SSC14-IV-5

HatchBasket System for ISS-Enabled SmallSat Deployments and Externally-Hosted Tech Demo Payloads

Jonathan A. Goff, Michael C. Cross, and William G. Bolton
Altius Space Machines, Inc.
511 E. South Boulder Road, Louisville, Colorado 80027; (303) 827-1574
jongoff@altius-space.com

Michael D. Johnson and Richard S. Pournelle
NanoRacks, LLC
18100 Upper Bay Road, Suite 150 Houston, Texas 77058; (832) 573-7424
mjohnson@nanoracks.com

ABSTRACT

Access to space is still a challenge for many types of small spacecraft, especially for small un-encapsulated microsatellites. Altius Space Machines and NanoRacks LLC are developing the HatchBasket™ SmallSat deployment system, which leverages elements of the International Space Station (ISS) ecosystem to: provide additional launch opportunities for small spacecraft, address the short lifetime of payloads launched directly from the ISS, and provide additional unique services for technology demonstration launches. HatchBasket is a spacecraft deployer carrier system that: flies to ISS as pressurized cargo in a cargo vehicle such as Orbital Sciences Cygnus or the JAXA HTV, is installed by the ISS crew into the cargo vehicle's hatchway in lieu of the pressure hatch prior to departure of the cargo vehicle from the ISS, and deploys payloads in a controlled manner after the cargo vehicle has maneuvered to the desired orbit (below ISS altitude and up to 500km circular altitude). This paper will discuss the physical concept for the HatchBasket system, the concept of operations for satellite deployment missions, some of the unique capabilities that can be provided by HatchBasket for technology demonstrations and other payloads, as well as the current status of HatchBasket development.

INTRODUCTION

Over the past several years, there has been a significant increase in the number of CubeSats and microsats being developed and flown[1], for applications including earth observation[2,3], technology demonstrations[4], and even interplanetary CubeSats and microsats[5]. While there are many interesting proposed systems for launching CubeSats and smallsats, there are two main currently existing approaches to launch; secondary payload "hitchhiking" on upper stages[6] or deployment from ISS using companies such as NanoRacks for the integration and manifesting of these payloads[7]. Each of these methods has its benefits and drawbacks.

Spacecraft riding as secondary payloads can access a wide variety of orbital inclinations and altitudes and can be relatively volume unconstrained. However, repeat launch opportunities to the same orbit may be infrequent, primary payload customers often cause launch schedule uncertainty and delays, primary payload customers also often drive safety requirements, particularly for un-encapsulated microsat payloads, and many rideshare opportunities are on foreign launchers, which can present ITAR challenges for some payloads.

As an alternative to secondary payload "hitchhiking", ISS deployment provides a gentler ride to space via soft-packaging, enables astronaut checkout of some payloads prior to deployment, and offers regular flight opportunities to the same orbit. However, all current ISS deployments are below ISS altitude (400-415km), which typically limits spacecraft lifetime to approximately 6-18 months unless the payload has station-keeping propulsion[8], and all current ISS deployments use the Japanese Experiment Module (JEM) equipment airlock, which is dimension-constrained in the spacecraft "height" dimension.

This paper will discuss efforts underway by Altius Space Machines (Altius) and NanoRacks LLC (NanoRacks) to develop a new system for ISS deployments that improves on the deployed lifetime and volume constraints and provides other unique benefits for deployed payloads. The following sections describe the physical concept for the HatchBasket system, its concept of operations, unique capabilities, and current development status.

HATCHBASKET PHYSICAL CONCEPT

The HatchBasket SmallSat Deployment System is a small satellite carrier system, which is installed into the hatchway of an ISS cargo vehicle prior to departure allowing payload deployments after the primary mission of cargo delivery is completed. The HatchBasket is designed to be leak-tight, retaining atmospheric pressure inside the cargo vehicle after departure from ISS.

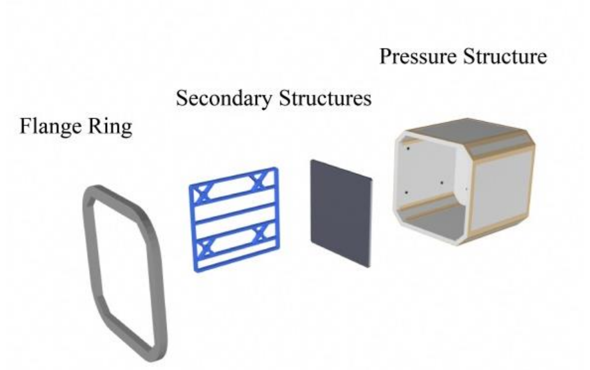

Figure 1: HatchBasket Components

As illustrated above in Figure 1, the HatchBasket system is comprised of three main structural components: a pressure structure, a flange ring, and a secondary structure, as well as several components that are not shown, including a deployer controller, one or more encapsulated or un-encapsulated payloads, and optional hosted payloads. The following sections describe each of these components and their key design drivers.

Pressure Structure

The HatchBasket Pressure Structure is a box with one side open, which surrounds the payload deployers and forms a leak-tight pressure barrier between the cargo vehicle's pressurized volume and the vacuum of space. In order to resist external pressure loads from the retained atmosphere in the cargo vehicle as efficiently as possible, Altius is investigating honeycomb structures, iso-grid machined aluminum structures, and composite structures for the Pressure Structure design.

The reason the Pressure Structure is designed to retain the internal pressurization in the cargo vehicle is due to both experiments such as the NASA Saffire fire safety experiment[9], which will utilize the Cygnus cargo vehicle's pressurized environment following departure from the ISS, as well as concerns regarding the outgassing of volatiles in the trash stowed in the cargo vehicles if exposed to vacuum.

The maximum cross-section dimensions for the Pressure Structure are driven by the hatchway dimensions for the cargo vehicles, as the HatchBasket has to be loaded into the cargo vehicles via the hatchway with sufficient clearance on all sides to avoid damage to the hatchway or Pressure Structure. In the case of Cygnus, the hatchway opening is 95.0 x 95.0 cm with the four corners rounded with a radius of approximately 22.8cm.

The Pressure Shell depth is not as constrained as the cross-section, only by keep-in volume considerations after installation. Altius is currently investigating methods to ensure trash and mid-deck lockers are secured in a manner that does not overly constrain the depth available to HatchBasket.

Flange Ring

The Flange Ring is a high strength aluminum ring that is designed to bolt to the Pressure Structure, forming a leak-tight seal between the two main pressure-bearing HatchBasket components, and then be clamped to the cargo vehicle hatchway in a manner that provides sufficient pre-load on the hatch seal to form a leak-tight seal between HatchBasket and the cargo vehicle. The Flange Ring is designed to interface with the existing cargo vehicle hatchway in a manner similar to the cargo vehicle pressure hatches, to avoid modifications to the cargo vehicle structures. The Flange Ring also contains all of the pass-through electrical connections, minimizing penetrations in the Pressure Structure.

The reason why the Flange Ring and Pressure Structure are designed to be two separate pieces is because the Flange Ring interfaces to the existing pressure hatch seal on the inside face of the hatchway bulkhead, in a similar manner to the existing hatch. This seal is secured to the inside of the cargo vehicle around the hatchway opening, and requires the Flange Ring to be larger than the hatchway opening. The only way the Flange Ring can be loaded into the cargo vehicle is by orienting the Flange Ring diagonally in the hatchway opening as it passes through, after which it can be bolted to the Pressure Structure before launch.

Secondary Structure

The HatchBasket includes a Secondary Structure that mounts the various combinations of payloads, and that reacts their launch loads into the Pressure Structure and Flange Ring, in a way that can be reconfigured for each mission without having to modify and re-qualify the Pressure Structure. The payloads or payload deployers are mechanically attached to the Secondary Structure, which is subsequently fastened to the sides and/or rear of the Pressure Structure, and potentially to the inside of the Flange Ring. The Secondary Structure also isolates the payload deployers from pressure-induced deformations in the pressure structure. The Secondary Structure can be easily modified to support each unique launch manifest, with an almost unlimited mixture of CubeSats and microsats.

Deployer Controller

The Deployer Controller is an electronics box that triggers the deployment of the HatchBasket payloads once the cargo vehicle has reached its destination orbit, and provides electrical inhibits to the deployers prior to reaching the destination orbit. The Deployer Controller for HatchBasket is an Ecliptic Enterprises Payload Sequencer and Controller, which is based on their modular, flight-proven Digital Video System, shown below in Figure 2.

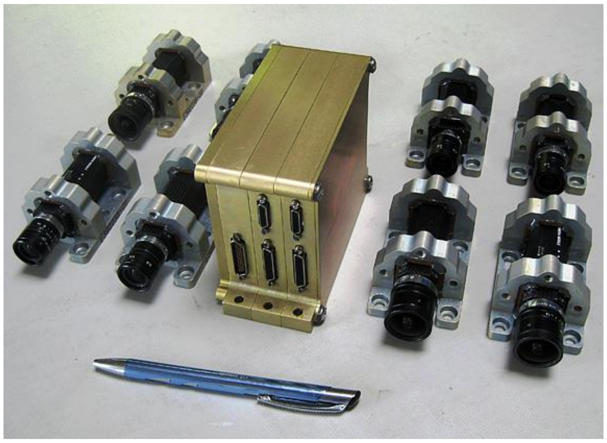

Figure 2: Ecliptic Digital Video System shown here with Ecliptic RocketCams™

The Deployer Controller uses a PC/104 architecture with “slices” that can be added to the avionics stack to accommodate up to forty redundantly controlled payloads as well as cameras, sensors, illuminators, and other externally-mounted hosted payloads. The Deployer Controller communicates with the cargo vehicle and receives power and command signals via a wire harness that is attached prior to securing the HatchBasket in the cargo vehicle hatchway. For initial flights on the Cygnus cargo vehicle, Altius is investigating the use of either the NASA Saffire electrical interface or the powered mid-deck locker interface.

Payload Deployers and MicroSat Elevator/Deployers

As discussed above in the Secondary Structure section, HatchBasket is designed to be deployer agnostic, supporting, NanoRacks Cubesat Deployers and other styles of CubeSat deployers, as well as microsats in either fully-encapsulated elevator/deployers or in an un-encapsulated state. The deployers are mechanically attached to the Secondary Structure either on their sides or on their back (or both), depending on the deployer design, and cables connect each individual deployer system to the Deployer Controller box, using the Secondary Structure for securing the cable harness against launch vibrations.

In addition to existing deployer systems, Altius is developing a fully-encapsulated elevator/deployer box for microsats. Microsats are typically secured to a launch vehicle using a separation system such as Planetary Systems’ Motorized Lightband[10]. However these separation systems are typically used to deploy spacecraft off the side of a launch vehicle, where there are no nearby collision hazards, and thus may not have low enough tip-off rates to successfully deploy a microsat from inside a cavity like HatchBasket without colliding with walls after ejection.

The MicroSat Elevator/Deployer as shown below in Figure 3, consists of a sliding elevator platform mounted inside of an enclosure box, with two front doors and a drive system that opens the front doors and raises the elevator platform and payload to the front of the elevator once activated. Once in place at the front of the elevator/deployer box, the elevator platform latches in place to provide a stable platform for deployments.

This elevator/deployer system can provide much tighter microsat packaging within the HatchBasket, while also providing microsats with the encapsulation benefits that PPODs provide to CubeSats, including privacy, the ability to contain a battery failure, containment of secondary debris caused by launch loads, etc. The elevator/deployer box elements are all highly modular enabling low-cost custom designs to suit different microsat shapes and sizes.

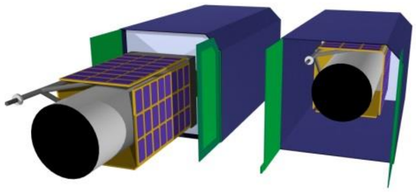

Figure 3: Altius MicroSat Elevator/Deployer System with elevator platform extended and retracted

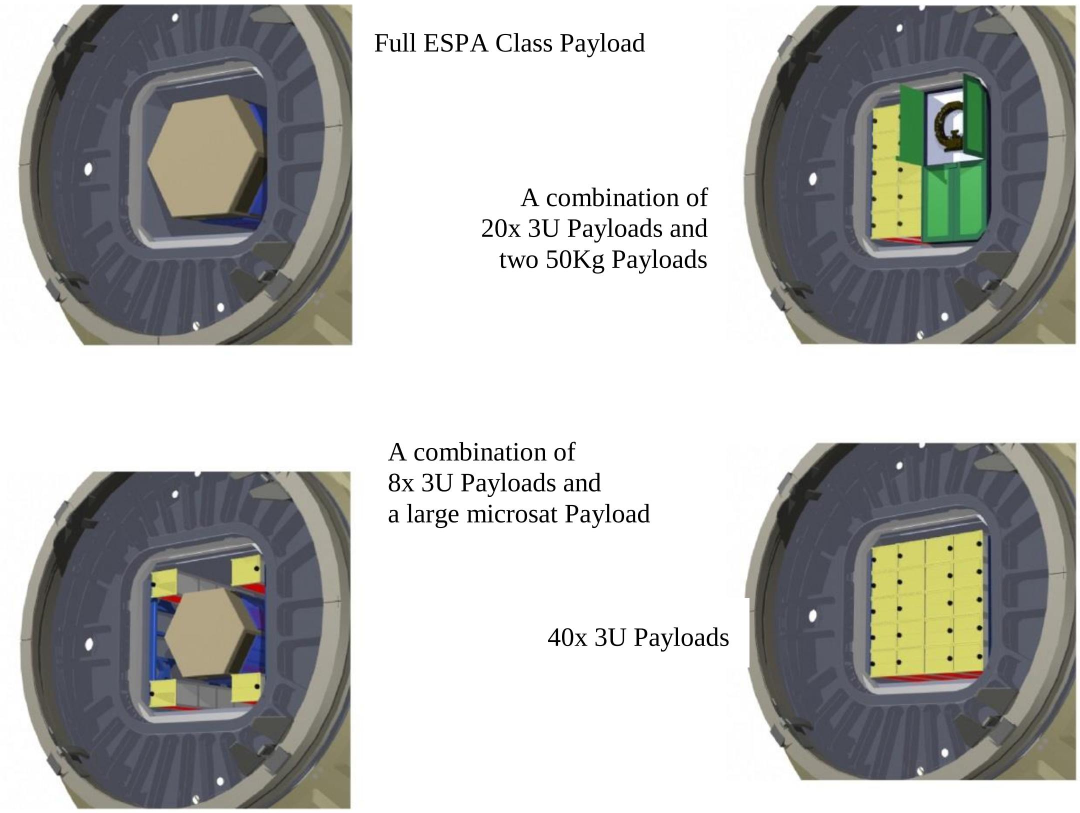

Figure 4: Example Payload Configurations

These elements can be combined to enable a wide variety of unique configurations of microsats and CubeSats for HatchBasket deployment. Figure 4 above shows a few example configurations that HatchBasket can support.

Hosted Payloads and Services

In addition to deployed spacecraft, HatchBasket can optionally also support externally-hosted payloads, and can support externally-hosted hardware to provide services to other deployed or hosted payloads. These hosted payloads can include cameras, illuminators, sensors, communications relay systems, or even robotic manipulators.

The hosted payloads can be mounted in several potential ways, including mounting inside HatchBasket, mounting in an elevator/deployer box, or mounting to the stringer structures on the front bulkhead of the cargo vehicle, similar to what is shown below in Figures 5 or 6. In this case, while the cargo vehicle is still attached to the station, the MLI blankets over that portion of the bulkhead can be rolled back, clamps can be attached to the stringers, and various payloads can then be mounted to the clamps. The hosted payloads can be provided with power and data from via the Deployer Controller using an external wire harness connected to the Flange Ring. Payloads hosted in this way can be launched soft-packaged, do not require launch locks, do not require custom modifications to the cargo vehicle external hardware, and can be checked-out on-orbit before departure of the cargo vehicle from ISS.

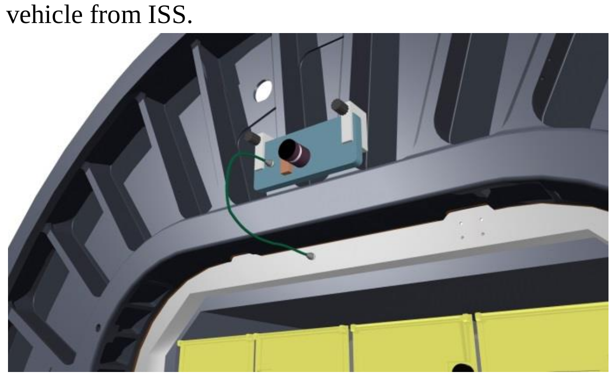

Figure 5: Sensor Package as an Externally-Mounted Hosted Payload

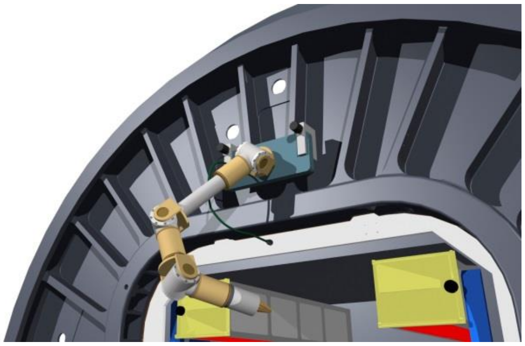

Figure 6: Robotic Manipulator as an Externally-Mounted Hosted Payload

HatchBasket Size and Dimensions

The internal dimensions of the HatchBasket are 84.8cm x 84.8cm x 100.6cm deep exclusive of the Secondary Structure. This volume permits a range of payloads from forty 3U CubeSats up to a full ESPA class payload (60x60x100cm) and anything in between. Figure 7 below shows the external dimensions of the current HatchBasket design concept.

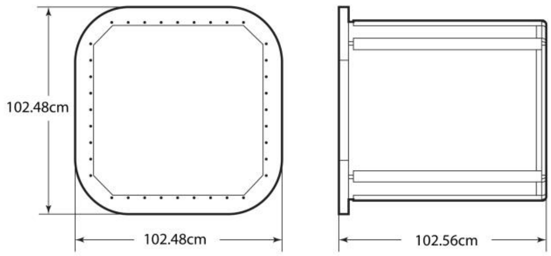

Figure 7: HatchBasket External Dimensions

HATCHBASKET CONCEPT OF OPERATIONS

HatchBasket operations can be divided into the three phases, which will be described in the following subsections:

1. Ground Integration and Launch to ISS
2. ISS Crew Operations and Installation
3. Post-Departure On-Orbit Operations.

Ground Integration and Launch to ISS

Prior to launch, customer payloads are loaded into their respective deployers or elevator/deployers and readied for launch. These deployers are then assembled together and fitted to the Secondary Structure which is then mated to the Pressure Structure. After the two are mated together, they and the other HatchBasket components are shipped to the cargo vehicle manufacturer for integration with the cargo vehicle. Alternately, if that is too massive, the components could be soft-packaged and shipped to the launch provider separately.

As the payloads are being loaded into cargo vehicle, the Pressure Structure is loaded first, followed by the Flange Ring. The Flange Ring is then bolted to the Pressure Structure, and the two are then leak checked. The HatchBasket is then strapped-down for launch.

ISS Crew Operations and Installation

After arrival at the ISS, the crew opens and latches the cargo vehicle pressure hatch out of the way and the pressurized cargo is unloaded. The HatchBasket can then be temporarily moved to a location near the hatchway to enable trash to be loaded into the cargo vehicle behind the HatchBasket. Before departure from the ISS, the HatchBasket wire harness is connected to the appropriate connector on the cargo vehicle, the electrical connection and Deployer Controller operations are checked, the HatchBasket is positioned into the hatchway and secured with latches, and cargo vehicle ISS departure operations (leak checks, communications checks etc.) continue as normal from that point forward.

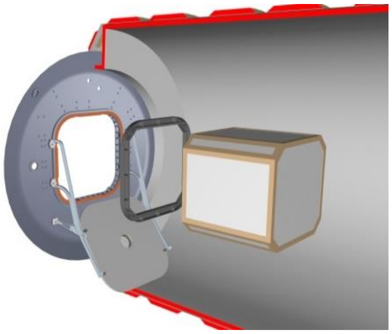

Figure 8: Flange Ring and Pressure Structure ready for ground assembly

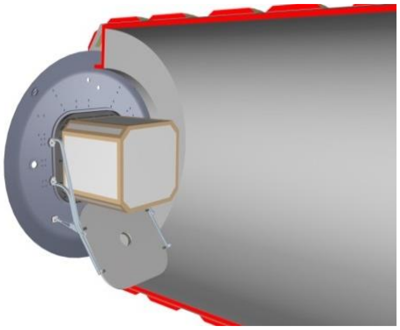

Figure 9: HatchBasket Installed in Cargo Vehicle Hatchway

The planned cargo vehicle maneuvers to the deployment orbit(s) are accomplished using contingency fuel that the cargo vehicles maintain to compensate for off-nominal booster performance and for backup berthing attempts with ISS. These reserves should be unused by the cargo vehicle on most missions. In the situation where the cargo vehicle uses up too much of this contingency propellant traveling to ISS, the HatchBasket Flange Ring and Pressure Structure could potentially be unbolted, and the HatchBasket and payloads temporarily stowed inside ISS to await a future cargo vehicle mission which would be launched without a HatchBasket inside, at which point the Pressure Structure and Flange Ring would be loaded into the new cargo vehicle after the pressurized cargo was removed.

Post-Departure On-Orbit Operations

After release and separation from the ISS, any secondary missions (such as NASA's Saffire experiment) are completed first. Following completion of these activities, and while the data from the experiments is being downlinked to the ground, the cargo vehicle maneuvers away from ISS to the deployment orbit and begins preparations for HatchBasket payload deployments.

In many cases these deployments will take place at altitudes higher than the station, though some payloads such as reentry system demonstrators may prefer elliptical or circular orbits below the ISS. In the case of deployments above the station, maneuvers will be planned to minimize the risk of accidental re-contact of the cargo vehicle or deployed payloads with the station.

The specific payload deployment order that will be used will be determined on a mission-by-mission basis, but large un-encapsulated larger payloads will typically be deployed before encapsulated or canisterized payloads. During payload deployment operations, telemetry from the deployer will be actively downlinked, enabling Altius to modify the deployment program as necessary using commands uplinked to the cargo vehicle. Also, any hosted payload experiments will be performed concurrently with the spacecraft deployment operations, unless they need to be performed after deployment operations are completed.

Once the payloads are all deployed and all data from the deployments has been downlinked, the cargo vehicle will perform its deorbit burn as normally, to complete the mission.

UNIQUE DEPLOYMENT OPTIONS AND OTHER HOSTED SERVICES

In addition to normal spacecraft deployment operations, the use of a vehicle as sophisticated as the Cygnus or HTV cargo vehicles potentially enable two unique deployment options as well as other hosted services that can enhance or enable technology demonstration SmallSat missions.

HatchBasket-Enabled Constellation Deployments

Many emerging SmallSat applications involve the use of constellations of multiple satellites evenly spaced in multiple orbital planes. For most small secondary payloads that cannot afford the expense of a sophisticated deployer system, deployments are typically in a "string-of-pearls" configuration, after which the spacecraft are phased into their proper locations within the plane using either differential drag[11], or propulsive maneuvering. Differential drag phasing can take a long amount of time, and propulsive phasing requires an on-board propulsion system, which many SmallSats lack. Altius has conceived of a potential new approach for constellation deployments enabled by HatchBasket hardware.

HatchBasket constellation deployments involve first maneuvering the cargo vehicle into an elliptical orbit in the correct deployment plane, with the apogee at the desired constellation circular orbit apogee, but with the velocity at apogee 5-10 m/s slower than a circular orbit. This elliptical phasing orbit has a period slightly shorter than the circular orbit, so that by the time the cargo vehicle has returned to apogee it is now phased a slight bit ahead of where it intersected the circular orbit at its previous apogee. With a 10 m/s velocity deficit at apogee, it will take approximately two weeks to phase through the full 360 degrees of the orbital plane.

At each deployment orbit apogee that aligns with a desired spacecraft location within the plane, the HatchBasket deploys the spacecraft with a sufficient deployment delta-V to circularize the orbit. HatchBasket provides a unique method for providing this circularization delta-V without requiring the deployed spacecraft to have on-board propulsion. This is accomplished by replacing the deployment spring in the deployer mechanism with a pneumatic spring. The differential pressure of the inside of the pressurized cargo section compared to the vacuum of space is sufficient to provide significant deployment velocity without exceeding the launch accelerations the spacecraft have to be designed for anyway.

The pneumatic deployment and associated plumbing will require further development to enable a safe,

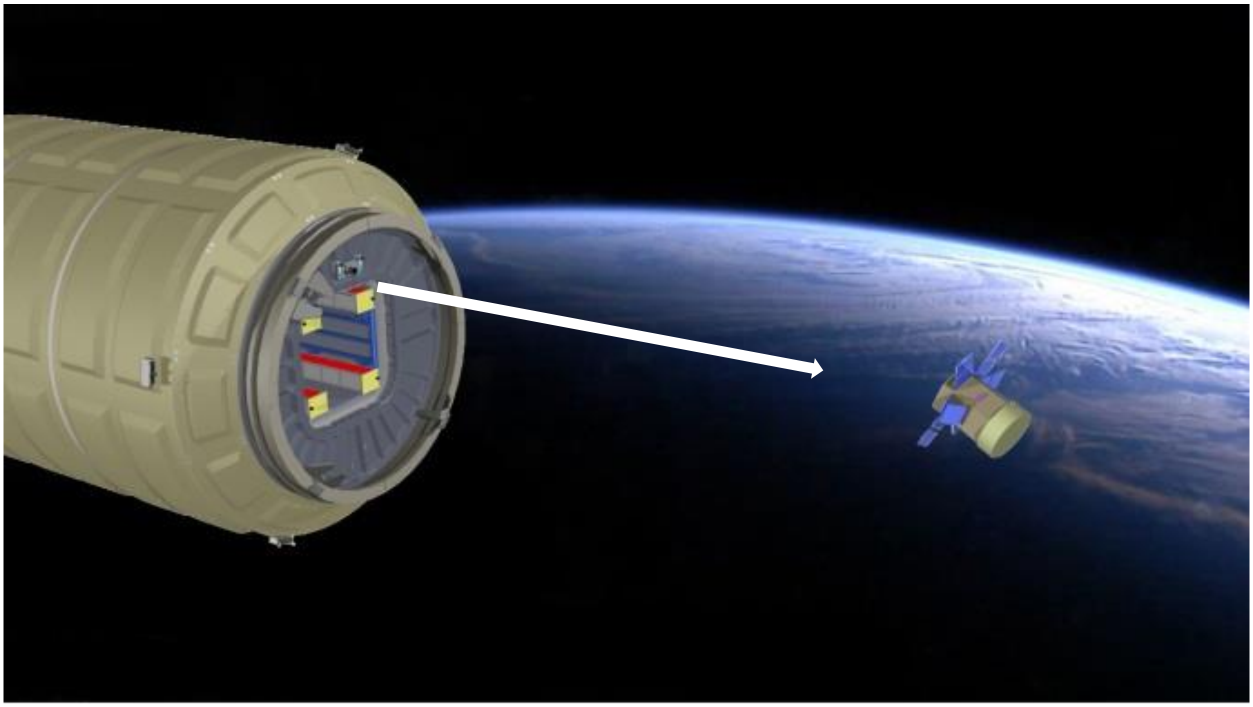

Figure 10: Cygnus as Chase Plane Observing a Payload

reliable, and consistent delta-V increment, but can provide a unique way of deploying constellations that is not available using traditional externally mounted deployment systems.

HatchBasket Chase-Plane Operations

Due to the built-in proximity operations capabilities of ISS cargo vehicles, HatchBasket enables a special type of post-deployment service similar to terrestrial “chase-planes” often used during flight testing of aircraft as shown above in Figure 10.

For a HatchBasket Chase-Plane mission, the HatchBasket hosts one or more sensors or cameras on the cargo vehicle forward bulkhead, as described previously. These can include high-speed or high-resolution cameras, LIDAR, Radar, IR or UV sensors, spectrometers, radiation sensors, and IR, visible, or UV illuminators.

The cargo vehicle maneuvers into the desired deployment orbit, HatchBasket deploys one or more payloads, and then the cargo vehicle performs a maneuver to match the deployment velocity imparted into the deployed payloads, enabling the cargo vehicle to follow the payloads at a predetermined distance and orientation. The cargo vehicle and HatchBasket then can provide significantly enhanced sensor capabilities to the deployed payload as it performs its designed mission, such as extension of a deployable structure, firing of an electric propulsion system, performing proximity operations and docking between two deployed spacecraft[12], or operation of a plasma magnetoshell aerocapture system[13]. Standoff observation such as can be provided by HatchBasket Chase Plane services can significantly augment data taken by sensors mounted on the CubeSat or microsat, providing a much better experimental setup than could be provided using other deployment options, at only a modest increase of cost and mission complexity.

Other Hosted Services

In addition to the above options, Altius and NanoRacks have conceived of other potentially useful services that can be provided to deployed spacecraft or hosted payloads using hosted hardware on the cargo vehicle:

- Videos or still images of deployments for quality assurance purposes.
- Communication Relay services, where the cargo vehicle uses its significantly better communications hardware to augment spacecraft-to-ground communications for satellites, potentially significantly shortening the commissioning phase for the satellites.
- Spacecraft manipulation, inspection, and/or assembly using hosted robotic manipulators.
- Post-ISS departure propellant transfer to spacecraft with propulsion systems, avoiding the risk of energetic and/or toxic propellants inside ISS.

While many of these services do require additional development, many of them are unique capabilities that only HatchBasket can easily provide and requires no special modifications to the cargo vehicle.

CURRENT STATUS

Altius Space Machines is working with NanoRacks to develop the HatchBasket system. Altius is providing the engineering, design, manufacturing, and flight control of HatchBasket and NanoRacks is providing the knowledge and experience to shepherd the project through the NASA Safety Process and Manifesting process and will be the sales channel and primary customer interface for HatchBasket, once approved for launch.

Altius and NanoRacks are in discussions with NASA ISS Program Office to evaluate potential hazards that Altius will need to mitigate in order to receive permission to fly HatchBasket. One of the key hazards is the risk of accidental re-contact with the ISS posed both by maneuvering the cargo vehicle to a higher altitude than the ISS, and subsequently deploying payloads. Altius and NanoRacks are working with the ISS Program Office to determine a safe methodology that is feasible with the propulsion capabilities of the ISS cargo vehicles to be used with HatchBasket.

Another key hazard is that of potential Pressure Structure failure due to the pressure differential once the inside of HatchBasket is depressurized. Altius is working with multiple potential partners to assess potential structural solutions, identify the required analyzes, and prepare for a rigorous qualification process for the Pressure Structure.

Altius and NanoRacks are also investigating potential technology demonstration missions that can be enabled by HatchBasket, and are working with NASA to determine manifesting opportunities for HatchBasket.

While HatchBasket is not yet manifested for flight to the ISS, Altius and NanoRacks are now discussing launch opportunities with potential spacecraft and hosted payload customers.

CONCLUSION

The Altius HatchBasket deployer system provides many unique capabilities that complement existing and future SmallSat launch methodologies. While there is still significant work to be completed before HatchBasket can be manifested and flown, it is an enabling, near-term launch option, particularly for technology demonstration payloads and microsatellites.

REFERENCES

1. Buchen, E. and D. DePasquale, "2014 Nano/Microsatellite Market Assessment," http://www.sei.aero/eng/papers/uploads/archive/SpaceWorks_Nano_Microsatellite_Market_Assessment_January_2014.pdf
2. Dyer, J., et al. 2014. "SkyBox Imaging and SkySat-1," Proceedings of the AIAA/USU Conference on Small Satellites, Private Endeavors.
3. Marshall, W. and C. Boshuizen. 2013. "Planet Labs' Remote Sensing Satellite System," Proceedings of the AIAA/USU Conference on Small Satellites, Pre-Conference: CubeSat Developers' Workshop, SSC13-WK-15. http://digitalcommons.usu.edu/cgi/viewcontent.cgi?filename=0&article=2872&context=smallsat&type=additional
4. Dyer, J., A. Dinardi, and K. Anflo. 2013. "First Implementation of High Performance Green Propulsion in a Constellation of Small Satellites," Proceedings of the AIAA/USU Conference on Small Satellites, Propulsion, SSC13-VII-2. http://digitalcommons.usu.edu/cgi/viewcontent.cgi?filename=0&article=2957&context=smallsat&type=additional
5. Christian, E., M. Desai, and N. Murphy, "Space Weather Science with Interplanetary CubeSats," Proceedings of the Third Interplanetary Cubesat Workshop, Caltech, May 2014. https://icubesat.files.wordpress.com/2014/05/icubessat-org_2014_a-1-2-weather_-christian_20140527.pdf
6. Spaceflight: Secondary Payload Basics http://spaceflightservices.com/resources/secondary-payload-basics/
7. NanoRacks: Smallsat Deployment http://nanoracks.com/products/smallsat-deployment/
8. Qiao, L., C. Rizos, and A. Dempster, "Analysis and Comparison of Cubesat Lifetime." http://www.gmat.unsw.edu.au/snap/publications/qiao_etal2012b.pdf
9. Orbital's Cygnus Spacecraft Selected by NASA to Host Experimental Fire Safety Payload

https://www.orbital.com/NewsInfo/release.asp?prid=862

10. Holemans, W., "The Lightband as Enabling Technology for Responsive Space," Proceedings from the 2nd Responsive Space Conference, Los Angeles, CA, April 2004. http://www.responsivespace.com/Papers/RS2/SESSION%20PAPERS/SESSION%207/HOLEMANS/7005P.pdf
11. Shuford, S., "Feasibility of CubeSat Formation Flight Using Rotation to Achieve Differential Drag," AIAA, June 2013. http://digitalcommons.calpoly.edu/cgi/viewcontent.cgi?article=1122&context=aerosp
12. MacGillivray, S., "Proximity Operations Nano-Satellite Flight Demonstration (PONSFD) Overview," Proceedings of the 10th Annual CubeSat Developers Workshop 2013, Cal Poly, April 2013. http://mstl.atl.calpoly.edu/~bklofas/Presentations/DevelopersWorkshop2013/MacGillivray_Proximity_Operations.pdf
13. Altius Space Machines Displays MIDAS Touch with Deep Space CubeSats http://www.parabolicarc.com/2014/05/05/altius-space-machines/