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A Decade of Technology Maturation Through NASA's Flight Opportunities Program

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Abstract

The Flight Opportunities program, within NASA's Space Technology Mission Directorate (STMD), facilitates rapid demonstration of promising technologies for space exploration, discovery, and the expansion of space commerce through suborbital testing with industry flight providers. Over the past ten years, the program has matured capabilities needed for NASA missions and commercial applications while strategically investing in the growth of the U.S. commercial spaceflight industry. These flight demonstrations take technologies from ground-based laboratories into relevant environments to increase technology readiness and validate feasibility while reducing the costs and technical risks of future missions. Awards and agreements for flight demonstrations are open to researchers from industry, academia, non-profit research institutes, and government organizations. These investments help advance technologies of interest to NASA while supporting commercial flight providers and expanding space-based applications and commerce. The impact of Flight Opportunities over the past decade has been significant, with numerous Flight Opportunities-supported innovations advancing to support NASA missions, including the Mars 2020 Perseverance mission, technologies for Commercial Lunar Payload Service (CLPS) lander vehicles and payloads, and technologies to support human landing systems (HLS). This paper will highlight the evolution of the program, the breadth of technologies that have been tested on a variety of suborbital platforms, and the impacts of these innovations both for NASA missions and the advancement of the commercial space industry.

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I. Nomenclature

ACO = Announcement of Collaborative Opportunity
AFO = Announcement of Flight Opportunities
AFRL = Air Force Research Laboratory
AFTS = Autonomous Flight Termination System
AVA = Affordable Vehicle Avionics
CLPS = Commercial Lunar Payload Services
DSOC = Deep Space Optical Communications
FY = Fiscal Year
GPS = Global Positioning System
GN&C = Guidance, Navigation & Control
HLS = Human Landing Systems
JPL = NASA's Jet Propulsion Laboratory
LVS = Lander Vision System
NRA = NASA Research Announcement
SBIR = Small Business Innovation Research
SLS = Space Launch System
Space Tech REDDI = Space Technology Research, Development, Demonstration, and Infusion
STMD = Space Technology Mission Directorate
TRL = Technology Readiness Level
TRN = Terrain-relative Navigation

II. Introduction

In the 2010 report "Revitalizing NASA's Suborbital Program: Advancing Science, Driving Innovation and Developing Workforce," the National Academy of Sciences found that suborbital science missions were absolutely critical to building an aerospace workforce capable of meeting the needs of current and future human and robotic space exploration. In 2011, the Flight Opportunities program was established by NASA as a response to the NASA Authorization Act of 2010, Sec. 907: Commercial Reusable Suborbital Research Program. This act stated that the Administrator "…shall fund the development of payloads for scientific research, technology development, and education, and shall provide flight opportunities for those payloads to microgravity environments and suborbital altitudes." The program is still in place nearly a decade later and continues to play a critical role in helping NASA achieve its space exploration objectives.

Flight Opportunities facilitates rapid demonstration of promising technologies for space exploration, discovery, and the expansion of space commerce through suborbital testing with industry flight providers. The program matures capabilities needed for NASA missions and commercial applications while strategically investing in the growth of the U.S. commercial spaceflight industry. These flight tests take technologies from ground-based laboratories into relevant environments to increase technology readiness and validate feasibility while reducing the costs and technical risks of future missions.

Awards and agreements for flight test are open to researchers from industry, academia, non-profit research institutes, and government organizations, including NASA programs seeking suborbital testing to support technology development. These investments help advance technologies of interest to NASA while supporting commercial flight providers and expanding space-based applications and commerce. The technologies are tested on a variety of suborbital platforms, including high-altitude balloons, parabolic aircraft, and rocket-powered vehicles that include both suborbital reusable rocket systems that reach high altitudes, as well as vertical takeoff vertical landing systems that simulate lander vehicles.

III. Flight Opportunities by the Numbers

The impact of Flight Opportunities has been significant and far-reaching. While it is not possible to capture this impact in its entirety through numbers, a few simple metrics do tell a compelling story. Since 2011, Flight Opportunities has, as of June 30, 2020:

- Selected 262 technologies into the portfolio, approximately one-third of which have transitioned to missions, programs, commercial partners, or further testing
- Supported 193 successful flights
- Enabled 689 tests of payloads
- Worked with 12 active commercial flight providers

Over the course of ten years, a number of the flight-test proposals selected by Flight Opportunities have been evolutionary iterations of an initial innovation, resulting in a portfolio of approximately 160 distinct technologies that are of interest to NASA.

The principal investigators responsible for the development and testing of these technologies determine the type of environment that is required to evaluate or advance the innovation. Many investigators leverage the ability to cost-effectively and rapidly access suborbital flights to test their technology multiple times on the same vehicle, making adjustments to the technology between flights. Others take advantage of the variety of suborbital vehicles offered by the commercial providers to test on multiple platforms, enabling investigation of technology performance in various environmental conditions. In many cases, several technology payloads are carried on a single suborbital flight, enabling simultaneous technology tests with a single launch. As a result, through the 193 successful Flight Opportunities-supported flights, a total of 689 payloads tests have been conducted. These tests have played a significant role in advancing technologies that have been selected to provide critical capabilities for NASA missions.

IV. Flight Opportunities Community

Principal investigators testing technology through Flight Opportunities are part of a wide range of entities, including NASA, other government agencies, academic institutions, private research institutions, and non-profit organizations. Figure 1 demonstrates the diversity of types of entities that make up the researcher community.

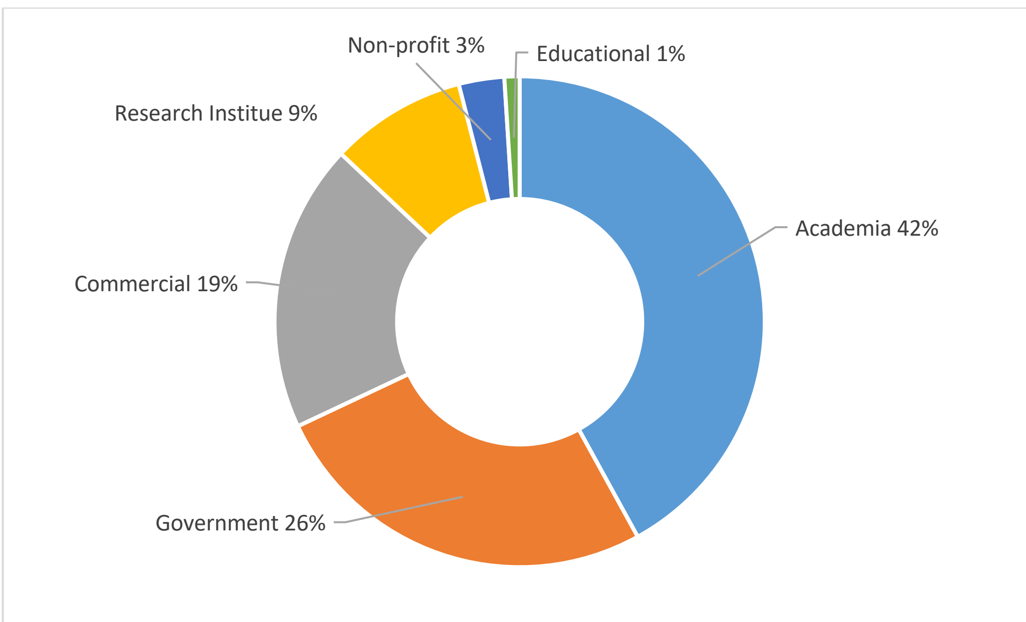

Fig. 1 Distribution of principal investigators by entity type (as of end of fiscal year [FY] 2019)

Flight Opportunities supports testing on a variety of vehicles, depending on the type of environment required to evaluate or advance the readiness of the technology. Commercial providers offer access to many vehicle types, each with its own unique environment and capabilities for testing. Suborbital flights enable researchers to test their hardware and procedures in conditions such as:

- Variable gravity (micro-, lunar, and Martian gravity levels)

- Planetary re-entry (high-altitude entry/descent and low-altitude descent/landing)
- Solar and radiation exposure
- Extreme temperatures and vacuum

The vehicles are generally grouped into three categories:

- *High-altitude balloons* - Large balloon systems reach a nominal altitude of 30 km and can also typically sustain the longest flight time of the suborbital vehicles—hours, days, or even weeks at a time. This makes them ideal for payloads that benefit from extended periods of data collection.
- *Parabolic aircraft* - These specialized airplanes achieve brief periods of variable gravity through a series of maneuvers called parabolas. They can be used for demonstrating technologies that need to operate in a specific gravity environment (e.g., lunar, Mars).
- *Rocket-powered vehicles* - These vehicles include both reusable rocket systems that reach high altitudes, as well as lander vehicles. Both of these classes of vehicles are typically recoverable and reusable after launch.

Suborbital testing can provide a cost-effective means to bridge the maturity gap between ground testing and orbital missions, as shown in Fig. 2. These flight tests offer an option for iterative testing as well as the opportunity to facilitate technology maturation, validate feasibility, and reduce technical risks for future missions.

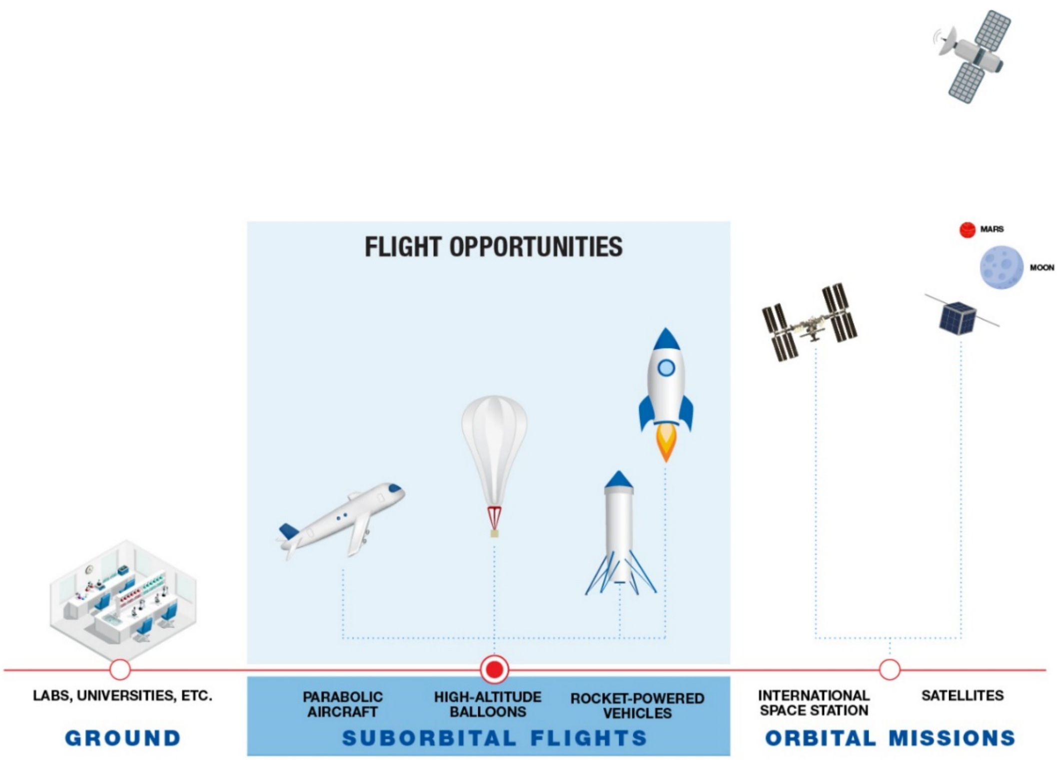

Fig. 2 Suborbital testing serves as a bridge between ground tests and orbital missions

The type of vehicle selected for testing depends on the required test conditions (e.g., gravity level needs, length of microgravity period). Figure 3 highlights the breakdown of flight vehicle types requested by researchers. In some cases, multiple flights on a combination of vehicle types were requested.

As of August 2020, there are 12 active commercial flight providers participating in Flight Opportunities-supported tests. Some of these companies have a contract with NASA Flight Opportunities, while others are contracted independently by principal investigators that have received awards from NASA to fund suborbital flight tests. Current flight providers active with the program include:

- Angstrom Designs
- BlackSky Aerospace
- Blue Origin
- EXOS Aerospace Systems and Technologies
- Masten Space Systems
- Near Space Corporation
- Raven Aerostar
- Stratodynamics
- Virgin Galactic
- UP Aerospace
- World View Enterprises
- Zero Gravity Corporation

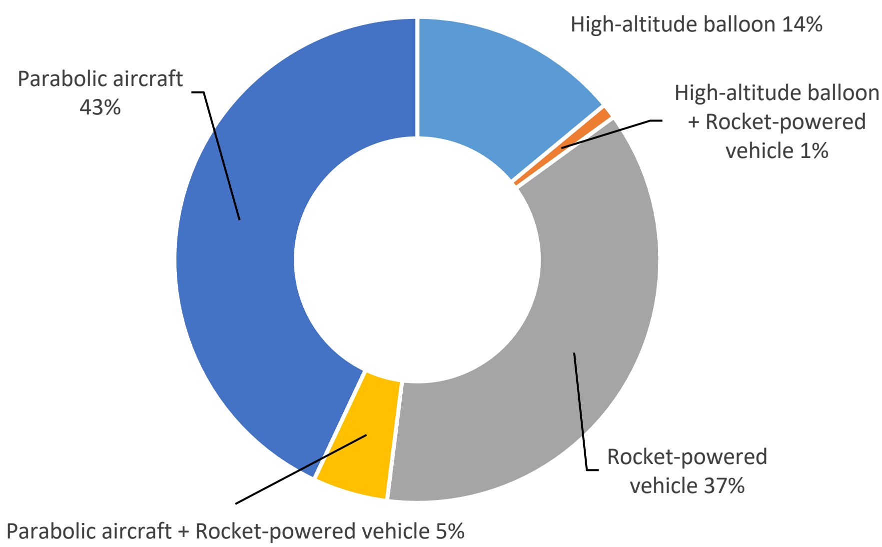

Fig. 3 Distribution of requested flight vehicle type (as of end of FY 2019)

V. Technology Selection and Support Agreements

Over the ten-year history of the program, Flight Opportunities has continually worked to maximize impact. There were many challenges associated with the start of the program, particularly because NASA had not previously interacted with the commercial community in this fashion. One of the key challenges was matching technology development and testing needs to available flight-testing capabilities in a nascent marketplace. As the capabilities of both researchers and commercial flight providers have advanced, the technology selection and agreement mechanisms from NASA have evolved. The program continues to refine its support of technology development and testing in order to optimize results for NASA and the commercial marketplace.

Flight Opportunities focuses on technologies that fall between 4 and 7 on NASA's Technology Readiness Level (TRL) scale (https://www.nasa.gov/directorates/heo/scan/engineering/technology/txt_accordion1.html). In the early days of the program, Flight Opportunities played a significant role in arranging flights for researchers and providing support in preparing payloads for flight test. The Announcement of Flight Opportunities (AFO) solicitation started in

FY2011 to select and demonstrate payloads using commercial suborbital flights. Open to investigators both inside and outside of NASA, the AFO was the primary means of bringing technologies into the program.

In 2014, a solicitation named “Technology Advancement Utilizing Suborbital Flight Opportunities” was introduced as an Appendix to the NASA Research Announcement (NRA) titled "Space Technology Research, Development, Demonstration, and Infusion (Space Tech REDDI)” under the Space Technology Mission Directorate (STMD) umbrella. This solicitation, now known as REDDI Tech Flights, replaced the AFO in FY2015. It uses grants and cooperative agreements to fund flights for the U.S. space research and technology development community.

NASA also has contracts in place with several commercial companies to provide testing for NASA payloads. Through these contracts, Flight Opportunities can support suborbital flight-testing requirements for researchers leading NASA technology advancement initiatives.

VI. Flight Opportunities Impacts

Testing performed with commercial flight providers can help increase the speed and effectiveness of the technology development process. As technologies are matured through rapid testing (and in many cases, reflight), they climb the technology readiness ladder, often transitioning to longer duration (e.g., orbital) testing opportunities or inclusion in NASA missions. In fact, nearly one-third of the 160 unique innovations tested with support from Flight Opportunities have gone on to support missions or become part of larger technology systems. The success of the Flight Opportunities-supported technologies below highlights how suborbital flight testing is helping NASA, the commercial space industry, and other government agencies achieve their goals.

A. NASA Commercial Lunar Payload Services Providers

Four of the companies that were selected as eligible to bid on Commercial Lunar Payload Services (CLPS) contracts for NASA-contracted payload delivery services to the lunar surface leveraged Flight Opportunities-supported suborbital flights to test technologies that are incorporated into their landers. These companies include Astrobotic, Blue Origin, Draper, and Masten Space Systems. Under CLPS, these companies bid on various aspects of NASA payload delivery, including payload integration and operations, launching from Earth, and landing on the surface of the Moon. Under the Artemis program, early commercial delivery missions will perform science experiments, test technologies, and demonstrate capabilities to help NASA explore the Moon and prepare for human missions. The first CLPS missions are slated for 2021.

B. NASA Human Landing System Providers

Two of the three teams selected by NASA to develop human landing systems (HLS) for the Artemis program include companies that have served as flight providers or tested technologies through Flight Opportunities. Blue Origin is leading a team that includes Draper, and Draper is also part of a team led by Dynetics. The HLS will take astronauts to the lunar surface in the Artemis lunar exploration program. On early missions, the astronauts will live inside the pressurized crew cabin portion of the lander for up to a week.

C. Commercial Lunar Payload Services Selections

In 2019, NASA also selected science and technology payloads that will fly to the Moon aboard commercial landers. Several technologies that have been matured in part through commercial flight tests facilitated by Flight Opportunities were among the selections, including:

- *PlanetVac from Honeybee Robotics* – This pneumatic device attaches to the leg of a lander vehicle and enables fast, simple, and reliable collection of regolith for analysis. In addition to being selected for CLPS, the device was also infused into the Japan Aerospace Exploration Agency’s Martian Moons Exploration mission where it will capture regolith from the surface of Phobos. Flight Opportunities-supported demonstrations in 2018 proved the device’s ability to successfully capture a sample of simulated regolith in the Mojave Desert.
- *Reconfigurable, Radiation-Tolerant Computer System from Montana State University* – This system is implemented on a commercial off-the-shelf field programmable gate array and provides a reconfigurable and redundant architecture as well as robust, self-healing capabilities. Radiation-tolerant computing will be needed on the Moon, where the lack of atmosphere as well as the magnetic field and radiation from the Sun will be a challenge for most terrestrial electronics. Suborbital testing enabled researchers to test the power and data logging systems, evaluate thermal control analysis and data analysis systems, and confirm that the system was robust enough to survive tumultuous launch conditions.

- *Lunar Magnetotelluric Sounder from Southwest Research Institute* – The Lunar Magnetotelluric Sounder is designed to characterize the structure and composition of the Moon's mantle by studying electric and magnetic fields. Flight Opportunities-supported tests to explore magnetometer technologies helped inform development of this sounder.

D. Lander Vision System for Mars Perseverance Rover

NASA's Perseverance rover will rely on the lander vision system (LVS) developed by NASA's Jet Propulsion Laboratory (JPL) to safely touch down on the Red Planet in February 2021. At the heart of the LVS is JPL's terrain-relative navigation (TRN) system, which captures photos of the Mars terrain in real time and compares them with onboard maps of the landing area, autonomously directing the rover to divert around hazards and obstacles as needed. Successful closed-loop flight tests facilitated by Flight Opportunities demonstrated the system's ability to autonomously change course on descent and adopt a newly calculated path to reach a target landing site.

E. Space-Based Additive Manufacturing

In 2016, Made in Space's additive manufacturing facility went into service on the International Space Station, where it has produced over 200 tools, assets, and parts. Manufacturing of critical components in space can reduce operational costs and improve on-site repair capabilities for long-duration human exploration missions. Suborbital tests proved the ability to use additive manufacturing to produce parts in microgravity while also identifying operational challenges that were addressed through technology development and validated in additional suborbital flights prior to deployment to the station.

F. Autonomous Flight Termination System

This subsystem from NASA's Kennedy Space Center allows a rocket to independently determine if it is off course and, if necessary, self-destruct. Because off-course rockets can place people and property in danger, a process to terminate a launch is essential. The Autonomous Flight Termination System (AFTS) eliminates many of the time-consuming and costly measures historically taken to monitor launches and issue destruction commands, such as ground personnel, transmitters, telemetry receivers, and radar. Suborbital testing enabled the technology to advance to TRL 9. It has been transferred to at least 35 recipients, including Department of Defense agencies and industry (e.g., Rocket Lab, SpaceX) and is the focus of a NASA collaboration with the Italian Space Agency.

G. Astrobotic Auto-landing System

This system, which includes TRN, is a complete solution for applications in which GPS cannot be used. It is designed to achieve high precision and simplified mission integration at a relatively low cost. Astrobotic's TRN system was further matured via a NASA Tipping Point award and is scheduled to fly on the company's first lander trip to the Moon in 2021.

H. Radial Core Heat Spreader

This passive thermal control system from NASA's Glenn Research Center uses a wick capillary mechanism to provide orders-of-magnitude improvement in thermal-to-electric power conversion efficiency and thermal conductance. This technology has been infused into the Nuclear Fission Project, an effort to develop an affordable fission nuclear power system that could enable long duration stays on planetary surfaces and power human outposts. Suborbital flights facilitated by Flight Opportunities verified the technology's thermal performance and enabled testing of best- and worst-case configurations for future spacecraft.

I. Vibration Isolation Platform

The vibration isolation platform is a payload mounting interface that includes active stabilization and 6-degree-of-freedom, non-contact isolation for suborbital and orbital flights. It allows a payload to be undisturbed and float freely in the sway space of the platform. Controlled Dynamics was awarded several Small Business Innovation Research (SBIR) awards, which led to selection of the vibration isolation platform for NASA's Deep Space Optical Communications (DSOC) platform. DSOC is scheduled to launch in 2022 aboard NASA's Psyche asteroid mission.

J. Microgravity Propellant Gauging

This non-invasive, inexpensive, robust method for gauging settled and unsettled propellant is designed to address immediate needs of NASA's Space Launch System (SLS)/Orion architecture. Researchers from Carthage College leveraged flights supported by Flight Opportunities to help establish a baseline technology for the development of a NASA SLS/Orion demonstration project under development at NASA's Johnson Space Center for Artemis III.

VII. Seeking Continuous Improvement

The Flight Opportunities team is keenly interested in the outcomes of the technology flight testing activities, including lessons learned. Team members are constantly evaluating testing performance so that researchers and flight providers can ensure their work is as impactful as possible. The program has embarked on an effort to review flight-test reports from 2011-2019 and analyze data to identify lessons that can be shared with the community.

As a first step, the program reviewed final reports from parabolic and high-altitude balloon flights, looking for lessons throughout the payload development and flight-test activities. One area of analysis was the achievement of flight objectives. Figure 4 shows the breakdown of flight tests based on the level of achievement of flight-test objectives. The categories are as follows:

- High: 90% – 100% of flight test objectives met
- Medium: 65% - 89% of flight test objectives met
- Low: 0% - 64% of flight test objectives met

The green area of Fig. 4. illustrates that for nearly 90% of flight tests, 90% or greater of the flight test objectives were achieved.

Although a large percentage of the flight-test activities for parabolic and balloon flights were successful, an analysis of the final reports indicates that there were challenges and lessons reported in numerous categories, including hardware, software, electrical, mechanical, procedural, experimental design, and communications/telemetry. Flight Opportunities actively seeks to understand when and why these challenges occur and communicate these findings to the suborbital research community with the goal of furthering the reliability and success of suborbital payload hardware and testing procedures. Ultimately, the information gained from the challenges and lessons learned encountered by suborbital researchers over a more than 10-year period will help researchers avoid preventable challenges while also enabling significant savings of time and resources. Relaying this information back to the community will also help ensure that mistakes are not repeated. The program strives to help both researchers and flight providers anticipate and overcome challenges so that they are more successful moving forward.

The effort to identify lessons learned and cultivate a culture of continuous improvement within the suborbital flight test community is a work-in-progress. Flight Opportunities is currently analyzing data and final reports for rocket-powered flights. In addition, the team is exploring options for the community to share this type of data more broadly.

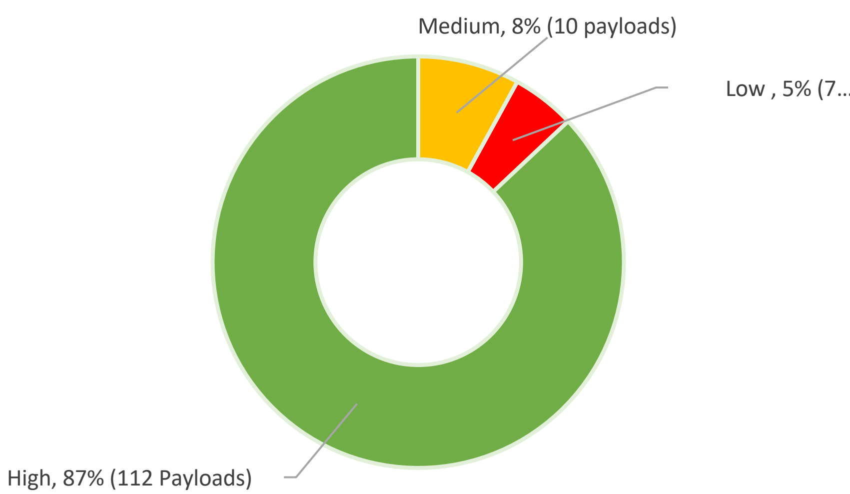

Fig. 4 Breakdown of achievement of flight test objectives

VIII. Support for Small Launch Vehicle Technology Development

Flight Opportunities has supported the development of affordable U.S. commercial capabilities for dedicated small launch vehicles. Announcement of Collaborative Opportunity (ACO) partnerships and Tipping Point cost-contribution contracts were the two mechanisms through which NASA provided resources and expertise to aid industry partners in maturing key small launch technologies.

Several successful ACO collaborations are represented in the following examples:

A. LauncherOne Collaborative Opportunity to Advance Emerging Space Capabilities – Virgin Orbit and NASA's Ames Research Center

Completed in 2018, this collaboration had three main research areas. The first—to develop aerodynamic and thermal models for the combined vehicle configuration of Cosmic Girl (a modified 747 carrier aircraft) and the LauncherOne launch vehicle—resulted in a large number of use cases developed by Ames and transferred to Virgin Orbit, including takeoff and landing, captive carry, and release scenarios. The second task was to develop an integrated simulation using NASA's B747-400 flight simulator. Virgin Orbit pilots flew the Cosmic Girl/Launcher One simulator to validate the handling characteristics of the aircraft flight and release profiles. For the final task, the partners investigated various payload accommodation architectures and conducted a LauncherOne upper-stage trade study. Based on findings from this partnership, Virgin Orbit fabricated a 3D printed model of the third stage structure and prepared the associated design report. The successes from the partnership also facilitated a key drop test of LauncherOne from the Cosmic Girl aircraft at 35,000 feet on July 10, 2019 from the Mojave Air and Space Port.

B. Technology Maturation and Flight Validation for Air Launched Liquid Rockets – Generation Orbit and NASA's Armstrong Flight Research Center

This partnership involved a flight test campaign for an inert test article simulating the X-60A (formerly called GOLauncher1) integrated with a NASA C-20A aircraft, a military version of the Gulfstream III aircraft. The X-60A is an airdropped liquid rocket under development at Generation Orbit, designed for hypersonic flight research. The partnership between Generation Orbit and Armstrong was successfully completed in 2018 with three captive-carry flight tests of the test article. These tests provided valuable flight integration and performance data for the X-60A program, which will use a modified Gulfstream III carrier aircraft owned by Calspan Corporation. Generation Orbit continues work on the X-60A program via SBIR Phase III funding from the Air Force Research Laboratory (AFRL). The X-60A is slated to be flight tested at Cecil Field Spaceport in Jacksonville, FL, in the near future.

C. Propulsion System and Second Stage Structural Loads Interaction Test Platform – Relativity Space and NASA's Stennis Space Center

This partnership aimed to mature the use of additive manufacturing in rocket propulsion and vehicle structures. The effort culminated in testing Relativity's 3D-printed engine, Aeon 1, with a Terran 1 second stage structural test article printed in the company's proprietary large-scale metal 3D printer, Stargate. The first integrated tests of a new configuration and delivery of a structural test article—a 7-ft diameter, 11-ft tall aluminum tank shell printed in one piece—took place in December 2018. Additional testing of the ignitor and engine was completed in July 2019, demonstrating a substantial increase in performance.

D. 3D-Printed Bimetallic Combustion Chamber Material – Virgin Orbit and NASA's Marshall Space Flight Center and Goddard Space Flight Center

This collaborative effort helped to evolve 3D-printed bimetallic combustion chamber material technology. Testing of an advanced manufacturing technology chamber was completed in late 2018 and early 2019. A total of 29 tests were completed on two advanced manufacturing chambers and one reduced-length chamber. The work is helping to establish technology supply chains for use by NASA and industry, with advancements that can significantly reduce lead times and costs of liquid rocket engine hardware and ultimately lower launch costs.

E. Spyder Technology Guidance Navigation and Control Affordable Vehicle Avionics Development – UP Aerospace and Ames Research Center

Research was performed leading to potential integration of Affordable Vehicle Avionics (AVA), developed at NASA's Ames Research Center, into UP Aerospace's developmental Spyder orbital launch vehicle, including launch vehicle simulations and evaluations of AVA Guidance, Navigation and Control (GN&C) software, and AVA hardware. The AVA technology was successfully flight tested on an UP Aerospace *SpaceLoft* sounding rocket and transitioned to a commercial license.

Four representative successful Tipping Point cost-contribution projects are summarized below:

A. Maturing the M10A 25,000lbf-Thurst Liquid Oxygen/Methane Broadsword Engine – Masten Space Systems

Masten is developing a liquid oxygen/methane reusable lander engine with 25,000 lbf-thrust liquid oxygen/methane Moon or Mars reusable lander engine. In 2018, the research team conducted a hot-fire test and developed an improved additively manufactured aluminum metal matrix composite material for a rocket engine and thrust chamber. The work stands to advance the state of the art of aluminum thrust chambers, cooling channel design, and additive manufacturing. In particular, the activity may benefit landing and sample return missions to the Moon and Mars. Masten successfully completed this project in late 2019 by demonstrating a hot firing of their 25,000 lbf-thrust engine in the test stand at the Air Force Rocket Propulsion Laboratory at Edwards Air Force Base in California.

B. Carbon Nanotube Infused Launch Vehicle Structures – Northrop Grumman (formerly Orbital Sciences Corporation)

Northrop Grumman is developing a toolkit focused on eliminating the need for payload isolation systems—typically a necessity to insulate one experiment from disturbances that may be caused by others on the same flight. The development leverages carbon nanotube infused structures to achieve dampening in aerospace structures with a lower cost per pound of payload sent to orbit. In 2018, the Shock Characterization Box—which reduces mass and improves damping— underwent dynamic test methods demonstration, completed a technical readiness review, and commenced Phase 2 development efforts. Three interstages were built for the Black Brant XII and achieved considerable mass savings compared to the heritage aluminum interstage. The lattice bulkhead constructed using these methods yielded a 40% weight savings and 6 decibel attenuation compared to the heritage bulkhead.

C. Spyder: Critical Technology Demonstration Tests – UP Aerospace

UP Aerospace collaborated with NASA's Marshall Space Flight Center to advance high-performance propulsion for its Spyder orbital launch vehicle and hypersonic mission capabilities. In 2018, the research team completed detailed motor designs, enabling transition to motor demonstrations. The company also developed hypersonic flight test bed configurations for NASA's Kennedy Space Center and Wallops Flight Facility to facilitate testing of AFTS. In November 2019, UP Aerospace's SL-14 launch successfully demonstrated AFTS as well as the dual-use capabilities for Spyder motors and other key advanced manufacturing and cost-reduction technologies for casting rocket components.

D. Development and Flight-Testing of a High-Performance Electric-Pump Fed Launch Vehicle – Astra Space

The objective of this task was to further progress in developing and flight testing a low-cost launch vehicle capable of on-demand launch of small payloads including small satellites to low Earth orbit. A preliminary flight test of Astra's Rocket 3.1 was performed at the Pacific Spaceport Complex in Alaska on September 10, 2020.

IX.Conclusion

What began as an adventure into unchartered territory ten years ago has evolved into a robust program that is having significant impact for NASA's missions as well as missions being pursued by the commercial space industry. Technologies tested with support of the program are slated for missions to the Moon, Mars, and beyond. Flight Opportunities will continue to seek opportunities to increase the efficiency and effectiveness of testing to ensure its continued impact and looks forward to working with the community to another decade of pursuing creative collaborations to advance space technologies.