National Aeronautics and Space Administration

SPACE TECHNOLOGY MISSION DIRECTORATE

Flight Opportunities

2017 Annual Report

Front cover (main): The additive manufactured injector from NASA's Marshall Space Flight Center is shown here being successfully hot-fire tested by Vector Space Systems using liquid oxygen/propylene propellant. Credit: Vector Space Systems

Front cover (insets): Top two images, credit: World View Enterprises. Bottom image, credit: NASA

Back cover: Interior of the G-FORCE ONE parabolic aircraft. Credit: Zero Gravity Corporation

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Executive Summary

NASA's Flight Opportunities program strives to mature enabling technologies of interest to the agency while simultaneously fostering the development and use of commercial services and capabilities in the U.S. spaceflight industry.

Flight Opportunities' commitment to supporting technology developers by providing access to relevant space-like environments is helping to advance innovations that will enable future scientific discovery and exploration. In addition, Flight Opportunities continues to nurture the commercial space market through its early adoption of commercial flight services, helping flight providers advance their goals and secure new customers in the broader market.

In FY2017, the program made significant progress in the following key strategic areas:

A view of the Earth from World View's Stratollite high-altitude balloon system. Credit: World View Enterprises

Supporting Technology Development and Demonstration

Flight demonstrations bridge the critical gap between ground-based testing and operational use in the mission environment. FY2017 saw the demonstration of 16 technologies across eight flight campaigns, supporting both NASA and non-NASA researchers. These enabling technologies represent significant potential for future space missions. In addition, the program managed the selection of NASA material samples to be flown as part of the Materials International Space Station Experiment (MISSE) program. Upcoming missions will include six NASA samples for MISSE-9, four for MISSE-10, and five for MISSE-11.

Expanding Commercial Small Launch Capabilities

Through NASA's Announcement of Collaborative Opportunity (ACO) and Tipping Point activities, Flight Opportunities was able to strategically stimulate the commercial space industry through public-private partnerships to deliver commercially led technologies and capabilities for future missions. FY2017 saw significant progress through the signing of six cost-contribution contracts and three Space Act Agreements (SAAs) to advance small launch vehicle capabilities. These firm, fixed-price contracts (valued at $11.7 million) and SAAs are awarded to commercial flight service providers, vendors, and suppliers to deliver new capabilities to the marketplace. In September 2017, three public-private partnerships valued at $3.5 million in NASA contributions were made through the ACO 2017 solicitation, with SAAs underway.

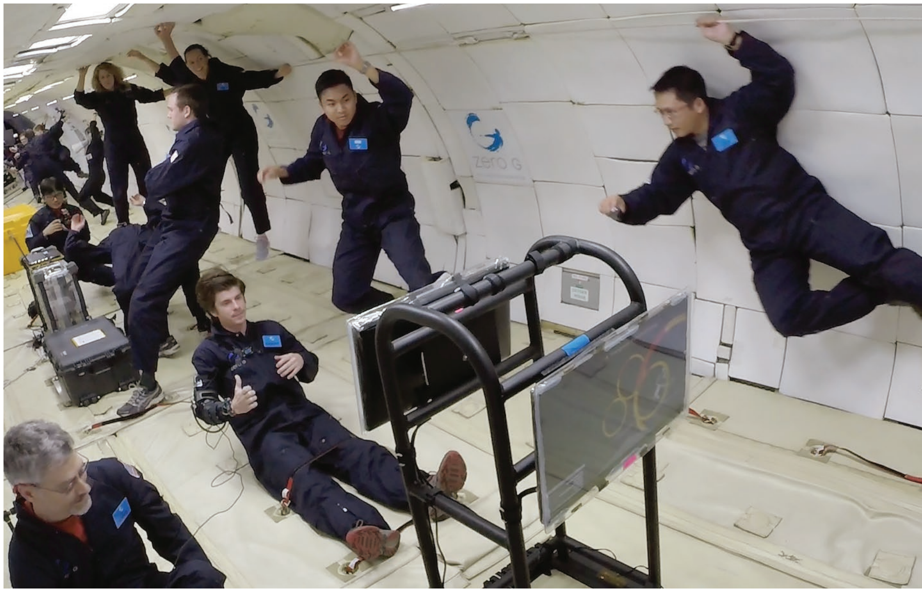
Strengthening Relationships

Ongoing relationships between Flight Opportunities and both researchers and flight providers continued to grow in FY2017. Outreach efforts, including a monthly newsletter and regular online news features, reach this growing and engaged community on a consistent basis. Also, Flight Opportunities' regular presence at industry events has proved fruitful in helping interested researchers get involved. In addition, flight providers have seen business growth as a result of their involvement with the program, in terms of expanding their capabilities and growing their customer base. Flight Opportunities also continues to work with other NASA programs and government agencies to help advance critical technologies and achieve mission goals.

Aligning Efforts with STMD Strategic Objectives

In FY2017, the activities of the Flight Opportunities program were closely aligned with the objectives of NASA's Space Technology Mission Directorate (STMD). Through its partnerships with the commercial suborbital and small satellite orbital launch industries, Flight Opportunities is able to:

- Demonstrate high-priority technologies related to exploration and other key mission directorate goals in a suborbital environment
- Foster the availability of commercial suborbital flight services by serving as an early customer for industry providers
- Accelerate the commercial availability of dedicated suborbital and small satellite orbital launch capabilities



Researchers test NASA's Jet Propulsion Laboratory's Biosleeve Gesture Control Interface for Telerobotics on a FY2017 flight demonstration. Credit: NASA

Looking Ahead

As Flight Opportunities moves forward, flight demonstrations are planned for testing a range of promising technologies with an increasing focus on supporting NASA's exploration campaign. In addition, progress on ACO and Tipping Point activities will continue, accelerating to market the development and demonstration of technologies that help lower costs and enable reliable access to space. We look forward to continuing along our path of maturing technologies that advance NASA priorities with a particular focus on future exploration missions.

Robert Yang
Program Executive
NASA Headquarters

Ronald Young
Program Manager
NASA's Armstrong Flight Research Center

Near Space Corporation prepares for a balloon demonstration in Tillamook, Oregon, using its High-Altitude Shuttle System (HASS). Credit: NASA

Flight Opportunities Impacts

Flight Demonstrations

Flights for testing and demonstrating new enabling technologies have been—and continue to be—a cornerstone of the Flight Opportunities program. Suborbital flight demonstrations play a critical role in maturing promising new cross-cutting technologies.

Flight demonstrations in FY2017 provided researchers from academia, commercial companies, NASA, and other government organizations access to relevant space-like environments in order to:

- Raise the technology readiness level (TRL) of their innovations, an important metric in demonstrating the advancement of a technology towards final infusion into a space application
- Obtain critical experimental data not otherwise attainable in ground-based experiments

Balloon Flight Demonstrates ADS-B Technology for U.S. NextGen Air Transportation System

Automatic dependent surveillance-broadcast (ADS-B) is one of several transformative technologies included in the Federal Aviation Administration (FAA) Next Generation (NextGen) campaign to modernize the U.S. air transportation system. ADS-B uses GPS satellites to determine a space vehicle's location, ground speed, and other data. ADS-B Out broadcasts an aircraft's position, altitude, and velocity to a network of ground stations that relays the information to air traffic control displays and nearby aircraft that are equipped to receive the data. Optional ADS-B In sends traffic information directly to the cockpit of properly equipped aircraft.

On May 19, 2017, Near Space Corporation flew its Small Balloon System to loft a Gemini-SV-1,090 MHz ADS-B transponder prototype (T0159) to test whether messages sent by the payload at float altitude could be received with mobile and dedicated receivers on the ground. The successful demonstration raised the transponder to TRL 7 (system prototyping demonstration in an operational environment)—an important milestone in the development of this critical technology for the future of air transportation.

Small Balloon System demonstration flight of an ADS-B transponder prototype for the Federal Aviation Administration. Credit: Near Space Corporation

MIT Advances Microrobot Technology Through Iterative Parabolic Flights

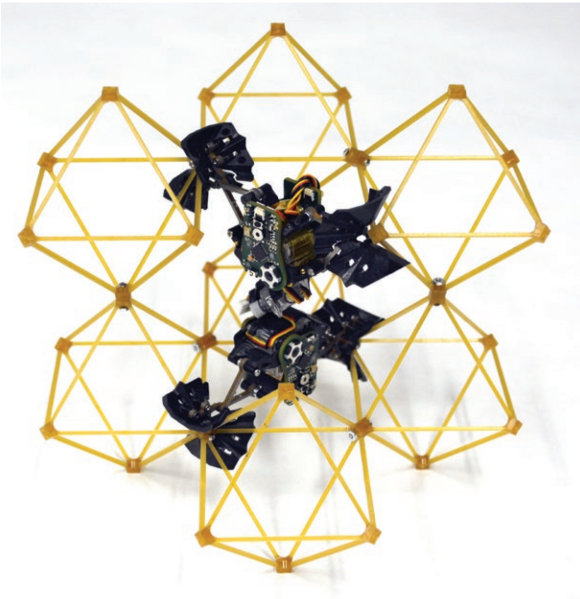
The nature of flight testing through NASA's Flight Opportunities program allows many researchers to improve the performance of their technologies from one flight to the next. For researchers in the Center for Bits and Atoms (CBA) at the Massachusetts Institute of Technology (MIT), having two rounds of flight tests for their tiny MOJO-Micro robot (T0163) proved to be an iterative success. As the researchers had hoped, the second set of parabolic flights in FY2017 allowed them to validate fixes they had worked on after a challenging first round of tests.

Designed to traverse and inspect a three-dimensional lattice structure, CBA's robotic system aims to assist and enable automated, in-space assembly of large space structures for scientific missions, exploration platforms, and even deep space habitats.

Weighing in at just 50 grams, the three-inch tall MOJO-Micro robot is able to traverse through the openings of a custom-designed lattice structure to monitor structural health. Aimed at assessing the impact of microgravity on the robot's performance, the iterative flight tests on Zero Gravity Corporation's (ZERO-G's) G-FORCE ONE enabled the researchers to make adjustments between flights, including preparing a new robotic interface.

The researchers were able to make in-flight adjustments as well, improving the gripping action of the robot to boost its performance and strengthen its alignment to the lattice structure.

Now, with a wealth of both quantitative and qualitative data from the parabolic flight tests in hand, the research team is looking ahead to investigations involving multiple MOJO-Micros working together as well as engineering different robots for different tasks in space, such as building extraterrestrial habitats and other structures.



The MOJO-Micro robot is designed to traverse and inspect a 3D lattice structure. Credit: MIT's Center for Bits and Atoms

> *Everything that we struggled with in the first round of parabolic test flights we were able to figure out and get great success with on the second round.*
>
> Benjamin Jenett, lead researcher for MOJO-Micro, NASA Space Technology Research Fellow, MIT

University and Commercial Research Teams Validate Payloads on Parabolic Flights

Several payloads from a range of research teams were matured during two Zero Gravity Corporation (ZERO-G) parabolic flight campaigns, completed in November 2016 and March 2017. Funded by NASA's Space Technology Research, Development, Demonstration, and Infusion (SpaceTech REDDI) awards, the research teams were able to procure flight services from a provider of their choice (in this case, ZERO-G) and negotiate the ideal number of flights.

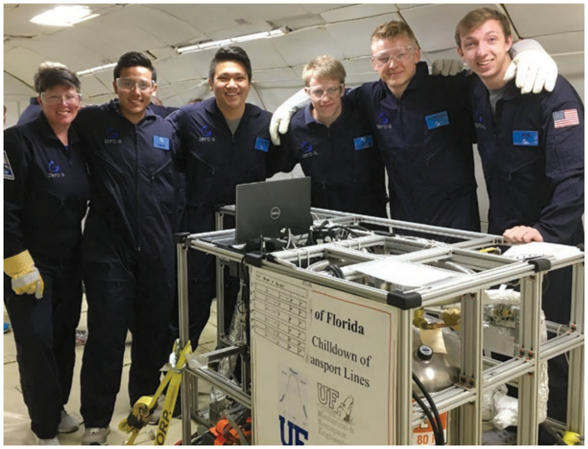
On ZERO-G's G-FORCE ONE parabolic aircraft, the research teams experienced approximately 30 parabolas per flight, with periods of microgravity during each parabola. In some cases, the research teams and their payloads flew during both campaigns, enabling them to leverage data and lessons learned from the initial flights to further advance their research in the second campaign.

> *"What absolutely amazes me is seeing that 'Aha!' moment that happens on almost every flight. And often it's with the students involved. Seeing them discover the unexpected or experience microgravity and suddenly they can envision the future of their research—doors open that they didn't even realize were there before."*
>
> Michelle Peters, director of research and education, Zero Gravity Corporation

A Revolutionary Approach for Efficient Microgravity Transfer Line Chilldown

T0172 — University of Florida

This special coating for the inside of a propellant transfer pipe promises to enable faster cooling and minimize cryogen loss—a key capability for long-duration space travel requiring the use of liquid-oxygen and -hydrogen cryogens as rocket propellant. The parabolic flight verified the integrity and viability of the system in extreme temperature changes and microgravity.



Members of the research team for the Microgravity Transfer Line Chilldown payload pose with their experiment in the cabin of G-FORCE ONE. Credit: Zero Gravity Corporation

Measuring Propellant Levels in Low Gravity

T0147 and T0160 — Carthage College

The Modal Propellant Gauging project is a non-invasive, real-time, cost-effective method of measuring liquid propellant volume by analyzing sound waves produced by vibrations applied to propellant tanks. The flight tests verified a vast improvement in the margin of error over current methods of gauging spacecraft propellant in low gravity. This can benefit any space application utilizing a propellant tank and also helps to address a challenge associated with NASA's goal of sustained human presence in space.

Water Capture Device

T0167 — Orbital Technologies Corporation, now Sierra Nevada Corporation

The Water Capture Device provides an efficient means of capturing, transporting, and collecting sparse airborne liquid droplets. It can be used for a variety of human spaceflight applications, such as humidity removal, integrated temperature and humidity control, condensate and wastewater recycling, food production, and hybrid life support. The parabolic flights validated the device's functionality in microgravity.

Advancing Diaphragm Modeling Technology for Propellant Management

T0150 — Purdue University

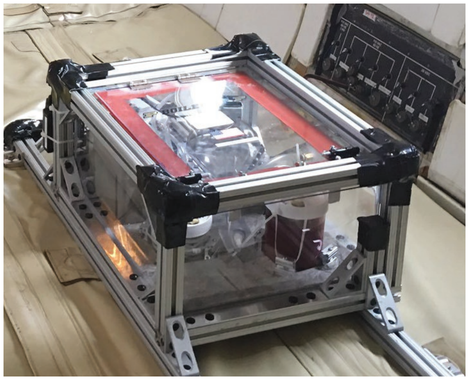
Researchers work with their propellant management payload during a period of microgravity on G-FORCE ONE. Credit: Zero Gravity Corporation

High-acceleration spaceflight missions require use of diaphragms to control propellants. The interaction of the liquid and diaphragm (a coupled liquid and deformable solid) in these situations has implications for mission success and safety, but it is extremely difficult to model. Researchers are working to streamline the design process to make the computations simpler, leading to more affordable diaphragm propellant management systems. The parabolic flights enabled testing of the system's dynamic responses to create validated criteria for design use.

Evolved Medical Microgravity Suction Device

T0162 — Orbital Medicine, Inc.

Suction is an important need for medical procedures and treating traumatic injuries, yet it is difficult to achieve in the microgravity environment. A thoracic drainage device with a two-phase separator that functions in microgravity will allow for treatment of medical emergencies during long-duration spaceflight. The parabolic flights enabled testing of the experimental apparatus in microgravity to confirm the evolved design.



Orbital Medicine's payload is shown here aboard G-FORCE ONE. Credit: Zero Gravity Corporation

Creating Reliable Models for the Effects of Gravity on Flow Boiling Heat Transfer

T0170 — University of Maryland, College Park

Researchers developed a heat transfer database and models for heat removal from two-phase thermal systems—an important component for future space missions that will require lighter, smaller, more powerful spacecraft. The parabolic flights enabled the team to collect data to determine how wall heat flux, inlet subcooling, and flow rate are affected by varied gravity environments in preparation for a possible International Space Station (ISS) flight.

The University of Maryland team works with their experiment during a parabolic flight. Credit: Zero Gravity Corporation

COBALT Demonstrations Validate Precision Landing Results

> *These COBALT technologies give Moon and Mars spacecraft the ability to land much more precisely, improving access to interesting sites in complex terrain and to any exploration assets previously deployed to the surface. Landings will also be more controlled and gentle, potentially allowing smaller landing legs and propellant reserves, and resulting in lower mission risk, mass, and cost.*

LaNetra Tateis,
program executive,
NASA's Game Changing
Development Program

Many regions in our solar system beckon for exploration, but they are considered unreachable due to technology gaps in current landing systems. That could change with the Cooperative Blending of Autonomous Landing Technologies (COBALT) project, conducted by NASA's Space Technology Mission Directorate and Human Exploration and Operations Mission Directorate. The technologies within COBALT could provide the guidance, navigation, and control capabilities to enable precision landing for future exploration missions.

The technologies promise to reduce the risk associated with developing future landing systems and enable autonomous precision landing for robotic landers to touch down on planetary surfaces.

The COBALT project paired new landing sensor technologies that yielded the highest precision navigation solution ever tested for NASA space landing applications. The technologies included a navigation Doppler lidar, which provides ultra-precise velocity and line-of-sight range measurements, and the Lander Vision System (LVS), which provides terrain-relative navigation.

The FY2017 flight campaigns were aboard Masten Space Systems' Xodiac, a rocket-powered vertical takeoff and vertical landing (VTVL) platform. The technologies were flight tested to collect sensor performance data and to check their integration and communication with the landing vehicle.

A researcher from Masten prepares the Xodiac vehicle and the navigation Doppler lidar (the three black cylinders) for the COBALT demonstration. Credit: Masten Space Systems

The data will be used for subsequent modifications prior to follow-on flight tests.

Moving forward, researchers expect the knowledge gained from these flight tests to be incorporated into the development of deployment systems for future NASA missions to land on the Moon and Mars.

Masten's Xodiac lifts off the launchpad for the COBALT demonstration. Credit: Masten Space Systems

Transitioning to SPLICE

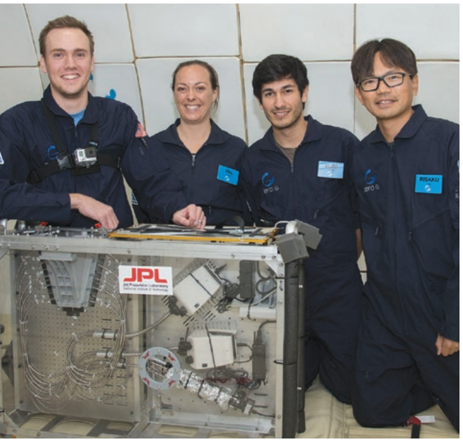
In FY2017, the COBALT project transitioned to NASA's **Safe and Precise Landing Integrated Capabilities Evolution (SPLICE)** project. SPLICE supports technology maturation in line with NASA's technology roadmap for entry, descent, and landing. The project will enable rapid technology readiness level (TRL) advancement of precision landing and hazard avoidance systems.

Specifically, the navigation Doppler lidar technology is on track to achieve TRL 6 (system/subsystem model or prototyping demonstration in a relevant end-to-end environment) in FY2019 as part of SPLICE. The technology will ultimately provide NASA with a next-generation velocimeter for controlled soft landing.

In addition, the Lander Vision System is slated to play a prominent role in NASA's Mars 2020 mission.

JPL Researchers Validate Two Space Technologies on Parabolic Flights

A series of parabolic flights with Zero Gravity Corporation (ZERO-G) in FY2017 enabled researchers to test and validate the performance of two promising technologies from NASA's Jet Propulsion Laboratory (JPL). The flight tests helped ensure flight readiness of JPL's innovations for future missions and raise their technology readiness level (TRL).



The research team for the Comet Sample Verification System poses with their payload in the cabin of ZERO-G's parabolic aircraft. Credit: Zero Gravity Corporation

Comet Sample Verification System

T0164

The Comet Sample Verification System is a tool that enables researchers to verify the quantity and volume of a sample from a comet surface before bringing it back to Earth for analysis—a capability of interest to scientists for many reasons. Not only would comet sample analysis help fill in gaps in the scientific community's understanding of how our solar system formed, but collecting comet surface samples is also a high priority identified by the National Research Council's 2013–2022 Decadal Survey.

JPL's system uses fiberscope imaging to measure a sample before it returns to Earth. A bundle of nine fiberscopes observes a comet sample soon after acquisition. If the sample quantity is insufficient, reacquisition is attempted until a large enough sample is obtained.

Testing the performance of the system's fiberscope sample imager on ZERO-G's parabolic flights validated TRL 6 (system/subsystem model or prototyping demonstration in a relevant end-to-end environment) and helped ensure that the technology is capable of supporting the objectives of a potential Comet Surface Sample Return mission. Such a mission would seek to acquire and return to Earth for laboratory analysis a macroscopic (≥500 cm^3) comet nucleus surface sample.

Biosleeve Gesture Control Interface

T0161 and T0185

The Biosleeve Gesture Control Interface for Telerobotics is a gesture-recognition system that translates arm, hand, and finger movements into computer commands that can be used to remotely control systems, such as a robotic arm or rover. It has the potential to be embedded in clothing worn by astronauts working on the International Space Station (ISS) and for other missions.

The parabolic flights helped JPL's researchers understand the gesture-recognition performance of the Biosleeve in a microgravity environment. They collected operational data that will influence the future design, development, and test program as the technology advances toward other flight testing, including a possible ISS test mission.

Researchers evaluate the performance of their Biosleeve prototype on a parabolic flight with ZERO-G. Credit: NASA

Monitoring Technology Could Allow Multiple Systems to Be Flown Together

An FY2017 flight on Masten Space Systems' Xodiac platform tested an environmental monitoring experiment that may allow for multiple technologies on the same vehicle while checking for possible interference from electrical and magnetic sources. The November 2016 flight carried an electromagnetic field measurement experiment dubbed JANUS (T0015)—after the Roman god of transitions and new beginnings—from the Johns Hopkins University (JHU) Applied Physics Laboratory (APL).

This was the first flight for the JANUS system, which will ultimately facilitate routine integration and flight testing of multiple future experiments and technology demonstrations. For this flight, Masten's Xodiac carried the measurement experiment, reaching an altitude of approximately 1,476 feet.

By allowing multiple experiments to be flown together, JANUS may ultimately save time and lower the costs of such flight demonstrations.

> *This initial flight is JHU APL's first step into a new era of exploiting commercial suborbital low-cost access to space for scientific research and technology development. NASA's Flight Opportunities program offers a critical pathway toward achieving these goals.*
>
> Dr. H. Todd Smith, senior scientist and JANUS principal investigator, JHU APL

Researchers prepare the JANUS experiment for a demonstration on Masten's Xodiac platform at the Mojave Air & Space Port. Credit: NASA

World View Successfully Demonstrates Advanced Altitude Control Technology

Long-duration stratospheric research missions could allow scientists to collect vast amounts of data continuously for their payloads. Such missions could benefit NASA by maturing future space technology as well as allowing for Earth observations, such as storm monitoring and forest fire tracking.

Previously, technological challenges have limited the duration of balloon flights in the stratosphere due to the lack of trajectory control necessary for longer flights. Now, a system developed by World View Enterprises promises the capability to perform large altitude changes to achieve meaningful trajectory control of balloon flights in the stratosphere.

World View's novel altitude control technology (T0169) was demonstrated in flight tests in FY2017, validating the system's capability and putting World View one step closer to shifting the status quo of lack of altitude control.

World View has been diligent in its development of the altitude control technology, which is just one component in a complex network of advances making up the company's Stratollite system. The system acts as a satellite for the stratosphere but provides more coverage—the instrument can sustain observation of a specific point within about 100 miles of a target.

During the FY2017 demonstrations on the Stratollite, all proposed success criteria were met, including demonstrating altitude changes, maintaining altitude levels during periods of both high and low solar elevation, and showing that the system is able to perform station keeping over a 24-hour flight.

> *The end goal is to be able to fly these for six, nine, even 12 months at a time so researchers can gather months of data and have a very high level of confidence that their system is going to work.*
>
> Iain Beveridge, principal investigator, World View Enterprises

In addition to achieving its primary objectives, the vehicle also performed a large altitude excursion of 25,000 feet, limited only by the commercial airspace ceiling. The flight test raised the technology readiness level (TRL) of the Stratollite system to TRL 9 (actual system "mission proven" through successful mission operations).

World View personnel prepare their advanced altitude control technology for a flight test on the Stratollite high-altitude balloon system. Credit: World View Enterprises

By making meaningful shifts between altitudes as needed within a given trajectory, World View's system may be able to support much longer balloon missions than previously possible, with significant implications for scientific payload testing. With an operational cost of less than one percent that of sending payloads to space, long-duration balloon flights have the potential to save significant time and cost, and lower complexity.

The value beyond payload testing is also clear: Long-duration altitude control can be used for weather monitoring, forest fire tracking, disaster relief efforts, maritime surveillance, and possibly homeland security missions.

World View is continuing development of this technology, with a 2018 manifest that includes an increasing number of payload providers interested in this platform capability.

> *Rather than flying multiple flights, World View's technology may enable researchers to achieve their goals with a single long-duration flight. This capability will also enable experiments requiring long-term exposure, which are currently very difficult to achieve.*
>
> Paul De León, campaign manager,
> NASA's Flight Opportunities program

The World View Stratollite is shown here in its stand-up configuration prior to launch. Credit: World View Enterprises

Transitions to Orbital Demonstrations

Researchers aim to advance many technologies matured through Flight Opportunities demonstrations for further development and use in low-Earth orbit (LEO)—an operational environment allowing further maturation along the technology readiness level (TRL) path beyond the threshold of suborbital space.

Platforms in LEO include the International Space Station (ISS) and automated free-flying CubeSats. Successful demonstrations on these platforms enable technologies to advance to TRL 7 and higher, moving them closer to inclusion in future NASA missions to the Moon, Mars, and beyond.

In FY2017, several technologies previously demonstrated through Flight Opportunities made significant progress along the LEO demonstration path. The following is a sampling.

> *"The opportunity to demonstrate our computer system on a suborbital vehicle through the Flight Opportunities program was instrumental in maturing our technology to TRL 6. The ISS was the perfect platform for the next stage of our development."*
>
> Brock LaMeres, principal investigator, Montana State University

Radiation Tolerant Computer System Completes a Year of ISS Testing

Following suborbital demonstrations in 2014 and 2016, Montana State University's Radiation Tolerant Computing System (RadSat) (T0088) was delivered to the ISS in December 2016 for one year of testing.

Funded by NASA's Established Program to Stimulate Competitive Research (EPSCoR), the ISS demonstration evaluated the novel computer architecture's resistance to the harmful effects of space radiation. The experiment was powered down in December 2017 and is scheduled to return to Earth in 2018 to be examined for radiation damage. Preliminary results show that the experiment ran for long durations (months at a time) without faults, achieving TRL 7. Although further analysis is needed, the demonstration provided the team with critical information about additional instrumentation needs.

Next for the technology is a demonstration on a stand-alone 3U CubeSat called RadSat-g, which is slated to be deployed into LEO from the ISS in summer 2018.

Montana State University's RadSat experiment is installed on the ISS. Credit: Montana State University

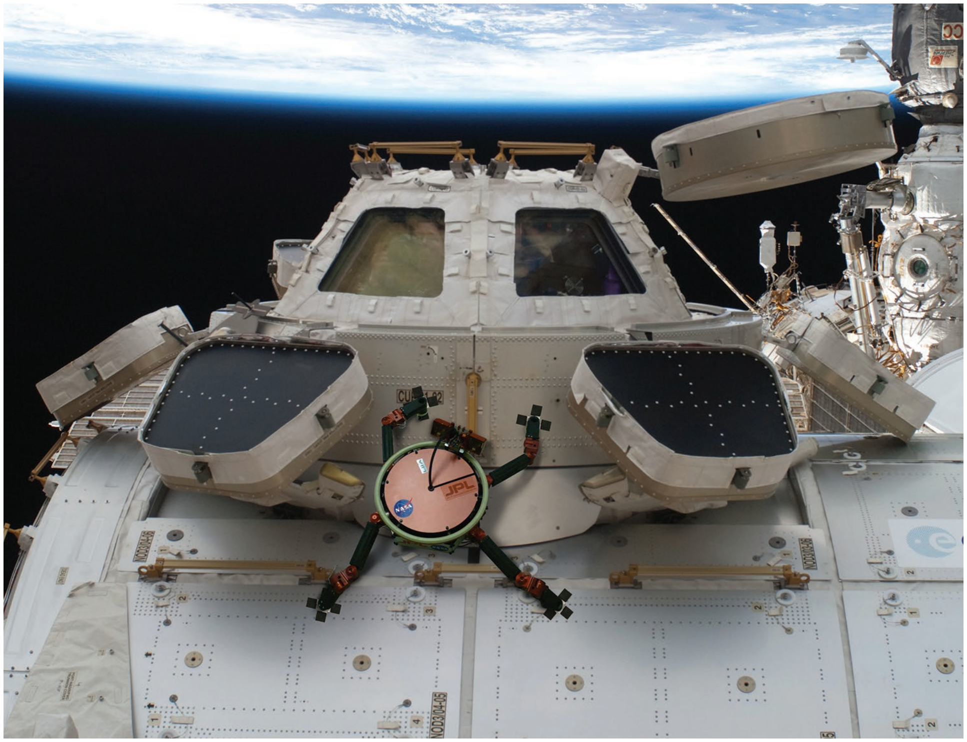
Gecko-Like Adhesives Show Successful Stickiness on the ISS

In looking for adhesives for space-based missions, innovators from NASA's Jet Propulsion Laboratory (JPL) zeroed in on the bottom of geckos' feet, which have tiny hairs that enable them to cling to surfaces with ease. These hairs formed the basis for the Gecko Grippers (T0135), featuring a synthetic hair-like material with sticking power unaffected by temperature, pressure, and radiation.

Following successful suborbital demonstrations in 2014 and 2015 aboard NASA's C-9B aircraft, the Gecko Grippers were tested on the ISS in 2016 and 2017 to validate their performance in a long-duration microgravity environment and demonstrate their readiness for future space-based missions.

Test results show that a Gecko Gripper with two 5x5-cm pads supported a maximum of 39 N of force and showed no degradation of capability after remaining in operation for two weeks. A smaller model with two 2.5x2.5-cm pads supported a maximum of 19 N of force and showed similarly consistent performance.

Next steps include ongoing efforts by Stanford University to integrate the technology on a free-floating robot called Astrobee for another interior ISS test as well as performing exterior ISS testing.



This artist's concept image shows how an inspection robot could stick to the outside of the ISS using a gecko-inspired gripping system. Credit: NASA

Freeze Casting Ceramic and Metallic Foams on a CubeSat and the ISS

> “What we’ve learned through the Flight Opportunities program testing has put us in a position to better design our experiment for the CubeSat. In the two years we spent with the program, we were able to continue to improve our process and understanding—and that puts us in a much better position to actually succeed with the CubeSat testing.”
>
> David Dunand, James N. and Margie Krebs Professor of Materials Science and Engineering, Northwestern University

Freeze casting in microgravity is a novel materials-processing technique with the potential to provide scalable, affordable in-space manufacturing of materials and structures. Numerous advantages for space exploration include reduced launch costs and enabling transport of raw materials to build structures that would otherwise be too large to launch.

Parabolic demonstrations of Northwestern University’s microgravity freeze-casting experiments (T0100 and T0149) in 2013, 2014, and 2016 showed promising results for the manufacture of titanium-oxide (ceramic) and titanium (metal) foams and resulted in the team receiving additional NASA funding to move the research into LEO. Demonstrations are planned on both a CubeSat and the ISS.

In collaboration with the University of Illinois at Urbana-Champaign, the team designed a six-month CubeSat mission (dubbed SpaceICE). While parabolic flight limited freezing times to within 10 seconds, the CubeSat platform will allow testing a range of freezing velocities. SpaceICE was selected and manifested for launch through NASA’s CubeSat Launch Initiative.

The experiment was also selected by NASA’s Physical Sciences Research Program as part of NASA’s Materials Lab Open Science Campaign, which will support a demonstration on the ISS in 2022. For this sample return mission, samples will be solidified in microgravity and returned to Northwestern for microstructural investigations. With this experiment, the team hopes to learn more about the effect of gravity during solidification by comparing microstructures of samples solidified on the ISS to those solidified under normal terrestrial conditions such as a ground-based lab.

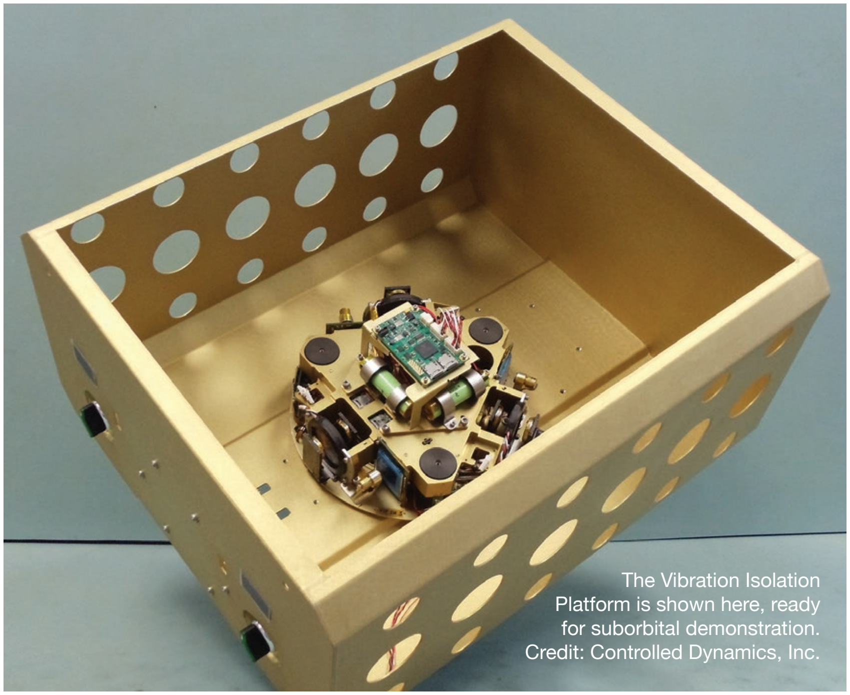
Researchers from Northwestern University and Los Alamos National Laboratory work with the freeze-casting process during a parabolic flight. Credit: NASA

Payload Isolation Technology Performs Successfully in ISS Demonstration

Controlled Dynamics Inc.'s (CDI's) high-performance facility for microgravity research and submicroradian stabilization—the Vibration Isolation Platform (T0077)—was originally designed to be integrated into suborbital reusable launch vehicles (sRLVs). The aim of the technology was to provide quiescent environments for research payloads on the order of 1 micro-g rms or better over a broadband frequency range during the coast phase of an sRLV flight. The result was a reduction in the ambient flight environment by over two orders of magnitude during operation.

Suborbital flight demonstrations completed through the Flight Opportunities program provided data that backed up CDI's research studies showing that this non-contact isolation approach was capable of achieving the best possible payload isolation during flight—helping to improve payload performance and stability during demonstrations. The success of CDI's suborbital flight research qualified the technology to be demonstrated aboard the ISS.

Through a 2015 grant awarded by the Center for the Advancement of Science in Space (CASIS), the payload (now known as the Programmable Isolation Mount) was delivered to the ISS in the Cygnus OA-5 vehicle in October 2016. After several months in storage, it was installed in April 2017 and operated for 130 days until it was uninstalled in August 2017. The flight experiment successfully tuned and characterized on-orbit operation and configuration of the isolation technology, using an interface for command and control from a remote ground workstation. Final performance characterizations are pending as the payload and final flight data logs are in transit back to CDI for analysis.



The Vibration Isolation Platform is shown here, ready for suborbital demonstration. Credit: Controlled Dynamics, Inc.

CDI is also building on this foundation of suborbital and orbital demonstration with a NASA Phase I/II Small Business Innovation Research (SBIR) contract with NASA's Jet Propulsion Laboratory (JPL) to develop the platform for deep space optical communication links. These provide higher data transfer rates with lower mass, power, and volume than conventional radio-frequency links. Current tests and analyses have advanced the technology to TRL 4, and SBIR Phase II work is ongoing to continue development and prototype testing in a simulated low-gravity environment.

Materials International Space Station Experiment

NASA's Materials International Space Station Experiment (MISSE) enables researchers to test long-term exposure of materials—such as composites and polymeric specimens—to the harsh space environment.

Hosted on the International Space Station (ISS), the MISSE flight facility allows researchers to assess how long-term exposure to the extreme environment of space affects the performance of their materials. This information can be applied to the design of future exploration vehicles, systems, and components needed for long-duration space missions.

Flown 220 miles above Earth and fixed to the exterior of the ISS, MISSE hosts innovative experiments for long durations, subjecting them to extreme levels of solar and charged-particle radiation, atomic oxygen, temperature extremes, micrometeoroids, orbital debris, and contamination. Subjecting materials to these conditions gives 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 program provides NASA and its partners with crucial insight into the challenges of protecting astronaut health, establishing a sustained human presence in space, and designing more resilient spacecraft for long-duration space missions.

Since its inception in 2001, MISSE has facilitated the testing of more than 4,000 material samples. These have included composites, lubricants, paints, fabrics, container seals, and solar cells. NASA's Flight Opportunities program currently manages the selection of NASA-led research payloads for the MISSE program.

Kim de Groh (left) of NASA's Glenn Research Center and Sheila Thibeault of NASA's Langley Research Center pose with their material samples, slated to be tested on a MISSE mission in 2018. Credit: NASA

MISSE-9 Set to Debut New Flight Facility

In FY2017, the MISSE program adopted a new flight facility to expose material samples to the space environment. The MISSE flight facility was co-funded by the International Space Station Program Office and Alpha Space Test & Research Alliance, which also built and integrated the hardware and manages payload integration and testing. Forty percent of the space is allocated for material samples from NASA researchers, while the remaining 60 percent is offered to commercial and non-NASA organizations to test their specimens.

The new flight facility will debut during the MISSE-9 mission. It will be mounted on the ISS, and samples will remain in the facility for at least one year before returning to Earth for analysis.

A Hardware Evolution

MISSE has been a successful part of ISS research since 2001, when its original hardware became the first payload installed on the outside of the space station. The original suitcase-style design opened to form a platform that was used to expose samples to the space environment.

The newly designed flight facility features a box configuration, enabling exposure of all four sides: ram, wake, zenith, and nadir orientations.

Facilitating Significant Data Acquisition

Material specimens on the MISSE-9 mission are pursuing a range of research goals, including:

Improving Model Predictions for Material Performance

Researchers from NASA's Glenn Research Center will continue adding to flight data from their previous MISSE missions to predict the erosion of new polymers, composites, and coatings in space. The data should also help improve predictions of component lifetimes in space.

Evaluating Space-Based 3D Printed Materials

NASA's Marshall Space Flight Center researchers will study several additively manufactured (3D printed) materials in an effort to advance space-based manufacturing. The ISS has housed a 3D printer since 2014, and during MISSE-9 researchers will investigate its capabilities for supporting longer missions by evaluating how 3D printed materials hold up in space.

Supporting STEM Educational Outreach

MISSE-9 continues NASA's tradition of fostering education in science, technology, engineering, and math (STEM) with an experiment from the University of Delaware. Faculty and students are working to improve astronaut spacesuits with textiles intercalated with shear-thickening fluid, aiding resistance to damage from orbital debris.

The new MISSE flight facility hardware was designed and implemented by Alpha Space Test & Research Alliance. The four-sided structure offers more space for material samples from NASA researchers and commercial organizations. Credit: Alpha Space Test & Research Alliance

MISSE-10 and MISSE-11 Selections Announced

In FY2017, Flight Opportunities announced the selection of NASA material specimens that will fly on the MISSE-10 and MISSE-11 missions. These projects will add to the substantial body of data gathered about material durability already acquired through the MISSE program.

From materials that will aid future human exploration of Mars to those under consideration for NASA's Orion mission, these specimens are of significant interest to NASA as it ushers in a new era of deep-space exploration.

MISSE-10

- **Polymers and Composites Experiment**

  NASA's Glenn Research Center

  This experiment aims to determine the low-Earth orbit (LEO) atomic oxygen erosion yield, level of LEO contamination, and other measurements. The findings will be compared with data from similar samples flown on previous MISSE missions, the Long-Duration Exposure Facility flown in the 1980s, and the Hubble Space Telescope's Teflon™ insulation. The experiment aims to advance the technology readiness level (TRL) of polymers, composites, and inorganic pigment-filled spacecraft materials and sensor materials.

- **High-Efficiency, Low-Mass Solar Cell Systems**

  NASA's Marshall Space Flight Center

  Researchers will test flexible Lightweight Integrated Solar Array and Transceiver (LISA-T) solar cell assemblies. These thin-film, low-mass, low-volume solar arrays aim to address power generation limitations for small satellites.

- **Radiation Protection Technologies Demonstration**

  NASA's Langley Research Center

  This three-technology experiment aims to (1) demonstrate high-hydrogen radiation shielding materials, (2) validate the performance of radiation-sensitive field effect transistor (RADFET) dosimeters, and (3) test an experimental methodology that could be used in future MISSE-based or CubeSat experiments for demonstrating such technologies.

- **Innovative Coatings Experiment**

  NASA's Goddard Space Flight Center

  This experiment will evaluate the optical stability and performance of three types of next-generation coatings—thermal control, molecular absorber, and low surface energy—designed to improve thermal design, environmental compatibility, and contamination control for future NASA missions.

> *On the ground, we can test for one condition and then another and so forth, but we can't test for these things all at the same time in the way they exist in space. That's why we really need to test these material specimens in the actual space environment.*

Dr. Sheila Thibeault, engineer and co-pioneer of the MISSE program, NASA's Langley Research Center

MISSE-11

- **3D-MAT On-Orbit Exposure**

  NASA's Ames Research Center

  This experiment aims to assess the effects of LEO exposure on a new structural ablative composite heat shield material developed by NASA specifically to meet the requirements of the Orion mission.

- **Electrodynamic Dust Shield Experiment**

  NASA's Kennedy Space Center

  This active dust mitigation technology uses dynamic electric fields to remove dust from surfaces. The experiment will test its performance under long-duration space exposure.

- **Space Qualification Studies of Quad Photodiode, Focal Plane Array, and Solar Paint**

  NASA's Langley Research Center

  This experiment will evaluate the impact of the space environment on the performance of various technologies for imaging, sensing, and power generation.

- **Risk Reduction for Mars Ice Home Materials**

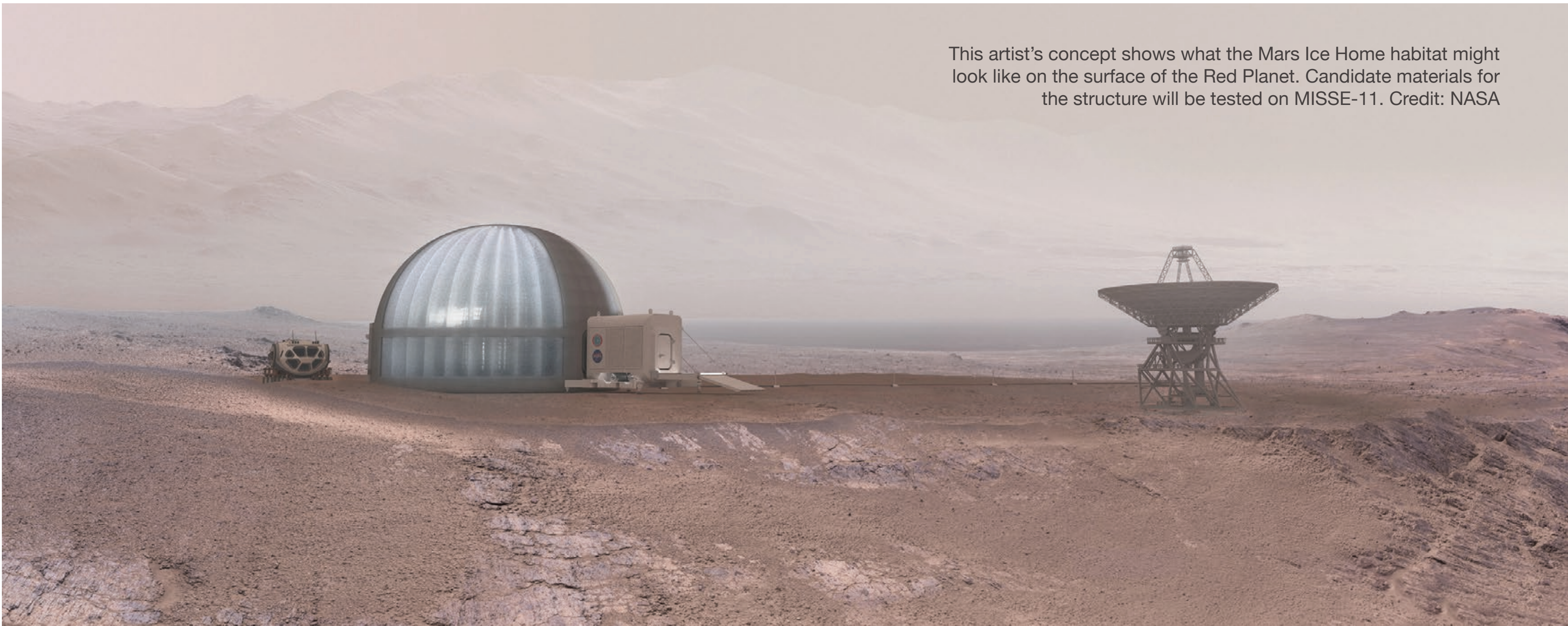
  NASA's Langley Research Center

  This experiment will help researchers evaluate a candidate material for a Martian habitat, including its strength, flexibility, mass erosion yield, and transparency to light in the visible range.

- **Materials Experiment for Long-Duration Exploration**

  NASA's Marshall Space Flight Center

  Determination of atomic oxygen erosion yield and optical property changes due to the LEO environment is the aim of this experiment, which will evaluate a variety of materials proposed for use in NASA missions and other space applications.



This artist's concept shows what the Mars Ice Home habitat might look like on the surface of the Red Planet. Candidate materials for the structure will be tested on MISSE-11. Credit: NASA

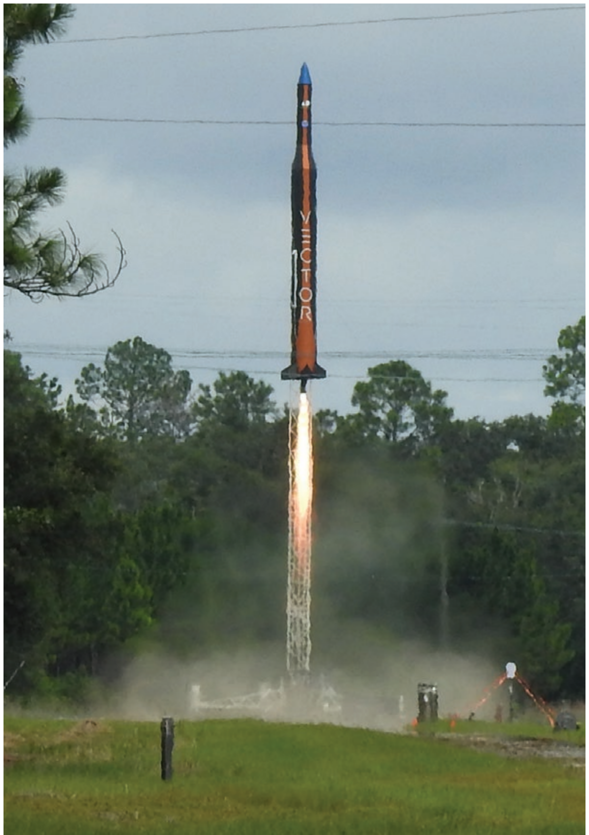
Small Launch Vehicle Technology Development

Through public-private partnerships, Flight Opportunities supported the development of affordable U.S. commercial capabilities for dedicated small satellite launches.

NASA's interest is focused on accelerating the development of commercial capabilities that improve efficiency and reduce the time and cost of human exploration and robotic missions. By providing access to NASA expertise and facilities, the agency is enabling development of new capabilities for the small launch vehicle industry, while helping to achieve the goals of current and future NASA missions.

Announcement of Collaborative Opportunity (ACO) partnerships and Tipping Point cost-contribution contracts are two primary mechanisms through which NASA provided resources to aid industry partners in maturing key dedicated small satellite launch technologies. ACO partnerships involve a non-reimbursable Space Act Agreement (SAA) between NASA and the industry partner. These agreements enable NASA centers to provide technical expertise and test facilities, as well as hardware and software, to commercial companies for the purpose of accelerating the development of promising technologies. The Tipping Point program facilitates U.S. industry–led space technology demonstration projects executed through cost-contribution firm, fixed-price contracts.

> *"This is a significant accomplishment for Vector and for NASA's initiatives to advance enabling technologies for suborbital and orbital small launch vehicles. NASA's role in helping the industry develop small satellite launch capabilities through the ACO awards enables companies such as Vector to offer this capability to the commercial marketplace sooner."*
>
> Ron Young,
> program manager,
> Flight Opportunities



A rocket ascends from the launch pad for an engine test. Credit: Vector Space Systems

ACO Partnership Highlights

In November 2015, the first five public-private partnerships with U.S. companies, valued at $5.6 million of NASA contribution, were selected through the ACO 2015 solicitation. In September 2017, three additional partnerships were selected as part of ACO 2017. Flight Opportunities is responsible for the project management of these ACO partnerships.

Significant project advancements were made in FY2017.

Vector Space Systems: Using 3D Printing to Cut Development Time and Costs

Additive manufacturing, or 3D printing, is making it increasingly possible to manufacture complex parts critical to rocket launches in less time and at a lower cost. In turn, these savings may result in lower costs for researchers looking to test their payloads on the next generation of small orbital launch vehicles.

Through its partnership with NASA's Marshall Space Flight Center, Vector Space Systems is advancing its goals of delivering increased access for research organizations looking to launch microsatellites more affordably and at a higher frequency than previously possible. The partnership is enabling Vector to leverage Marshall's capabilities in additive manufacturing to fabricate and flight test an integrated injector for a 5,000 lbf-thrust liquid oxygen/propylene rocket engine.

From December 2016 to August 2017, Vector successfully completed three important milestones: A ground hot-fire test of Marshall's injector; launch of its first vehicle for a low-altitude test flight using Marshall's injector; and a vehicle flight test of a second injector produced by Marshall.

A 3D-printed injector from NASA's Marshall Space Flight Center is hot-fire tested by Vector using liquid oxygen/propylene propellant. Credit: Vector Space Systems

Generation Orbit: Advancing Reusability for Air-Based Launches

Generation Orbit's (GO) partnership with NASA's Armstrong Flight Research Center involves a flight test campaign for the company's GOLauncher 1 Inert Test Article (GO1-ITA), a mass properties and aerodynamics simulator. Researchers plan to launch GOLauncher 1—a single-stage liquid rocket—from a Gulfstream III, which is capable of delivering payloads of up to 1,000 pounds on high-altitude suborbital and suppressed hypersonic trajectories.

This public-private partnership represents a major step forward in the ability to launch rockets from an aircraft to achieve reusability in small orbital launch services. In addition, the air-launched rockets are much smaller and less expensive than ground-launched rockets, lowering the size, cost, and weight of every launch.

In FY2017 the company delivered the GO1-ITA to Armstrong, where it underwent ground and telemetry testing and preparation for integration with the Gulfstream aircraft. In December 2017, Armstrong successfully completed a series of flight tests simulating abort release of the ITA. The flights validated GO's simulation models and exercised its concept of operations. The flights also validated Armstrong's engineering analysis of computational fluid dynamics and aircraft flutter and control.

NASA's C-20A undergoes a flight test with Generation Orbit's hypersonic pod attached. Credit: NASA

Virgin Orbit: Increasing Payload Carrying Capacity for Air Launches

Virgin Orbit collaborated with NASA's Ames Research Center to mature critical areas of development for the air-launched LauncherOne vehicle. Virgin Orbit leveraged the center's specific expertise in aerothermodynamics, aircraft simulation, and enabling technologies for small satellite launch vehicles.

LauncherOne is designed to deliver approximately 300–500 kg of payload to low-Earth orbit. After its release from a modified Boeing 747 carrier aircraft, LauncherOne uses an expendable two-stage liquid-propulsion rocket to launch the vehicle to a high altitude, where it releases its payloads into orbit.

In FY2017, Ames successfully completed all three tasks that were part of the SAA, including aerothermodynamics analysis of integrated carrier aircraft and launch vehicle, carrier aircraft simulation, and conceptual design of a payload adaptor for small satellites.

LauncherOne is shown being carried by Virgin Orbit's Cosmic Girl carrier aircraft. Credit: Virgin Orbit

"With these new partnerships, we are not only enabling our industry partners, but we're proving that they're instrumental in maturing critical space technologies aligned with NASA's strategic goals. These partnerships support the innovation economy, create U.S. jobs, and provide critical capabilities for future exploration and science missions."

Steve Jurczyk, associate administrator, NASA

Dynetics: Developing and Testing a New Peroxide/Kerosene Engine

Dynetics partnered with NASA's Marshall Space Flight Center to design and fabricate a 1,000 lbf-thrust peroxide/kerosene upper-stage engine. By combining their capabilities, the ACO partners are expected to get over a technology development hurdle.

Testing is being conducted at Marshall to verify engine performance parameters. In FY2017, Marshall and Dynetics completed an initial test series. A second round of testing is to be completed in FY2018, with the test stand being upgraded to accommodate new engine thrust levels.

As a result of initial engine testing, Dynetics was able to secure an engine development contract, enabling the small company to take a significant step toward becoming an engine supplier.

Dynetics performs an engine hot-fire test at NASA's Marshall Space Flight Center using peroxide/kerosene propellant. Credit: NASA

UP Aerospace: Advancing from Suborbital to Orbital Capabilities

Through its ACO partnership with NASA's Marshall Space Flight Center, UP Aerospace is leveraging the center's capabilities to accelerate the design and lower the costs of high-efficiency, upper-stage solid rocket motors (SRMs) for Spyder, its orbital small launch vehicle currently under development.

The partnership is enabling UP Aerospace to move from providing only suborbital capabilities to venturing into the orbital market. The technology development work on the SRMs during FY2017 prepared the company to leverage its Tipping Point award, which will demonstrate other key elements of Spyder. In 2016, UP Aerospace's propellant manufacturer suffered an accident in its manufacturing facility. As a result, the progress of this ACO task has been delayed. UP Aerospace has since developed a new propellant manufacturing facility at its Spaceport America, New Mexico, site and will resume work on this ACO effort.

Researchers conduct a rocket motor qualification test at the Space Propulsion Center, Spaceport America, New Mexico. Credit: UP Aerospace

ACO 2017 Partnerships

ACO 2017 partnerships were awarded in September 2017, with project execution initiating in FY2018. Three companies were selected for ACO Topic 1: Small Launch Vehicle Technology Development:

- **LauncherOne Small Launch Vehicle Propulsion Advancement**

  Virgin Orbit partnering with NASA's Marshall Space Flight Center and NASA's Glenn Research Center

  A continuation of its ACO 2015 work, the scope of the partnership focuses on additive manufacturing of liquid rocket ending thrust chambers and nozzles, integrating materials expertise from Marshall and Glenn with Virgin Orbit equipment and engineering. The outcome of this work could potentially be deployed on existing Virgin Orbit manufacturing machines and be quickly commercialized.

- **Propulsion System and Second-Stage Structural Loads Interaction Test Platform**

  Relativity Space partnering with NASA's Stennis Space Center

  The partnership aims to further the development of innovative orbital launch vehicle additive manufacturing technologies. The partners will investigate a 3D printed pressure-fed propulsion system and second-stage structural vibration and acoustic load interactions in hot-fire testing at Stennis' test stand E3-C2.

- **Spyder Technology Guidance Navigation and Control Affordable Vehicle Avionics (AVA) Development**

  UP Aerospace partnering with NASA's Ames Research Center

  UP Aerospace is leveraging this partnership to pursue risk reduction activities. Ames will provide launch vehicle simulation, guidance, navigation, and control software and AVA hardware for both ground testing and suborbital flight.

Tipping Point Project Highlights

Through its annual “Utilizing Public-Private Partnerships to Advance Tipping Point Technologies” solicitation, NASA seeks U.S. industry–led proposals for space technology demonstration projects executed through firm, fixed-price contracts with milestone payments. A space technology is at a “tipping point” if an investment in a ground or flight demonstration will result in a significant advancement of the technology’s maturation and a significant improvement in the company’s ability to successfully bring the technology to market.

Six companies were selected for Tipping Point contracts in June 2017 with project activities commencing in late FY2017.

HRL Laboratories, LLC

HRL Laboratories will develop additive manufactured high-temperature ceramic materials applicable to rocket engine components. Working with its subcontractor Vector Space Systems, HRL will then mature these materials via a hot-fire test of a high-performance liquid oxygen/propylene rocket engine.

In 2017, HRL made progress on both material and manufacturing process development. The company has acquired a large ceramic parts printing machine to enable the manufacturing of 1,000 lbf-thrust size chamber and nozzle. In addition, HRL has manufactured a subscale thrust chamber, which successfully underwent hot-fire testing by Vector.

Masten Space Systems, Inc.

Masten Space Systems is developing a 25,000 lbf-thrust liquid oxygen/methane Mars lander engine, which incorporates advanced additive manufacturing techniques. When successfully demonstrated, these techniques will reduce both the costs of building the hardware and the technology development cycle time.

In FY2017, Masten conducted its 25,000 lbf-thrust liquid oxygen/methane engine hot-fire test for its second-generation engine design, achieving one of its development milestones. Masten has four generations of engine design development evolution planned as part of this Tipping Point effort. The company aims to position itself as an independent propulsion (engine) system supplier

Masten conducts a hot-fire test of its liquid oxygen/methane Mars lander engine. Credit: Masten Space Systems to vehicle manufacturers. Once this technology is matured, the industry will benefit from the availability of these commercial-off-the-shelf components, which can help accelerate the development of other promising technologies.

Northrup Grumman

Northrup Grumman is incorporating carbon nanotube (CNT)-infused composite structures to evaluate their impact on launch vehicle structural damping during flight. Improvements to structural damping could be revolutionary for launch vehicle design. This activity will include building subsystem-level prototypes and executing flight-like testing. Later, the company will build full-scale flight structures and complete end-to-end testing with either ground and/or flight tests.

In FY2017, Northrup Grumman built over 30 CNT test coupons and evaluated the damping performance in vacuum conditions. They have also tested interlaminar tension coupons and completed the preliminary dynamic environment models correlated to test data.

Tyvak Nano-Satellite Systems, Inc.

Tyvak Nano-Satellite Systems will produce a commercial micro-avionics platform and create a real-time system for launch scenario simulation. Activities will include three test flights to demonstrate the micro-avionics platform. The company's proposed Micro-Avionics Multi-Purpose Platform will provide a low-cost common avionics architecture supporting microsatellites, launch vehicles, and upper-stage carrier platforms.

In FY2017, Tyvak worked with potential launch vehicle providers and NASA to complete development of project requirements and a systems requirements review.

UP Aerospace, Inc.

Aligned with its ACO work, UP Aerospace will demonstrate seven different technologies to reduce development risk of its in-development low-cost orbital small launch vehicle, Spyder. These technologies include a guidance, navigation, and control system; nose-fairing separation system; and lightweight staging system for Spyder. Activities will include ground testing and a suborbital flight test.

In FY2017, UP Aerospace completed its solid rocket motor manufacturing facility, which will support all Spyder motor propellant casting and hot-fire testing. The company also completed its detailed development schedule for each of the seven Tipping Point technologies.

Ventions, LLC

Ventions is working to provide a liquid-bipropellant (LOX/RP-1), electric-pump fed, two-stage launch vehicle for low-cost and on-demand ground launch of small payloads. The vehicle is initially targeted for payloads in the 20- to 40-kg size class (and ultimately up to 100 kg), launching them to 250–750km in altitude, thereby reaching low-Earth orbit (LEO). The proposed launch vehicle uses components matured over more than 10 years under projects funded by the Defense Advanced Research Projects Agency (DARPA) and NASA. Ventions plans to complete development and initial flight testing of its launch vehicle for dedicated launch of small payloads before the end of the 18-month Tipping Point contract.

In FY2017, Ventions completed the initial program kickoff review with NASA. The company initiated the construction and assembly of its Transporter, Erector, Launch platform; propellant skids; and Launch Operations Control Center.

ORBITEC Water Capture Device (WCD) Parabolic Flight Test. Credit: Zero Gravity Corporation

Flight Provider Profiles

Flight Providers Overview

Flight Opportunities flight providers offer researchers 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.

A view of Zero Gravity Corporation's G-FORCE ONE parabolic aircraft during a research flight. Credit: NASA

Flight providers execute flight services through the program via two mechanisms.

Flight Services for Researchers from Industry, Academia, and Research Institutes

Non–U.S. government researchers may submit proposals in response to the Space Technology Research, Development, Demonstration, and Infusion (REDDI) NASA Research Announcement Appendix F. REDDI grants provide funding for flights; researchers whose payload proposals are selected choose their own suitable commercial flight provider. Cost estimates for the requested flight services and the associated flight provider(s) are included in proposal submissions.

Flight Services for U.S. Government Research

Flight Opportunities periodically solicits flight services from industry based on a set of required flight profile capabilities. Eligible flight providers are awarded Indefinite Delivery, Indefinite Quantity (IDIQ) contracts with NASA. Task orders for these services are issued based on the research goals and payload requirements of selected NASA and other U.S. government researchers.

The flight providers showcased on the following pages directly impact the advancement of promising space technologies. In many cases, their collaboration with the Flight Opportunities program has also helped to advance their own businesses and market penetration, enabling them to provide flight services to other customers as well.

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Through the Flight Opportunities program, World View has been able to connect and work with many new and key customers to grow our high-altitude flight services business significantly. Through a REDDI grant, Flight Opportunities has also provided critical support for early-stage development of World View's breakthrough navigable stratospheric vehicle, the Stratollite. The program's continued support of commercial space development efforts is helping to usher in a new age of commercial exploration in the stratosphere and beyond.

Jane Poynter, chief executive officer, World View Enterprises

NSC has benefited greatly from being associated with NASA's Flight Opportunities program. We have been providing similar flight test services to payload providers for more than 20 years, but the standardized structure of Flight Opportunities helps streamline the procurement process and facilitates the establishment of mission requirements and the services needed to meet them.

Tim Lachenmeier, president/
chief executive officer,
Near Space Corporation

Flight Opportunities has been instrumental in helping Masten grow its business. Having a contract with NASA Flight Opportunities was essential in helping the company secure funding from investors. In addition, the technology development work Masten did to support Flight Opportunities payloads helped the company expand its capabilities, which in turn has allowed Masten to bid on and win additional government contracts.

Sean Mahoney, chief executive officer, Masten Space Systems

The technologies funded by Flight Opportunities are helping us to expand our commercial offerings. As a result of the work being done with Johns Hopkins University Applied Physics Laboratory, we will soon offer a new interface option with direct space exposure, which is of interest to a variety of other customers.… The market development that is happening because of Flight Opportunities is resulting in business growth for our company.

Erika Wagner, business development manager, Blue Origin

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Masten Space Systems

www.masten.aero

Headquarters:	Mojave, California
Launch Facility:	Mojave, California
Flight Platform Type:	Vertical takeoff and vertical landing (VTVL)
Focus/Specialization:	Flight testing of technologies that focus on precision entry, descent, and landing methods

Available Flight Platform

- Xodiac
  - Primarily used for terrestrial demonstrations
  - Ideal for testing lunar and Martian landing technologies

FY2017 Flights

Masten completed two flight campaigns for Flight Opportunities in FY2017, both on its Xodiac VTVL platform. Among the payloads demonstrated were the Navigation Doppler Lidar Sensor Demonstration for Precision Landing on Solar System Bodies from NASA's Langley Research Center (part of COBALT, read more on page 10), the Fuel Optimal and Accurate Landing System (FOALS) from NASA's Jet Propulsion Laboratory, and Johns Hopkins University's Electromagnetic Field Measurements Experiment. (Read more about this work on page 13.)

The Xodiac VTVL platform. Credit: Masten Space Systems

World View Enterprises

www.worldview.space

Headquarters:	Tucson, Arizona
Launch Facility:	Tucson, Arizona, as well as mobilization capabilities for remote launches
Flight Platform Type:	High-altitude balloons
Focus/Specialization:	Payload testing for technologies requiring long-duration stratospheric access

Available Flight Platforms

- Stratollite
  - Provides navigable and station-keeping high-altitude balloon flights for payload missions over customer-specific areas of interest for long durations (days, weeks, etc.)
  - Reaches altitudes up to 29 km
  - Accommodates a standard payload mass range of 0–50 kg (capable of heavier mass with customization)
- Z-Class
  - Provides balloon flights at a fixed altitude for short durations (5 minutes to 12 hours)
  - Reaches altitudes up to 46 km
  - Accommodates a payload mass range of 0–10,000 kg

FY2017 Flight

World View completed one flight campaign for Flight Opportunities in FY2017. The successful Stratollite flight was a milestone for testing the company's novel balloon altitude control technology—a key factor in its ability to provide long-duration stratospheric missions for scientific payloads. (Read the full story on page 14.)

The Stratollite high-altitude balloon system.
Credit: World View Enterprises

Near Space Corporation

www.nsc.aero

Headquarters:	Tillamook, Oregon
Launch Facilities:	Tillamook, Oregon Madras, Oregon South Point, Hawaii
Flight Platform Type:	High-altitude balloons
Focus/Specialization:	Extended-duration balloon flights in stratospheric conditions

Available Flight Platforms

- High-Altitude Shuttle System (HASS)
  - Includes a special high-altitude remotely piloted shuttle for payload recovery, enabling rapid payload turnaround for reflight
  - Accommodates payloads up to 10 kg or 5 kg per payload slot
  - Reaches altitudes up to 28 km for flights up to 2 hours
- Nano Balloon System (NBS)
  - Accommodates payloads with minimal integration requirements up to 40 kg or 3 kg per payload slot (10 slots available per flight)
  - Reaches altitudes up to 30 km for flights up to 2 hours
- Small Balloon System (SBS)
  - Includes a parachute payload recovery system
  - Accommodates payloads up to 40 kg or 20 kg per payload slot
  - Reaches altitudes up to 30 km for flights up to 2 hours

FY2017 Flights

The High-Altitude Shuttle System carried by a high-altitude balloon. Credit: Near Space Corporation

Near Space Corporation (NSC) completed two flights for Flight Opportunities in FY2017. One of these used NSC's SBS qualified platform and the other used the HASS. The SBS flight successfully tested a prototype 1,090 MHz automatic dependent surveillance-broadcast (ADS-B) system for the Federal Aviation Administration (read more on page 6). The HASS flight was the second of a two-flight campaign begun in 2016 to evaluate a low-cost suborbital reusable launch vehicle (sRLV) surrogate to evaluate the concept of operations associated with sRLV re-entry into the National Airspace System. Sub-payloads included an ADS-B/Mode-S transponder, an A/C band VHF radio, and a radar reflector.

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

Zero Gravity Corporation

www.gozerog.com

Headquarters:	Arlington, Virginia
Launch Facility:	Orlando, Florida
Flight Platform Type:	Parabolic aircraft
Focus/Specialization:	Crewed parabolic flights for payload testing of academic and commercial technologies in reduced-gravity conditions as well as consumer parabolic flights

FY2017 Flights

ZERO-G completed three flight campaigns for Flight Opportunities in FY2017. Seven notable academic and commercial payloads were demonstrated in the campaigns, including MIT's MOJO-Micro robot; the Evolved Medical Microgravity Suction Device from Orbital Medicine, Inc.; and myriad other technologies with promise for contributing to long-term sustained human presence in space. (Read more about these technologies on pages 7–9.)

Available Flight Platform

- G-FORCE ONE
  - Boeing 727-200F three-engine aircraft, modified for reduced-gravity environments
  - Contains up to 34 seats for researchers and crew
  - Includes an open research area approximately 67 feet long
  - Offers 30 parabolas, with mix of Martian, lunar, and zero gravities
  - Allows for 20–30 seconds of microgravity per parabola
  - Provides flight durations of approximately 2 hours

The G-FORCE ONE parabolic aircraft.
Credit: Zero Gravity Corporation

Blue Origin

www.blueorigin.com

Headquarters:	Kent, Washington
Launch Facility:	West Texas
Flight Platform Type:	Vertical takeoff and vertical landing (VTVL)
Focus/Specialization:	Testing for scientific payloads, including large sizes

Available Flight Platform

- New Shepard
  - A fully reusable VTVL space vehicle
  - Reaches an apogee of over 100 km, with approximately 3 minutes of high-quality microgravity exposure
  - 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 slated to launch several Flight Opportunities program payloads in FY2018, including its first dedicated NASA payload manifest.

The New Shepard VTVL space vehicle. Credit: Blue Origin

UP Aerospace

www.upaerospace.com

Headquarters:	Denver, Colorado
Launch Facility:	Spaceport America, New Mexico
Flight Platform Type:	Suborbital reusable launch vehicles (sRLVs)
Focus/Specialization:	Payload testing for microgravity research

Available Flight Platforms

- SpaceLoft XL
  - 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
  - Accommodates payloads up to 36 kg
  - Offers the option of payload ejection
- Spyder (in development, read more on pages 27 and 29)
  - Expected to accommodate up to six 1U-sized CubeSats (4x4x4 in. each)
  - Projected to launch to an altitude of 200 km

Upcoming Flights

UP Aerospace is continuing its plans toward technology demonstration flights for the Flight Opportunities program in FY2018 and beyond.

The SpaceLoft XL sRLV.
Credit: NASA

Virgin Galactic

www.virgingalactic.com

Headquarters:	Mojave, California
Launch Facility:	Spaceport America, New Mexico
Flight Platform Type:	Air-launched suborbital space plane
Focus/Specialization:	Scientific payload testing in microgravity environments as well as space tourism

Upcoming Flights

Virgin Galactic is slated to launch its first fully manifested payload flight for the Flight Opportunities program in FY2018.

Available Flight Platform

- VSS Unity
  - Mates to a carrier aircraft and takes off from a conventional runway, releasing from the carrier aircraft once appropriate altitude is reached
  - Provides 3–4 minutes of microgravity per flight
  - Enables quick recovery of payloads, with pre-flight and post-flight access within hours of a launch
  - Offers payload capacity of 450+ kg

The VSS Unity suborbital space plane. Credit: Virgin Galactic

Credit: World View Enterprises

NASA material samples selected for long-duration testing on the International Space Station as part of the Materials International Space Station Experiment (MISSE) program. Credit: NASA

Program Highlights

Program Progress

In FY2017, Flight Opportunities completed eight suborbital flight campaigns and saw additions to the technology portfolio as well as progress for the MISSE program and small launch technology development.

Specific achievements included:

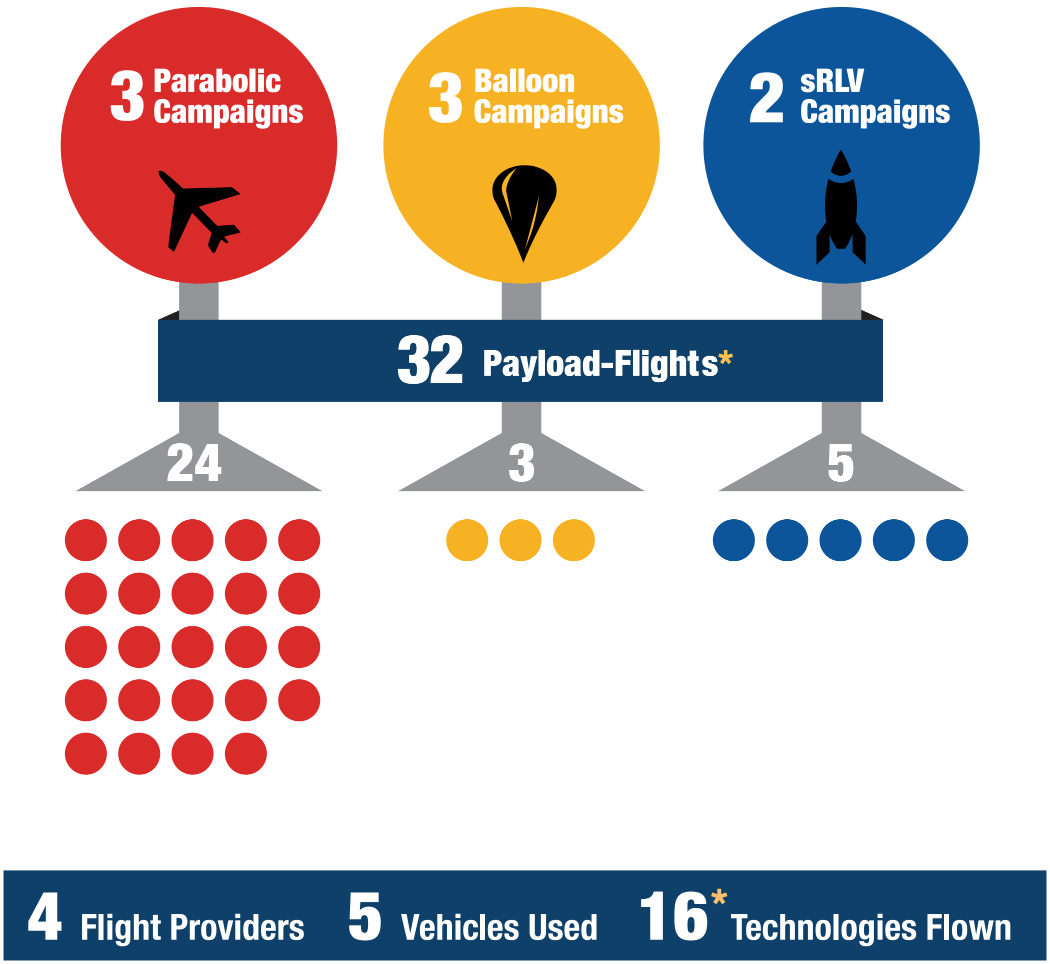
- **Nine new technologies** added to the Flight Opportunities portfolio for suborbital technology demonstration, bringing the total of new technologies to 186 since the program's inception
- Completion of **two REDDI solicitations** and **two NASA internal calls** for technologies to be demonstrated in suborbital environments
- **Nine materials selections** for two MISSE missions (MISSE-10 and MISSE-11)
- Significant progress on small launch capability development, including **three Announcement of Commercial Opportunity and six Tipping Point projects selected**
- Continued **outreach and program awareness** through conference presence, community networking, and publications
- **Sustained collaboration across NASA organizations**, including a notable alignment with the Space Technology Mission Directorate (STMD) strategic objectives

> "*We have been and continue to be proud of the Flight Opportunities team and extended community of flight providers, researchers, and partners whose efforts result in great breadth and depth of activities across the program—activities that we can quantify as having significant measurable impact year after year.*"
>
> Ronald Young, program manager, Flight Opportunities

Sustaining Significant Program Breadth and Impact

With eight suborbital flight campaigns (made up of 14 separate flights) across a variety of platforms carrying a range of technology payloads, the Flight Opportunities program continued to demonstrate significant impact in FY2017.

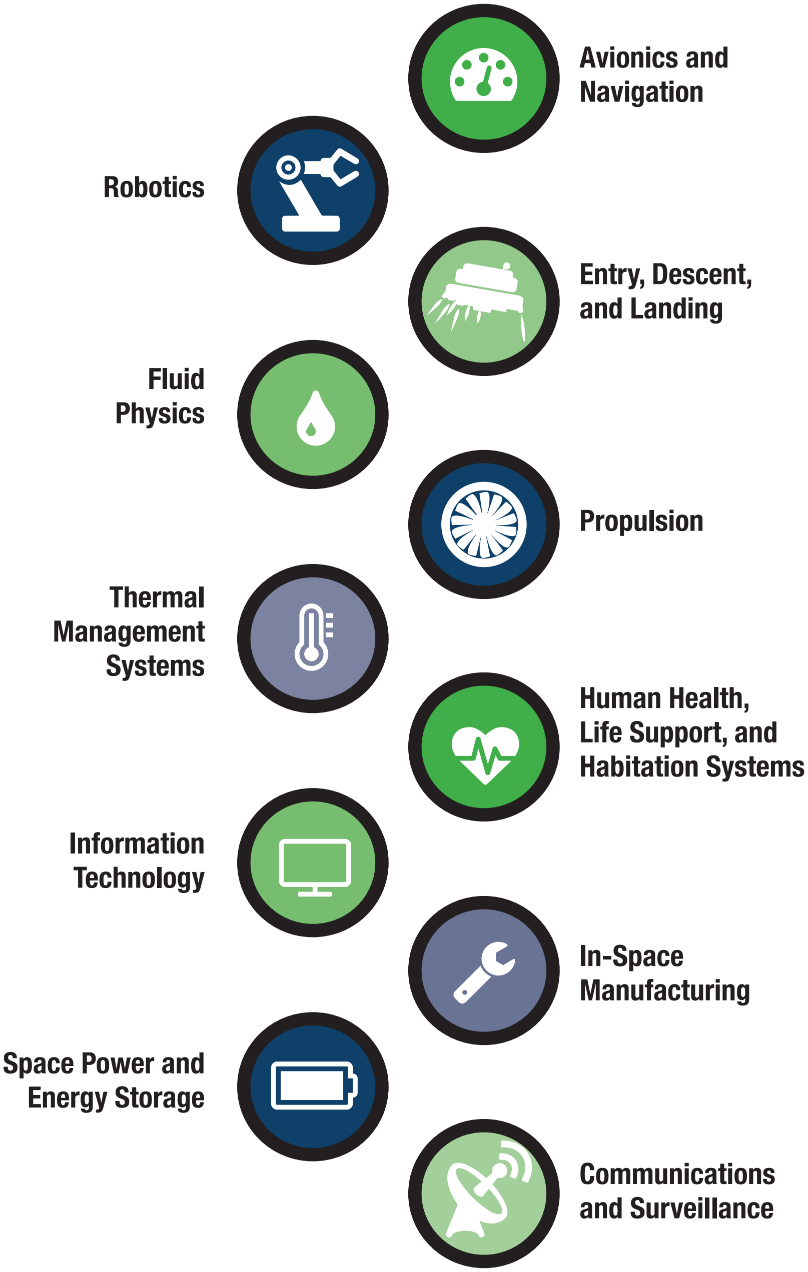
8 Flight Campaigns in FY2017



* Some technologies flew more than once. Each time a technology flies in a particular configuration, it is considered a payload. Each time a payload flies, it is considered one payload-flight.

Technology Impact Areas

The eight flight campaigns in FY2017 helped to mature 16 technologies in a wide range of research areas.



Flight Date	Flight Provider and Platform
Nov 2, 2016	Masten Space Systems *Xodiac*
Nov 15 – Nov 16, 2016	Zero Gravity Corporation *G-FORCE ONE*
Mar 21 – Mar 24, 2017	Zero Gravity Corporation *G-FORCE ONE*
Mar 28 – Mar 29, 2017	Zero Gravity Corporation *G-FORCE ONE*
Apr 6 and Apr 13, 2017	Masten Space Systems *Xodiac*
May 19, 2017	Near Space Corporation *Small Balloon System*
Aug 27, 2017	World View Enterprises *Tycho-20*
Sept 2, 2017	Near Space Corporation *High Altitude Shuttle System*

Payload	Organization	Principal Investigator
T0015 — Electromagnetic Field Measurements on Reusable Launch Vehicle (sRLV)	Johns Hopkins University Applied Physics Laboratory	H. Todd Smith
T0147 — Modal Propellant Gauging in Microgravity	Carthage College	Kevin Crosby
T0150 — Advancing Diaphragm Modeling Technology for Propellant Management	Purdue University	Steven Collicott
T0162 — Evolved Medical Microgravity Suction Device	Orbital Medicine, Inc.	C. Marsh Cuttino
T0163 — MOJO-Micro: Multi-Orthogonal Jaunting Robot in Microgravity	Massachusetts Institute of Technology (MIT)	Neil Gershenfeld
T0167 — ORBITEC Water Capture Device Parabolic Flight Test	Orbital Technologies Corp. (now Sierra Nevada Corp.)	David Hoerr
T0160 — Microgravity Propellant Gauging Using Modal Analysis: Phase II	Carthage College	Kevin Crosby
T0163 — MOJO-Micro: Multi-Orthogonal Jaunting Robot in Microgravity	MIT	Neil Gershenfeld
T0170 — Ground-Based Study of Gravity Effects on Flow Boiling Heat Transfer in Preparation for an ISS Flight Experiment	University of Maryland, College Park	Jungho Kim
T0172 — Development of a Revolutionary Approach for Efficient Microgravity Transfer Line Chilldown	University of Florida	Jacob Chung
T0185 — Evaluation of the Biosleeve Gesture Control Interface for Telerobotics in Microgravity	NASA's Jet Propulsion Laboratory (JPL)	Christopher Assad
T0164 — Microgravity Testing of Comet Sample Verification System	JPL	Risaku Toda
T0098 — Navigation Doppler Lidar Sensor Demonstration for Precision Landing on Solar System Bodies	NASA's Langley Research Center	Farzin Amzajerdian
T0137 — Fuel Optimal and Accurate Landing System Test Flights	JPL	Andrew Johnson
T0159 — 1,090 MHz Automatic Dependent Surveillance-Broadcast (ADS-B) Demo	Federal Aviation Administration	Nick Demidovich
T0169 — A Novel Approach to Balloon Altitude Control for the Purpose of Stratospheric Balloon Trajectory Control	World View Enterprises	Iain Beveridge
T0106 — Low-Cost Suborbital sRLV Surrogate to Test ADS-B	GSSL Inc.	Tim Lachenmeier

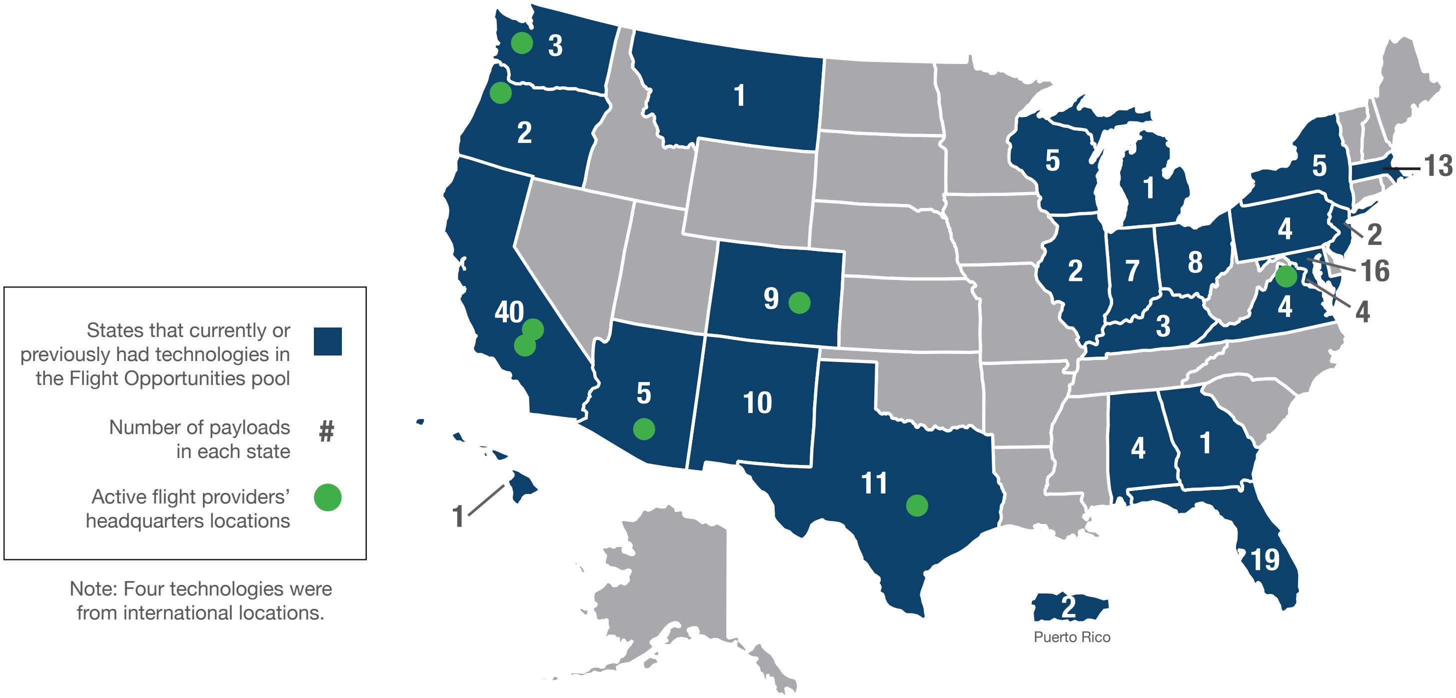
Supporting a Variety of Research Organizations

Suborbital research payloads flown in FY2017 were led by principal investigators and research teams from a diverse array of organizations.

NASA	8	payload-flights from NASA
	17	payload-flights from universities
	6	payload-flights from commercial organizations
	1	payload-flight from other government agencies

Growing Our Geographic Impact

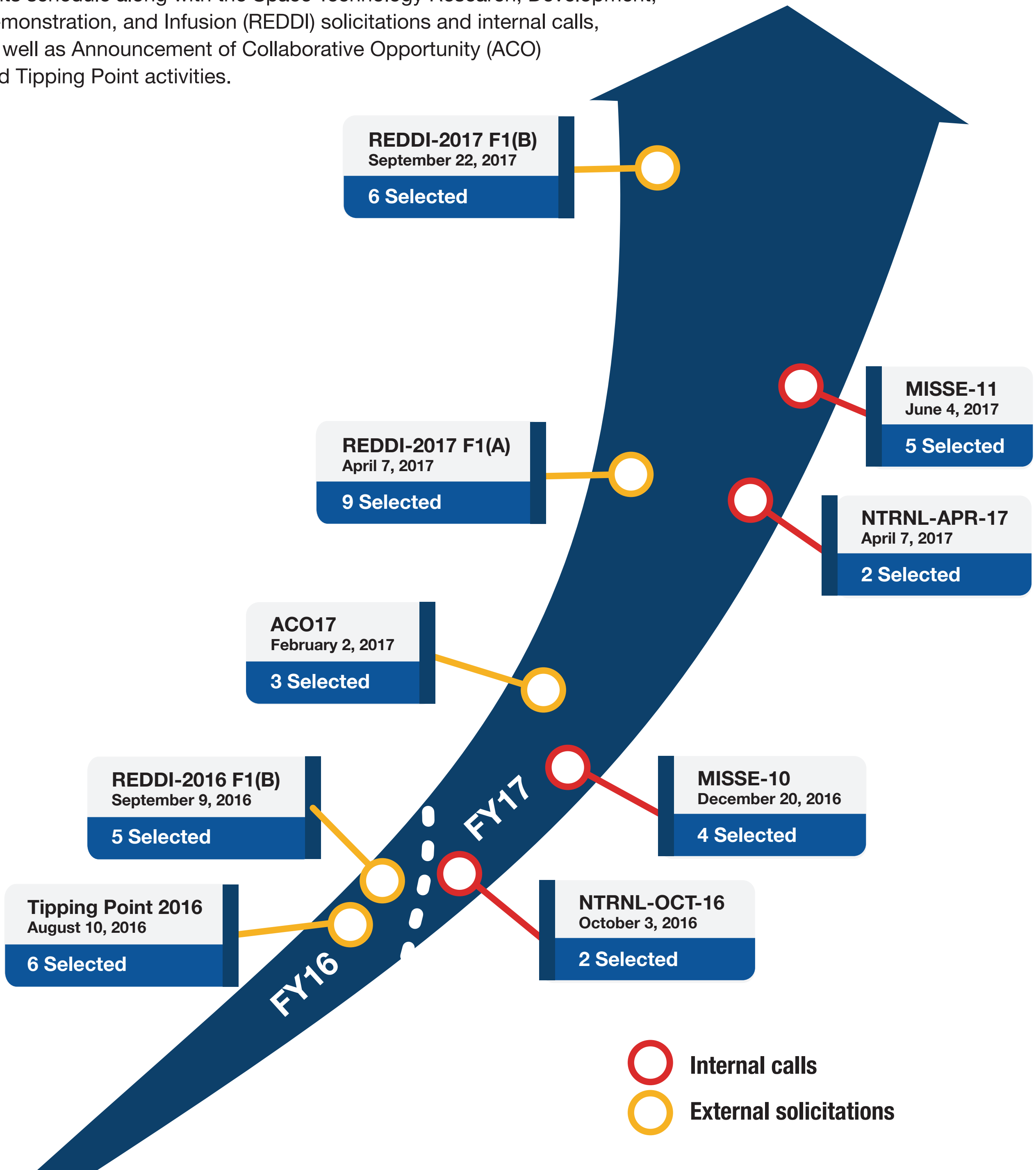
The geographic reach of the Flight Opportunities suborbital technology demonstration efforts continues to expand, with involvement from flight providers and research organizations across nearly half of the U.S. since the program's inception. In FY2017, additional launch locations expanded this impact even more.



Note: Four technologies were from international locations.

Technology Solicitation Schedule

In FY2017, Flight Opportunities added the established MISSE program calls to its schedule along with the Space Technology Research, Development, Demonstration, and Infusion (REDDI) solicitations and internal calls, as well as Announcement of Collaborative Opportunity (ACO) and Tipping Point activities.

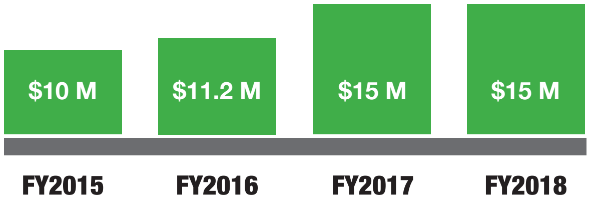


Program Progress

With a diverse array of activities under its umbrella, Flight Opportunities tracks a variety of metrics each year to demonstrate the reach and impact of the program. These include the overall program budget, small launch capability development, suborbital technology demonstrations, flight campaigns, and selections for MISSE missions.

Budget

The Flight Opportunities budget has increased incrementally over the last three fiscal years—a reflection of the increased activities supported by the program, including suborbital flight demonstrations, MISSE selections, and small launch capability development collaborations.



Small Launch Capability Development

In recent years, Flight Opportunities has engaged in public-private partnerships with companies aiming to advance small launch capabilities. These partnerships are administered through NASA's Announcement of Collaborative Opportunity (ACO) and Tipping Point mechanisms. (Read more about these partnerships on pages 24–29).

	FY2015	FY2016	FY2017
	Number of Partnerships Signed		
ACO		5	3
Tipping Point			6

"The forward momentum and growth of the Flight Opportunities program can be seen in our metrics and successes as well as in the growth of our relationships with the suborbital launch community."

Robert Yang, program executive, Flight Opportunities

Campaigns by Provider

In FY2017, Flight Opportunities facilitated flights across a variety of platforms.

Platform	Provider	FY2015	FY2016	FY2017
sRLV	UP Aerospace	1	1	
sRLV	NASA's Wallops Flight Facility	1	1	
sRLV	Masten Space Systems	3		2
Balloon	Near Space Corporation	2	2	2
Balloon	World View Enterprises	1	1	1
Parabolic	Zero Gravity Corporation		2	3
Parabolic	NASA's Reduced Gravity Office	5	2	
	TOTAL	**13**	**9**	**8**

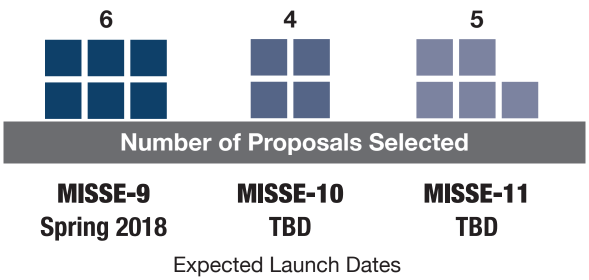
Suborbital Technology Demonstration Portfolio

	FY2015	FY2016	FY2017
Solicitations/Calls	1	4	3
Technologies Selected	7	21	9
Technologies Completed	29	10	24
Active Technologies at Year-End	61	52	58

A significant number of technologies completed their suborbital research objectives, readying them for the next phase of research.

MISSE Selections

In late 2016, Flight Opportunities took on the role of administering proposal review and payload selection for the MISSE program, with the aim of ensuring that the process efficiently and effectively identifies the material specimens with the highest potential for these missions.



Active Technologies Index

The following table shows all payloads that were matured in FY2017, have upcoming test flights planned, or were otherwise in an active status with the program as of the end of FY2017. Refer to the far right column for page numbers in which these payloads are mentioned.

Tech #	Title	PI	Organization	Origin	Page
T0001	Suborbital Flight Environment Monitor (SFEM)	Steve Ord	NASA's Ames Research Center	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	—
T0015	Electromagnetic Field Measurements on Suborbital Reusable Launch Vehicle (sRLV)	H. Todd Smith	Johns Hopkins University Applied Physics Laboratory	AFO1	—
T0020	Microgravity Multiphase Flow Experiment for Suborbital Testing (MFEST)	Kathryn M. Hurlbert	NASA's Johnson Space Center	AFO2	—
T0021	Application of Controlled Vibrations to Multiphase Systems	Ricard Gonzalez-Cinca	University of Alabama–Huntsville	AFO2	—
T0022	Environment Monitoring Suite on sRLV	H. Todd Smith	Johns Hopkins University	AFO2	—
T0023	Measurement of the Atmospheric Background in the Mesosphere	Sean Casey	Silicon Valley Space Center	AFO2	—
T0024	Radio Frequency Gauging of the Liquid Oxygen Tank on sRLV	Gregory A. Zimmerli	NASA's Glenn Research Center	AFO2	—
T0035	Near-Zero Gravity Cryogenic Line Chilldown Experiment in an sRLV	Jacob Chung	University of Florida	AFO3	8, 47
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's Glenn Research Center	AFO3	—

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.

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.

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

Tech #	Title	PI	Organization	Origin	Page
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	AFO4	—
T0054	Stratospheric Parabolic Flight Technology	Steven Collicott	Purdue University	AFO4	—
T0061	Flight Testing of a Universal Access Transceiver Automatic Dependent Surveillance-Broadcast (ADS-B) Transmitter Prototype for Commercial Space Transportation Using Reusable Launch Vehicles	Richard Stansbury	Embry-Riddle Aeronautical University	AFO5	—
T0064	Deployable Rigid Adjustable Guided Final Landing Approach Pinions (DRAG FLAPs)	Joey Oberholtzer	Masten Space Systems	AFO5	—
T0075	Exo-Atmospheric Aerobrake	Marc Murbach	NASA's Ames Research Center	Directed	—
T0076	Demonstration of Vertically Aligned Carbon Nanotubes for Earth Climate Remote Sensing	H. Todd Smith	Johns Hopkins University	NRA1 GCD Appx A	—
T0077	Facility for Microgravity Research and Submicroradian Stabilization Using sRLVs	Scott Green	Controlled Dynamics	NRA1 GCD Appx A	19
T0079	Autonomous Flight Manager for Human-in-the-Loop Immersive Simulation and Flight Test of Terrestrial Rockets	Rick Loffi	Draper Laboratory	NRA1 GCD Appx A	—
T0081	Demonstration of Variable Radiator	Richard "Cable" Kurwitz	Texas A&M Engineering Experiment Station	NRA1 GCD Appx A	—
T0083	Design and Development of a Microsatellite 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	SwRI	NRA1 GCD Appx A	—

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

Tech #	Title	PI	Organization	Origin	Page
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	16
T0095	Test of Satellite Communications Systems Onboard Suborbital Platforms to Provide Low-Cost Data Communications for Research Payloads, Payload Operators, and Space Vehicle Operators	M. Brian Barnett	Satwest Consulting	AFO6	—
T0097	Planetary Atmospheres Minor Species Sensor (PAMSS)	Robert Peale	University of Central Florida	AFO6	—
T0098	Navigation Doppler Lidar Sensor Demonstration for Precision Landing on Solar System Bodies	Farzin Amzajerdian	NASA's Langley Research Center	AFO6	10, 34, 37
T0106	Low-Cost sRLV Surrogate to Test ADS-B	Tim Lachenmeier	GSSL Inc.	AFO6	36, 47
T0110	Wet Lab 2	Macarena Parra	NASA's Ames Research Center	Directed	—
T0114	Technology Demonstration of Graphene Ion Membranes for Earth and Space Applications	H. Todd Smith	Johns Hopkins University	NRA2 GCD Appx E	—
T0115	Entry, Descent, and Landing Technology Development for the Maraia Earth-Return Capsule	Alan Strahan	NASA's Johnson Space Center	NRA2 GCD Appx E	—
T0126	Validating Microgravity Mobility Models for Hopping/Tumbling Robots	Issa Nesnas	NASA's Jet Propulsion Laboratory	AFO8	—
T0128	Zero-Gravity Green Propellant Management Technology	Steven Collicott	Purdue University	AFO8	—
T0129	Testing of a Microgravity Rock Coring Drill Using Microspines	Aaron Parness	NASA's Jet Propulsion Laboratory	AFO8	—
T0137	Fuel Optimal and Accurate Landing System (FOALS) Test Flights	Andrew Johnson	NASA's Jet Propulsion Laboratory	AFO8	34, 47
T0139	Adaptable Deployable Entry and Placement Technology (ADEPT)	Paul Wercinski	NASA's Ames Research Center	Directed	—
T0142	Affordable Vehicle Avionics (AVA)	Carl Kruger	NASA's Ames Research Center	Directed	27
T0143	Bi-Static Radio Frequency Imager	Charles L. Finley	Air Force Research Laboratory Space Vehicles Directorate	Directed	—
T0144	Programmable Ultra Lightweight System Adaptable Radio (PULSAR)	Arthur Werkheiser	NASA's Marshall Space Flight Center	Directed	—

Tech #	Title	PI	Organization	Origin	Page
T0145	Low-Gravity Flow Boiling on Modern Textured Surfaces	Steven Collicott	Purdue University	REDDI-2014	—
T0146	Droplet Pinning in Microgravity	Amir Hirsa	Rensselaer Polytechnic Institute	REDDI-2014	—
T0147	Modal Propellant Gauging in Microgravity	Kevin Crosby	Carthage College	REDDI-2014	8, 47
T0149	Microgravity Fabrication of Freeze-Cast Titanium Foams	David Dunand	Northwestern University	REDDI-2014	18
T0150	Advancing Diaphragm Modeling Technology for Propellant Management	Steven Collicott	Purdue University	REDDI-2014	9, 47
T0151	Preliminary Research Aerodynamic Design to Land on Mars (PRANDTL-M)	Dave Berger	NASA's Armstrong Flight Research Center	Directed	—
T0153	Mars Electric Reusable Flyer	David D. North	NASA's Langley Research Center	Directed	—
T0154	PRIME-4.0: Miniaturized and Reusable Asteroid Regolith Microgravity Experiment for Suborbital and Orbital Use	Josh Colwell	University of Central Florida	REDDI-2015	—
T0155	Suborbital Evaluation of an Aqueous Immersion Surgical System for Reduced Gravity	George Pantalos	University of Louisville	REDDI-2015	—
T0156	Suborbital Particle Aggregation and Collision Experiment-2 (SPACE-2)	Julie Brisset	University of Central Florida	REDDI-2015	—
T0157	Global Positioning System Fading	Nick Demidovich	Federal Aviation Administration	Directed	—
T0158	Zero-Gravity Mass Measurement Device (ZGMMD) Parabolic Flight Test	John Wetzel	Orbital Technologies Corp. (now Sierra Nevada))	REDDI-2015	—
T0159	1,090 MHz ADS-B Demo	Nick Demidovich	Federal Aviation Administration	Directed	6, 36, 47
T0160	Microgravity Propellant Gauging Using Modal Analysis: Phase II	Kevin Crosby	Carthage College	REDDI-2016	8, 47
T0161	Evaluation of the Biosleeve Gesture Control Interface for Telerobotics in Microgravity	Christopher Assad	NASA's Jet Propulsion Laboratory	REDDI-2015	3, 12, 47
T0162	Evolved Medical Microgravity Suction Device	C. Marsh Cuttino	Orbital Medicine	REDDI-2015	9, 37, 47
T0163	MOJO-Micro: Multi-Orthogonal Jaunting Robot in Microgravity	Neil Gershenfeld	Massachusetts Institute of Technology	REDDI-2016	7, 37, 47

Tech #	Title	PI	Organization	Origin	Page
T0164	Microgravity Testing of Comet Surface Sample Return (CSSR) Sample Verification System	Risaku Toda	NASA's Jet Propulsion Laboratory	REDDI-2016	12, 47
T0165	Autonomous Flight Terminator	Lisa Valencia	NASA's Kennedy Space Center	Directed	—
T0166	High-Altitude Electromagnetic Sounding of Earth and Planetary Interiors	Robert Grimm	Southwest Research Institute	NTRNL-JUL-16	—
T0167	ORBITEC Water Capture Device (WCD) Parabolic Flight Test	David Hoerr	Orbital Technologies Corp. (now Sierra Nevada)	REDDI-2016	8, 30, 47
T0168	Suborbital Flight Experiment Monitor-2 (SFEM-2)	Kathryn M. Hurlbert	NASA's Johnson Space Center	NTRNL-JUL-16	—
T0169	A Novel Approach to Balloon Altitude Control for the Purpose of Stratospheric Balloon Trajectory Control	Iain Beveridge	World View Enterprises	REDDI-2016	14, 13, 35, 47
T0170-P	Ground-Based Study of Gravity Effects on Flow Boiling Heat Transfer in Preparation for an International Space Station Flight Experiment	Jungho Kim	University of Maryland, College Park	REDDI-2016	9, 47
T0171	Zero-Gravity Condensation Droplets and Flow in Phase-Change Loops	Steven Collicott	Purdue University	REDDI-2016	—
T0172	Development of a Revolutionary Approach for Efficient Microgravity Transfer Line Chilldown	Jacob Chung	University of Florida	REDDI-2016	8, 47
T0173	Flow Boiling in Microgap Coolers: Embedded Thermal Management for Space Applications	Franklin Robinson	NASA's Goddard Space Flight Center	NTRNL-OCT-16	—
T0174	Low-Cost, Lightweight, and Reusable Radiation Nose Payload	Meyya Meyyappan	NASA's Ames Research Center	NTRNL-OCT-16	—
T0175	Testing of a Novel Intra-Vehicular Activity (IVA) Space Suit	Ted Southern	Final Frontier Design	REDDI-2015	—
T0176	Automated Radiation Measurements for Aerospace Safety - High-Altitude (ARMAS-Hi)	W Kent Tobiska	Space Environment Technologies (SpaceWX)	REDDI-2016	—
T0177	Rapid Calibration of Space Solar Cells in Suborbital Environments	Justin Lee	The Aerospace Corporation	REDDI-2016(B)	—
T0178	Characterization of 3D Printing Processes Under Microgravity Conditions	Suzanne Smith	University of Kentucky	Directed	—
T0179	Honeybee Robotics PlanetVac on Masten Lander	Kris Zacny	Honeybee Robotics	REDDI-2016	—

Tech #	Title	PI	Organization	Origin	Page
T0180	A New Spin on Suborbital Microgravity Research: Developing a Centrifuge for Blue Origin's New Shepard	Mariel Rico	Nanoracks	REDDI-2016	—
T0181	Biochip Suborbital Lab (BCSOL): An Automated Microfluidic and Imaging Platform for Live-Cell Investigations in Microgravity	Daniel O'Connell	HNU Photonics	REDDI-2016(B)	—
T0182	Strata-S1: Refining a Testbed to Evaluate the Behavior of Regolith Under Microgravity Conditions	Adrienne Dove	University of Central Florida	REDDI-2016(B)	—
T0183	Protein-Drop Pinning in Microgravity	Amir Hirsa	Rensselaer Polytechnic Institute	REDDI-2016(B)	—
T0184	SPECTRE 2: Sample Pinning Experiment for Capture Technology in a Reduced-Gravity Environment	Laura Jones-Wilson	NASA's Jet Propulsion Laboratory	NTRNL-APR-17	—
T0185	Evaluation of the BioSleeve Gesture Control Interface for Telerobotics in Microgravity	Christopher Assad	NASA's Jet Propulsion Laboratory	NTRNL-APR-17	3, 12, 47
T0186	Guided Parafoil High Altitude Research II	Garrett (Storm) Dunker	Airborne Systems North America	REDDI-2016(B)	—

The following technologies have transitioned out of the Flight Opportunities portfolio but are mentioned in this report.

Tech#	Title	PI	Organization	Origin	Page
T0077	Vibration Isolation Platform	Scott Green	Controlled Dynamics, Inc.	AF05	19
T0088	A Field Programmable Gate Array (FPGA)-based, Radiation Tolerant, Reconfigurable Computer System with Real Time Fault Detection, Avoidance, and Repair (RadSat)	Brock Lameres	Montana State University	NRA-1 GCD Appx A	16
T0135	Gecko Grippers	Aaron Parness	NASA's Jet Propulsion Laboratory	AF08	17
T0149	Microgravity Fabrication of Freeze-Cast Titanium Foams	David Dunand	Northwestern University	AF08	18

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