Proceedings of the ASME 2013 International Mechanical Engineering Congress & Exposition
IMECE2013
November 15-21, 2013, San Diego, California, USA

IMECE2013-64703

FLIGHT OPPORTUNITIES FOR TESTING AND DEMONSTRATING EMERGING SPACE TECHNOLOGIES

Douglas (Dougal) C. Maclise
NASA Ames Research Center
Moffett Field, California, USA

Richard C. Mains
Mains Associates
Berkeley, California, USA

Alexander van Dijk
Mission Critical Technologies
El Segundo, California, USA

ABSTRACT
NASA's Flight Opportunities Program has two primary goals – provide flight opportunities to be used to mature new technologies and foster the new commercial space industry. Since 2010 the Program has contracted with seven commercial flight providers and has flown over 18 campaigns that carried over 45 technology payloads. The flight opportunities are awarded through an open competitive solicitation called the Announcement of Flight Opportunities (AFO) or through other NASA solicitations for new technology development. To date over 100 technologies have been selected for flight testing. This paper profiles four examples of the technologies that have been tested or demonstrated on suborbital flights: 3-D Printing in Space developed by Made In Space Inc., Fine Water Mist Portable Fire Extinguisher developed by ADA Technologies and NASA/Glenn Research Center, Precision Landing Exploration Technology developed by Draper Labs, and On-orbit Propellant Storage Stability developed by Embry-Riddle Aeronautical University.

NOMENCLATURE
Technology Readiness Level (TRL) – a scale of 1 to 9 that classifies the maturity of the development of new technologies.

INTRODUCTION
The Flight Opportunities Program (FOP) is one of 9 programs in NASA's Space Technology Mission Directorate (STMD). The program has two primary goals: (1) to provide frequent, low-cost flights for new space technologies to be demonstrated and validated in relevant environments, and (2) to foster the development of the U.S. commercial space transportation industry by contracting with competitively selected vehicle providers to flight-test these technologies [1] [2].

The Program solicits and selects proposals for technologies to be tested in space relevant environments in order to demonstrate that the technology will function properly in its intended operational environment. Flight campaigns on parabolic aircraft, high-altitude balloons as well as suborbital re-usable launch vehicles are used to simulate the appropriate relevant environment. These flight opportunities allow "technology maturation" and risk reduction of high-priority NASA-relevant "emerging technologies" [3].

The FOP has been operational since 2010 and is developing a "pipeline" of technology payloads that can fly quickly, frequently and safely. The new cost-effective commercial flight capabilities help to rapidly drive technology advancement in support of future upper atmospheric, orbital and planetary missions as well as commercial applications. The relevant environments accessed will include: micro, lunar and Martian gravity; upper atmosphere chemistry and weather; planetary and Earth observations; and entry, descent and landing scenarios. Orbital insertion of small payloads during near-space flights is also being planned.

For the purposes of this paper we will define "emerging technologies" in part as proposed recently at the World Economic Forum [4]. "Technologies arising from new knowledge or the innovative application of existing knowledge; those that lead to the rapid development of new capabilities…and have the potential to disrupt or create entire industries." Within the FOP we consider "technology maturation" to be a process of technology testing, modification, retesting and sequential upgrading that can lower risk and validate a potential application in a specific relevant environment. The FOP uses common Technology Readiness Level (TRL) guidelines and typically engages with developers whose technology has a minimum readiness level of TRL 4 (Component/subsystem validation in laboratory environment) [5]. The developers then modify and integrate their technologies into payloads compatible with the selected flight platform. Upon completion of their flights, the technologies often “graduate” from the FOP with a TRL of about 6 (System prototype demonstration in an relevant environment).

TECHNOLOGY EXAMPLES

Four examples of technology maturation via the Flight Opportunities program are profiled below. These profiles are based on the publicly releasable information that each Principle Investigator provided in their final reports to the Program. Additional information can be found on the Program website [1] or requested from the Principle Investigator via links provided on the same website.

3D Printing in Space (PI: J. Dunn, Made in Space, Inc.)

Figure 1 3D printing technology being tested onboard the Boeing 727 aircraft by Made in Space Inc. A nylon wrench that has just been printed in microgravity is floating above the researcher’s hand.

Made in Space Inc. (MiS) was selected as a technology developer to validate and demonstrate the functionality of 3-D printing technology in a micro-gravity and variable-gravity environment (Figure 1). The ability to produce parts in space has many potential benefits including the possibility of using in-situ materials from extra-terrestrial sources. It is estimated that perhaps one-third of the parts on the International Space Station could be fabricated with replacements made of advanced plastics. Also fabrication of some systems in space could benefit from not having to withstand the stresses of launch.

The preferred flight platform has been the customized commercial aircraft operated by Zero Gravity Corporation that flies parabolic trajectories to create a series of micro-g and hyper-g periods lasting several seconds each. The program can accommodate research team participants as well as their technology payloads on Zero-G flights. Three 4-day flight campaigns were conducted during the summer of 2011 and another was successfully concluded in the summer of 2013. A follow-on flight aboard a Flight Opportunities-sponsored suborbital Reusable Launch Vehicle (sRLV) has also been approved for MiS.

The MiS goal is to validate 3-D printing technology comparing some commercial units with their customized version. By making inflight observations and modifying both their hardware and software between flights, MiS was able to rapidly optimize their technology for operation in space. Several parts were fabricated using extrusion-based printing and the layer resolution, tolerances and strength characteristics studied in detail.

After the 2011 flights, a Phase-3 NASA Small Business Innovation Research Grant (SBIR) was obtained by MiS to develop a 3-D printer for testing onboard the ISS in 2014. They hope to develop an Additive Manufacturing Facility (AMF) for shipment to the ISS as a follow-on project.

A Water Mist/Nitrogen Fire Extinguisher for ISS (PI: T. Carrier, ADA Technologies)

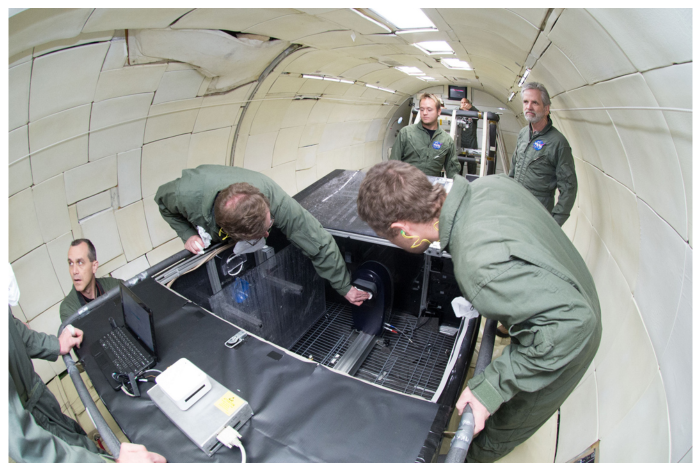

Figure 2 Fine Water Mist Portable Fire Extinguisher developed by ADA Technologies is being prepared for flight testing onboard the Boeing 727 aircraft.

ADA Technologies partnered with NASA/Johnson Space Center, NASA/Glenn Research Center and the Colorado School of Mines on development of their Fine Water Mist (FWM) Portable Fire Extinguisher (PFE) for in-space applications (Figure 2). The initial development was carried out under a NASA SBIR grant. The system was designed to provide effective, safe fire suppression in space environments typically inhabited by human crews. The FWM-PFE is targeted to replace current carbon dioxide systems on the ISS that can create a hazardous environment for humans. The FWM-PFE uses a water/nitrogen agent that is environment and people-safe. It was tested with success in all aspects of manned spacecraft environments except for its functionality in microgravity.

Figure 3 The GENIE autonomous guidance, navigation and control system is shown on the right and is shown mounted on the Masten Space Systems vehicle, Xombie, on the left.

ADA Technologies was selected to fly on the Zero Gravity Corporation aircraft that flies parabolic trajectories and provides short-duration (~10sec) microgravity exposure to payloads. The FWM-PFE technology payload was developed and flown on a 4-day campaign in 2011. The system was enclosed and designed to test water droplet size distribution in micro-g and validate that it was similar to that seen in ground-based tests. The efficient transport of the water droplets through a space with obstructions was also evaluated since good mist/nitrogen distribution is important for fire suppression (cooling the flame and reducing the oxygen content of the air).

The results indicated that droplet size in microgravity was similar to that in ground tests and the tendency for droplet size behind obstructions to be smaller was also similar. The larger droplets in both gravity conditions tended to hit obstructions first and be removed from the mist. Laser light scattering by the water mist indicated that the density of the plume in microgravity was double that seen in ground tests indicating that water droplets traveled more effectively inflight. Thus ground tests are a worst-case scenario for the FWM-PFE and microgravity appears to improve water mist distribution around objects, a very positive observation.

ADA Technologies is now proceeding with development of ISS-compatible FWM-PFE systems. They will also be a good candidate to provide these systems for fire suppression on commercial suborbital vehicles that propose to fly humans such as Virgin Galactic and Blue Origin as well as orbital vehicles such as Sierra Nevada and SpaceX.

Precision Landing Exploration Technology (PI: D. Zimpfer/Draper Laboratories)

Draper Labs partnered with NASA/Johnson Space Center to develop the experimental "Morpheus" Vertical Take-off, Vertical Landing (VTVL) vehicle and wanted to further validate their Autonomous Guidance, Navigation and Control technology (GENIE) subsystem (Figure 3). They proposed, via the Flight Opportunities Program, use of the evolving Masten Space Systems "Xombie" VTVL suborbital Reusable Launch Vehicle (sRLV) as a testbed for the GENIE system since it could be designed to take over control of the Masten vehicle during flight trajectories and control its precise landing. The broad goal was to validate and demonstrate GENIE capabilities for conducting the Autonomous Landing and Hazard Avoidance operations needed for future planetary missions.

Developmental flights with GENIE mounted on Xombie began in December 2011 and culminated in a March 2013 flight to almost 500m in altitude with a 300m translation and landing at the Mojave Air & Spaceport. GENIE has now progressed to TRL 6 (System/subsystem prototyping demonstration in a relevant end-to-end environment, ground or space). Additional flights on Xombie are anticipated to higher altitudes with GENIE controlling a larger portion of the reentry, descent and landing trajectory.

On-orbit Propellant Storage Stability (S. Gangadharan, Embry-Riddle Aeronautical University)

Embry-Riddle Aeronautical University (ERAU) partnered with the NASA Launch Services Program, United Launch Alliance (ULA) and some if its students to develop prototype systems that will allow precursor testing of in-space propellant storage and transfer technologies. ERAU was selected to fly on the Zero-g parabolic aircraft in the summer of 2011 and they hope to utilize their preliminary results on a flight on a suborbital Reusable Launch Vehicle (sRLV) which can provide up to 4 minutes of microgravity at a time.

The ULA is developing on-orbit propellant storage and transfer systems derived from the Centaur upper-stage of the Atlas launch vehicle. Once on-orbit these systems will be spin stabilized about their major axis while several propellant transfers take place. A scaled electromechanically controlled device called the "Tri-Axis Spin Rig (TASR)" was developed that would spin a two-compartment liquid storage system. During the flight the propellant storage and transfer system was released within the rig enclosure so it could spin freely in microgravity.

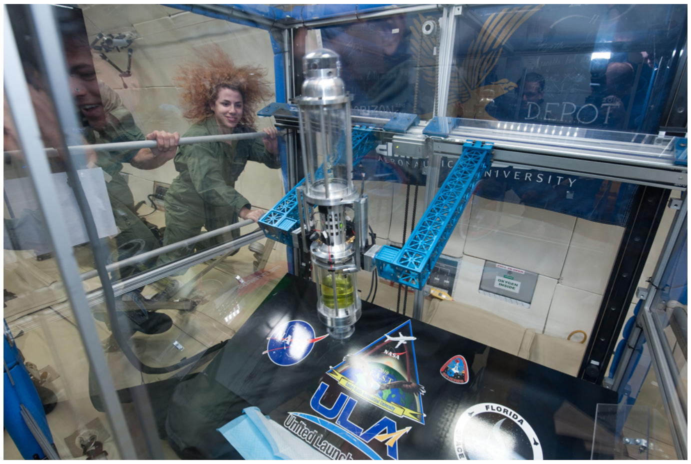

Figure 4 This image shows the test apparatus for studying technologies needed for on-orbit propellant storage. A double ended 'tank' is about to be released by the grappling arms to free-float in micro-gravity.

The results obtained during the flight tests confirmed all the hypotheses that proposed that the system would automatically settle into a stable state when spun about its minor axis, quite the opposite of when it is spun about its major axis. These results will be used in the development of a larger test bed, the Cryogenic Orbital Testbed which will be tested further onboard the International Space Station.

It is envisioned that the test results gathered during these flights will be critical and "game-changing" for technology development of on-orbit spacecraft refueling system. This capability is envisioned as essential for future missions to Near Earth Objects (NEOs) and future interplanetary travel.

CONCLUSION

NASA's new Space Technology Mission Directorate (STMD) is dedicated to discovering and developing new and emerging technologies that will enable unprecedented use and exploration of space. A vital part of that work is testing and demonstrating these technologies in the environments that they will be used in. Another essential component for the use and exploration of space is the development of a strong and affordable commercial space industry. The Flight Opportunities Program is dedicated to both these goals.

ACKNOWLEDGMENTS

The authors would like to thank the technology developers: Jason Dunn of Made In Space Inc., Douglas Zimpfer of Draper Laboratories, Thierry Carriere of ADA Technologies, and Sathya Gangadharan of Embry-Riddle Aeronautical University for their efforts to advance technologies for space exploration and for sharing the results of their flight testing for this paper. More information about their (and others') technologies can be found on the Flight Opportunities website (https://flightopportunities.nasa.gov/).

REFERENCES

[1] Flight Opportunities website (http://flightopportunities.nasa.gov).

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[5] Technology Readiness Level (TRL) Guidelines (http://en.wikipedia.org/wiki/Technology_readiness_level)

