National Aeronautics and
Space Administration

Flight Opportunities:
A Stepping Stone to ISS and Beyond

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ISPCS
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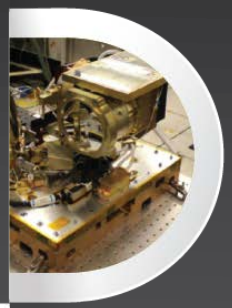
Space Technology Portfolio

Transformative & Crosscutting Technology Breakthroughs

Technology Demonstration Missions bridges the gap between early proof-of-concept tests and the final infusion of cost-effective, revolutionary technologies into successful NASA, government and commercial space missions.



Small Spacecraft Technology Program develops and demonstrates new capabilities employing the unique features of small spacecraft for science, exploration and space operations.

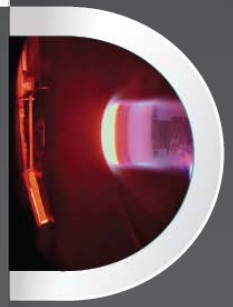
Game Changing Development seeks to identify and rapidly mature innovative/high impact capabilities and technologies that may lead to entirely new approaches for the Agency's broad array of future space missions.

Pioneering Concepts/Developing Innovation Community

NASA Innovative Advanced Concepts (NIAC) nurtures visionary ideas that could transform future NASA missions with the creation of breakthroughs—radically better or entirely new aerospace concepts–while engaging America's innovators and entrepreneurs as partners in the journey.

Space Technology Research Grants seek to accelerate the development of "push" technologies to support future space science and exploration needs through innovative efforts with high risk/high payoff while developing the next generation of innovators through grants and fellowships.

Center Innovation Fund stimulates and encourages creativity and innovation within the NASA Centers by addressing the technology needs of the Agency and the Nation. Funds are invested to each NASA Center to support emerging technologies and creative initiatives that leverage Center talent and capabilities.



Creating Markets & Growing Innovation Economy

Centennial Challenges directly engages nontraditional sources advancing technologies of value to NASA's missions and to the aerospace community. The program offers challenges set up as competitions that award prize money to the individuals or teams that achieve a specified technology challenge.

Flight Opportunities facilitates the progress of space technologies toward flight readiness status through testing in space-relevant environments. The program fosters development of the commercial reusable suborbital transportation industry.

Small Business Innovation Research (SBIR) and **Small Business Technology Transfer (STTR)** Programs provide an opportunity for small, high technology companies and research institutions to develop key technologies addressing the Agency's needs and developing the Nation's innovation economy.

Flight Opportunities Program Charter

To facilitate maturation of cross-cutting space technologies for NASA's Space Technology [Mission Directorate] . . .

. . . while achieving a goal of the National Space Policy to "Encourage and Facilitate" the growth of the U.S. commercial space industry

Create the innovative new space technologies for our exploration, science, and economic future.

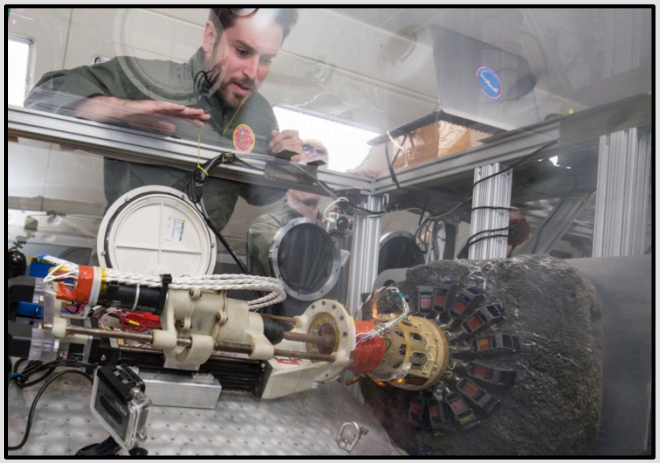
- NASA Strategic Goal 3

Energize competitive domestic industries

- National Space Policy Goal 1

About Flight Opportunities

The Flight Opportunities Program within the NASA Space Technology Mission Directorate (STMD) helps foster the growth of the commercial spaceflight market while helping fulfill the overall goal of advancing space technology to meet future mission needs. The program achieves these self-reinforcing objectives by selecting promising technologies from industry, academia and government, and testing them on commercial suborbital launch vehicles. This approach takes technologies from a laboratory environment and gives them flight heritage, while also feeding the development of the spaceflight technologies and infrastructure being used by the companies Flight Opportunities purchases flights from.

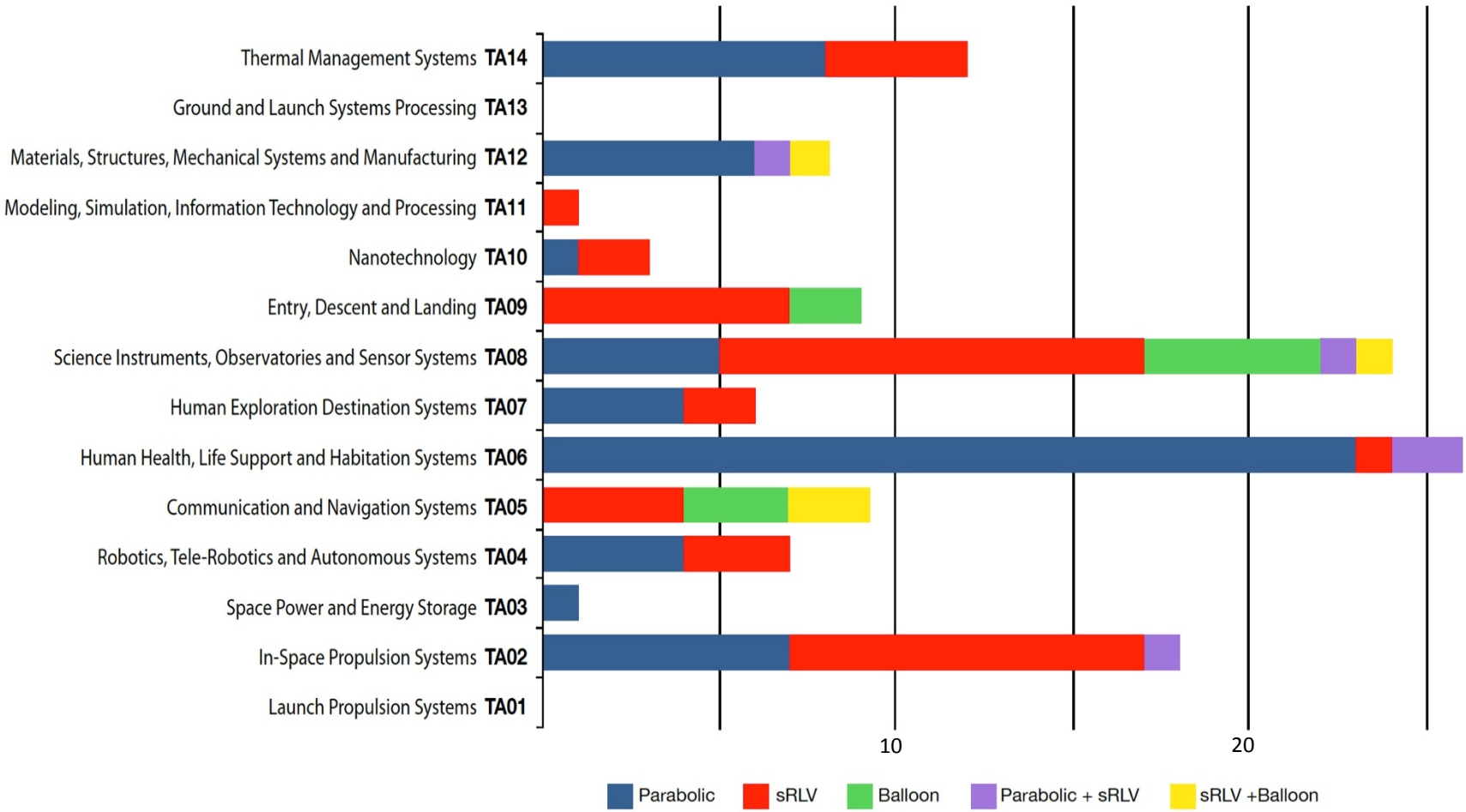


Flight Opportunities Overview

FY 2014 Highlights:

- 140 technology payloads in the program pipeline
- Conducted 5 parabolic flight campaigns and 7 reusable suborbital flight campaigns flying 38 technology payloads in relevant flight environments
- **UP Aerospace Corporation:** Successfully launched SpaceLoft-8 (SL-8) with six program sponsored technology payloads in Nov 2013 from the New Mexico Spaceport America
- **Masten Space Systems**: Flew in Feb & Jun 2014 open-loop and closed-loop flights, respectively, of Astrobotic Technology's newly developed autonomous landing system. These tests validated Astrobotic's optical and Light Detection and Ranging (LIDAR) based system that will be used to perform a lunar soft landing in 2015 for the Google X-Prize
- **Near Space Corporation:** Successfully flew a small balloon from Madras, Oregon for University of Central Florida's Planetary Atmosphere Minor Species Sensor (PAMSS) payload in July 2014
- **Virgin Galactic**: Program has selected 12 technology experiments to fly on the first commercial research flight SpaceShipTwo. This flight is planned for early 2015

Technologies Being Demonstrated by Flight Opportunities



From Suborbital to Orbital:
Electromagnetic Formation Flight

Resonate Inductive Near-field Generation System (RINGS)

Constellations are seen as less expensive, more resilient and more responsive than traditional satellite architectures. However, propellant is required to maintain formation and maneuver the individual components. RINGS generates electromagnetic forces between satellites to **enable propellant-less maneuvering and station keeping.** Interaction between magnetic fields generated by the satellites allows relative motion within a constellation. By reducing propellant use, **Electromagnetic Formation Flight can extend the usable life of satellite constellations.**

From Suborbital to Orbital:
Hazardous Particle Detection

Hazardous Particle Detection

DIAPASON air sampler can **alert astronauts to nanoparticles hazardous to human health**.

Nanoparticles can present an invisible danger to human heath in enclosed environments like the ISS. Stemming from an agreement between NASA and the Italian Space Agency (ASI), the DIAPASON system was developed to detect these particles with an eye towards using the detector onboard the ISS.

Demonstrated to work in microgravity using an Up Aerospace SpaceLoftXL suborbital flight, DIAPASON was subsequently **deployed for testing onboard the ISS.**

From Suborbital to Orbital:
Additive Manufacturing in Space

Additive Manufacturing in Space

Made in Space 3D printer headed to the ISS to be the **first manufacturing device in space.**

Launch as raw material means less mass needs to be put in orbit. Structures don't need to withstand launch and can be larger than the payload shroud. Spare parts can be fabricated in situ, reducing stockpiles. Broken components may be recyclable back in to raw materials.

ISS printer design informed by microgravity flights. First printer will work with plastic. Metal and other materials are being studied. Engineering development printer slated for flight on Virgin Galactic SpaceShipTwo. **Suborbital flight maintains high pace of innovation.**

From Suborbital to Planetary Exploration:
Entry Descent and Landing Systems

Navigation and Hazard Avoidance

New precision landing capabilities need to access science targets in hazardous terrain and for human exploration.

- **Areas of scientific interest are often hazardous** (Canyons, craters, mountains, etc.)
- **For crewed Mars missions precision is required to pre-stage supplies or habitats.**

Suborbital testing allows evaluation of new technologies for infusion into missions like the Mars 2020 rover. JPL and companies like Astrobotic Technology Inc. have used the Masten Space Systems lander test bed to demonstrate landing diverts, terrain relative navigation, and autonomous hazard avoidance.

- JPL Guidance for Fuel Optimal Large Diverts (G-FOLD) can counteract deceleration drift by providing **6x more divert range for a Mars Curiosity class lander**.
- Astrobotic's Autolanding System is designed to precisely navigate landers through terrain relative navigation and autonomous hazard avoidance. **Increased accuracy allows closer landings to canyons, craters, mountains and other currently inaccessible areas.**

Technologies for Human Health and Life Support

Effects of Microgravity on Intracranial Pressure	Univ. Texas SW Medical Center
Evaluation of Medical Chest Drainage System	Orbital Medicine, Inc.
Activity Monitoring during Parabolic Flight	University of Washington
Microgravity Effects of Nanoscale Mixing on Diffusion Limited Processes Using Electrochemical Electrodes	University of Puerto Rico, Rio Pedras
Effects of Reduced and Hyper Gravity on Functional Near-Infrared Spectroscopy (fNIRS) Instrumentation	NASA GRC
Parabolic Flight Evaluation of a Hermetic Surgery System for Reduced Gravity	University of Louisville
Non-Invasive Hemodynamic Monitoring in Microgravity	Stanford University
High Eccentric Resistive Overload (HERO) Device Demonstration during Parabolic Flight	NASA GRC
Assessing Otolith-Organ Function with Vestibular Evoked Myogenic Potentials (VEMPs) in Parabolic Flight	Johns Hopkins University School of Medicine
Testing Near-Infrared Neuromonitoring Devices for Detecting Cerebral Hemodynamic Changes in Parabolic Flight	Massachusetts General Hospital
Monitoring Tissue Oxygen Saturation in Microgravity	University of Oxford
Optical Coherence Tomography (OCT) in Microgravity	Wyle Laboratories
Wet Lab (gene expression analysis of samples)	NASA ARC
Enhanced Dynamic Load Sensors for ISS (EDLS-ISS) Operational Feasibility for ARED	Aurora Flight Sciences

Technologies for ISS Support and Experimentation

EDL Technology Development for the Maraia Earth Return Capsule	NASA JSC
Human Exploration Telerobotics (HET) Smartphone	NASA ARC
Reduced Gravity Flight Demo of SPHERES Universal Docking Ports	Massachusetts Institute of Technology
Reduced Gravity Flight Demonstration of SPHERES INSPECT	Massachusetts Institute of Technology
Dragon V2 Propellant Management Device Microgravity Testing	Space Exploration Technologies
Indexing Media Filtration System	Aerfil (and NASA GRC)
On the performance of a nanocatalyst-based direct ammonia alkaline fuel cell (DAAFC) under microgravity conditions for water reclamation and energy applications	University of Puerto Rico, Rio Pedras
Evaporative Heat Transfer Mechanisms within a Heat Melt Compactor (EHeM HMC) Experiment	NASA GRC
Validation of a Fine Water Mist Fire Extinguisher	ADA Technologies
Demonstration of Food Processing Equipment	Makel Engineering, Inc.
Facility for Microgravity Research and Submicroradian Stabilization using sRLVs*	Controlled Dynamics, Inc.

* Technology development funded by STMD/Game-Changing Development Program
Suborbital flights provided by STMD/Flight Opportunities Program
Selected by CASIS (10/15/14) as an enabling technology to support science in space

Technologies for Satellite Servicing and CubeSats

Autonomous Robotic Capture	NASA GSFC
DYMAFLEX: DYnamic MAnipulation FLight EXperiment	University of Maryland
Dynamic and Static Behavior of a Flexible Fuel Hose in Zero-G	Jackson and Tull
Deployable Solar and Antenna Array Microgravity Testing	Boston University
Structural Dynamics Test of STACER Antenna Deployment in Microgravity	Massachusetts Institute of Technology
UAH ChargerSat - 2 Parabolic Flight Testing	University of Alabama, Huntsville
Caging System for Drag-free Satellites	Stanford University
Design and Development of a Micro Satellite Attitude Control System	State University of New York, Buffalo
Robotics-Based Method for In-Orbit Identification of Spacecraft Inertia Properties	New Mexico State University
Technology Maturation of a Dual-Spinning CubeSat Bus	Massachusetts Institute of Technology
Testing the Deployment and Rollout of the DragEN Electrodynamic Tether for CubeSats.	Saber Astronautics Australia Pty. Ltd.
Testing a CubeSat Attitude Control System in Microgravity Conditions	University of Central Florida
Characterizing CubeSat Deployer Dynamics in a Microgravity Environment	California Polytechnic State University
Reinventing the wheel: parabolic flight validation of reaction spheres	NASA GSFC
Payload Separation Performance of a New 6U CubeSat Canisterized Satellite Dispenser	Air Force Research Laboratory

Technologies for Exploration

Fuel Optimal Large Divert Guidance for Planetary Pinpoint Landing (G-FOLD)	NASA JPL
Fuel Optimal and Accurate Landing System Test Flights	NASA JPL
Autolanding for Robotic Precursor Missions	Astrobotic Technology, Inc.
Flyover Mapping and Modeling of Terrain Features	Carnegie Mellon University
Navigation Doppler Lidar Sensor Demonstration for Precision Landing on Solar System Bodies	NASA LaRC
Validating Microgravity Mobility Models for Hopping/Tumbling Robots	NASA JPL
Testing of a Microgravity Rock Coring Drill Using Microspines	NASA JPL
Testing ON-OFF Gecko Adhesive Grippers in Microgravity	NASA JPL
OSIRIS-REx Low-Gravity Regolith Sampling Tests	Lockheed Martin Inc.
On-Orbit Propellant Storage Stability	Embry-Riddle Aeronautical University
Advanced Optical Mass Measurement System	Mass Dynamix, Inc.
Microgravity Experiment on Accretion in Space Environments	University of Central Florida
Gannon University's Cosmic-Ray Calorimeter (GU-CRC)	Gannon University
Cryocooler Vibrational Characterization	Ad Astra Rocket Company
Heat Pipe Limits in Reduced Gravity Environments	NASA GRC
Sintering of Composite Materials under Reduced Gravity Conditions	Advanced Technical Institute I.T.I.S "E. Fermi"

Revised Approach to Payload Solicitation

- Program to Continue Technology Demonstration Partnerships with Technology Developers

- STMD NASA Research Announcement Appendix F1
  - Topic 1: Demonstration of Space Technology Payloads
  - Topic 2: Demonstration of Vehicle Capability Enhancements and Onboard Research Facilities for Payload Accommodation
  - Proposals Due – November 20, 2014
  - Details at http://goo.gl/iBsa7V

- Program to Fund Standard Payload Integration and Flight Costs
  - Proposers to purchase flights on their own from U.S. commercial parabolic and suborbital flight vendors

Program Vision: NASA is one among many customers

Collaboration with Science & Education

- Why STMD/Science Mission Directorate (SMD) Partnership?
  - Access to Frequent Lower Cost Commercial Flight Opportunities
  - Retire Technology Maturation Risks Prior to SMD Proposal
  - Program Flight Platforms Offered in ROSES and USIP
  - Working on a Joint STMD/SMD Solicitation

- Why STMD/Education Partnership?
  - Start Early to Train the Future Workforce
  - Fly Often to Develop Technology Capabilities
  - Fly Thousands of Payloads Tomorrow instead of Tens of Payloads Today

Demand Stimulates Suborbital Flight Supply

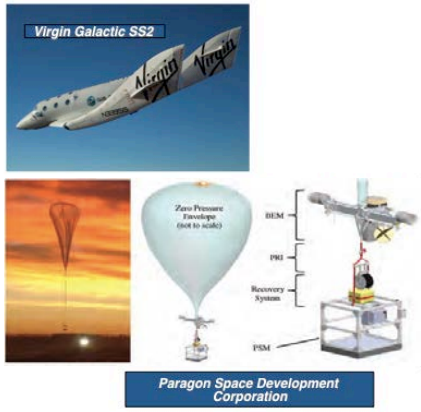
New Commercial Flight Providers

IDIQ2 Providers Selected September 2014

Company	Payload Capacity	Flight Profile
Masten Space Systems	40kg	Up to 0.8km alt. 1.0km down-range vertical takeoff/landing
Paragon Space Development Corp	20-285kg	Up to 43km alt.; minimum 1hr flight time
UP Aerospace	37kg	115km alt. 3-4 minute micro-g
Virgin Galactic	453kg	80-100km alt. 3-4 minute micro-g

- Indefinite Delivery Indefinite Quantity Contracts – Round #2 (IDIQ2)
- Firm-Fixed Price, Multiple Awards
- Five Year Performance Period
- New Flight Vendor Solicitation limited to **Vendors with Operational Capability**
- Must Provide Commercial Operations
- Purchase can be a **payload slot** or full manifest
- Provision to **On-Ramp** New Vendors
- Provision to Solicit **Technology Expansion** in future

UP Aerospace



Paragon Space Development Corporation

Masten Space Systems Xombie

Annual On-Ramp for New Flight Providers

Opportunities for Vendors with Emerging Capabilities

- Public Private Partnership for Development of Reusable Suborbital and Orbital Launch Systems
- Transfers and capitalizes on NASA's long history in investments, knowledge, and expertise in launch systems
- NASA contribution could include technical expertise, test facilities, hardware, and software
- Partnership arrangements could include non-reimbursable Space Act Agreements, Cooperative Agreements, etc.
- Successful partnership could enable vendors to compete for IDIQ2 on-ramp opportunities
- Seeking input until Oct 31 from partners: http://go.usa.gov/VRJW

NASA can Help Emerging Flight Providers

FY2015 and Beyond

- Program will continue to utilize and foster U.S. commercial sRLV capabilities
- Program expects to on-ramp flight providers annually
- Program plans to fund PIs to purchase flights directly from commercial flight vendors
- Program plans to collaborate with NASA science and education to expand scope of suborbital flight demonstrations
- With increasing demand for flights, the program will support additional flights on suborbital reusable platforms, conducting one or more flights every month

Contact Information

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Links:

Payload Solicitation (due 11/20):	http://goo.gl/iBsa7V
Suborbital Vendor RFI (due 10/31):	http://go.usa.gov/VRJW
Program Website:	http://flightopportunities.nasa.gov
Program Annual Report:	http://goo.gl/e1xsAb

Questions?

Backup Charts

From Suborbital to Orbital and Beyond

Iterative testing in suborbital flight allows risk reduction for new spaceflight hardware at significantly lower cost than orbital launch.

Laboratory performance is not always indicative of how fluid and mechanical systems will behave in space.

Successful suborbital testing demonstrates performance in a relevant environment, allowing infusion into future missions or advancement to the next level of testing in orbit.

Systems as diverse as fire suppression and air filtration systems for the International Space Station (ISS), CubeSat subsystems and deployment mechanisms, and next generation entry decent and landing systems have benefited from suborbital and microgravity flights.

Technologies tested have been launched to the ISS, are to be used in commercial Lunar missions, and are candidates to help land the next Martian rover.

Testing Critical Exploration Technologies

In support of NASA's overall mission, Flight Opportunities has facilitated the testing of technologies for exploration and the commercial utilization of space. To date, the program has helped test technologies that will help: guide the next generation of spacecraft to safe landings on the moon, Mars, and back on Earth; track spacecraft though the national airspace; facilitate in situ repair and construction of spacecraft; and enable on-orbit refueling and spacecraft servicing.

Through in-atmosphere microgravity testing, Flight Opportunities has provided valuable flight time for fire suppression, water purification, air filtration and other life support systems. Without the orientation provided by a strong gravity vector, laboratory performance is not always indicative of how fluid and mechanical systems will behave in space. Iterative testing in microgravity through parabolic or suborbital flight allows risk reduction for new spaceflight hardware at significantly lower cost than orbital launch.

From Suborbital to Orbital:
Additive Manufacturing in Space

Additive Manufacturing in Space

Structures fabricated in space do not need to withstand the stress of launch or even the normal force of gravity experienced on the surface of Earth. This reduces the structural density required and decreases the mass that needs to be lifted to orbit. Cost effectively launched as raw material, structures manufactured in space can be lighter and are unconstrained by the geometry of the launch system.

The capacity to fabricate hardware in space can dramatically change future human mission architectures. A spacecraft or habitat outfitted with additive manufacturing capabilities can fabricate new or replacement components onboard. A smaller quantity of versatile raw material can replace voluminous stockpiled spare parts. Coupled with the potential to recycle damaged parts for raw materials or extract resources in situ, this technology can reduce the reliance on resupply from Earth for future missions.

Redesigned to work in 0g though knowledge gained on Flight Opportunities flights, the 3D printer technology developed by Made in Space Inc. will be further tested on the International Space Station (ISS) as the first additive manufacturing system in space.

"Made In Space credits much of its early innovation to the work performed through the Flight Opportunities Program. During 2011 we flew over two hours of microgravity manufacturing time with our 3D printers on the G-Force One parabolic aircraft. From this we developed a foundation for the development of our 3D Printer for the ISS."

- Jason Dunn, CTO Made in Space Inc.

From Suborbital to Orbital:
Electromagnetic Formation Flight

"For the first time we were able to submit the payload to 6 Degrees of Freedom testing under multiple operational scenarios, including system mass and inertial identification and fundamental formation control maneuvers."

- Ray Sedwick, University of Maryland (RINGS PI)

Electromagnetic Formation Flight

Multiple small spacecraft can replace monolithic satellites in a manor that is more responsive, more resilient, and less expensive. However, such distributed constellations must maintain the desired position and orientation relative to each other. Using traditional thrusters, this shortens the operational lifetime of the constellation due the limited onboard propellant.

Electromagnetic formation flight mitigates this constraint by using electromagnetic forces to orient and reposition the satellites. Magnetic forces and torques are generated by circulating electrical current through a coil attached to each spacecraft. The interaction between spacecraft effectively creates a propellant-less propulsion technology for relative station keeping and maneuvering within the satellite constellation.

Prior to testing on the ISS, the Resonant Inductive Near-field Generation System (RINGS) was put through its paces on Flight Opportunities microgravity flights, allowing full six degree of freedom motion for the first time. This activity gathered the data necessary to develop control models for electromagnetic formation flight experiments on the ISS using RINGS.

From Suborbital to Planetary Exploration:
Entry Descent and Landing Systems

Entry Descent and Landing Systems

Targets of scientific interest are often located in formidable terrain. For robotic missions, increased landing accuracy and autonomous hazard avoidance open up new areas for exploration. New capabilities allow future missions to currently inaccessible science targets in hazardous terrain on Mars, the moon or the jagged icy surface of Europa. To prepare for human missions to Mars or extended lunar expeditions, increased precision is required to land payloads in close proximity to pre-stage supplies or habitats.

Guidance for Large Diverts

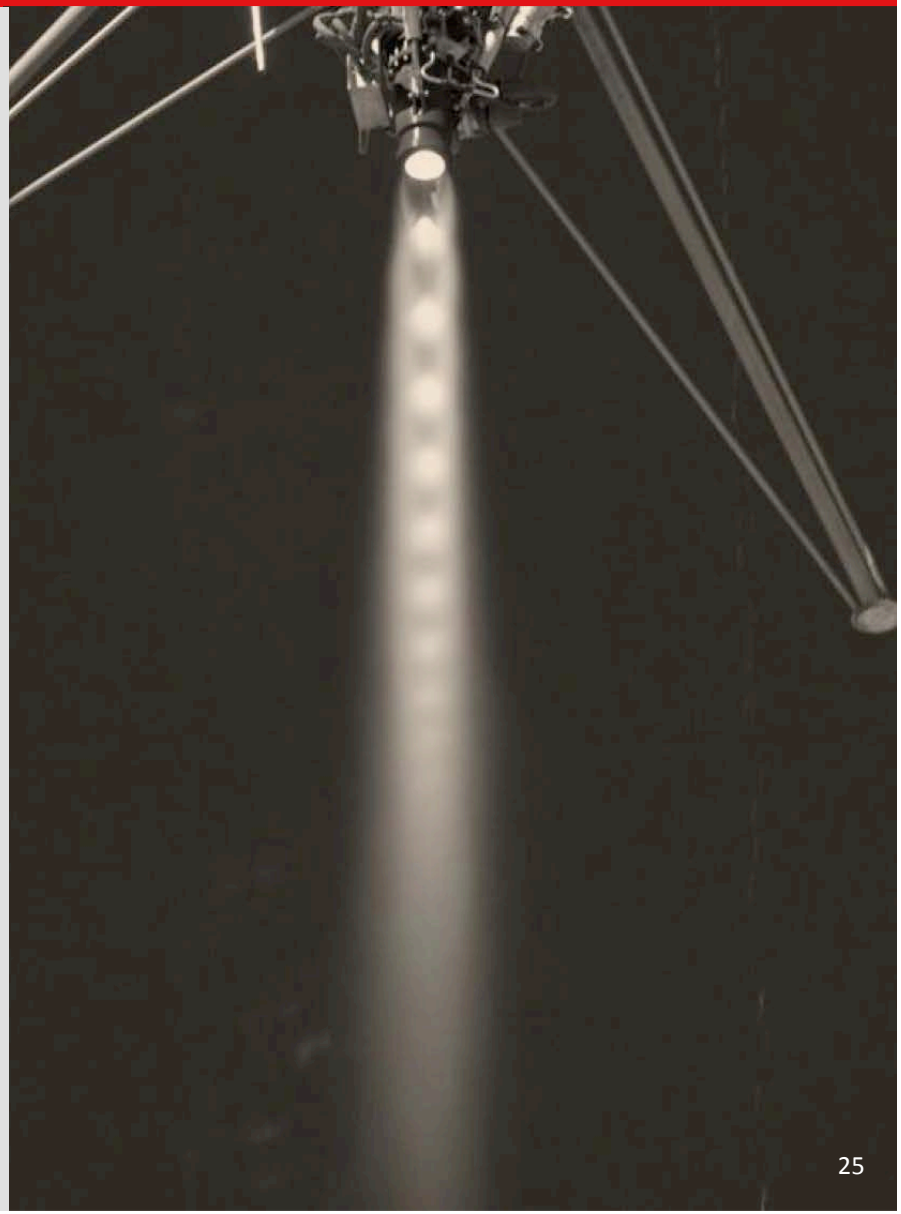
When entering the Martian atmosphere, a spacecraft will drift while decelerating or under parachute. The current state of the art is to attempt recovery from this drift during a subsequent period of powered flight. However, current powered-descent guidance algorithms do not optimize fuel usage and significantly limit how far a landing craft can be diverted back on course.

Compared to the software used to land the Mars Curiosity rover in 2012, the Guidance for Fuel Optimal Large Diverts (G-FOLD) algorithm developed by the NASA Jet Propulsion Laboratory can provide six times more divert range for a lander of that class. A future rover similar to Curiosity might be able to land right next to a target of scientific interest like Mount Sharp instead of driving for a year to get there.

Utilizing the XA-0.1B “Xombie” commercial lander testbed designed and operated by Masten Space Systems, the Flight Opportunities Program helped JPL demonstrate G-FOLD in flight on a rocket-powered vehicle that operates analogous to a Martian lander. A propulsive lander like the XA-0.1B has the same general flight control architecture and subsystems that G-FOLD would be integrated into for a Martian lander. Unlike a helicopter or small UAV, the XA-0.1B has no rotor blades to slow it’s decent and can drop altitude much faster than either of those platforms, better mimicking a planetary entry flight profile. This allows JPL to test technologies like G-FOLD under conditions closer to an operational space mission. A subsequent flight series will test the JPL Lander Vision System that is designed to work with G-FOLD to help precisely navigate landers for future missions like the Mars 2020 rover.

From Suborbital to Planetary Exploration:
Entry Descent and Landing Systems

Terrain Relative Navigation and Hazard Avoidance

Already used for military applications in GPS denied environments, Terrain Relative Navigation (TRN) is an essential tool for accurate landing of spacecraft beyond Earth and its orbiting GPS constellation. TRN uses sensor systems and feature recognition software to match observed terrain with a preloaded map to determine a spacecraft's position relative to the surface. The increased navigational accuracy reduces the size of the potential landing area and allows landing targets to be moved away from the center of large flat plains and closer to canyons, craters, mountains and other important but challenging terrain features. Applying terrain feature recognition on a smaller scale, future missions can be aided by navigation systems that can autonomously detect and avoid rocks, pits and other hazards.

In addition to the work being performed at JPL and within NASA, private companies are investing in landing systems for commercial use. Astrobotic Technology Inc. has developed and tested a terrain relative navigation and lidar based hazard detection system for their commercial lunar lander. Through flights enabled by Flight Opportunities, the Astrobotic system successfully command Masten's XA-0.1B to a safe landing in a simulated lunar hazard field at the Mojave Air and Space Port. Astrobotic, a Google Lunar X-Prize contender and recently announced NASA Lunar CATALYST awardee, plans to utilize the now tested system to overfly and map a pit in the Lacus Mortis ("Lake of Death") lava plain before safely landing on the lunar surface nearby.