"Coach Class to Orbit:" the NPS CubeSat Launcher

Christina M. Hicks, Adam C. DeJesus, Anthony D. Harris, Matt R. Crook, Felix Rossberg, Daniel Sakoda, Rudolf Panholzer, and James H. Newman
Space Systems Academic Group, Naval Postgraduate School
1 University Circle, Monterey, CA 93943; 831-656-2487
jhnewman@nps.edu

ABSTRACT

To meet the challenge of improving CubeSat access to space, a team of graduate students at the Naval Postgraduate School (NPS) is developing the NPS CubeSat Launcher (NPSCuL). NPSCuL is an enabling technology that seeks to utilize excess capacity on US launch vehicles to provide CubeSat developers with routine, high capacity, low-cost access to space. The launcher currently integrates eight Cal Poly Poly-Picosatellite Orbital Deployers (P-PODs) with a deployment sequencer in a simple structure. NPSCuL will be able to accommodate up to twenty four units of CubeSat volume on a single launch using only one ESPA-class payload interface. This capability has the potential to advance US space technology and ensure that the next generation of US space professionals will remain on the cutting edge of very small satellite development. A flight-qualified NPSCuL is expected to be complete in late 2009 with a potential launch as early as August of 2010. NPSCuL provides "coach-class-to-orbit:" a high-capacity, low-cost way to deliver CubeSats to space that is consistent with US launch capability, the CubeSat specification, the needs of the growing CubeSat community, and US national interests.

BACKGROUND

CubeSats are nano or pico satellites that conform to the standard that was developed by California Polytechnic University (Cal Poly) and Stanford University in 1999[1]. The standard is a 10 cm x 10 cm x 10 cm cube weighing no more than 1 kilogram. Compared to other satellites, they are relatively inexpensive and quick to develop and build, making them ideal for educational purposes, which is why the majority of CubeSat developers have been universities. Due to advances in miniaturizing technology and an environment of tight budget constraints, corporations and government agencies have been developing CubeSats as well. Despite this rapidly growing CubeSat development community, launch opportunities for CubeSats in the United States remain scarce, despite the thousands of kg of excess payload capacity on US military and Government Evolved Expendable Launch Vehicles (EELVs). Of the large number of CubeSats in development, only 44 CubeSats have been launched and only 28 have made it to orbit. Furthermore, there have only been five CubeSats successfully launched in the U.S.

This paper provides an update to the NPSCuL program, first described at the 21st Annual AIAA/USU Conference on Small Satellites.[2] To leverage the affordable capabilities of the CubeSat and provide high capacity access to space from the U.S. for the CubeSat community, a team of students at the Naval Postgraduate School (NPS) are developing the NPS CubeSat Launcher (NPSCuL, pronounced NPS "cool").

DESIGN

The NPSCuL integrates existing standards and interfaces such as the EELV Secondary Payload Adapter (ESPA)[3] and Cal Poly's Poly-Picosatellite Orbital Deployer (P-POD).[4]

Figure 1: EELV Secondary Payload Adapter (ESPA) with 15" Adapter Ring

The original design of the NPSCuL accommodated up to fifty 1U CubeSats, but was modified to a more compact and lightweight version, the NPSCuL-Lite, in order to be compatible with a launch opportunity on the

Atlas V Aft Bulkhead Carrier (ABC). The National Reconnaissance Office (NRO) CubeSat Program Office, or QbX, is promoting the flight of ADaMSat, the Advanced Systems and Technology (AS&T) Development and Maturation Satellite on NRO L-41, an Atlas V currently scheduled to launch no earlier than August 2010. ADaMSat comprises NPSCuL-Lite, a sequencer, and the P-PODs and CubeSats.

As shown in Figure 3, the NPSCuL-Lite itself is a simple box-like structure that incorporates eight P-PODS in a pinwheel configuration in the interior of the structure, accommodating up to twenty-four 1U CubeSats. Attached on the bottom plate is an adapter ring that is compatible with the ESPA fifteen-inch circular bolt hole pattern. A deployment sequencer is mounted externally on one of the four side walls. The NPSCuL-Lite dimensions and mass are compatible with both the ESPA and the ABC secondary payload volumes. The NPSCuL-Lite structure with the adapter ring is approximately 21 inches high and 18.5 inches in length and width. Fully loaded with P-PODs, CubeSats, and a sequencer the NPSCuL-Lite weighs nearly 170 lbs.

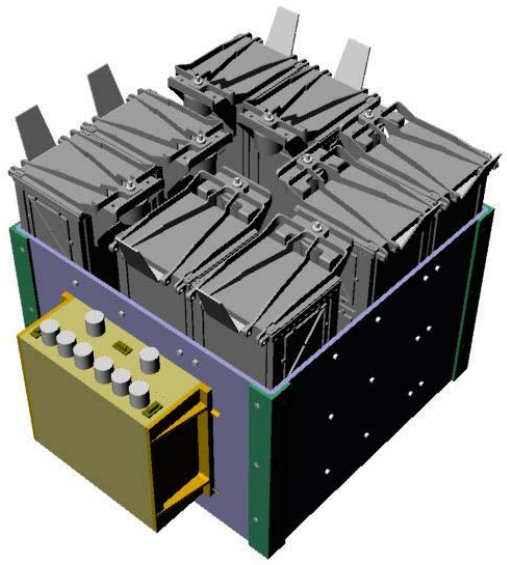

Figure 3: NPSCuL-Lite

Sequencer

The sequencer acts as an electrical interface between the launch vehicle and the P-PODs, controlling the deployment sequence and the routing of P-POD door status telemetry data. The sequencer is powered by the launch vehicle and accepts primary and redundant command signals to begin deploying the P-PODs. The sequencer contains the logic which fires the P-POD non-explosive actuators (NEAs) in a predetermined deployment sequence. Each P-POD has a door micro-switch that sends 'door open' or 'door closed' status back to the launch vehicle via the sequencer. The NPSCuL team built and integrated a mass model for structural qualification testing based on a sequencer being designed by Design-Net for United Launch Alliance (ULA).

TESTING

Mass Models

The NPSCuL qualification unit consists of a flight-like structure with aluminum mass models of the P-PODs and sequencer.

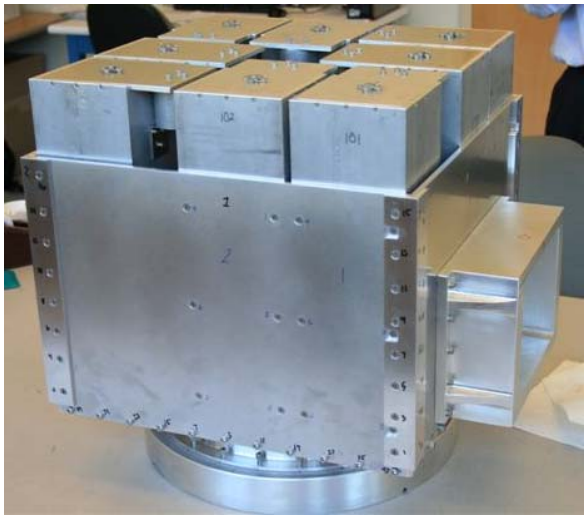

Figure 4: NPSCuL-001 Qualification Unit

The use of mass models keeps the cost of the project down; although it does decrease the fidelity of the testing as the mass models are not flight-like. The mass models are made of Aluminum 6061 and are representative of the center of gravity and moments of inertia of the actual P-PODs and sequencer. The P-POD weight is based on a maximum 3U CubeSat weight of about 4.5 kg, and the sequencer mass model, also 4.5 kg, was built to weigh approximately 25 percent more than the expected weight of the actual unit. These mass model designs are expected to be worst case masses to ensure an adequate margin of safety.

Preliminary testing has shown the importance of ensuring flat mating surfaces and careful fastener selection and analysis. Work is continuing towards performing a full vibration and shake test with flight-similar hardware to ensure valid test results.

Environmental Test Parameters

The testing of the NPSCuL qualification unit includes a sine sweep of 15-1500 Hz between each test, a sine burst of five pulses at 40 Hz with a 12.4 g peak, and a random vibration to four times the expected launch loads for three minutes on each axis. Due to the location of the ABC on the aft end of the upper stage, the qualification vibration loads are more severe than those normally seen on an ESPA. In addition, the thermal environment may pose challenges to ADaMSat. The location of ABC and its payload is at the aft end of the Centaur upper stage and so is exposed to radiation from the 1900°F nozzle for a maximum duration of 920 seconds with an estimated view factor of 0.5 for preliminary analysis. Following thermal analysis that takes into account the various mission parameters, thermal-vacuum test parameters will be defined for the Cubesats and the ADaMSat payload.

PROGRAM MANAGEMENT

In the interest of educating our future Aerospace workforce, the NPSCuL project is led and manned by a team of students. Guided by NPS faculty, students are able to participate in all facets of spacecraft development including design, production, testing, integration and documentation. They have the experience of working through the operational and engineering challenges inherent in construction and qualification of flight hardware. From the beginning, the project has been led by student program managers who gain experience in creating and managing a budget and schedule as well as handling program risk. NPSCuL has risk in several areas including budget, schedule and technology.

Funding

In late 2007, the California Space Authority and California Space Education and Workforce Institute (CSEWI), through a Department of Labor grant for the "WIRED" Program, provided funding to design and build an NPSCuL model and produce appropriate documentation. Partial funding was subsequently provided by the NRO QbX to build a qualification unit. Recently, both CSEWI and QbX have provided additional funding to support testing and flight unit build of the NPSCuL-Lite structure. CSEWI's goal is to foster space technology development efforts that contribute to the development of the workforce in the California Innovation Corridor; therefore, they are specifically interested in NPSCuL providing university student CubeSat developers' rides on missions such as the STP ESPA-ring, expected to fly in 2012.

Schedule and Risk

The schedule is success oriented, with a limited budget and a timeline for development, test, and delivery of sixteen months. The goal is to deliver a flight-qualified NPSCuL-Lite and associated products by February of 2010, with a potential launch as early as August of 2010. The schedule risk was exacerbated by two significant issues. First, an integration manager was not available until fairly late to facilitate technical interchanges and coordinate documentation and hardware deliverables. Second, the flight-specific launch vehicle to payload interface control document (ICD) was also not available until fairly late for the proposed flight. Nonetheless, the program has had to move forward accepting these risks to have any chance of producing flight hardware by the required timeframe to meet the launch provider's requirements. As the ICD is being finalized, the primary technical risk is ensuring that the NPSCuL-Lite is structurally sound and capable of supporting the P-PODs, sequencer, and cables while being subjected to the launch vibration and thermal environments. By managing these risks and challenges, the students gain a valuable education in spacecraft development and program management.

Education and Outreach

The goal of NPSCuL is not only to provide education and experience to NPS students, but also to provide access to space for US Government CubeSats and also affordable access for university-developed CubeSats. The operational concept anticipates that NPSCuL may have excess capacity after accommodating NPS and other US Government CubeSats. These flight opportunities could then be offered as educational outreach to university students and businesses to stimulate innovative thinking in CubeSat technology and interest in working in aerospace. Partnering with Cal Poly (San Luis Obispo) as a liaison to universities building CubeSats enables a collaboration that builds on the strengths of each community. In addition, it is anticipated that NPS satellite test and checkout facilities, including, but not limited to: the thermal vacuum chambers, vibration facilities, solar simulator, EMI chamber, etc, could be made available to the university CubeSat builders, helping to enable their success in building CubeSats and also exposing the students to government service through their interaction with the personnel at NPS.

INTEGRATION

Although NPSCuL is scheduled for launch in August 2010, one of the goals of the program is to be routinely manifested on EELV launches. In support of this goal, a Payload Planner's Guide[5] was developed in order to suggest a payload integration process for manifesting

and routinely launching NPSCuL. The process will involve procuring and integrating Cal Poly's P-PODs with the NPSCuL. As shown in Figure 5, launch providers such as QbX or STP manifesting NPSCuL and having excess capacity could then coordinate with NPS and Cal Poly to offer spots to other developers, specifically U.S. universities and businesses. Candidate CubeSats from universities and industry will be nominated for launch on NPSCuL and their selection coordinated with the launch provider. In this way, U.S. Government CubeSats will have first priority on launches sponsored by the U.S., but excess capacity could be utilized for potential educational and innovation outreach opportunities. Cal Poly could be the point of contact (POC) for non-government CubeSat providers as well as ensuring that all CubeSats to be launched on NPSCuL have met the test and verification requirements as standardized by the CubeSat community and the P-POD launcher. An integrating contractor must be responsible for ensuring that all components including the NPSCuL structure integrated with the P-PODs, CubeSats, and sequencer meet the launch provider's test and verification requirements. The integrating contractor would also be responsible for final satellite mechanical and electrical integration and preparations prior to delivery to the launch provider.

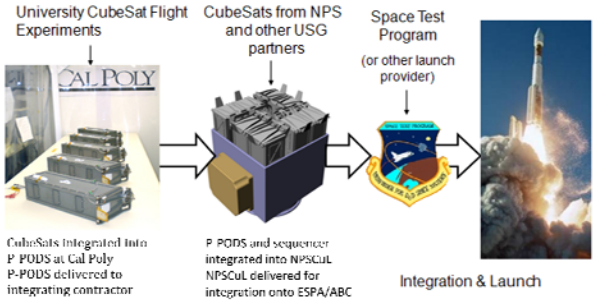

Figure 5: NPSCuL Integration Process

SUMMARY

Unfortunately there currently exists no domestic capability of launching a significant volume or number of CubeSats on the scale enabled by the NPSCuL. The growing realization and acceptance of the use of the CubeSat form factor for focused research objectives motivates the need for such a CubeSat Launcher. Furthermore, the NPSCuL enables the development of the future Aerospace workforce not only by providing a learning experience for the students developing the launcher but also by providing a low cost means for university students to access space.

Coach Class to Orbit

In the world of launch vehicles, the primary payload pays a premium price for its first class accommodations with plenty of "leg room" and provided services. On the other hand, CubeSats launched in the NPSCuL structure are riding in a low cost, high capacity launcher with only minimal services from the launch provider - coach class to orbit!

Acknowledgments

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