National Aeronautics and Space Administration

Space Technology Mission Directorate

Flight Opportunities

2016 Annual Report

www.nasa.gov

[Front cover image]
A high-altitude balloon drop of the Deployable Rigid Adjustable Guided Final Landing Approach Pinions (DRAG FLAPs).
Photo credit: Near Space Corporation

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Executive Summary

Thank you for reading the FY2016 Flight Opportunities program annual report. This year has been one of growth—new flight providers, enhanced flight capabilities, additional payloads matured through flight tests, and exciting expansion of the breadth of Flight Opportunities activities.

NASA's Flight Opportunities program strives to advance the operational readiness of crosscutting space technologies while also stimulating the development and utilization of the U.S. commercial spaceflight industry, particularly for the suborbital and small launch vehicle markets. Since its initiation in 2010, the program has provided frequent access to relevant space-like environments for over 100 payloads across a variety of flight platforms.

Flight Opportunities employs a variety of strategies to achieve its objectives, including:

- **Leveraging emerging commercial services**
  As an early adopter of commercial flight testing opportunities, the program is now an experienced and reliable customer in a growing market.
- **Providing assistance to other customers**
  From academia to the private sector, the Flight Opportunities program provides assistance in the form of grants, customer agreements, and public-private partnerships.
- **Accelerating maturation of commercial capabilities**
  The program offers flight providers access to unique NASA expertise and facilities, helping them advance their flight test offerings faster.

Maturing Technologies for Spaceflight

The transition of technologies flown with Flight Opportunities into NASA missions and other programs demonstrates clear program impact. For example, technologies demonstrated through Flight Opportunities have been selected for inclusion in the Mars 2020 mission, longer term demonstrations on the International Space Station (ISS), and NASA CubeSat missions —to name just a few.

T20-02 balloon launch at Benson Airport, Tuscon, AZ. Photo credit: Southwest Research Institute

Establishing a Solicitation Cadence

Evidence of the maturity of the Flight Opportunities program was apparent throughout the course of the year. The robustness of the payload pipeline increased as the schedule of calls and solicitations became predictable, allowing researchers to plan for and respond to opportunities. In addition, outreach efforts to engage with prospective investigators and educate them about how to get involved with the program have been highly successful, resulting in an increase in both the number and quality of proposal submissions.

Adding MISSE to the Flight Opportunities Program

In FY2016, NASA's Materials International Space Station Experiment (MISSE) Flight Facility was brought into the Flight Opportunities program. MISSE offers researchers extended exposure to on-orbit environments for their research payloads through a facility on the ISS.

Looking Ahead

We hope you enjoy reading about the accomplishments and activities of FY2016. As we move forward into FY2017, Flight Opportunities is increasing its coordination with other NASA programs to further the impact of its efforts, and we are excited to continue our work with our ever-expanding community.

Robert Yang
Program Executive
NASA Headquarters

Ronald Young
Program Manager
NASA's Armstrong Flight Research Center

UP Aerospace SpaceLoft 9 launched from Spaceport America. Photo credit: NASA


ZIN Technologies

Flight Opportunities Impacts

- Technology Demonstrations (p. 6)
- Small Launch Vehicle Technology Development (p. 18)
- Materials International Space Station Experiment (MISSE) (p. 21)

[Photo opposite page] Hybrid ultimate lifting kit (HULK) device demonstration on a parabolic flight. Photo credit: NASA

Technology Demonstrations

Flight Opportunities provided flight testing of new crosscutting space technologies in FY2016 by enabling frequent access to relevant space-like environments to researchers from academia, industry, non-profit research organizations, NASA, and other government agencies. Flight Opportunities has made measurable impact on critical space technology maturation for future spaceflight, with achievements including:

- Helping researchers increase technology readiness levels (TRLs)
- Providing microgravity experiences that drive critical design and engineering changes to improve the robustness of next-generation technologies
- Accelerating research and technology maturation with frequent flight tests on multiple types of platforms
- Offering the capability to obtain critical experimental data not otherwise measurable in ground-based experiments

Microgravity Multi-phase Flow Experiment for Suborbital Testing (MFEST) at Ellington Field on NASA's C-9 aircraft. Photo credit: NASA

Test Flights Approximate Planetary Conditions for New Mars Landing Technology

T0137

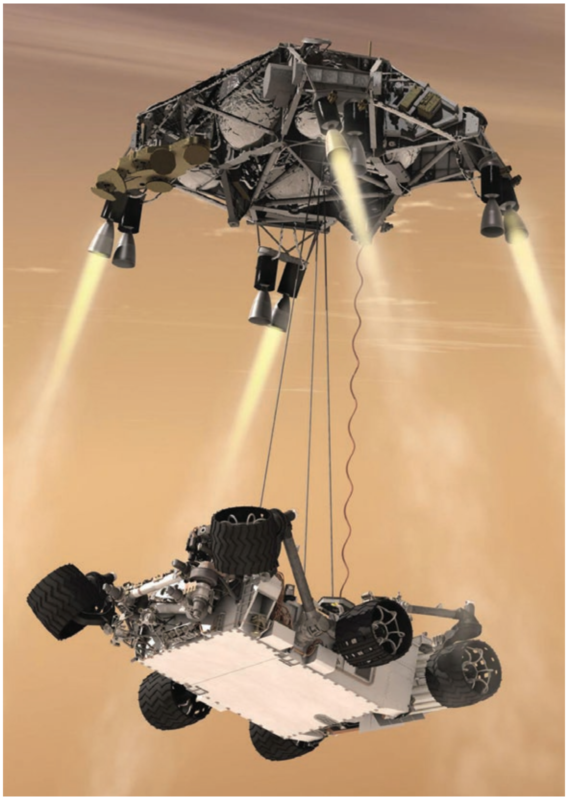
New technology developed by NASA's Jet Propulsion Laboratory (JPL) and tested in part through Flight Opportunities is helping address previous limitations of Mars landers and will be flown on NASA's upcoming Mars 2020 mission to the Red Planet.

Typically, spacecraft landing on the moon or Mars have lacked the ability to detect and react to hazards, requiring mission planners to select only benign landing sites with mostly flat terrain. As a result, landers and rovers were limited to areas with relatively simple geological features and were unable to access many sites of high scientific interest with more complex and hazardous surface morphology. JPL's Lander Vision System (LVS) provides new "eyes" for NASA's next Mars rover mission and will enable safe landing at these scientifically compelling Mars sites.

Flight Opportunities coordinated a flight test with Masten Space Systems in 2014, launching LVS 1,066 feet into the air aboard Masten's rocket-powered Xombie test platform. LVS helped guide the rocket to a precise landing at a predesignated target, flying as part of a larger system of experimental landing technologies called the Autonomous Descent and Ascent Powered Flight Testbed (ADAPT).

LVS, a camera-based navigation system, photographs the terrain beneath a descending spacecraft and matches it with onboard maps, allowing the craft to detect its location relative to landing hazards, such as boulders and outcroppings. The system can then direct the craft toward a safe landing at its primary target site or divert touchdown toward better terrain if there are hazards in the approaching target area. These capabilities enable a broad range of potential landing sites for Mars missions.

With LVS slated for inclusion on Mars 2020, JPL researchers are now focused on building the flight system.



An artist's concept of the 2012 Mars Curiosity Landing. Mars 2020 will use a nearly identical landing system but with added precision from the Lander Vision System. Photo credit: NASA/JPL-Caltech

"By providing funding for flight tests, Flight Opportunities motivated us to build guidance, navigation, and control payloads for testing on Xombie. In the end, we showed a closed-loop pinpoint landing demo that eliminated any technical concerns with flying the Lander Vision System on Mars 2020."

—Andrew Johnson, principal investigator for LVS, NASA's Jet Propulsion Laboratory

Leveraging Test Flights to Mature New Techniques for In-Space Manufacturing

QUICK FACT

In-space manufacturing can help reduce launch costs for missions by enabling manufacturing of structures in space that would otherwise be too large to launch. Testing through Flight Opportunities is bringing these research goals closer to operational reality.

Building spacecraft and objects on Earth and launching them to space is costly and logistically complicated. But new processes to address these challenges look promising, as both academic and commercial researchers refine various methods of in-space manufacturing. Two groups of researchers—one from Northwestern University and another from Made In Space—have recently matured their respective processes through Flight Opportunities.

Freeze Casting in Microgravity (T0149)

Northwestern University researchers have developed a novel materials-processing technique involving the production of titanium (metal) foams and titanium-oxide (ceramic) foams using a freeze-casting method.

To better understand the properties of the foams manufactured using this technique, the university scientists leveraged parabolic flight testing through Flight Opportunities in 2014 and 2015 to mature their process. The flights enabled researchers to refine and validate hypotheses and assumptions about the freeze-casting process. Specifically, the 2014 flight tests revealed that gravity had a substantial impact on the freeze-casting results.

- Structures created in near space exhibited far more desirable properties than those created on Earth (one of the leading assumptions guiding the research).
- Subsequent testing in 2015 allowed the researchers to isolate other factors, such as convective fluid motion and sedimentation of particles in the titanium and titanium-oxide foams.

Combining these observations helped researchers better understand the materials' properties in order to improve their process for longer duration testing. Additional parabolic testing was conducted in February 2016.

Northwestern University's work with Flight Opportunities has increased the process's TRL to 6, contributing to its selection for a 6-month NASA CubeSat mission. It has also been selected under the NASA MaterialsLab Open Science Campaign for an International Space Station (ISS) demonstration expected to launch in 2019 or 2020.

Northwestern University student researcher Felicia Teller and Bryce Tappan of Los Alamos National Laboratory work with the freeze-casting process during a test flight.
Photo credit: NASA

3-D Printing in Space (T0004)

Researchers from Made In Space are focusing on the possibility of using additive manufacturing, or 3-D printing, to enable in-space manufacturing in the future. Initial parabolic flights of the company's customized 3-D printer designed for use in microgravity were coordinated through Flight Opportunities and conducted in the summer of 2011. By making in-flight observations and modifying both the hardware and the software in between flights, the team was able to rapidly optimize the technology for operation in microgravity. Based in part on the validation from the initial parabolic flights, Made In Space received a Phase III award from the Small Business Innovation Research (SBIR) program to develop a 3-D printer for deployment aboard the ISS. In 2013, the prototype performed successfully during the microgravity test flights and was deployed to the ISS in 2014. And in FY2016, a new parabolic test flight helped to further mature the technology for future missions.

ISS astronaut Barry "Butch" Wilmore holds a science sample container that took 2 hours to make. The container was the first object to be printed with two parts: a lid and a container. NASA wants to make science equipment in space rather than launch it. Photo credit: NASA

The Additive Manufacturing Facility (AMF) at Made In Space headquarters. Photo credit: Made in Space.

Test Flights Help Validate First Technology to Grow Plants on the Moon

T0140

Researchers at NASA's Ames Research Center have developed a process for growing plants on the moon—a method tested successfully in the lab and matured in part through the Flight Opportunities program.

Prior to flight tests of Ames's Lunar Plant Habitat, no plant-based biological spaceflight experiment had ever hydrated seeds in lunar gravity. Scientists had only performed hydration of seeds at *1 g* because they anticipated that the presence of bubbles or of uneven dispersion would result in inferior water distribution in lunar gravity. Ames's Lunar Plant Habitat employs a direct-pressure pump that works even with air bubbles present, passing water to osmosis paper to distribute it evenly to plant seeds. The technology, which also received a NASA Center Innovation Fund (CIF) award, promises to be the first method of growing plants on the moon and is a direct response to the Decadal Survey calling for investigations into the role of plants in long-term lunar life support.

With the habitat tested successfully in ground-based experiments, researchers turned to Flight Opportunities to test whether the technology would work as anticipated in lunar gravity—and, if not, to determine if the system's sensors would detect the failure. In an experiment sponsored by Lockheed Martin, the payload was flown on a December 2015 parabolic flight campaign, evaluating flight performance of its microfluidics systems under lunar gravity as well as camera image capture and system performance. The test flights increased the habitat's TRL to 6, and it is now flight qualified for microgravity, low-gravity, and *1-g* ground and spaceflight applications.

Lunar Plant Habitat testing during a parabolic flight campaign. Photo credit: NASA

New High-Altitude COA Lays Groundwork for Winged Commercial sRLV Flights at the Edge of Space

T0106

Near Space Corporation (NSC) is taking advantage of a new Federal Aviation Administration (FAA) High-Altitude Certificate of Authorization (COA) that enables a drone flying from the edge of space to operate as a surrogate testbed for technologies being developed to support commercial suborbital reusable launch vehicle (sRLV) operations.

The unmanned flight test in September 2016, coordinated through the Flight Opportunities program, was designed to help evaluate the application of FAA NextGen surveillance technologies to the tracking of winged sRLVs as they descend from the stratosphere down through Class A airspace. It was also the first unmanned aerial system (UAS) flight to be conducted under NSC's High-Altitude COA granted by the FAA. Supported by the FAA's Office of Commercial Space Transportation, NSC integrated an advanced surveillance payload into an unpowered version of its High-Altitude Shuttle System (HASS), a winged lifting body glider with performance similar to commercial sRLVs developed for suborbital flight. The successful flight demonstrated basic proof of concept for use of the HASS as a "flying testbed" for advanced surveillance technologies, as well as other safety-enabling technologies in the future, for winged commercial sRLVs.

Near Space Corporation's HASS vehicle. Photo credit: Near Space Corporation

Crew-Autonomous Biological Imaging in Parabolic and Suborbital Applications

T0053

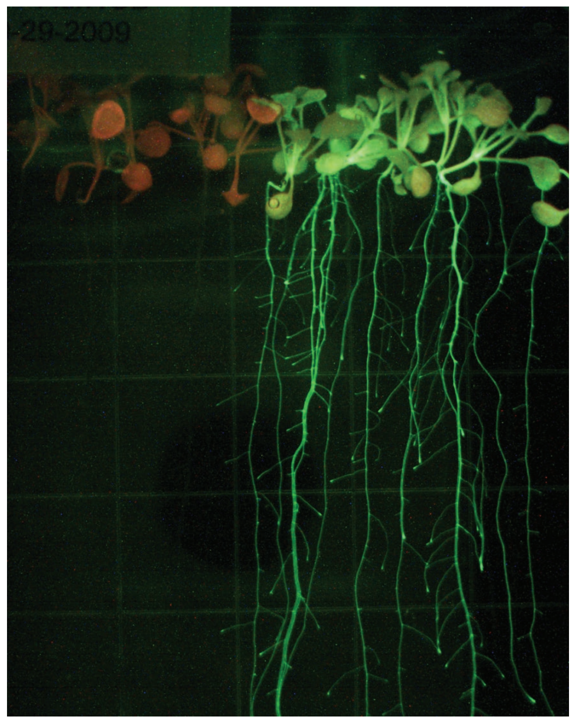
University of Florida researchers have made considerable inroads in maturing a technology designed to image and monitor the biological response of a plant, plant tissue, or any small biological system to various types of gravity and spaceflight environments. Over a series of five parabolic flight campaigns with Flight Opportunities, the research team has increased the system's TRL from 2 to 9.

The University of Florida's technology was born out of the need to see and record important biological phenomena at the molecular level during transitions in gravity in spaceflight. The technology has considerable implications on human health, life support, and habitation systems for missions to the moon, Mars, and potentially other planets. The insights gained during the team's flight testing may benefit future GeneSat and other satellite missions, as well as planetary lander applications.

The course of parabolic flight campaigns arranged by Flight Opportunities has helped the research team make critical improvements to the biological imaging system—specifically matching imaging modalities with key biological phenomena and engineering the system to work in a middeck locker environment for parabolic flight. The team's first flight campaign revealed further work needed to mature the system's imager (camera). Subsequent flights provided insight into necessary changes to the system's environmental controls and thermal imaging capabilities to be compatible with the duration of parabolic flight. These iterative improvements have positioned the technology for upcoming suborbital flight testing in 2017.

"The ability to be near the aircraft, in the aircraft, see the connections, and to see how those affect your experiment and your technology during all phases of flight, all of those things are extraordinarily instructive. There's just no substitute for it. The amount of information, wonder, and experience you gain by being there and doing it is almost immeasurable. It's a very special thing that Flight Opportunities does."

—Dr. Robert Ferl, principal investigator, distinguished professor, and director of the Interdisciplinary Center for Biotechnology Research, University of Florida



The plant arabidopsis imaged using technology developed by the University of Florida. Photo credit: University of Florida

The University of Florida research team conducts experiments during flight testing. Photo credit: University of Florida

The research team ready for flight testing their biological imaging technology. Photo credit: University of Florida

"This flight would not be possible if it weren't for the Flight Opportunities and Game Changing Technology programs at NASA. Demonstrating that you can do science more cheaply and more effectively than before is very challenging. These programs help overcome the tremendous barrier of proving that the new approach can work; otherwise they would be too risky to incorporate into complete science programs. Being able to flight-prove new instrument technologies is absolutely critical to advancing science in the long run."

—Craig DeForest, principal investigator for SSIPP, Southwest Research Institute

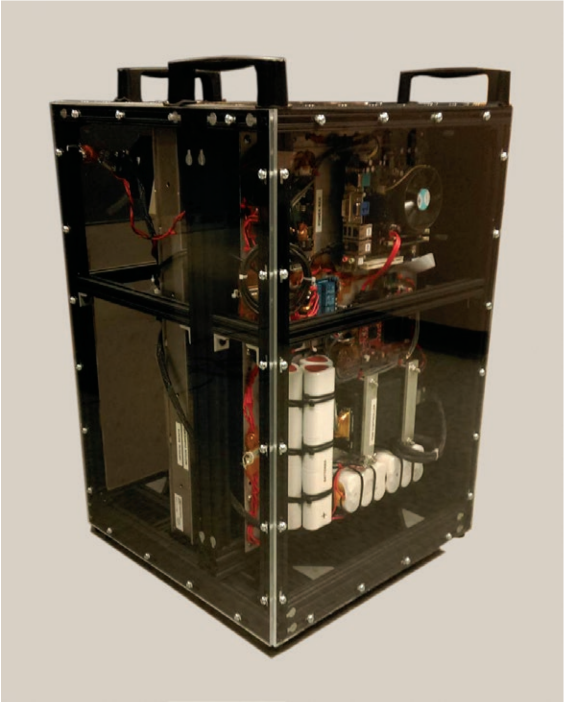
Southwest Research Institute Matures Its Suborbital Science Observatory Through Balloon Flights

T0085

Southwest Research Institute (SwRI) has made a significant achievement with its Solar Instrument Pointing Platform (SSIPP), offering a flexible, optical table–based system that locks onto a solar limb and delivers an arcsecond-grade pointed beam to an instrument. The technology effectively creates a novel suborbital science observatory. This unique setup enables researchers to test instruments in a space-like environment with minimal complexity and effort.

To make the desired measurements, researchers must have arcsecond-class stability—and preferably sub-arcsecond stability—of the pointing technology in order to resolve features that are smaller than 100 miles across. This requires an active pointing system to stabilize the inherently dynamic test flight. Existing balloon gondolas capable of this level of stability come at a very expensive price, whereas SSIPP will make certain types of investigations available to a much wider range of researchers.

SwRI flew the instrument in 2016 on a high-altitude balloon provided by World View Enterprises, offering an avenue to help lower barriers to near-space science. The flight confirmed that major elements of the SSIPP system work as expected. A follow-up flight is planned for 2017.



The SwRI Solar Instrument Pointing Platform technology. Photo credit: SwRI

QUICK FACT

SSIPP dramatically reduces the complexity and cost involved with testing instruments in a space-like environment.

[Photo opposite page] The research team prepares the SwRI Solar Instrument Pointing Platform for flight. Photo credit: SwRI

"Working with NSC was a really great experience. We were very curious to see how other service providers handle their interaction with the payload provider, and I think both of our companies were able to learn a lot from each other. And working with NASA was incredibly valuable. Our technical contact, Paul De León, had so much experience to bring to the table from his experience with similar tests, so we had more resources and were set up for a really successful flight campaign given everyone involved."

—Joey Oberholtzer, principal investigator for the DRAG FLAPs technology, Masten Space Systems

A high-altitude balloon launch of the Deployable Rigid Adjustable Guided Final Landing Approach Pinions (DRAG FLAPs). Photo credit: Near Space Corporation

Masten Space Systems Leverages Test Flights from a Fellow Flight Provider for Its Advanced Entry, Descent, and Landing Technology

T0064

Deployable Rigid Adjustable Guided Final Landing Approach Pinions (DRAG FLAPs), developed by Masten Space Systems, are poised to enable capabilities for precision entry, descent, and landing (EDL) trajectories. The advancement enables higher altitudes, engine-off descent, and safe and precise landings. With drop tests completed in August 2016 by Near Space Corporation (NSC), Masten is currently reviewing data from the successful flights to assess next steps in the technology's development.

The DRAG FLAPs technology was conceived because of Masten's interest in adding new control features to future vehicles it will use as a flight provider for the Flight Opportunities program. These new features have the potential to benefit not only NASA but also all researchers testing payloads on Masten vehicles through NASA's program in the future.

The DRAG FLAPs technology is specifically designed to augment the aerodynamic characteristics of a vehicle during the descent phase. Employing such devices provides aerodynamic stabilization and control while improving landing. It also expands the descent timeframe researchers have to accomplish critical events and increases the weight of the payload that can be flown to the same altitude.

While Masten and Flight Opportunities partners stand to benefit from the technology, the advantages of the technology extend to planetary science missions as well. As plans for these missions become more ambitious and complex, they demand larger payloads with an emphasis on precision landing—exactly what the DRAG FLAPs technology is designed to achieve.

Masten's 2016 flight tests with NSC were a success—the drop tests on NSC's platform reached the required altitude of 35 km, and the payload release and descent were successful, with the majority of collected data recoverable. The flight will likely increase the DRAG FLAPs' TRL, and results from the recovered data analysis will inform the next steps in the development process. The ultimate goal is to make the technology available for future Masten flights and potentially other NASA missions.

Small Launch Vehicle Technology Development

Flight Opportunities is helping to support the commercial development of small launch vehicles through public-private partnerships. These collaborations provide commercial partners with access to NASA's unique expertise and facilities to address challenges in the development of small satellite launch vehicle technologies.

Announcement of Collaborative Opportunity Partnerships

Through its Announcement of Collaborative Opportunity (ACO) solicitation, "Utilizing Public-Private Partnerships to Advance Emerging Space Technology System Capabilities," NASA selected five partner companies in FY2016 to receive awards related to Flight Opportunities objectives. The partnerships cover efforts in two key areas:

- Nanosatellite and Suborbital Reusable Launch Systems Development
- Small, Affordable, High-Performance Liquid Rocket Engine Development.

Through these partnerships, NASA provides technical expertise and test facilities to aid industry partners in maturing key space technologies. Highlights on the progress of each of these efforts can be found on pages 19-20.

Tipping Point Technologies

In FY2016, NASA's Space Technology Mission Directorate issued the "Utilizing Public-Private Partnerships to Advance Tipping Point Technologies" solicitation as part of its efforts to identify industry-developed space technologies that can foster the development of commercial space capabilities and benefit future NASA missions. A technology is considered at a "tipping point" if an investment in a demonstration of its capabilities will result in a significant advancement of the technology's maturation. One of the topics for this release, "Small Launch Vehicle Technology Development," aims to accelerate the development of commercial capabilities to enable frequent launches of small spacecraft to low Earth orbit (LEO) at a cost per kilogram of payload much lower than currently available. Selection announcements are expected in early 2017.

SBIR/STTR 2017 Phase I Partnerships

Flight Opportunities partners with other NASA programs, including the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs, to achieve NASA's Space Technology Mission Directorate goals through greater alignment between programs focused on technology maturation. SBIR/STTR-funded firms are eligible for flight testing of key aspects of their research and technology development through the Flight Opportunities program. Flight Opportunities is involved with the following subtopics for the 2017 SBIR/STTR Program Solicitation:

- Z9.01 — Small Launch Vehicle Technologies and Demonstrations (SBIR Focus Area 21)
- T1.01 — Affordable Nano/Micro Launch Propulsion Stages (STTR Focus Area 1)

ACO Partnerships

Through ACO partnerships, NASA provides technical expertise and test facilities to aid industry partners in maturing key space technologies. The work covered by these partnerships is made possible through Non-Reimbursable Space Act Agreements between selected companies and NASA centers. Five ACO partnerships advanced forward in FY2016.

Generation Orbit: Air-Launched Liquid Rockets

Generation Orbit has partnered with NASA's Armstrong Flight Research Center to conduct a flight test campaign for its GOLauncher 1 Inert Test Article—a mass properties and aerodynamics simulator for the GOLauncher 1 rocket vehicle. The flight test aims to encompass aircraft integration testing, captive-carry flight testing, and release testing. Preliminary stress analysis was completed, and results are being incorporated into flight test plans.

GOLauncher 1 is an air-launched single-stage rocket under development to serve microgravity, astrophysics, and hypersonics researchers. Photo credit: Generation Orbit

Virgin Orbit: Advancing Emerging Space Capabilities

Virgin Orbit's new dedicated SmallSat launch vehicle, LauncherOne, is designed to deliver approximately 300 to 500 kg of payload to LEO. An expendable two-stage liquid propulsion rocket, LauncherOne is designed to be released at a high altitude from a modified Boeing 747 carrier aircraft. In partnership with NASA's Ames Research Center, work has commenced on efforts to support critical areas for the launcher's development, including assessment of its aerothermodynamics; simulation of the aircraft and separation flight profiles; and launch vehicle enabling technologies, such as precision orbital insertion systems and payload accommodation architectures.

Virgin Orbit's LauncherOne vehicle in flight. Photo credit: Virgin Galactic

UP Aerospace's Spyder: A Dedicated CubeSat Launcher

UP Aerospace is leveraging advanced manufacturing capabilities through NASA's Marshall Space Flight Center to accelerate the timeline and reduce the costs of developing its new dedicated SmallSat launcher. These efforts will aid in the development of upper-stage motors and support ground testing of the new launcher.

Dynetics: Hydrogen Peroxide/Kerosene Engine Development

Dynetics is leveraging its partnership with Marshall to develop 1,000 lbf peroxide/kerosene upper-stage engines. Dynetics is designing, fabricating, and providing an engine that will be delivered to Marshall, which will design, build, and operate a test stand capable of hot-fire testing the engine using 90 percent hydrogen peroxide and RP-1 as propellant.

Vector Space Systems: Enhancing a Nanosat Launch Vehicle Booster Main Engine

Vector Space Systems is working with Marshall to develop a propulsion system for the company's two-stage nanosat launch vehicle, using an additive manufacturing approach. Significant milestones were achieved in FY2016, including fabrication of the Phase 1 Injector and assembly of water flow test hardware.

The Marshall additive-manufactured injector was successfully hot-fire tested by Vector Space Systems using liquid oxygen/propylene propellant. Photo credit: Vector Space Systems

Materials International Space Station Experiment

NASA's Materials International Space Station Experiment (MISSE) Flight Facility offers researchers extended exposure to on-orbit environments for their research payloads through a new external facility on the ISS. In 2016, the MISSE-Flight Facility platform was funded by the ISS program, and the NASA research payloads fell under the Flight Opportunities umbrella. The latest call for proposals—MISSE-9—closed in August 2016.

Selected payloads are exposed to the relevant environment of space—providing a better understanding of material durability, which could be applied to future spacecraft designs. Since 2001, more than 4,000 materials specimens have been tested through MISSE—including composite materials, lubricants, paints, fabrics, container seals, and solar cells.

Flown 220 miles above Earth and fixed to the exterior of the ISS for periods of up to 4 years, these innovative experiments have endured extreme levels of solar and charged-particle radiation, atomic oxygen, hard vacuum, temperature extremes, micrometeoroids, orbital debris, and contamination—giving researchers unprecedented insight into developing durable materials for spacecraft, flight hardware, and even astronaut clothing. Because such research is difficult to simulate effectively in ground-based laboratories, the MISSE series provides NASA and its partners with crucial insight into the challenges of protecting astronaut health and establishing a permanent human presence in space.

Six experiments selected for flight on MISSE-9 are expected to launch in 2017:

- Polymers and Composites Experiment [PI: Kim K. de Groh, NASA's Glenn Research Center]
- Polymeric Materials Experiment [PI: Sheila A. Thibeault, NASA's Langley Research Center]
- Space Environment Exposure: Tantalum Fiber Laminates and Charge Dissipation Film [PI: D. Laurence Thomsen, Langley]
- Improved Extravehicular Activity (EVA) Suit Micrometeoroid and Orbital Debris (MMOD) Protection Using Shear-Thickening Fluid (STF) Armor and Self-Healing Polymers [PI: Norman J. Wagner, Experimental Program to Stimulate Competitive Research (EPSCoR), University of Delaware, and NASA's Johnson Space Center]
- Space Environmental Effects on Additively Manufactured Materials [PI: Miria M. Finckenor, NASA's Marshall Space Flight Center]
- Ultraviolet Radiation Sensor [PI: Miria M. Finckenor, Marshall]

Materials International Space Station Experiment Flight Facility. Image credit: NASA

Calls for MISSE experiments are expected to be issued every 6 months. In addition, Flight Opportunities partnered with NASA's SBIR and STTR programs to make opportunities for experiment development available through an SBIR subtopic, ISS Utilization and Microgravity Research.

Spaceport America, New Mexico.
Photo credit: NASA

Flight Provider Overviews

Flight Opportunities flight providers offer researchers from academia, industry, non-profit research organizations, NASA, and other government agencies a wide variety of capabilities for flight testing their payloads. Suborbital reusable launch vehicles (sRLVs), parabolic aircraft, and high-altitude balloons all provide access to relevant space-like environments, helping to advance technologies for future missions to the International Space Station, the moon, Mars, and beyond.

The following pages include an overview of entities providing flights through NASA's indefinite delivery/indefinite quantity (IDIQ) contracts as well as those providing services for technologies selected through the Research, Development, Demonstration, and Infusion (REDDI) process. These flight providers either have or are making progress toward a commercial license for flight.

UP Aerospace launch pad.
Photo credit: NASA

UP Aerospace

HQ: Denver, CO | **Launch:** Spaceport America, NM
www.upaerospace.com

UP Aerospace developed its SpaceLoft XL suborbital reusable launch vehicle (sRLV) to help reduce the cost and scheduled time of launching experiments and commercial payloads for microgravity research. UP Aerospace is also working to develop Spyder, a dedicated CubeSat launcher, adding to the company's flight platform portfolio to benefit research teams seeking to mature promising technologies.

Status

- Involved with the Flight Opportunities program since 2012
- Highlighted its new payload ejection capability with the ejection of the Maraia capsule in 2016
- Collaborative efforts continue to aid the development of Spyder—a small rocket for launching six-unit CubeSat payloads—in partnership with NASA's Marshall Space Flight Center (see full story on page 20)

Available Flight Platforms

- **SpaceLoft XL**
  An sRLV for launching experiments and commercial payloads for microgravity research
  - In service since 2006
  - Reaches an altitude of 115 km on average for commercial flights (160 km maximum altitude)
  - Achieves typical flight durations of 13 minutes, including 4 minutes of microgravity
  - Optimized for flying payloads of up to 36 kg
  - Offers the option of payload ejection

Flights in FY2016

SL-10: November 6, 2015

Several payloads on board SpaceLoft XL benefitted from the SL-10 flight test, including:

- New Mexico State University's Robotics-Based Method of In-Orbit Identification of Spacecraft Inertia Properties (T0084)
- NASA's Johnson Space Center's Entry, Descent, and Landing Technology Development for the Maraia Earth-Return Capsule (T0115)
- Purdue University's Zero-Gravity Green Propellant Management Technology (T0128)
- NASA's Ames Research Center's Affordable Vehicle Avionics (T0142)

"UP Aerospace is pleased to work with the Flight Opportunities program, providing access to a relevant environment for developing and flight testing new technologies. This access is helping researchers save development costs and provides a pathway toward orbital flights."

—Tracey Larson, vice president of public relations, UP Aerospace

Blue Origin

HQ: Kent, WA | **Launch:** West Texas
www.blueorigin.com

One of the newest Flight Opportunities commercial flight providers, Blue Origin has been flying its New Shepard vertical takeoff, vertical landing (VTVL) space vehicle since April 2015 in a test flight capacity. The company's engineering, manufacturing, and business teams work in a 420,000 ft^2 facility on 26 acres in Kent, Washington, and the company conducts engine and suborbital flight testing at its privately owned and operated launch site 2 hours east of El Paso, Texas. A new orbital launch site and 750,000 ft^2 manufacturing facility are in development in Cape Canaveral, Florida.

"A lasting legacy of what we do in space is the benefit to the research community and how it can impact technology development and education… We can work with a researcher on a payload and then fly it again and answer new questions and really start to do science the way science is meant to be done."

—Erika Wagner, business development manager, Blue Origin

Status

- Joined the Flight Opportunities roster of commercial flight providers in 2016

Available Flight Platforms

- **New Shepard**
  A fully reusable VTVL space vehicle
  - Reaches an apogee of over 100 km
  - Provides payload lockers in two sizes, supporting experiments up to 22 kg
  - Offers custom solutions for larger payloads
  - Enables fast turnaround times from launch to recovery and potentially reflight

Upcoming Flights

Blue Origin is gearing up for its first flight through the Flight Opportunities program in 2017.

Blue Origin's New Shepard VTVL space vehicle lifting off the launch pad.
Photo credit: Blue Origin

EXOS Aerospace Systems & Technologies

HQ: Caddo Mills, TX | **Launch:** Spaceport America, NM
www.exosaero.com

EXOS Aerospace Systems & Technologies has developed and tested more than 100 rocket engines and dozens of flying vehicles. Under a university grant funded by Flight Opportunities, University of Central Florida professor Julie Bissett will conduct SPACE2.0 research in microgravity onboard EXOS SARGE.

The EXOS SARGE provides a zero-gravity environment for scientific payloads. The vehicle can be flown multiple times, as soon as the next day, with minimal and low-cost refurbishment time between flights. A no-spin rocket with a gimbaled engine, SARGE lands within 50 to 200 m of the launch site, and payloads may be recovered within 15 to 30 minutes of launch. EXOS aims to use this capability to lower costs and decrease wait times through reliability, recoverability, and reusability.

Status

- Plans underway for the company's first commercial payload flight in 2017

Available Flight Platforms

- **Suborbital Active Rocket with Guidance (SARGE)**
  A rocket 0.5 m in diameter by 11 m in height
  - Capable of lifting payloads up to 50 kg to an altitude of 100 km
  - Offers 2 to 4 minutes of microgravity
  - Provides proven liquid oxygen/ethanol engine technology that allows a soft launch (~7 *g*)
  - Enables researchers to communicate with experiments throughout flight and retrieve their payloads within minutes of landing

Upcoming Flights

The EXOS team is working toward a Federal Aviation Administration (FAA) Office of Commercial Space Transportation license, expected to be issued in 2017 and is preparing to fly the University of Central Florida's Suborbital Particle Aggregation and Collision Experiment-2 (T0156) in 2017 under a university grant.

An EXOS rocket at liftoff. Photo credit: EXOS Aerospace Systems & Technologies


Virgin

Virgin Galactic

HQ: Mojave, CA | **Launch:** Spaceport America, NM
www.virgingalactic.com

While Virgin Galactic continues its ventures into space tourism, the company also serves as a flight provider for testing scientific payloads in relevant microgravity environments. In 2016, the FAA issued a launch license to Virgin Galactic to continue flight testing of its suborbital space plane, Virgin Spaceship Unity (VSS Unity). Under this license, the company is able to begin commercial payload flights for hire.

Status

- Plans underway for the company's first research flight for Flight Opportunities in 2017

Available Flight Platforms

- **VSS Unity**
  An air-launched suborbital space plane
  - Typical flights are mated to a carrier aircraft and take off from a conventional runway, releasing from the carrier aircraft once appropriate altitude is reached
  - Capable of providing 3 to 4 minutes of high-quality microgravity for payloads per flight
  - Suborbital spaceflight payload capacity of 450+ kg

Upcoming Flights

Virgin Galactic is scheduled to fly its first "full manifest" indefinite delivery/indefinite quantity (IDIQ)–contracted VSS Unity research flight in 2017.

[Photo opposite page] Virgin Spaceship Unity glides over the Mojave Desert. Photo credit: Virgin Galactic

Masten's Xodiac main engine start and liftoff. Photo credit: Masten Space Systems

Masten Space Systems

HQ and Launch: Mojave, CA
www.masten.aero

As one of Flight Opportunities' first commercial flight providers, Masten is currently focused on flight testing entry, descent, and landing (EDL) technologies that help ensure precise and safe landings on future missions to the moon and potentially other planetary bodies. Masten is also a partner in NASA's Lunar Cargo Transportation and Landing by Soft Touchdown (Lunar CATALYST) initiative, which assists in the development of commercial capabilities to deliver payloads to the moon.

For Flight Opportunities, Masten's Xombie vehicle has been used for seven flight campaigns, notably:

- Successful testing in 2015 of Astrobotic Technology's lunar landing system, garnering the company its third Milestone Prize in the Google Lunar XPrize competition
- Critical testing in 2015 to prepare Carnegie Mellon University's flyover mapping and modeling technology for a potential future lunar mission
- Successful demonstration of NASA's Jet Propulsion Laboratory's (JPL's) Fuel Optimal and Accurate Landing System (FOALS) for real-time terrain-relative navigation along with fuel-optimal large-divert guidance

Now entering retirement, the Xombie vehicle is being replaced by Masten's Xaero and Xodiac platforms.

Status

- Has been performing flight campaigns for Flight Opportunities since 2011
- Currently focused on lowering barriers to space access through flight testing technologies that focus on precision EDL

Available Flight Platforms

Although Xombie has been retired, the company has two other vertical takeoff, vertical landing (VTVL) platforms currently in service:

- **Xodiac**
  - Primarily used for terrestrial demonstrations
  - Ideal for lunar and Martian landing technologies
- **Xaero**
  - Focused on cradle landing technology

Notable Flights

In 2014, NASA tested new "eyes" for its next Mars rover mission on a rocket built by Masten Space Systems, thanks in part to the Flight Opportunities program. JPL's Terrain Relative Navigation (TRN) technology was a component of the FOALS payload flown on Masten's Xombie. The TRN system, which can direct a craft toward a safe landing at its primary target site or divert touchdown toward better terrain, was recently selected to be part of the Mars 2020 rover's Lander Vision System, representing a significant accomplishment for this innovation (see full story on page 7).

Near Space Corporation

HQ: Tillamook, OR | **Facilities:** Tillamook, OR; Madras, OR; and South Point, HI

www.nsc.aero

Near Space Corporation (NSC) specializes in stratospheric balloon flights for payload testing. The company operates from facilities at the former Naval Air Station in Tillamook, Oregon. NSC also offers access to the Tillamook Unmanned Aerial System (UAS) Test Range for UAS testing up to 130,000 feet. The company has also established balloon launch locations in central Oregon and Hawaii.

"Near Space Corporation is pleased to have been a part of the Flight Opportunities program over the past several years and looks forward to continuing to provide access to flight platforms and services that help advance the development of payloads."

—Tim Lachenmeier, president, Near Space Corporation

Status

- Has been performing flight campaigns for Flight Opportunities since 2013
- Specializes in increasing payload TRLs through extended-duration balloon flights in stratospheric conditions

Available Flight Platforms

- **High-Altitude Shuttle System (HASS)**
  Ideal for payload providers needing enhanced flight path control or the ability to make iterative payload changes between frequent high-altitude flight tests
  - Includes a special high-altitude unmanned shuttle for payload recovery, enabling rapid payload turnaround for reflight
  - Accommodates payloads of up to 10 kg or 5 kg per payload slot
  - Reaches altitudes of up to 28 km for flights of up to 6 hours
- **Nano Balloon System (NBS)**
  Aimed at payloads with minimal integration requirements
  - Accommodates payloads up to 40 kg or 3 kg per payload slot (10 slots available per flight)
  - Reaches altitudes of up to 30 km for flights of up to 6 hours
- **Small Balloon System (SBS)**
  Aimed at small satellites and other compact payloads
  - Includes a parachute payload recovery system
  - Accommodates payloads of up to 40 kg or 20 kg per payload slot
  - Reaches altitudes of up to 30 km for flights of up to 6 hours

Non-standard services are available for these balloon systems as well, including longer durations, higher altitudes (up tp 40 km), higher payload masses, and custom payload configurations.

Flights in FY2016

SBS10: August 3, 2016

NSC used its SBS to fly Masten Space Systems' Deployable Rigid Adjustable Guided Final Landing Approach Pinions (DRAG FLAPs) technology. (See full story on page 17.)

HASS-03: September 26, 2016

NSC used its HASS to fly the Low-Cost Suborbital Reusable Launch Vehicle (sRLV) Surrogate to Test Automatic Dependent Surveillance Broadcast (ADS-B) technology. (See full story on page 11.)

NSC demonstrates enabling communications technologies for future low-cost, small Earth-return vehicles.
Photo credit: NSC

World View Enterprises

HQ and Launch: Tucson, AZ

www.worldview.space

World View Enterprises aims to provide affordable options for small payloads while also offering proven heavy-lift capabilities in near-space environments. The company has spent the last several years refining its technology, with plans to also eventually carry researchers and private citizens to the edge of space inside a pressurized spacecraft suspended by a high-altitude balloon.

"We're thrilled to be part of NASA's Flight Opportunities program—helping drive innovation and increasing access to space, while at the same time fueling industry growth in the commercial space sector."

—Jane Poynter, chief executive officer, World View Enterprises

Status

- Has been performing flight campaigns for Flight Opportunities since 2015
- Currently specializes in innovative, high-altitude balloon flight platforms for payload testing

Available Flight Platforms

- **Stratollite**
  Provides navigable high-altitude balloon flights for uncrewed payload missions over specific areas of interest for long durations (days, weeks, etc.)
- **Tycho**
  A two-vehicle family of flight platforms (Tycho-20 for payloads up to 20 kg and Tycho-285 for payloads up to 285 kg) providing stratospheric access
  - Both vehicles share the same avionics, balloon envelope technology, and recovery systems
  - Reach altitudes of up to 43 to 46 km
  - Carry payloads for flight durations of 5 minutes to 12 hours

Flights in FY2016

T20-02: September 3, 2016

Southwest Research Institute's Solar Instrument Pointing Platform (SSIPP) technology was flown on World View's Tycho-20 balloon, with a second flight planned for 2017 (see full story on page 15).

Tycho-20 launch in Tucson, AZ. Photo credit: World View Enterprises

NASA's Reduced Gravity Office (vehicle decommissioned)

HQ: Johnson Space Center, Houston, TX
www.nasa.gov/centers/johnson

Status

NASA's Reduced Gravity Office (RGO) continued service of Johnson's C-9 aircraft in FY2016 beyond the vehicle's planned decommissioning. While commercial parabolic providers worked to advance their capabilities, the C-9 provided parabolic flight testing for Flight Opportunities. NASA has now divested from microgravity flight operations, and the C-9 was decommissioned from NASA's inventory in March 2016.

NASA Johnson's C-9 aircraft. Photo credit: NASA

Flights in FY2016

RGO22: November 18, 2015
RGO22R: January 12-14, 2016
RGO23: December 15-18, 2015

Several payloads flew on the RGO22, RGO22R, and RGO23 flight campaigns:

- Made In Space's Printing the Space Future (T0004) (see full story on page 9)
- NASA's Johnson Space Center's Microgravity Multi-Phase Flow Experiment for Suborbital Testing (MFEST) (T0020)
- University of Puerto Rico's Nanocatalyst-Based Direct Ammonia Alkaline Fuel Cell (T0059)
- Texas A&M University's Demonstration of Variable Radiator (T0081)
- Fermi Institute's Sintering of Composite Materials Under Reduced-Gravity Conditions (T0044)
- NASA's Glenn Research Center's Evaporative Heat Transfer Mechanisms Within a Heat Melt Compactor Experiment (T0045)
- University of Louisville's Parabolic Flight Evaluation of a Hermetic Surgery System for Reduced Gravity (T0049)
- NASA's Ames Research Center's Lunar Plant Growth Experiment (T0140) (see full story on page 10)

Parabolic flight evaluation of a hermetic surgery system for reduced gravity. Photo credit: NASA

Zero Gravity Corporation

HQ: Arlington, VA | **Facility:** Orlando Sanford International Airport, FL
www.gozerog.com

Zero Gravity Corporation (ZERO-G) enables researchers to achieve a reduced-gravity environment for research payloads. G-FORCE ONE, its specially modified 727 aircraft, does this by flying through a series of parabolic maneuvers, resulting in short periods of microgravity. The length of these reduced-gravity periods depends on the *g* level required for the specific test. Typical missions on G-FORCE ONE consist of 30 parabolic maneuvers and offer the reduced gravity needed to achieve a near-space environment. ZERO-G is slated to fly additional payloads in 2017 and beyond.

Status

- Began flying payloads for Flight Opportunities in 2008
- Currently specializing in reduced-gravity operations

Available Flight Platforms

- **G-FORCE ONE**
  A Boeing 727-200F three-engine aircraft modified for reduced-gravity environments
  - Contains up to 36 seats for researchers and crew
  - Includes an open research area approximately 67 feet long
  - Accommodates small experiments in the rear of the cabin
  - Provides flight durations of approximately 2 hours

Flights in FY2016

P0001: February 25–27, 2016
P0002: June 14, 2016

Several payloads flew on the P0001 and P0002 flight campaigns:

- Purdue University's Low-Gravity Flow Boiling on Modern Textured Surfaces (T0145)
- Purdue University's Advancing Diaphragm Modeling Technology for Propellant Management (T0150)
- Rensselaer Polytechnic Institute's Droplet Pinning in Microgravity (T0146)
- Carthage College's Modal Propellant Gauging in Microgravity (T0147)
- Northwestern University's Microgravity Fabrication of Freeze-Cast Titanium Foams (T0149) (see full story on page 8)
- Orbital Technologies Corporation's Zero-Gravity Mass Measurement Device (ZGMMD) Parabolic Flight Test (T0158)

ZERO-G's G-FORCE ONE aircraft.
Photo credit: ZERO-G

Sintering of composite materials under reduced-gravity conditions during a parabolic flight. Photo credit: NASA

Program Highlights

The Flight Opportunities program has continued to expand its breadth and reach, demonstrating considerable impact. FY2016 saw an expansion of program activities, a carefully planned and executed solicitation and call schedule, and positive progress toward strategic goals for both the program and NASA.

- **Program Progress (p. 40)**
- **Expanding Program Breadth, Increasing Impact (p. 41)**
  - Flight Campaigns
  - Technology Impact Areas
  - Research Organizations
  - Geographic Impact
- **Technology Solicitation Schedule (p. 45)**
- **Budget (p. 46)**
- **Multi-Year Data (p. 46)**

Program Progress

FY2016 saw the completion of ***9 flight campaigns*** *as well as enhancements in technology and payload demonstrations and new collaborations that increase the program's capabilities. Specific achievements included:*

- **21 new technologies** added to the Flight Opportunities portfolio, bringing the total of new technologies to 164 since the program's inception
- Commercial provider progress spurring **further commercial suborbital flight interest** and **lowering costs** through competition, including:
  - The addition of Blue Origin to the commercial flight provider list, which now includes 6 suborbital flight providers with indefinite delivery/indefinite quantity (IDIQ) contracts
  - The initial payload flights for Research, Development, Demonstration, and Infusion (REDDI) grantees on Zero Gravity Corporation flights
- Completion of **2 SpaceTech-REDDI-F1 solicitations** and **2 NASA internal calls**, with both opportunities running smoothly on regular intervals
- More **Flight Opportunities outreach and program awareness** through conference presence, community networking, and publications
- **Broader collaboration across NASA organizations**, including:
  - Space Technology Mission Directorate (STMD)
  - Human Exploration and Operations Mission Directorate (HEOMD)
  - Space Launch Systems Program (SLSP)
  - Advanced Exploration Systems (AES)
  - Science Mission Directorate (SMD)
  - Other government agencies such as the Defense Advanced Research Projects Agency (DARPA) and the Federal Aviation Administration (FAA)

Examples include:

- A collaboration with DARPA for a future flight demonstration on Blue Origin's New Shepard vehicle
- A collaboration with SMD to provide suborbital flight demonstrations for 5 payloads that are part of NASA's Undergraduate Student Instrument Project (USIP)

STRATEGY

An integral part of NASA's strategy in FY2016, the Flight Opportunities program continued to address NASA's strategic goals and objectives.

The program accomplishments fall under NASA Strategic Goal #1, which is to expand the frontiers of knowledge, capability, and opportunity in space.

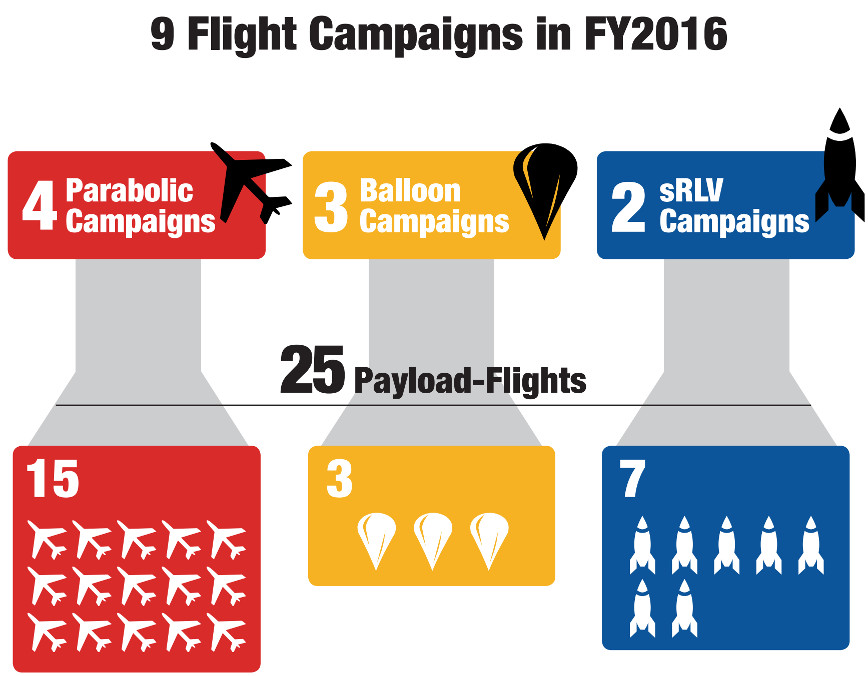
Flight Opportunities is helping to advanced this goal by addressing one of NASA's strategic objectives: To transform NASA missions and advance the nation's capabilities by maturing crosscutting and innovative space technologies.

Expanding Program Breadth, Increasing Impact

From the variety of flight campaigns conducted and the range of technologies matured to the diverse array of research organizations and the geographic reach of program involvement, the breadth of the Flight Opportunities program demonstrated its significant impact.

A Variety of Flight Campaigns

All aspects of the Flight Opportunities program were in play in FY2016. The 9 flight campaigns and 25 payload-flights covered the full spectrum of suborbital flight demonstration capabilities.



"We're excited about what's in store for the program as we see the number of commercial flight campaigns continue to increase. We're also seeing an increase in the number of high-quality technologies in the Flight Opportunities payload pool. There's a lot to look forward to in the Flight Opportunities future."

— Ron Young, program manager, NASA's Armstrong Flight Research Center

A Wide Range of Technology Impact Areas

Flights in FY2016 helped to mature technologies in a wide range of research areas.

Technologies Flight Tested in FY2016

Flight Date	Flight Provider & Platform	Flight Type
Nov 6, 2015	**UP Aerospace** SpaceLoft XL	
Nov 18, 2015 Jan 12–14, 2016	**NASA's Reduced Gravity Office** C-9B	
Dec 15–18, 2015	**NASA's Reduced Gravity Office** C-9B	
Feb 25–27, 2016	**Zero Gravity Corporation** G-Force One	
Mar 7, 2016	**NASA's Wallops Flight Facility** Terrier-Orion	
Jun 14, 2016	**Zero Gravity Corporation** G-Force One	
Aug 3, 2016	**Near Space Corporation** Small Balloon System (SBS)	
Sep 3, 2016	**World View Enterprises** Tycho-20	
Sep 26, 2016	**Near Space Corporation** High-Altitude Shuttle System (HASS)	

Payload	Organization	Principal Investigator
T0084 - Suborbital Test of a Robotics-Based Method for In-Orbit Identification of Spacecraft Inertia Properties	New Mexico State University	Ou Ma
T0115 - Entry, Descent, and Landing (EDL) Technology Development for the Maraia Earth-Return Capsule	NASA's Johnson Space Center	Alan Strahan
T0128 - Zero-Gravity Green Propellant Management Technology	Purdue University	Steven Collicott
T0142 - Affordable Vehicle Avionics (AVA)	NASA's Ames Research Center	Jim Cockrell
T0004 - Printing the Space Future	Made In Space	Jason Dunn
T0020 - Microgravity Multi-Phase Flow Experiment for Suborbital Testing (MFEST)	NASA's Johnson Space Center	Kathryn Hurlbert
T0059 - On the Performance of a Nanocatalyst-Based Direct Ammonia Alkaline Fuel Cell (DAAFC) Under Microgravity Conditions for Water Reclamation and Energy Applications	University of Puerto Rico	Carlos Cabrera
T0081 - Demonstration of Variable Radiator	Texas A&M University	Richard "Cable" Kurwitz
T0044 - Sintering of Composite Materials Under Reduced-Gravity Conditions	Fermi Institute	Carmelo Mandarino
T0045 - Evaporative Heat Transfer Mechanisms Within a Heat Melt Compactor (EHeM HMC) Experiment	NASA's Glenn Research Center	Eric Golliher
T0049 - Parabolic Flight Evaluation of a Hermetic Surgery System for Reduced Gravity	University of Louisville	George Pantalos
T0140 - Lunar Plant Growth Experiment (LPX)	NASA's Ames Research Center	Chris McKay
T0145 - Low-Gravity Flow Boiling on Modern Textured Surfaces	Purdue University	Steven Collicott
T0146 - Droplet Pinning in Microgravity	Rensselaer Polytechnic Institute	Amir Hirsa
T0147 - Modal Propellant Gauging in Microgravity	Carthage College	Kevin Crosby
T0149 - Microgravity Fabrication of Freeze-Cast Titanium Foams	Northwestern University	David Dunand
T0158 - Zero-Gravity Mass Measurement Device (ZGMMD) Parabolic Flight Test	Orbital Technologies Corp.	John Wetzel
T0075 - Exo-Atmospheric Aerobrake	NASA's Ames Research Center	Marc Murbach
T0077 - Facility for Microgravity Research and Submicroradian Stabilization Using sRLVs	Controlled Dynamics Inc.	Scott Green
T0088 - A Field Programmable Gate Array (FPGA)–Based, Radiation-Tolerant Reconfigurable Computer System with Real-Time Fault Detection, Avoidance, and Repair	Montana State University	Brock LaMeres
T0145 - Low-Gravity Flow Boiling on Modern Textured Surfaces	Purdue University	Steven Collicott
T0150 - Advancing Diaphragm Modeling Technology for Propellant Management	Purdue University	Steven Collicott
T0064 - Deployable Rigid Adjustable Guided Final Landing Approach Pinions (DRAG FLAPs)	Masten Space Systems	Joey Oberholtzer
T0085 - SwRI Solar Instrument Pointing Platform	Southwest Research Institute	Craig DeForest
T0106 - Low-Cost Suborbital Reusable Launch Vehicle (sRLV) Surrogate to Test Automatic Dependent Surveillance Broadcast (ADS-B)	GSSL Inc.	Tim Lachenmeier

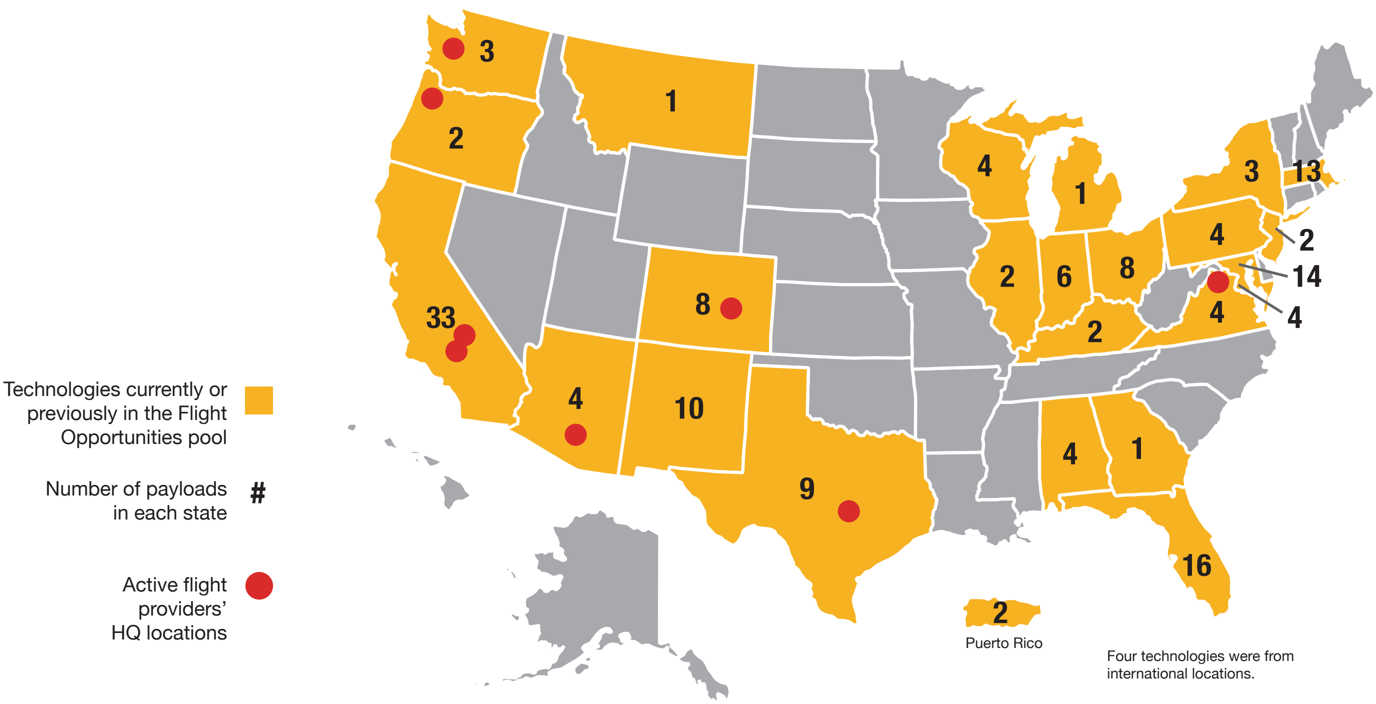
A Diverse Array of Research Organizations

Research payloads flown in FY2016 were led by principal investigators and research teams from a wide range of organizations.

6	**payloads from NASA**
12	**payloads from universities**
5	**payloads from commercial organizations**
1	**payload from a non-profit research organization**

A Significant Geographic Impact

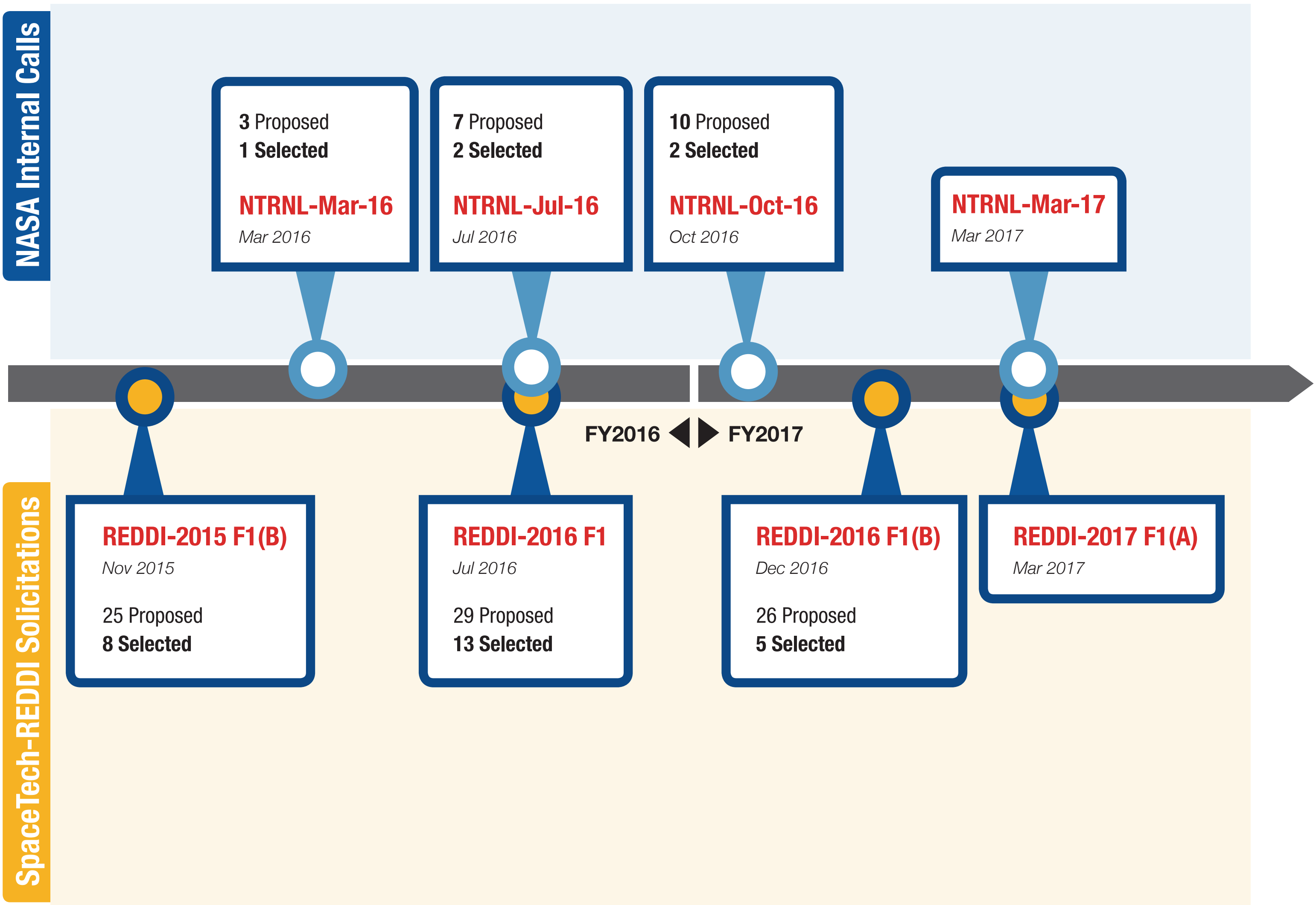
The geographic reach of the Flight Opportunities program continues to expand, with involvement from flight providers and research organizations across nearly half of the U.S. since the program's inception. Flight Opportunities looks forward to expanding the geographical reach of the program in coming years.



Four technologies were from international locations.

Technology Solicitation Schedule

In FY2016, the schedule of Space Technology Research, Development, Demonstration, and Infusion (SpaceTech-REDDI) solicitations and internal calls became regular, with REDDI Appendix F1 solicitations issued twice per year and NASA internal calls issued four times annually.



Budget

FY2016 saw an expansion in the Flight Opportunities budget. This increase corresponds to expansions in the program, in particular the integration of Announcement of Collaborative Opportunity (ACO) and Materials International Space Station Experiment (MISSE) under the Flight Opportunities umbrella.

Flight Opportunities FY2014–FY2016 Budget

FY2014	FY2015	FY2016
$10M	$10M	$15M

Multi-Year Data

Campaigns

		FY2014	FY2015	FY2016
sRLV	UP Aerospace	1	1	1
	NASA's Wallops Flight Facility		1	1
	Masten Space Systems	2	3	
Balloon	Near Space Corporation	4	2	2
	World View Enterprises		1	1
Parabolic	Zero Gravity Corporation	3		2
	NASA's Reduced Gravity Office	2	5	2
	TOTAL	12	13	9

Technology Portfolio Status

	FY2014	FY2015	FY2016
Solicitations/Calls	2	1	4
Technologies Selected	19	7	21
Technologies Completed	22	29	10
Active Technologies at Year-End	60	61	52

Technologies selected for the fiscal year are based on the date of solicitation. In some cases, solicitation and selection may not occur in the same year.

Teams from the University of Colorado Boulder and Masten Space Systems flew a set of tethered flights with a 26-inch starshade mounted to the Xaero vehicle. The campaign investigated using Masten Space Systems' vertical takeoff, vertical landing rocket as a stable platform to conduct high-contrast astronomy with an external occulter. Photo credit: NASA

Active Technologies

The following table shows all payloads that were matured in FY2016, have upcoming test flights planned, or were otherwise in an active status with the program as of the end of FY2016. Refer to the far right column for page numbers in which these payloads are mentioned.

Tech Number	Title	PI	Organization	Origin (Key page 51)	Page
T0001	Suborbital Flight Environment Monitor (SFEM)	Steve Ord	NASA Ames	Directed	—
T0003	On-Orbit Propellant Storage Stability	Sathya Gangadharan	Embry-Riddle Aeronautical University	AFO1	—
T0004	Printing the Space Future	Jason Dunn	Made In Space	AFO1	9, 36
T0015	Electromagnetic Field Measurements on sRLV	H. Todd Smith	Johns Hopkins University	AFO1	—
T0020	Microgravity Multi-Phase Flow Experiment for Suborbital Testing (MFEST)	Kathryn M. Hurlbert	NASA Johnson	AFO2	6, 36
T0021	Application of Controlled Vibrations to Multi-Phase Systems	Ricard Gonzalez-Cinca	University of Alabama, Huntsville	AFO2	—
T0022	Environment Monitoring Suite on Suborbital Reusable Launch Vehicle (sRLV)	H. Todd Smith	Johns Hopkins University	AFO2	—
T0023	Measurement of the Atmospheric Background in the Mesosphere	Sean Casey	Silicon Valley Space Center	AFO2	—
T0035	Near-Zero Gravity Cryogenic Line Chilldown Experiment in a Suborbital Reusable Launch Vehicle	Jacob Chung	University of Florida	AFO2	—
T0036	Collisions into Dust Experiment on a Commercial Suborbital Vehicle	Josh Colwell	University of Central Florida	AFO3	—
T0045	Evaporative Heat Transfer Mechanisms Within a Heat Melt Compactor (EHeM HMC) Experiment	Eric Golliher	NASA Glenn	AFO3	—
T0050	Flight Demonstration of an Integrated Camera and Solid-State Fine Steering System	Eliot Young	Southwest Research Institute	AFO3	—
T0052	Collection of Regolith Experiment (CORE) on a Commercial Suborbital Vehicle	Josh Colwell	University of Central Florida	AFO3	—
T0053	Validating Telemetric Imaging Hardware for Crew-Assisted and Crew-Autonomous Biological Imaging in Suborbital Applications	Rob Ferl	University of Florida	AFO3	12
T0054	Stratospheric Parabolic Flight Technology	Steven Collicott	Purdue University	AFO3	—
T0061	Flight Testing of a Universal Access Tranceiver (UAT) Automatic Dependent Surveillance Broadcast (ADS-B) Transmitter Prototype for Commercial Space Transportation Using Reusable Launch Vehicles	Richard Stansbury	Embry-Riddle Aeronautical University	AFO4	—

Tech Number	Title	PI	Organization	Origin (Key page 51)	Page
T0064	Deployable Rigid Adjustable Guided Final Landing Approach Pinions (DRAG FLAPs)	Joey Oberholtzer	Masten Space Systems	AFO4	17, 32
T0075	Exo-Atmosperic Aerobrake	Marc Murbach	NASA Ames	AFO5	—
T0077	Facility for Microgravity Research and Submicroradian Stabilization Using sRLVs	Scott Green	Controlled Dynamics Inc.	AFO5	—
T0081	Demonstration of Variable Radiator	Richard "Cable" Kurwitz	Texas A&M Engineering Experiment Station	Directed	36
T0083	Design and Development of a Micro Satellite Attitude Control System	Manoranjan Majji	State University of New York - Buffalo	NRA1 GCD Appx A	—
T0085	Southwest Research Institute (SwRI) Solar Instrument Pointing Platform	Craig DeForest	Southwest Research Institute	NRA1 GCD Appx A	15, 34
T0086	Saturated Fluid Pistonless Pump Technology Demonstrator	Ryan Starkey	University of Colorado Boulder	NRA1 GCD Appx A	—
T0088	A Field Programmable Gate Array (FPGA)–Based, Radiation-Tolerant Reconfigurable Computer System with Real-Time Fault Detection, Avoidance, and Repair	Brock LaMeres	Montana State University	NRA1 GCD Appx A	—
T0095	Test of Satellite Communications Systems On-board Suborbital Platforms to Provide Low-Cost Data Communications for Research Payloads, Payload Operators, and Space Vehicle Operators	M. Brian Barnett	Satwest Consulting LLC	NRA1 GCD Appx A	—
T0098	Navigation Doppler Lidar Sensor Demonstration for Precision Landing on Solar System Bodies	Farzin Amzajerdian	NASA Langley	NRA1 GCD Appx A	—
T0106	Low-Cost Suborbital Reusable Launch Vehicle (sRLV) Surrogate to Test Automatic Dependent Surveillance Broadcast (ADS-B)	Tim Lachenmeier	GSSL Inc.	NRA1 GCD Appx A	11, 32
T0115	Entry, Descent, and Landing (EDL) Technology Development for the Maraia Earth-Return Capsule	Alan Strahan	NASA Johnson	NRA1 GCD Appx A	25
T0119	Inductively Coupled Electromagnetic (ICE) Thruster System Development for Small Spacecraft Propulsion	John Slough	MSNW LLC	NRA1 GCD Appx A	—
T0128	Zero-Gravity Green Propellant Management Technology	Steven Collicott	Purdue University	AFO6	25
T0129	Testing of a Microgravity Rock Coring Drill Using Microspines	Aaron Parness	JPL	AFO6	—
T0137	Fuel Optimal and Accurate Landing System (FOALS) Test Flights	Andrew Johnson	JPL	AFO6	7, 31
T0139	Adaptable Deployable Entry and Placement Technology (ADEPT)	Paul Wercinski	NASA Ames	AFO6	—
T0142	Affordable Vehicle Avionics (AVA)	Jim Cockrell	NASA Ames	NRA2 GCD Appx E	25

Tech Number	Title	PI	Organization	Origin (Key page 51)	Page
T0143	Bi-Static Radio Frequency (RF) Imager	Charles L. Finley	Air Force Research Laboratory	NRA2 GCD Appx E	—
T0144	Programmable Ultra Lightweight System Adaptable Radio (PULSAR)	Arthur Werkheiser	NASA Marshall	NRA2 GCD Appx E	—
T0145	Low-Gravity Flow Boiling on Modern Textured Sufaces	Steven Collicott	Purdue University	NRA2 GCD Appx E	37
T0146	Droplet Pinning in Microgravity	Amir Hirsa	Rensselaer Polytechnic Institute	NRA2 GCD Appx E	37
T0147	Modal Propellant Gauging in Microgravity	Kevin Crosby	Carthage College	AFO8	37
T0149	Microgravity Fabrication of Freeze-Cast Titanium Foams	David Dunand	Northwestern University	AFO8	8, 37
T0150	Advancing Diaphragm Modeling Technology for Propellant Management	Steven Collicott	Purdue University	AFO8	37
T0153	Mars Electric Reusable Flyer	David D. North	NASA Langley	AFO8	—
T0154	PRIME-4.0: Miniaturized and Reusable Asteroid Regolith Microgravity Experiment for Suborbital and Orbital Use	Josh Colwell	University of Central Florida	Directed	—
T0155	Suborbital Evaluation of an Aqueous Immersion Surgical System for Reduced Gravity	George Pantalos	University of Louisville	Directed	—
T0156	Suborbital Particle Aggregation and Collision Experiment-2 (SPACE2.0)	Julie Brisset	University of Central Florida	Directed	27
T0157	Global Positioning System (GPS) Fading	Nick Demidovich	FAA Comm'l Space Transportation Office (FAA/AST)	Directed	—
T0158	Zero-Gravity Mass Measurement Device (ZGMMD) Parabolic Flight Test	John Wetzel	Orbital Technologies Corporation	REDDI-2014	37
T0159	1090 MHz ADS-B Demo	Nick Demidovich	FAA Comm'l Space Transportation Office (FAA/AST)	REDDI-2014	—
T0160	Microgravity Propellant Gauging Using Modal Analysis: Phase II	Kevin Crosby	Carthage College	REDDI-2014	—
T0162	Evolved Medical Microgravity Suction Device	C. Marsh Cuttino	Orbital Medicine Inc.	REDDI-2014	—
T0163	MOJO-Micro: Multi-Orthogonal Jaunting rObot in Microgravity	Neil Gershenfeld	Massachusetts Institute of Technology	REDDI-2014	—
T0164	Microgravity Testing of Comet Surface Sample Return (CSSR) Sample Verification System	Risaku Toda	JPL	REDDI-2014	—

Origin Key

Directed: Flight Opportunities was directed to provide flight testing for the technology by a manager within the Flight Opportunities program and/or NASA's Space Technology Mission Directorate (STMD).

AFO1 through AFO8: The technology was selected from submissions to an Announcement of Flight Opportunity (AFO) solicitation. A total of eight AFO solicitations were offered.

NRA1 GCD Appx A These technologies were selected by NASA's Game Changing Division (GCD) under the first NASA Research Announcement (NRA1). Appendix A (Appx A) of the solicitation assigned specific technologies to the Flight Opportunities pool.

NRA2 GCD Appx E These technologies were selected by NASA's Game Changing Division (GCD) under the second NASA Research Announcement (NRA2). Appendix E (Appx E) of the solicitation assigned specific technologies to the Flight Opportunities pool.

REDDI-2014 These technologies were selected through the 2014 Research, Development, Demonstration, and Infusion (REDDI) solicitation.

Use this space to jot down notes about your technology plans and proposals.

Have a question, idea, or feedback for Flight Opportunities? Write them down here, and then get in touch at NASA-FlightOpportunities@mail.nasa.gov or 650-604-5876.

UP Aerospace launch pad at
Spaceport America, New Mexico.
Photo credit: NASA

Commercial Flight Opportunities for the **Testing and Maturation** of new **Space Technologies**

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