology investments, foster open innovation, and facilitate technology infusion, ensuring the greatest national benefit.

Expand human presence into the solar system and to the surface of Mars to advance exploration, science, innovation, benefits to humanity, and international collaboration

Conduct research on the ISS to enable future space exploration, facilitate a commercial space economy, and advance the fundamental biological and physical sciences for the benefit of humanity.

Facilitate and utilize U.S. commercial capabilities to deliver cargo and crew to space.

Enable a revolutionary transformation for safe and sustainable U.S. and global aviation by advancing aeronautics research.

Advance the Nation's STEM education and workforce pipeline by working collaboratively with other agencies to engage students, teachers, and faculty in NASA's missions and unique assets;

Attract and advance a highly skilled, competent, and diverse workforce, cultivate an innovative work environment, and provide the facilities, tools, and services needed to conduct NASA's missions;

Ensure the availability and continued advancement of strategic, technical, and programmatic capabilities to sustain NASA's Mission;

Provide secure, effective, and affordable information technologies and services that enable NASA's Mission; and

Ensure effective management of NASA programs and operations to complete the mission safely and successfully.

Strategic Goals and Objectives

Strategic Goal 1

Expand the frontiers of knowledge, capability, and opportunity in space.

For more than 50 years, NASA has continually expanded the boundaries of science, technology, and imagination. Technologies and ideas that once only existed in the realm of science fiction have become science fact. Proving that the seemingly impossible is possible, NASA helps maintain U.S. leadership in space and creates new generations of space entrepreneurs and enthusiasts who believe humanity's future lies among the stars.

This goal, to expand the frontiers of knowledge, capability, and opportunity in space, encapsulates a cycle of discovery. Every advance in our knowledge provides us unique insights and opportunities to improve our understanding of the universe, which leads to enhanced capabilities in space and on Earth. This, in turn, raises new questions and leads not only to new answers, but also new tools. Expanding our knowledge, capabilities, and opportunities in space is critical for remaining a global leader and returning the dividends of discovery back to Earth.

(Above) Expedition 35 Flight Engineer Chris Cassidy against the Earth's limb during an inspection and repair spacewalk aboard the International Space Station in May 2013. Fellow Flight Engineer Tom Marshburn is reflected in the visor.

Over the next decade, we will develop the new technologies that will open the space frontier for private industry, non-profit organizations, and citizen explorers. We will leverage the ISS one-of-a-kind research and technology development facilities as a test bed for future human exploration missions to deep space, improving how we live, and work in space. We will promote use of the unique micro-gravity environment on the ISS for industrial and academic science and research. We will work with commercial partners to ensure a strong U.S. capability for launching crew and cargo into space. We will complete development of next-generation space systems like the Space Launch System (SLS) and the Orion Multi-Purpose Crew Vehicle to take us past low Earth orbit, and set a pathway to Mars and beyond. We will deploy the James Webb Space Telescope (JWST) to glimpse back in time to the formation of the first stars and galaxies, while our New Horizons mission will uncover knowledge about Pluto and Kuiper Belt objects in the farthest reaches of our solar system. We will advance our understanding of the Sun, its interactions with the solar system, and its impact on the space environment and travel.

NASA's mission continues to broaden our knowledge of the solar system and the universe, develop new technologies, and expand human and robotic exploration capabilities. The achievements of these efforts will benefit the Nation, maintain U.S. leadership in space exploration, and help lead humanity's journey into space. The knowledge and capabilities NASA builds will open new opportunities for discovery and ensure NASA is prepared for the challenges and rewards that come from space exploration.

Expanding the frontiers of knowledge, capability, and opportunity in space is an enduring and core goal for NASA. In the past decade alone, we increased our knowledge of the universe as evidenced by the discovery of more than 2,000 planets in other solar systems. Closer to home, we have expanded our exploration capabilities and sent out robotic sentinels to explore our solar system. The Curiosity rover landed more than 225 million kilometers from Earth and is actively exploring Mars. It has already accomplished its major science goal, discovering a location that could have supported microbial life in the past. We are planning to deepen our knowledge of the working of the interior of planetary bodies by placing a highly sensitive seismometer and associated geophysical instruments on the surface of Mars with the InSight mission. In 2020, we will continue our robotic exploration of Mars with a rover largely built upon the successful Curiosity rover and equipped with new, advanced instruments for in situ studies. It will prepare a scientifically selected cache of Mars samples that may be returned to Earth in the future for detailed analysis seeking possible signs of ancient life.

We are undertaking the detailed examination of near-Earth asteroids to determine what they can tell us about the early solar system, and whether any of these objects pose a threat to Earth. We are expanding our Near Earth Object Observation program, to find candidates for the proposed asteroid mission, and to catalogue asteroids larger than 140 meters across. Specifically, NASA will seek to increase the number of asteroid observations by the amateur astronomer community as a part of the Asteroid Grand Challenge. In 2016, we will launch the OSIRIS-REx mission to robotically approach and return a sample from a carbonaceous asteroid. This will aid in our investigation of planet formation and the origin of life in our solar system, as well as our understanding of asteroids that could impact Earth.

NASA is defining a bold new asteroid initiative that includes planning for an ambitious new mission to identify, capture, and redirect an asteroid to a stable lunar orbit, where astronauts may explore it. The mission will also include an increased role for innovative partnerships and approaches to help us amplify efforts to identify and track asteroids and protect us from any potential threats. This mission aligns our science, space technology, and human exploration capabilities while engaging new partners and seeking innovative ideas to achieve this bold human and robotic mission. The proposed asteroid mission will advance our solar system exploration capabilities, while helping us learn how to mitigate the danger posed by asteroids crossing Earth's orbit. The second component of the asteroid initiative, the Asteroid Grand Challenge, is to find all asteroid threats to human population and know what to do about them. It is an effort to reach beyond traditional boundaries and encourage partnerships and collaboration with a variety of organizations to solve this global problem. The overall effort will include resources from partners, thus increasing the impact of NASA's initial funding.

NASA has achieved great things for our Nation by embracing bold challenges while managing the associated risks to human lives and assets. Throughout our history, NASA's explorer spirit has led us deeper into the unknown, where we continue to learn from our endeavors.

The missions we pursue under this goal help address national challenges and are allowing us to take advantage of unique opportunities to bring benefits to the Nation. For example:

- **We are moving forward with critical research and technology demonstrations on the ISS.**

  Great advances in understanding human health have come from research on the ISS, which can help prepare us for long-duration space travel, as well as improve the quality of life for aging populations on Earth.

- **We are contributing to healthy, cutting-edge manufacturing and aerospace sectors.**

  For SLS, we are using 3D manufacturing technology to print custom parts for the system, marking a revolution in manufacturing.

- **We are enabling a robust commercial space industry.**

  We are leveraging our public-private partnerships to lower launch costs and create more opportunities for commercial space flight. NASA and its commercial partners have succeeded in maturing commercial cargo transportation capabilities to the point where NASA can buy cargo transport services to the ISS on a commercial basis. We are now working to achieve the same for crew transport to and from the ISS.

- **We are adding to the scientific understanding that may be needed to protect Earth.**

  Recent asteroid passes and the asteroid that exploded over Russia in February 2013 have underscored that we live on a fragile planet in the midst of a chaotic universe. We have been working for years to identify asteroids that could impact Earth. Our proposed asteroid initiative, comprised of both a bold new mission to an asteroid and a global grand challenge to find all asteroid threats to human populations, will help identify the threats posed by some asteroids as well as teach us how to possibly avoid future impacts.

- **We are moving outward, beyond low Earth orbit, into the broader solar system.**

  We are developing SLS and the Orion to carry astronauts farther into space than humans have ever been.

As we make progress toward this goal, we further the knowledge and capabilities of humanity and we open the door to countless opportunities–in research, technology development, space travel, the exploration of celestial bodies, and the development of commercial markets in space and on Earth. Moreover, we contribute to our Nation's continued role as a leader in space. As we learn more about the universe and improve our ability to explore and live in space, we fuel the innovation that will drive tomorrow's breakthroughs. NASA is proud to be the U.S. agency charged with reaching for the stars and pushing the limits of human knowledge, capabilities, and opportunities. Together with industry, academia, the general public, and other space agencies, we can build a bright future.

Objective 1.1: Expand human presence into the solar system and to the surface of Mars to advance exploration, science, innovation, benefits to humanity, and international collaboration.

NASA engineers and contractors conduct a water impact test of an 18,000-pound (8,165-kilogram) test version of the Orion spacecraft at NASA's Hydro Impact Basin. The first space-bound Orion capsule will launch on Exploration Flight Test-1 or EFT-1, an uncrewed launch planned for 2014. This test will see Orion travel farther into space than any human spacecraft has gone in more than 40 years. Orion will carry astronauts into space, providing emergency abort capability, sustaining the crew during space travel, and ensuring safe re-entry and landing.

Lead office: Human Exploration Operations Mission Directorate

Objective Overview:

Over the next decades, NASA intends to erase the boundaries to human exploration of space. We want to open new frontiers beyond low Earth orbit to humankind. NASA is expanding human exploration by developing the capability to transport humans to and from deep space, enabling the exploration of other planets and asteroids within our solar system using innovative, advanced technologies.

As a starting point, exploring deep space requires the capability to transport cargo and crew beyond low Earth orbit, or farther than 2,000 kilometers beyond Earth. NASA is developing a new transportation system that includes a crew capsule, a heavy-lift launch vehicle, and supporting ground facilities and systems.

NASA is developing technologies to enable the additional capabilities that will be required the farther away from Earth we travel. These include the capabilities for in-space propulsion, in-space operations, long-duration habitation, and other systems to support humans in hostile environments. Precursor robotics, robotic missions that investigate candidate destinations and provide vital information to prepare for human explorers, will lay the groundwork for humans to achieve new milestones in deep space.

The capability to transport humans to and from deep space will leverage incremental development of exploration capabilities that seed future discoveries and innovation, and eventually lead to creation of a permanent, long-term human space presence in the solar system. Our exploration of deep space will reward us with new knowledge. While new knowledge increases our understanding of our planet, our solar system, our universe, and ourselves, Americans expect tangible benefits and applications that we can use on Earth. If the past is prologue, scientists and entrepreneurs will generate new uses for the knowledge and technology resulting from NASA's investments in exploration systems, and this in turn will grow the U.S. economy.

Objective Strategy:

Voyages: Charting the Course for Sustainable Human Space Exploration outlines NASA's strategy for human exploration in deep space. First, it is capability-driven. Each capability provides a specific function that solves an exploration challenge, and in combination with other capabilities, it will advance human presence into our solar system. Second, it is multi-destination. Rather than creating specialized, destination-specific hardware, this provides adequate flexibility to carry out increasingly complex missions to a range of destinations over time. NASA is developing a core set of evolving capabilities to ensure that the Nation's space program is robust, sustainable, and flexible.

We recognize that human space exploration is a global endeavor that must include international partners, and have engaged the international community to jointly develop the *Global Exploration Roadmap*. The roadmap begins with the ISS and then identifies potential paths for human exploration of the solar system, describing a logical sequence of robotic and human missions. The ISS is the cornerstone of future deep-space habitation and exploration activities. Lessons learned from the construction and assembly of the ISS will guide future mission operations for servicing, pre-deploying, or constructing systems in cis-lunar or deep space. Knowledge gained from research and technology demonstrations on the ISS will enable us to design and build future deep space explorations systems.

However, developing the technologies and capabilities for humans to safely explore beyond the bounds of Earth presents challenges.

- **Maintaining Key Schedules**

  NASA is focusing on maintaining key schedules for missions in development, while funding ongoing and new research activities necessary to design future human exploration systems. Using a leaner, more efficient insight and oversight approach, NASA has partnered with industry to develop more cost-effective design and manufacturing techniques to build the systems necessary for exploration. One means is rapid prototyping and flight demonstration of new technologies.

- **New Processes and Tools**

  Although humans have operated space stations in low Earth orbit for over 40 years, we continue to evolve the tools and techniques necessary for deep space exploration. NASA is working to overcome radiation, logistics, and long-term reliability challenges; meet mission constraints; and ensure safe and efficient transport throughout deep space. Future exploration missions in cis-lunar space or beyond will require complex operational staging and phasing to ensure crew, cargo, and exploration systems all successfully arrive at the correct destination. New operational procedures for autonomous rendezvous and docking will be necessary to enable safe and effective missions.

- **Selecting an Asteroid**

  Because there are thousands of known Near Earth Asteroids (NEAs) and likely many more to be discovered, one of the first challenges of a NEA mission is choosing the ideal destination. Distance is another challenge. Although some NEAs pass close to Earth, even within the Moon's orbit, larger and more interesting NEA destinations may be tens of millions of miles away. To reach these NEAs, astronauts would have to travel about six months for a roundtrip, which is a long time to go without a resupply of water, food, or air—longer than has ever been attempted in space. Therefore, NASA has chosen to bring a small asteroid to us: robotically redirecting an asteroid to a safe orbit around the Moon and visiting it with astronauts via SLS and Orion.

- **Long Mission Durations**

  With current propulsion systems, it will take humans over six months to reach Mars, and due to available flight trajectories, astronauts will either have to leave within 30 days or stay on the surface for more than 500 days. These mission durations significantly exceed our demonstrated capability to sustain life in space without direct support from Earth. Mars missions will also have to overcome several health challenges, such as radiation and the potential health hazard of Martian dust. Once a crew embarks on the longest, farthest, and most ambitious space exploration mission in human history, they will need to be self-sufficient and flexible enough to adapt to changing and unforeseen circumstances. NASA has a multi-pronged approach to address this challenge. We are working with our ISS partners to fly a "one-year increment" on the ISS for an astronaut and a cosmonaut in 2015. And we are working with the broader science and engineering community to develop and fly an in situ resource utilization (ISRU) experiment on NASA's planned Mars 2020 rover mission.

Contributing Programs:

Orion Multi-Purpose Crew Vehicle Program, Space Launch System Program, Exploration Ground Systems Program, and Advanced Exploration Systems

Objective 1.2: Conduct research on the International Space Station (ISS) to enable future space exploration, facilitate a commercial space economy, and advance the fundamental biological and physical sciences for the benefit of humanity.

In the ISS's Kibo laboratory, NASA astronaut Chris Cassidy, Expedition 36 flight engineer, conducts a session with a pair of bowling-ball-sized free-flying satellites known as Synchronized Position Hold, Engage, Reorient, Experimental Satellites, or SPHERES. Each satellite is self-contained with power, propulsion, computers, and navigation equipment. The results are important for satellite servicing, vehicle assembly and formation flying spacecraft configurations.

Lead office: Human Exploration Operations Mission Directorate

Objective Overview:

NASA's contribution to society starts with scientific and technological achievement, but extends much further. We are using our resources to spur exploration as well as the new and robust commercial space market. The continued operation of the ISS is critical to achieving NASA's and the Nation's goals in science, technology, and human spaceflight. The ISS is the world's only orbiting, microgravity research and development (R&D) laboratory where researchers may perform multidisciplinary research and technology development to prepare for our exploration of the solar system. Results of research projects will continue to yield benefits in areas such as human health, telemedicine, physical science, Earth observations, space science, and education programs that inspire future scientists, engineers, and space explorers. The Center for Advancement of Science in Space (CASIS), is the sole manager of the ISS National Laboratory, which is a portion of the ISS, and is working to maximize use of the ISS for research in space. The Administration's decision to extend ISS operations until at least 2024 will allow us to maximize its potential and maintain American leadership in space.

The ISS is proving to be a catalyst for the growing commercial space enterprise, as well as a critical springboard for our future space exploration goals. NASA is buying hundreds of millions of dollars of cargo flights from new commercial launch services providers. With the collaboration of five space agencies, 15 nations, and private companies, the ISS is a model for cooperation on future human space exploration missions beyond low Earth orbit.

Objective Strategy:

To achieve this objective, we are designing and developing an exploration architecture that includes the technologies, systems, and operational processes, which can be tested and demonstrated onboard the ISS. The ISS is an outstanding location to test and mature selected technologies and processes, such as environmental control and life support, communications, and navigation and power and propulsion systems, which are required for exploration missions. Research performed on the ISS is essential to understanding how the human body responds and adapts to microgravity and the environment of space. Human research conducted on the ISS will help mitigate the health risks anticipated on exploration missions, such as visual impairment and intracranial pressure, pharmacology, nutrition, and muscle maintenance. We will continue to use innovative approaches on the ISS to develop new means to achieve sustainable exploration of the solar system.

Contributing Programs:

International Space Station Program, Human Research Program, and Human Space Flight Operations Program

Objective 1.3: Facilitate and utilize U.S. commercial capabilities to deliver cargo and crew to space.

A little more than two years after the end of the Space Shuttle Program, the United States now has available two space transportation systems capable of delivering science experiments and supplies from U.S. soil to the ISS. The rockets and spacecraft developed by NASA's partners Orbital Sciences Corp. (top) and SpaceX (bottom) significantly increased NASA's ability to conduct new scientific investigations aboard the orbiting laboratory. All current and planned U.S. experiments aboard the station will be facilitated in some way by a SpaceX or Orbital Sciences resupply mission.

Lead office: Human Exploration Operations Mission Directorate

Objective Overview:

Partnerships with American industry to enable U.S. commercial crew transportation to low Earth orbit will stimulate a commercial industry, promote job growth, and expand knowledge, as well as supply the ISS. NASA envisions commercial human spaceflight to low Earth orbit becoming a robust, vibrant, profit-making commercial enterprise with many providers and a wide range of private and public users. Our role in this enterprise is to provide expertise, incentives, and opportunities to the emerging human space flight industry. We will purchase transportation services to meet our International Space Station crew rotation and emergency return obligations. A vibrant, job-creating, profit-making transportation system for humans and cargo to low Earth orbit will significantly contribute to the national economy.

Objective Strategy:

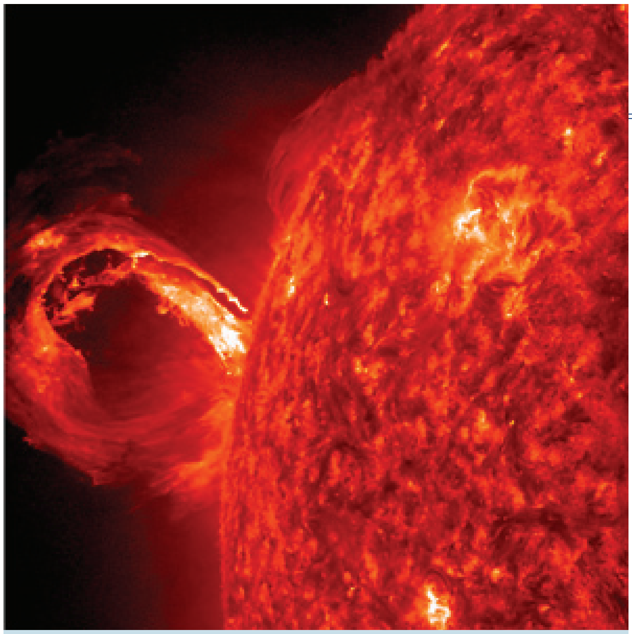
To facilitate and utilize commercial space capabilities, NASA will continue to work with U.S. industry partners to identify and enable emerging commercial space capabilities. This strategy will encourage innovative and entrepreneurial efforts between NASA and the private sector. NASA's existing partnerships with industry have made significant progress in the maturation of commercial human space transportation systems to low Earth orbit.

One of our key challenges in pursuit of this objective is our ability to sustain longer-term gains in the continued development of both the transportation and commercial products and services markets. The current competitive environment provides strong incentives for U.S. industry to meet or exceed NASA's safety requirements, and provides an incentive to industry partners to invest in this endeavor.

Contributing Programs:

Commercial Crew Program

Objective 1.4: Understand the Sun and its interactions with Earth and the solar system, including space weather.



In an increasingly technological world, space weather is a serious matter. Solar flares can temporarily alter the upper atmosphere, creating disruptions with signal transmission from a GPS satellite to Earth, causing it to be off by many yards. Another phenomenon produced by the Sun could be even more disruptive. Known as a coronal mass ejection (CME) these solar explosions propel bursts of particles and electromagnetic fluctuations into Earth's atmosphere. Those fluctuations could induce electric fluctuations at ground level that could blow out transformers in power grids. Particles can also collide with crucial electronics onboard a satellite and disrupt its systems.

Lead office: Science Mission Directorate

Objective Overview:

The domain of heliophysics ranges from the interior of the Sun, to the upper atmosphere and near-space environment of Earth (above 50 kilometers), and outward to a region far beyond Pluto where the Sun's influence wanes against the forces of interstellar space. Earth and the other planets of our solar system reside in this vast extended atmosphere of the Sun, called the heliosphere, which is made of electrified and magnetized matter entwined with penetrating radiation and energetic particles. To increase our understanding of the heliopshere, we seek to answer fundamental questions about this system's behavior: What causes the Sun to vary? How do geospace, planetary space environments, and the heliosphere respond? What are the impacts to humanity?

The emerging science of interplanetary space weather is crucial to NASA's human and robotic exploration objectives beyond Earth's orbit. Humans are presently confined to low Earth orbit, where the planetary magnetic field and the body of Earth itself provide substantial protection against solar storms. Eventually, though, astronauts will travel to distant places where natural shielding is considerably less. Our new long-term exploration initiatives directly rely on our ability to successfully understand, predict, and mitigate impacts of interplanetary space weather.

Objective Strategy:

Scientific priorities for future science missions are guided by the decadal surveys published by the National Academies. The goal of the decadal surveys is to articulate the priorities of the scientific community, and is therefore the starting point for our strategic planning process in Earth and space science. The scientific priorities for heliophysics are guided by the decadal survey, *Solar and Space Physics: A Science for a Technological Society*, published in 2012. Studying the Sun, the heliosphere, and other planetary environments as an interconnected system is critical for understanding the implications for Earth and humanity as we venture forth through the solar system. To that end, the NASA heliophysics program seeks to perform innovative space research missions to understand: (1) the Sun and its variable activity; (2) how solar activity impacts Earth and the solar system; and (3) fundamental physical processes that are important at Earth and throughout the universe by using space as a laboratory. Heliophysics also seeks to enable research based on these missions and other sources to understand the connections among the Sun, Earth, and the solar system for science and to assure human safety and security both on Earth and as we explore beyond it. A heliophysics roadmap has been developed to advance these scientific objectives and respond to the recommendations outlined in the decadal survey, as well as plan for the longer term. The roadmap includes technology development efforts and scientific research priorities to enable future missions in the priority areas. NASA leadership and program managers actively monitor and manage risks and external factors that pose challenges to our heliophysics science missions. Below, we describe our approach to managing some of the key challenges:

- **Mission Cost Estimation and Management**

  To better control mission cost estimation and management, we transformed how we manage programs and projects, acquisition strategies, and procurements, particularly for our most complex science missions. In particular, we have strengthened program and project management, established more rigorous cost estimation practices, gathered numerous external and internal cost estimates, and incorporated multiple, formal decision points as gates to the next stage of development. Following these steps in the last three years, six missions have launched either under or within their cost and schedule baselines, demonstrating progress in improving NASA's mission cost estimation and management tools. NASA is committed to controlling mission cost for the long-term. We will continue to be rigorous in maintaining these practices and taking additional steps to continue to improve schedule and cost performance to ensure that implementation is consistent throughout projects and programs.

- **Meeting Scientific and Societal Needs**

  NASA's heliophysics scientific research not only advances our understanding of the Sun-Earth-heliosphere system, but also is of growing importance to our Nation's economic well-being and security. Conditions on our variable Sun, its solar wind and atmosphere interact with Earth's electromagnetic environment and result in phenomena known as space weather. These events can disrupt communications, navigation, satellite operations, and electric power distribution. A severe geomagnetic storm has the potential to cause significant socioeconomic loss, as well as impacts to national security. To meet national and societal space weather needs, NASA coordinates its space weather activities with several interagency partners through the National Space Weather Program. NASA's fleet of spacecraft provides observations of solar and geophysical events that are incorporated into operational space weather forecasts and satellite anomaly assessments for use by the Nation. As many of the missions are well past their prime mission lifetime, NASA and the operational partner agencies are studying ways to develop new mission and instrument capabilities that will enable improved space weather prediction algorithms and models. We also develop partnerships with international organizations to enhance our understanding of the heliophysics and the science of space weather.

Contributing Programs:

Heliophysics Research Program, Living with a Star Program, Solar Terrestrial Probes Program, and Heliophysics Explorer Program

Objective 1.5: Ascertain the content, origin, and evolution of the solar system and the potential for life elsewhere.

A Curiosity self-image taken by the MAHLI (Mars Hand Lens Imager) camera on the robotic arm. The rover is at Rocknest, having taken several soil samples (bottom left) in Gale Crater, with Mt Sharp in the background. Findings indicate that chemical conditions in Gale Crater were once capable of supporting microbial life. Samples determined that Martian soil contains abundant and easily accessed amounts of water.

Lead office: Science Mission Directorate

Objective Overview:

Planetary science continues to expand our knowledge of the solar system, with active missions and Earth-based research programs exploring all the way from Mercury to Pluto and beyond. We seek to answer fundamental questions: How did our solar system form and evolve? Is there life beyond Earth? What are the hazards to life on Earth?

Robotic exploration is the principal method we use to explore the solar system, and is an essential precursor to human exploration of space. Ground-based observations, experiments, theoretical work, and analysis of extraterrestrial materials supplement our space-based assets. Each progression from flybys, to orbiting spacecraft, to landers and rovers, to sample return missions helps advance our understanding of the formation of planetary bodies, the chemical and physical history of the solar system, and the conditions that are capable of sustaining life. The successful Mars Science Laboratory Curiosity, for example, is allowing us to explore the potential habitats for past life on Mars.

Our investment in planetary science helps us protect Earth by identifying and characterizing celestial bodies and environments that may pose threats to our planet. Further, planetary science programs add to the pool of knowledge necessary for future human exploration missions. In support of the Asteroid Grand Challenge, we will enhance our Near Earth Objects Observation program to improve the detection and characterization of potential asteroid candidates for robotic and crewed exploration.

Objective Strategy:

Scientific priorities for future planetary science missions are guided by the recommendations of the decadal surveys published by the National Academies. The goal of the decadal surveys is to articulate the priorities of the scientific community, and the surveys are therefore the starting point for NASA's strategic planning process in science. The most recent planetary science decadal survey, *Vision and Voyages for Planetary Science in the Decade 2013 - 2022*, was released in 2011. This report recommended a balanced suite of missions to enable a steady stream of new discoveries and capabilities to address challenges such as sample return missions and outer planet exploration. NASA's Planetary Science Division is working to implement a balanced portfolio within the available budget and based on the decadal survey that will continue to make exciting scientific discoveries about our solar system.

NASA leadership and program managers actively monitor and manage risks and external factors that pose challenges to our planetary science missions. Below, we describe our approach to managing some of the key challenges:

- **Mission Cost Estimation and Management**

  To better control mission cost estimation and management, we transformed how we manage programs and projects, acquisition strategies, and procurements, particularly for our most complex science missions. In particular, we have strengthened program and project management, established more rigorous cost estimation practices, gathered numerous external and internal cost estimates, and incorporated multiple, formal decision points as gates to the next stage of development. Following these steps in the last three years, six missions have launched either under or within their cost and schedule baselines, demonstrating progress in improving NASA's mission cost estimation and management tools. NASA is committed to controlling mission cost for the long-term. We will continue to be rigorous in maintaining these practices and taking additional steps to continue to improve schedule and cost performance to ensure that implementation is consistent throughout projects and programs.

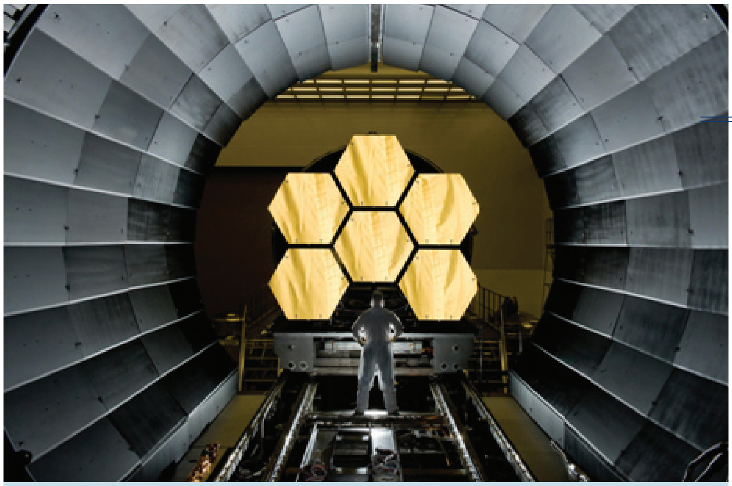
- **Availability of Plutonium 238**

  Plutonium 238 (Pu-238) activates and sustains the electrical power systems for spacecraft and planetary probes that cannot rely on solar energy because the Sun is too distant, not consistently observable, or too obscured. NASA's current supply of Pu-238 will be exhausted between 2017 and 2020, but working with the Department of Energy under a reimbursable agreement, NASA is in the process of developing the infrastructure, power system, and flight safety and handling procedures of Pu-238 for domestic production.

Contributing Programs:

Planetary Science Research Program, Discovery Program, New Frontiers Program, Mars Exploration Program, Technology, and Outer Planets.

Objective 1.6: Discover how the universe works, explore how it began and evolved, and search for life on planets around other stars.



A technician stands in front of six JWST primary mirror segments, which, when combined with the observatory's 12 other mirrors, will allow scientists to see the universe light up with the first stars and galaxies that formed after the Big Bang. The JWST is the scientific successor to the Hubble Space Telescope and is scheduled to launch in 2018.

Lead office: Science Mission Directorate

Objective Overview:

NASA leads the Nation and the world on a continuing journey to answer profound questions: How does the universe work? How did we get here? Are we alone? The scope of astrophysics is truly breathtaking, ranging from the birth of the universe and the development of stars and galaxies over cosmic time, to the search for life on planets around other stars.

NASA's astrophysics missions explore the extreme physical conditions of the universe and study the building blocks of our own existence at the most basic level: the space, time, matter, and energy that created the universe. Our telescopes have already measured the current age of the universe to be about 13.7 billion years and have uncovered remarkable new phenomena, such as the mysterious dark energy that dominates the universe. In the future, they will probe the origin and destiny of the universe, including the first moments of the Big Bang and the nature of black holes, dark energy, dark matter, and gravity.

We seek to understand the origin and evolution of the universe, as well as understand the processes for life on other planets. NASA's observatories allow astronomers to explore the processes of formation of stars, galaxies, and planets. We have observed star formation occurring when the universe was at only a few percent its current age. The upcoming James Webb Space Telescope (JWST) will allow us to uncover the mysteries of star formation at an even earlier age, as well as study in detail planets around other stars.

We are navigating a voyage of unprecedented scope and ambition: seeking to discover and study planets orbiting around other stars and to explore whether they could harbor life. NASA's astrophysics missions, in conjunction with ground-based telescopes, have already confirmed the existence of over 2,000 extrasolar planets. Of even greater interest, we are now finding that there are many small, rocky extrasolar planets where liquid water could exist. In the future, NASA's telescopes will continue this breathtaking journey, discovering new planets and observing signatures that could indicate possibilities for life.

Objective Strategy:

Scientific priorities for future astrophysics missions are guided by the decadal surveys published by the National Academies. The goal of the decadal surveys is to articulate the priorities of the scientific community, and is therefore the starting point for our strategic planning process in Earth and space science. The scientific priorities for astrophysics are outlined in the decadal survey, *New Worlds,* *New Horizons in Astronomy and Astrophysics*, published in 2010. These include understanding the scientific principles that govern how the universe works; probing cosmic dawn by searching for the first stars, galaxies, and black holes; and seeking and studying nearby habitable planets around other stars. We developed an *Astrophysics Implementation Plan* to advance these scientific objectives and respond to the recommendations outlined in the decadal survey. This plan includes technology development efforts, design studies, and scientific research to enable future space telescopes in the priority areas. Looking towards the longer term, NASA Advisory Council's Astrophysics Subcommittee developed the Astrophysics Roadmap that provides a compelling 30-year vision for astrophysics. The roadmap takes a long-range view and highlights the science possibilities over the next 30 years and provides the inspiration and rationale for continuing American leadership and investment in our astrophysics programs.

NASA leadership and program managers actively monitor and manage risks and external factors that pose challenges to our astrophysics science missions. Below, we describe our approach to managing some of the key challenges:

- **Mission Cost Estimation and Management**

  To better control mission cost estimation and management, we transformed how we manage programs and projects, acquisition strategies, and procurements, particularly for our most complex science missions. In particular, we have strengthened program and project management, established more rigorous cost estimation practices, gathered numerous external and internal cost estimates, and incorporated multiple, formal decision points as gates to the next stage of development. Following these steps in the last three years, six missions have launched either under or within their cost and schedule baselines, demonstrating progress in improving NASA's mission cost estimation and management tools. NASA is committed to controlling mission cost for the long-term. We will continue to be rigorous in maintaining these practices and taking additional steps to continue to improve schedule and cost performance to ensure that implementation is consistent throughout projects and programs.

- **Technology Development and Demonstration**

  To continue solving the mysteries of the universe and to study planets around other stars, NASA will need to develop and launch space telescopes that are more powerful than the current generation of space telescopes. New space telescopes will need to be larger and more capable without being heavier or more expensive. NASA is investing substantially in the technologies necessary to realize these future space observatories, and we are working with partners in the NASA Space Technology Program, industry, and other Government agencies to develop and infuse new technologies.

Contributing Programs:

Astrophysics Research Program, Cosmic Origins Program, Physics of the Cosmos Program, Exoplanet Exploration Program, Astrophysics Explorer Program, and James Webb Space Telescope

Objective 1.7: Transform NASA missions and advance the Nation's capabilities by maturing crosscutting and innovative space technologies.

NASA's X-1 Robotic Exoskeleton would help astronauts stay healthier in space with the added benefit of assisting those with physical disabilities here on Earth.

Lead office: Space Technology Mission Directorate

Objective Overview:

NASA invests in cross-cutting, transformational space technologies that have high potential for offsetting mission risk, reducing costs, and advancing existing capabilities, which makes achieving more challenging missions possible. These technologies enable a new class of space missions; strengthen our Nation's leadership in space-related science, technology, and industrial base; and foster a technology-based U.S. economy.

Drawing on talent from our workforce, academia, small business, and the broader space enterprise, NASA delivers innovative solutions that dramatically improve technological capabilities for our mission and the Nation. Development and infusion of these new capabilities improves the reliability of future missions and is vital to reaching new heights in space and sending American astronauts to new destinations, such as an asteroid or Mars.

Objective Strategy:

New pioneering technologies will increase the Nation's capability to perform space science, operate in space, and enable deep space exploration. Significant progress in technology areas, such as in-space power systems, solar electric propulsion, radiation protection, next generation life-support, human robotic systems, cryogenic fluid handling, and entry descent and landing capabilities, are essential for future science and human exploration missions. Developing these solutions will stimulate the growth of the Nation's economy by creating new markets in areas such as nanotechnology, robotics, advanced manufacturing, and synthetic biology. Space technology enables future space missions and simultaneously improves life on Earth.

NASA's Space Technology Mission Directorate (STMD) investment strategy addresses the broad range of technology areas identified in our Space Technology Roadmaps, as prioritized by the National Academies. This portfolio approach spans the entire technology life cycle, utilizing a combination of early stage conceptual studies, discovering entirely new technologies (technology readiness level (TRL) 1-3); rapid competitive development and ground-based testing (TRL 3-5) to determine feasibility; and flight demonstrations in a relevant environment to complete the final step toward mission infusion (TRL 5-7). This comprehensive portfolio approach, encompassing both near-term and long-term development, enables the discovery and advancement of necessary technologies that may fundamentally change the way we live and explore our world and the universe.

The Space Technology portfolio draws upon talent from across the space enterprise and leverages partnerships with industry, academia, other Government agencies, and international partners. We strive to be a model organization, demonstrating lean technology development through effective and efficient practices and principles. Through challenging new missions, multi-use technologies, and stimulation of commercial space markets, NASA's STMD expands capabilities in space and on Earth.

NASA leadership and program managers actively monitor and manage risks and external factors that pose challenges to technology development and maturation. Below, we describe our approach to managing key challenges:

- **The unique nature of NASA science and exploration technology needs**

  The objectives that science and exploration technology solutions must satisfy are often unique to NASA's Mission. Traditional market forces that drive commercial technology developments do not necessarily align with NASA's needs. NASA investments in technology development value partnerships and innovation, incentivizing the creation of new markets while achieving NASA technology goals.

Contributing Programs:

Crosscutting Space Technology Development, Exploration Technology Development, and Small Business Innovative Research/Small Business Technology Transfer

Strategic Goal 2

Advance understanding of Earth and develop technologies to improve the quality of life on our home planet.

NASA is committed to improving life right here on Earth. Whether developing new aircraft technologies for safer, more efficient air travel, uncovering the complexities of Earth's natural systems, or transferring technologies to the commercial marketplace, NASA has a record of accomplishment in advancing understanding of Earth and helping to improve life for its inhabitants. Every discovery NASA makes, all knowledge gained through our space endeavors, and every advance in technology benefits us on Earth.

We take pride in our ability to inspire people of all ages in the United States and around the world through our pursuits. From landing robots on Mars to teaching in classrooms around the country, we are excited to provide opportunities for people everywhere to engage and participate with us as we push the boundaries of human knowledge and exploration.

NASA will continue to advance research in aeronautics to enable both sustainable and efficient air transportation. Understanding our home planet and improving life on it is central to our mission and is a critical national priority. As we make new discoveries about Earth and environmental change, we are protecting our economic vitality and learning how to be better stewards of our home planet.

(*Above*) Astronauts aboard the ISS photographed these striking views of Pavlof Volcano in May 2013. The oblique perspective from the ISS reveals the three dimensional structure of the ash plume, which is often obscured by the top-down view of most remote sensing satellites.

The effects of climate change are all around us–more severe storms and hurricanes, droughts, and other natural disasters have both a human toll and an economic toll. NASA is working to understand the mechanisms and possible actions Federal, state, and local agencies and organizations and communities can take to minimize the impacts of environmental change.

NASA improves life on Earth by enhancing our economy through aeronautics research to enable more efficient air transportation. NASA has a long and successful history of pioneering technology breakthroughs that underlie most modern aviation systems. The millions of people and trillions of dollars in cargo that fly every year on commercial aircraft are benefiting from years of NASA research and collaboration with other agencies to get to their destinations faster and with greater safety.

NASA contributes to economic vitality and innovation through the transfer of technologies that generate new revenue for private companies or help foster creation of entirely new ventures. We lend expertise, facilities, and innovations to other Federal agencies and entrepreneurs. From emerging commercial launch providers to robotic mining ventures, NASA is working with U.S. companies to find the right way to encourage these nascent industries–whether through helping to advance key technologies, purchasing launch services for crews to low Earth orbit, lending expertise, or providing launch opportunities to small businesses conducting research.

The missions we pursue under this goal address national priorities and directly benefit both our Nation and the global community. For example:

- **We are tracking and characterizing the mechanisms of environmental change.**

  Our assets in space and on Earth are giving us unprecedented insight into the Earth system and how we can minimize the impacts of environmental change.

- **We are building the next generation air transport system.**

  Together with our partners in other agencies, we are bringing to life a future vision that will enable transformative change to the entire air transportation system.

- **We are strengthening the economy.**

  We are transferring knowledge and technologies, which strengthens the economy though innovation, increased revenue, and job creation.

- **We are cultivating a strong future workforce.**

  We are cultivating scientific literacy and a strong future workforce through STEM education.

As NASA makes progress in understanding Earth and improving the quality of life on it, we benefit through innovations in air travel and new products, services, and companies entering the marketplace. We gain greater understanding of how we can preserve and protect our natural resources while minimizing the impacts of natural disasters on our lives and our livelihoods. As part of our commitment to inspiring the Nation and the world, we will reach out to the public and share our missions and progress.

Objective 2.1: Enable a revolutionary transformation for safe and sustainable U.S. and global aviation by advancing aeronautics research.

The sub-scale experimental X-48C Hybrid Wing Body flies over Rogers Dry Lake in California. The X-48C is a modification of NASA's X-48B blended wing body aircraft modified to evaluate the low-speed stability and control of a low-noise version of a hybrid-wing-body design. The concepts and technologies being demonstrated through these test aircraft could find their way into all types of new aircraft over the next 20 years, enabling more sustainable, environmentally friendly aviation.

Lead office: Aeronautics Research Mission Directorate

Objective Overview:

Aviation is the transportation mode that connects nations, cities, businesses, and people to support a growing and vital global economy. Within the United States, aviation is essential to economic well-being. Aviation contributes more than $1.0 trillion annually to the U.S. economy and supports more than 10 million direct and indirect jobs, including more than one million manufacturing jobs. Aviation comprises more than five percent of the total U.S. gross domestic product. In the United States, more than $1.5 trillion in freight is transported by air every year and air travelers alone spend more than $635 billion a year. Globally, the aviation system is growing rapidly with the potential for more than five times as many passengers and 10 times the cargo in 2050 as today. Since our establishment, NASA has continually advanced America's aviation system to improve our quality of life and productivity on Earth.[1 2]

NASA contributes unique innovations to aviation through our research activities. These innovations serve as key enablers for the role of U.S. commercial aviation in sustaining American commerce and safe, environmentally sustainable mobility, and hence the Nation's economic well-being. NASA's role is to explore early stage concepts and ideas, develop new technologies and operational procedures through foundational research, and demonstrate the potential of promising new vehicles, operations, and safety technology in relevant environments. We are focused on the most appropriate cutting-edge research and technologies to overcome a wide range of aeronautics technical challenges for the Nation's and the world's current and future air transportation system.

Objective Strategy:

To continue our leadership in aviation innovation and enable a revolutionary transformation of the aviation system, NASA is focused on six major research areas, or thrusts, for the long-term future of aviation. These research thrusts utilize the full capability of NASA's in-house aeronautics expertise. Through high-risk, high-reward research and technology development, NASA seeks to enable: safe, efficient growth in global operations; innovation in commercial supersonic aircraft; ultra-efficient commercial vehicles; transition to low-carbon propulsion; real-time, system-wide safety assurance; and assured autonomy for aviation transformation.

Each thrust is designed to address an important area of research and technology development that will further U.S. leadership in the aviation industry and enhance global mobility. Our research is performed with an emphasis on multi-disciplinary collaboration focused on the critical, integrated challenges aligned to the six research thrusts–what we refer to as convergent research. Together, these research thrusts combine to enable safe, sustainable growth in the overall global aviation system, while pioneering transformative capabilities that will create game-changing opportunities.

We work with our partners in other Government agencies, aligned with the principles, goals, and objectives of the *National Aeronautics Research and Development Policy* and its related *National Aeronautics Research and Development Plan*, to achieve our missions. We also partner with industry and academia to support new and innovative concepts and technologies, and with international counterparts to leverage complementary investments. These partnerships enable innovation, research, and efficient technology transfer.

In pursuit of this objective, we encounter and manage several challenges, including:

- **Inherent Risk**

  We pursue challenging, cutting-edge technology advances and aeronautics research goals that are inherently high-risk. In accepting this risk, we gain valuable knowledge and advance the capabilities of NASA, even when results fall short of expectations. By increasing our knowledge base and developing potential new solutions, we are able to make better-informed decisions regarding committing future research resources and pursuing promising high-return investments.

- **Domestic Partnership Influences**

  Our domestic aeronautics partnerships enable us to leverage investments in support of mutual objectives and avoid duplication of effort. They ensure we are moving forward on the right challenges and improve the transition of research results to users. Through continual coordination with our partners, we mitigate the risk that challenges faced by partners in turn negatively influence our schedules and research output.

- **Growing System Demands**

  As demand for greater global mobility increases, so too does the pressure for the current aviation system to evolve to accommodate that demand, reduce environmental impacts, and improve safety. Because the rate of system change may be greater than that achievable through incremental change, NASA may need to reach for more transformational concepts, which inherently carry more technical and acceptance risk.

- **Strategic Global Partnerships**

  Many developing economies are rapidly developing infrastructure and embracing next generation technologies, and partners around the world increasingly have advanced technical capabilities which complement our own. By carefully fostering international partnerships in pre-competitive areas, NASA supports the efficient and safe growth in global aviation important to the United States and improves the potential for leveraging their investments to reduce duplication while bringing knowledge back into NASA's research programs to improve our own capabilities.

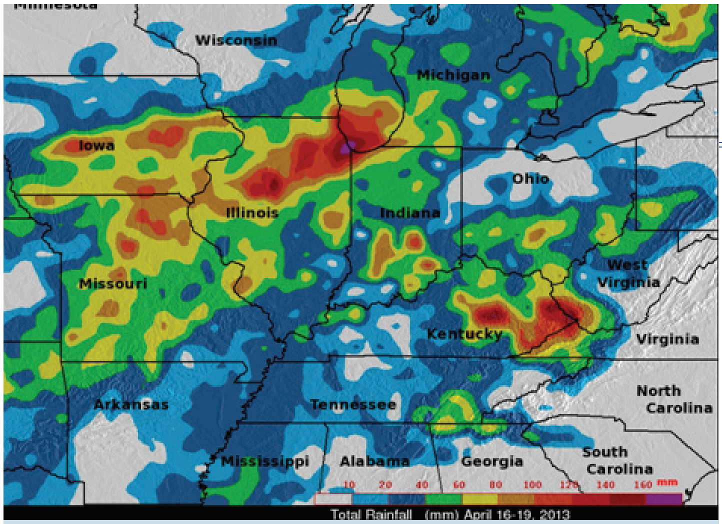
Contributing Programs:

Airspace Operations and Safety Program, Advanced Air Vehicles Program, Integrated Aviation Systems Program, and Transformative Aeronautics Concepts Program

[1] "The Economic Impact of Civil Aviation on the U.S. Economy," August 2011, FAA, (http://www.faa.gov/air_traffic/publications/media/FAA_Economic_Impact_Rpt_2011.pdf)

[2] "IATA Vision 2050," Page 61, IATA, February 2011, Table 16, PDF. (http://www.iata.org/pressroom/facts_figures/documents/vision-2050.pdf)

Objective 2.2: Advance knowledge of Earth as a system to meet the challenges of environmental change, and to improve life on our planet.



In April 2013, significant flooding occurred in the Midwest and the surrounding region because of extreme amounts of rainfall. NASA's Tropical Rainfall Measuring Mission (TRMM) satellite provides core data sets for such events. TRMM is a research satellite designed to help understand the water cycle in the current climate system. By covering the tropical and semi-tropical regions of Earth, TRMM provides much needed data on rainfall and the heat release associated with rainfall. TRMM data helps begin the process of understanding the interactions between water vapor, clouds, and precipitation that is central to regulating the climate system.

Lead office: Science Mission Directorate

Objective Overview:

Earth's changing environment impacts every aspect of life on our planet and climate change has profound implications on society. Studying Earth as a single complex system is essential to understanding the causes and consequences of climate change and other global environmental concerns. NASA addresses the issues and opportunities of climate change and environmental sensitivity by answering the following questions through our Earth Science programs: How is the global Earth system changing? What causes these changes in the Earth system? How will Earth's systems change in the future? How can Earth system science provide societal benefits?

NASA's Earth science programs shape an interdisciplinary view of Earth, exploring the interaction among the atmosphere, oceans, ice sheets, land surface interior, and life itself, which enables scientists to measure global and climate changes and to inform decisions by Government, organizations, and people in the United States and around the world. We make the data collected and results generated by our missions accessible to other agencies and organizations to improve the products and services they provide, including air quality indices, disaster prediction and response, agricultural yield projections, and aviation safety.

Objective Strategy:

The Earth Science program portfolio comprises the following areas: flight mission development, research, applications development, and technology development. These areas are responsible for conducting and sponsoring research, collecting and disseminating new observations, developing new technologies and predictive capabilities, and demonstrating innovative and practical uses of the program's data and results for societal benefit. In addition, we develop partnerships with other national and international organizations to enhance economic security and environmental stewardship to benefit society.

Scientific priorities for future Earth Science missions are guided by the recommendations of the decadal surveys published by the National Academies, and also are responsive to national priorities. The most recent Earth science decadal survey, *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond*, was released in 2007. In 2010, NASA released the report *Responding to the Challenge of Climate and Environmental Change: NASA's Plan for a Climate-Centric Architecture for Earth Observations and Applications from Space*. Coupled together, the reports recommended a balanced suite of missions to enable the study of Earth's global climate and the environmental impacts of climate change.

Our leadership and program managers actively monitor and manage risks and external factors that pose challenges to our Earth science missions. Below, we describe our approach to managing some of the key challenges:

- **Mission Cost Estimation and Management**

  To better control mission cost estimation and management, we transformed how we manage programs and projects, acquisition strategies, and procurements, particularly for our most complex science missions. In particular, we have strengthened program and project management, established more rigorous cost estimation practices, gathered numerous external and internal cost estimates, and incorporated multiple, formal decision points as gates to the next stage of development. Following these steps in the last three years, six missions have launched either under or within their cost and schedule baselines, demonstrating progress in improving NASA's mission cost estimation and management tools. NASA is committed to controlling mission cost for the long-term. We will continue to be rigorous in maintaining these practices and taking additional steps to continue to improve schedule and cost performance to ensure that implementation is consistent throughout projects and programs.

- **Meeting Scientific and Societal Needs**

  NASA's scientific research advances our understanding of Earth while allowing the Nation's decision makers, first responders, and scientific communities to observe the climate and predict extreme weather. Sustained global Earth observations are needed to monitor and study Earth's climate system, land use, and land cover change. NASA is studying the best options and approaches for conducting continuous measurements to meet current societal needs, while continuing to enhance our Nation's global observing capabilities, data systems, and research base required to advance Earth system science and enable further improvements in the products and services that are provided by our partners to citizens around the world.

Contributing Programs:

Earth Science Research Program, Earth Systemic Missions Program, Earth System Science Pathfinder Program, Earth Science Multi-Mission Operations Program, and Applied Sciences Program

Objective 2.3: Optimize Agency technology investments, foster open innovation, and facilitate technology infusion, ensuring the greatest national benefit.

Partnering with NASA, Innovative Scientific Solutions Inc. (ISSI) developed pressure-sensitive paint technology for gathering data from high-speed, unstable surfaces such as rotorcraft blades. The innovation gives NASA new capabilities in aeronautics, and ISSI now sells the product worldwide. Pictured here is a wind tunnel test using a helicopter model equipped with ISSI's paint.

Lead office: Office of the Chief Technologist

Objective Overview:

NASA's missions require that we expand the boundaries of our technological capabilities to explore our solar system, increase our understanding of space, and improve life on Earth. Innovation and invention are the necessary elements that will enable this progress and shape our future. Efficient management of technology investments is more critical than ever. NASA, like other technology development organizations, both Government and commercial, must balance technology investments and promote successful innovation with limited resources.

To optimize the technology portfolio, we seek to align mission directorate technology investments, eliminate duplication, and lower costs while providing critical capabilities that support missions and longer-term national needs. We strive to develop tools and processes to manage the technology portfolio, find better ways to analyze our portfolio, identify mission needs, create roadmaps, set priorities, establish partnerships, and engage scientists, engineers, and the public to invent extraordinary technologies for our future.

Objective Strategy:

NASA's space technology investments will be guided by the Strategic Space Technology Investment Plan (SSTIP), an actionable plan that lays out the strategy for developing technologies essential to the pursuit of NASA's mission and national goals. The SSTIP prescribes a framework and focused approach to guide near-term investment while ensuring the portfolio has the breadth to provide needed capabilities for the next 20 years. This plan will be updated biennially, incorporating emerging technologies, new mission needs, priorities, and partnerships. It will enable NASA to effectively integrate key stakeholder investment strategies in a common-focused approach, to sustain NASA's technological edge and provide benefits to the Nation.

Using innovative approaches to problem solving such as prizes, challenges, and collaborations, we will harness innovators, creating diverse pools of solvers that address NASA problems, advance technology development in a flexible, "on demand" way, and lower mission design costs to leverage Government dollars for technological breakthroughs. NASA embraces participation from partners in industry, academia, and the larger aerospace community with mutual interests in development of breakthrough capabilities that support our aeronautics and aerospace goals, and national priorities. Strategic partnerships are designed to expand and strengthen our ability to execute its mission, and range from non-traditional partnerships to systematic engagements with local, regional, state, national, and international partners. These partnerships enable us to leverage funding, capabilities, and expertise within and outside NASA to address technology barriers and advance technology. NASA is committed to developing all types of partnerships, including high-impact, multi-disciplinary collaborations to help provide solutions to ambitious yet achievable national targets that advance science, technology, and innovation.

As NASA develops critical components that prove themselves in the lab and advance from prototype to usable system, we will find innovative and better ways to successfully infuse the new technology into our missions, encouraging use beyond the original mission-specific purpose and increase infusion of these technologies into the American economy.

NASA's technology development activities will produce a robust supply of promising technologies that are critical to our missions, have applications to many industries, and boost our economy through the creation of new jobs and markets. We will continue to promote the availability of NASA technologies for use by the U.S. public and private sectors, and accelerate the technology-to-market cycle, enabling realization of benefits more quickly. NASA's growing number of patents, licenses, and software usage agreements demonstrate the giant leap of progress embodied by the technological advances in hardware and software made each year. NASA will make steps to improve the transfer of technology, paving the way for new advances and emerging technologies to serve as the foundation for new products and services, continuing the growth of our economy.

We have a large and diverse technology portfolio consisting of more than 1,000 active projects. Tracking and analyzing this work provides the basis for aligning investments across NASA to reduce costs, increase capability, and provide technologies for the future. Partnering with other Government agencies, U.S. industry, academia, and international entities can enable further progress. Successfully capturing the relevant features of these projects requires an internal cultural change, where mission directorates and offices provide such data openly and work collaboratively to remove internal barriers, creating technology portfolio optimization across NASA. The result of this optimization can be reduced duplication; better synergy among projects, and better use of NASA-developed technology. Further, NASA's chief scientist and chief technologist advise and advocate for NASA on matters concerning NASA-wide science and technology policy and programs. They encourage and foster integration and cooperation across NASA.

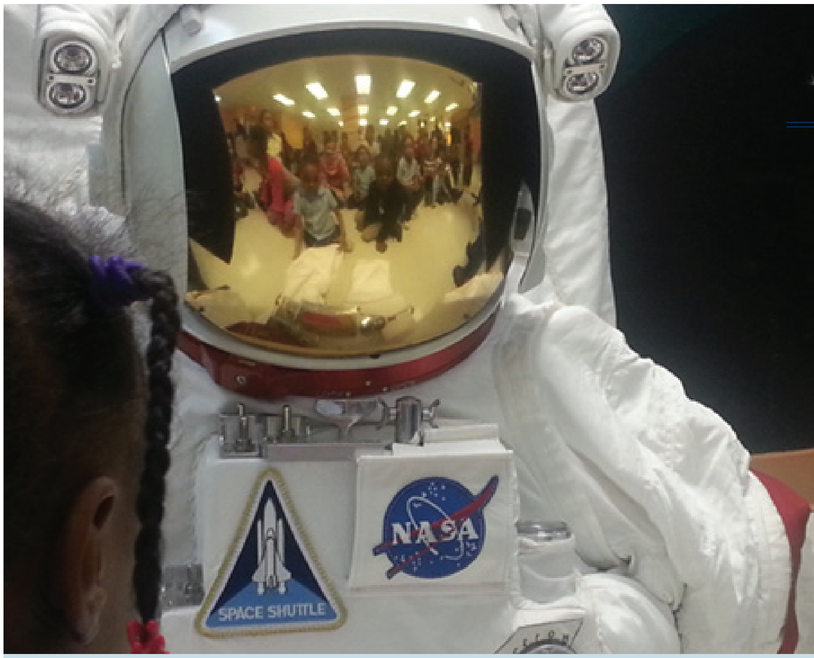
Once technology has been developed, we transfer the technology to external users, fostering the development of new products, services, and markets that benefit our Nation. There are a number of challenges that impact our ability to achieve this technology transfer objective. NASA must patent strategically—i.e., only when doing so accelerates transfer of the technology to U.S. industry—and must have an appropriate number of patent attorneys, intellectual property experts and technology transfer experts to do so.

Finally, once technology is transferred, measuring the actual benefit to the Nation is difficult. We have established a few mechanisms to determine the positive impact of our technology transfer; however, the data is incomplete because external users are not required to report to NASA on the positive impact of technology innovations. Despite the risks to success, we are seeking to improve technology-development tracking, analysis, portfolio decision-making, and technology transfer, enabling NASA and the Nation to receive the greatest possible return on investment.

Contributing Programs:

Partnership Development and Strategic Integration

Objective 2.4: Advance the Nation's STEM education and workforce pipeline by working collaboratively with other agencies to engage students, teachers, and faculty in NASA's missions and unique assets.



NASA Education addresses national needs in STEM education such as providing unique, STEM-based learning opportunities to populations underrepresented and underserved in STEM. This NASA Education event with the Homeless Children's Playtime Project provided students at the DC General Emergency Family Shelter in Washington, DC with an opportunity to interact with an astronaut, view shuttle models and spacesuits, and learn about NASA's exciting missions.

Lead office: Office of Education

Objective Overview:

NASA's education programs work in collaboration with other Federal agencies to improve the quality of science, technology, engineering, and math (STEM) education in the United States, which supports both NASA's strategic plan and the Administration's STEM policy. To maintain a globally competitive Nation, our education programs develop and deliver activities that support the growth of NASA's and the Nation's STEM workforce, help develop STEM educators, engage and establish partnerships with institutions, and inspire and educate the public. NASA's contribution to STEM education brings immediate benefits to schools and other institutions, while helping to ensure that future generations of Americans will have the technical skills needed to continue NASA's missions. We will continue to engage and involve the public and other stakeholders in our activities, and work to build an open, transparent and participatory organization.

Through effective use of our assets in our STEM education programs, we are able to share NASA's inspirational activities with a broader audience. NASA STEM engagement activities provide learners of all ages the chance to engage in science, technology, engineering, and math, and to understand the value of STEM in their lives. Our learners include: primary, secondary, and higher education students; parents and guardians; formal and informal educators and higher education faculty; and the general public at large. The quality of life we enjoy today is the direct result of the inspiration and achievements of scientists, engineers, mathematicians, and technologists of yesterday. We pursue our objective to ensure future generations of STEM professionals are inspired, experienced, and capable of achieving even greater accomplishments in STEM-related fields. We pursue this objective through a portfolio of NASA-unique STEM experiential learning opportunities (e.g. grants, internships, fellowships, scholarships, workshops) and challenges. These creative applications of NASA-related knowledge encourage innovation, critical thinking, and problem-solving skills, which are characteristics required of our Nation's future STEM workforce.

Objective Strategy:

Our strategy for progressing toward this objective has two components, strategic partnerships and delivery via strategic lines of business. NASA engages in strategic partnerships with intergovernmental, academic, industrial, entrepreneurial, and international communities to ensure NASA's education mission and vision reach a wider and diversified audience. We are determined to do more with less. We facilitate partnerships that support the evolution of our portfolio of projects and strategic objective. We achieve this by defining specific benefits and outcomes for each partnership, systematically managing the lifecycle of partnerships, and leveraging each organization's resources appropriately.

One of our key strategies for achieving effective partnerships in support of our strategic objective is our continued participation in the Administration's Committee on STEM Education (CoSTEM). Through that committee, we work closely with all relevant stakeholders as plans are created and unfold in support of the STEM coordination effort across Federal agencies. This venue allows us to share our best practices and ensure the committee is aware of the inspiring and unique content, assets, and programming that NASA Education can share via partnerships with other institutions and agencies.

NASA's Office of Education leverages its new organizational structure, which includes four key lines of business, and the NASA Office of Education Infrastructure Division (OEID) to enhance our effectiveness and efficiency as we progress in our strategic objective. The four key lines of business are centered on national STEM areas of need—educator professional development, institutional engagement, STEM engagement for all learners, and NASA internship, fellowship, and scholarship opportunities—and they will enable us to ensure our education investments are unique and non-duplicative. The OEID supports NASA's approach to STEM education by implementing the principles of transparency, participation, and collaboration throughout all of its education activities. Through strategic planning, collaborating with the Office of the Chief Information Officer, and supporting the areas of performance assessment, dissemination and Web services, information technology, and communications support using a systematic approach, the OEID lays the foundation for NASA education excellence. The OEID provides support that improves education policy and decision-making, provides better education services, and ensures more effective administration.

Contributing Programs:

Aerospace Research and Career Development Program and STEM Education and Accountability Program

Strategic Goal 3

Serve the American public and accomplish our Mission by effectively managing our people, technical capabilities, and infrastructure.

NASA is proud to be the U.S. agency charged with exploring the unknown in space and driving new advances in aerospace science and technology on behalf of the American public. Reaching for the stars requires dedicated, knowledgeable people and cutting-edge facilities and capabilities to provide the tools and support necessary to carry out our ambitious tasks. We strive to accomplish our mission with the utmost care—recognizing that we are stewards of taxpayer dollars, critical human capital, and one-of-a-kind facilities. We maintain a large and diverse set of technical capabilities and assets to support NASA missions and the work of other Federal agencies and the private sector to test, validate, and optimize innovations.

We understand that a skilled, valued, and diverse workforce is central to creating and maintaining the capabilities to explore the solar system and beyond and for understanding our home planet. NASA will continue to maintain and ensure the availability and safety of critical capabilities and facilities necessary for advancing our space-, air-, and Earth-based activities. We will provide the vision and leadership to advance critical spaceflight capabilities and ensure American launch vehicles can support our exploration activities. Our activities support a skilled, innovative, and diverse workforce

(Above) Contamination control engineers conduct a review of the James Webb Space Telescope's Mid-Infrared Instrument, as part of the standard receiving inspection. They are looking for the tiniest traces of dust or contamination which would have to be remedied because cleanliness is critical for such a sensitive instrument.

and the safety of that workforce. Further, we strive for management excellence and sustainable practices that assure the wisest uses of our resources.

Our goal is to support all of NASA's space-, air-, and Earth-based research and innovation activities producing the best return on the Nation's investment. We will diligently work to ensure that NASA has the resources necessary to further exploration and aeronautics, understand Earth, transfer knowledge, and share NASA's story. We will continue to engage and involve the public and other stakeholders in our activities and work to build an open, transparent, and participatory organization.

As part of this pursuit, we must ensure that our facilities, resources, and plans are sustainable. This means exploring new ways of doing business. We will advance our efficiency and sustainability through wise investments and innovative approaches to resource management, including divesting ourselves of infrastructure no longer needed, so that we can achieve our core mission within our budget.

The missions we pursue under this goal helps to address national challenges and allow us to take advantage of unique opportunities to bring benefits to the Nation. For example:

- **We are investing wisely**

  We are prioritizing investments and finding innovative ways to operate and sustain our capabilities.

- **We are sustaining and exercising critical national capabilities**

  We are ensuring that cutting-edge capabilities and facilities are maintained and used for advancing innovation and discovery.

- **We are increasing our accountability to the American public**

  We are providing unprecedented transparency into our operations and our performance so that we can share our successes and setbacks with the American public.

We will ensure that innovators, both inside and outside NASA, have access to the critical capabilities entrusted to us to help further NASA's exploration activities and to contribute to U.S. economic strength. Our work toward this goal will help maintain a robust scientific and technical workforce. Finally, we will ensure the long-term security and sustainability of NASA's resources and facilities.

Objective 3.1: Attract and advance a highly skilled, competent, and diverse workforce, cultivate an innovative work environment, and provide the facilities, tools, and services needed to conduct NASA's missions.

Helen Johnson, a Thermal Design Technician, works on one of the microsatellites before it and two others were shipped to Vandenberg Air Force Base for launch. NASA's highly skilled workforce shares the responsibility to perform challenging technical work with the highest levels of precision.

Lead office: Mission Support Directorate

Objective Overview:

NASA's workforce and institutional capabilities enable us to successfully conduct our missions. We are dedicated to innovation, bold ideas, and excellence, which enable us to provide the day-to-day operations required to support and achieve our missions.

People are our most important resource; without them, no mission can be achieved. We have a workforce that is skilled, competent, and dedicated. Our workforce is committed and passionate, and brings many dimensions of diversity, including ideas and approaches, to make our teams successful. To conduct our missions over the next 20 to 30 years, we must focus on attaining an increasingly diverse workforce with the right balance of skills and talents and provide an inclusive work environment in which employees with varying perspectives, education levels, skills, life experiences, and backgrounds work together and are fully engaged in NASA's Mission.

Objective Strategy:

Placing direct attention on diversity in the workforce is a strategy to further infuse the spirit of innovation into our workforce culture by ensuring that our workforce is equipped to acquire new skills demanded by missions, enhancing productivity, and motivating employees to find new solutions. One of the chief external challenges we face is attracting and building a cadre of science, technology, engineering, and math (STEM) leaders. We face competition from the private sector and academia in hiring top candidates for STEM professions. In addressing this challenge, we work to reach a broad pool of top-notch candidates in STEM disciplines and continue to cultivate an inclusive culture of innovation, one that ensures the near- and long-term well-being of our employees and enables them to work on the cutting edge of their technical or functional disciplines. We continue targeted outreach and recruitment efforts. In addition, we continue to use a variety of methods to increase inclusion and innovation in our workplace through our emphasis on work/life balance and continuous education and awareness opportunities on diversity and inclusion principles.

Our workforce depends on the availability of unique facilities, tools, capabilities, and services to successfully conduct our missions. Planning, operating, and sustaining this infrastructure and our essential services requires a number of critical institutional capabilities including management of:

human capital, finance, information technology, infrastructure, acquisitions, security, real and personal property, occupational health and safety, equal employment opportunity and diversity, small business programs, external relations, internal and external communications, stakeholder engagement, and other essential corporate functions. Providing strategic and operational planning and management over a wide range of functions and services ensures that resources are available when needed, and they support initiatives to help us operate in a more efficient and sustainable manner.

Sustainable management of our infrastructure ensures that our assets support our workforce in meeting mission requirements and schedules. Our strategy is to ensure our assets and overall footprint becomes more sustainable, efficient, and effective. For NASA, this means having a net zero growth in gross square feet in five years and reducing our footprint over the next 20 years. Across NASA, various programs and offices will support this strategy with activities that span demolition, outlease, recapitalization, and construction to mitigate mission risk, maintenance, and real property management, as well as implementing environmental and energy policies. NASA understands that diminishing resources such as workforce skills, funding, environmental systems, and technical capabilities, among others will be critical to achieving and sustaining success. To tackle these challenges, offices across NASA coordinate to optimize strategies for meeting mission requirements, whether that requirement is for equipment, a certain expertise provided by our workforce, or diversity of thought and experience to help foster innovation.

Contributing Programs:

Center Management and Operations, Agency Management, Institutional Construction of Facilities, and Environmental Compliance and Restoration

Objective 3.2: Ensure the availability and continued advancement of strategic, technical, and programmatic capabilities to sustain NASA's Mission

On February 11, 2013, NASA successfully launched the Landsat Data Continuity Mission (LDCM)/Landsat 8. This mission is currently providing repetitive acquisition of high resolution multi-spectral data of the Earth surface on a global basis. On May 30, 2013, NASA transferred control of LDCM/Landsat 8 to the United States Geological Survey.

Lead office: Human Exploration Operations Mission Directorate

Objective Overview:

We identify and prioritize our essential assets and implement strategic investment decisions to sustain, enhance, replace, modify, or dispose of them based on NASA and National needs. We ensure that our key capabilities and critical assets will be available in the future to support the missions that require them. For example, we provide launch services to NASA and civil sector missions, as well as an uninterrupted, reliable space communications network to allow data transmissions to Earth from space. Both of these capabilities are critical to making space missions feasible, safe, and efficient.

NASA's technical capabilities and assets support NASA missions as well as the work of others beyond NASA. Other Federal agencies and the private sector use our specialized facilities to test and evaluate items to mitigate risk and optimize engineering designs. We manage our technical capabilities and assets carefully through strategic investments and sustainable practices that ensure their readiness for NASA and other customers.

Objective Strategy:

Several NASA programs are dedicated to supporting this objective. For example, the Space Communications and Navigation Program manages the infrastructure, sustainment, and replenishment efforts necessary to maintain service capacity and capability consistent with our commitments and mission model. The Launch Services Program provides access to space for robotic missions through U.S. commercial industry.

Each of these programs and offices develop strategies to effectively deliver their contribution to the strategic objective, overcome challenges, and manage risks. These strategies complement our overarching efforts to keep critical capabilities available to support our missions and those of other customers.

Some of NASA's key strategies for this objective are:

- **Provide access to space**

  We have the responsibility, as the launch agent for the Nation's civil space sector, to certify and procure domestic commercial space transportation services for the launch of robotic science, communication, weather, and other civil sector missions. NASA relies on the Launch Services Program to provide robust, reliable, commercial, and cost-effective launch services. NASA achieves assured access to space through a competitive "mixed fleet" approach utilizing the breadth of U.S. industry's capabilities.

- **Ensure the continued full utilization of the NASA Space Network**

  The Space Network consists of a constellation of geosynchronous satellites, ground tracking stations for Earth missions, and the Deep Space Network and its associated ground elements. The network provides mission-critical communications services for the ISS, scientific satellites such as the Hubble Space Telescope, and numerous Earth-observing missions.

- **Manage capabilities effectively**

  NASA's Strategic Capabilities Assets Program (SCAP) is a corporately managed program that selects capabilities or types of assets ("asset classes") for prioritized investment and centralized management to support our needs. Some of these assets include thermal vacuum chambers, motion and space simulators, and wind tunnels. We are working to improve the overall management system of SCAP, including policies, guidance, hardware, software, databases, processes, procedures, and personnel. Our goal is to more efficiently and effectively manage SCAP's capabilities and assets and better collaborate with other Government agencies, academia, and industry. This effort will ensure that our current and future missions have access to needed capabilities and assets that are owned and operated by NASA and outside organizations. The improved management system is being designed and built to enable scaling and use—in part or in whole—for the management of newly identified portfolios of capabilities and assets. In support of NASA's mission, SCAP provides the vision and leadership for these nationally important assets and sustained support for their workforce, capability improvements, and new test technology development. By staying up to date on technological advances, industry demand, and issues that concern the public, we are able to make decisions on facility and capability investments and divestments.

Contributing Programs:

Space Communications and Navigation Program, 21st Century Space Launch Complex Program, Launch Services Program, Rocket Propulsion Testing Program, Exploration Construction of Facilities, Space Operations Construction of Facilities, and Strategic Capabilities Assets Program

Objective 3.3: Provide secure, effective, and affordable information technologies and services that enable NASA's Mission.

Onlookers watch the engaging "7 Minutes of Terror" video to learn about the entry, descent and landing system for NASA's Mars rover Curiosity from the engineers who designed the new landing system. Through the use of innovative information technologies and social media, NASA globally shared a vivid description of the Curiosity rover's final challenging moments before touchdown on August 6, 2012 (EDT). This video is available for you to view here.

Lead office: Office of the Chief Information Officer

Objective Overview:

Information technology (IT) is critical to NASA's infrastructure and mission success. To support NASA's missions effectively, we must inspire excellence in IT planning and service delivery across organizational and functional boundaries. We must find ways to use information technology that supports a more collaborative, geographically diverse and mobile working culture, keeps our IT skills and capabilities up-to-date to serve NASA's missions, and protects those missions from ever-evolving IT security threats.

Our approach to IT planning and service delivery emphasizes responsive innovation, transparency, and accountability. In planning, we take an agency-wide view that considers NASA's diverse mission needs to guide IT policy, investment decisions, and management practices. At the same time, our approach calls for rigorous assessments of investment trade-offs and sequencing to balance the cost, quality, and timing of our IT capabilities to optimize value while limiting mission risk. We will collaborate with NASA leaders to prioritize and sequence our information management investments to deliver the right blend of capabilities over time to effectively and affordably support NASA.

Objective Strategy:

Our invigorated customer focus will drive new capabilities to empower NASA's mobile workforce, simplify collaboration, and engage open public participation in our missions. At the same time, we will continue to improve service consistency and affordability by increasing the use of versatile "as-a-service" delivery models, such as cloud computing and inter- and intra-agency services. To maximize the potential of these approaches, we will evaluate opportunities to further consolidate our enterprise IT capabilities and pool our limited resources to optimize NASA's purchasing power. We will engage our workforce and sustain and develop the appropriate skills and training to chart and manage the ongoing IT transformation across NASA.

Maturing our cybersecurity practices and technologies will be at the forefront of our effort to ensure the secure and resilient delivery of mission support services. We recognize that cybersecurity is a critical driving force to protect the intellectual property, power of invention, and natural ingenuity that is at the heart of NASA. Risk-based information security will be embedded in our capabilities using an approach that balances reduced mission risk with affordability, in alignment with Federal cybersecurity priorities.

We have made significant progress in improving the effectiveness and efficiency of our IT systems.