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A conversation with William H. Gerstenmaier

Fast track to truly fast flight

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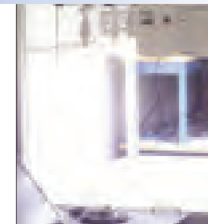


NOVA: Bright new star for CubeSat testing

In the early days of CubeSats, students and engineers would carry the 10-cm^3 satellites outside into the sunlight to test the cubes' ability to turn solar energy into electricity. Critical factors such as center of gravity, attitude control, and pointing accuracy might not be verified at all.

How did a student or instructor know if he had overlooked something? "Pretty much through just flying it," says satellite engineer Steve Wassom of Utah State University's not-for-profit Space Dynamics Laboratory (SDL) in North Logan, Utah. If the CubeSats worked, that was great—and any data gathered concerning space weather or magnetic fields would be a bonus on top of the learning experience for the students.

Today, that attitude is beginning to change. U.S. government customers have taken an interest, and CubeSats are becoming more and more complex. This has created a need for vigorous testing to characterize performance and validate requirements.

Small room with big prospects

Enter the Nanosat Operation Verification and Assessment (NOVA) Test Facility. Since August 2010, a 10x20-ft room at the SDL has been equipped with a Sun simulator and a magnetic-field-generating Helmholtz cage for verifying attitude control. There is also a mass measurement table containing numerous sensors for determining center of gravity to within 1 mm and mass to within 2 g. These, along with other equipment, are designed specifically for testing nanosatellites, loosely defined as satellites of up to 10 kg, which most often means a CubeSat. Universities and government agencies pay for services at the facility, and NOVA managers do their best to allow students and outside engineers to participate under legal liability constraints.

"NOVA is unique in its focus on servicing very small sats. Without such facilities we have to use standard much larger facilities, which are more costly and in some cases are not appropriate for CubeSats," explains Jordi Puig-Suari of Cal Poly, in an email.

Consider a spacecraft's center of gravity (cg). It must be known for precise pointing control. The designer of a large satellite might be satisfied to verify the spacecraft's cg to ±10 cm, but that margin of error would be the width of an entire CubeSat, says Wassom's colleague at NOVA, mechanical engineer Quinn Young. "When you scale down to these tiny little satellites, you have to be much more sensitive," says Young.

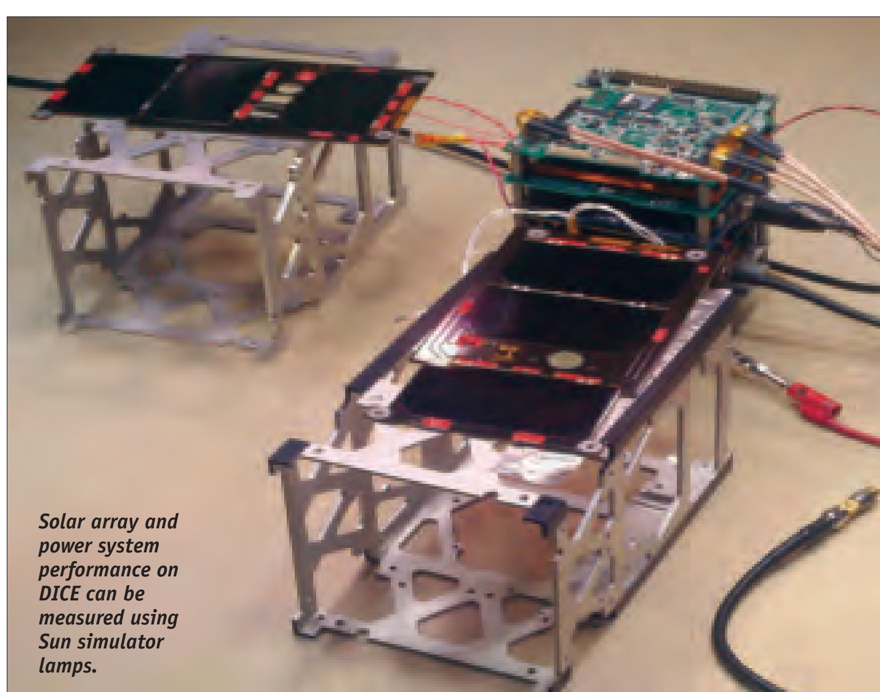
Testing for major customers

Universities are expected to remain important customers, but the low cost of CubeSats has caught the eye of the Air Force Research Laboratory (AFRL), the Air Force's Space and Missile Systems Center, the Naval Research Lab, NASA, and the intelligence community.

With tax dollars at stake, government CubeSat managers must rigorously test and characterize the performance of their spacecraft before launch.

So far, NOVA has tested a pair of identical space weather satellites called DICE, for Dynamic Ionosphere CubeSat Experiment. The satellites were built at SDL and were sponsored by the National Science Foundation. They will spin in orbit approximately 200 km from each other to study how magnetic storms and variations in the density of ionospheric plasma affect electric field properties. Engineers want to know how those variations might impact communications and navigation signals near Earth's surface and in space.

Next, NOVA officials are preparing to test PEARL, the Picosatellite Exo-Atmospheric Research Lab, for AFRL.



Solar array and power system performance on DICE can be measured using Sun simulator lamps.

This 30-cm-long satellite is called a 3U CubeSat because it will have the dimensions of three CubeSats joined together. PEARL is a nonspinning spacecraft that will serve as a prototype for a standard satellite design that could be configured for different payloads.

"It was that PEARL effort that got us thinking really hard about how you do a government-class spacecraft that requires validation of its requirements, and that led us to development of the NOVA lab," says Young.

AFRL's interest in CubeSats might not be surprising given its research mission, but the Air Force's Space and Missile Systems Center's (SMC) sudden interest was a big breakthrough for CubeSats, Young says. SMC is best known for overseeing the construction of giant military communications and missile warning satellites. In April 2011 Boeing announced it had received a $5-million contract from SMC for construction of the Space Environmental Nano-Satellite Experiment, or SENSE, a 30-cm-long CubeSat.

Large value in small packages

Professors Jordi Puig-Suari of Cal Poly in San Luis Obispo, California, and Bob Twiggs of Stanford began working on the CubeSat design standard in 1999 and published it in 2000. Their goal was to make use of unused volume aboard rockets and to give students valuable satellite building and flying experiences. Puig-Suari and Twiggs settled on a design that would be small and simple enough to be built and launched within the constraints of the average curricula.

By establishing standard dimensions for the CubeSats and a common launch mechanism, engineers would avoid having to conduct a lot of unique engineering for each launch. They would collaborate and share development costs across universities, says Puig-Suari. The CubeSats were small and light enough that universities would be able to afford the launch fees, which run on the order of $80,000.

Today, about 100 CubeSats have been orbited since the first batch was launched in 2003 aboard a Rockot from Plesetsk, Russia. CubeSats are dispensed from canisters called P-PODs—poly-picosat orbital deployers—which are typically attached to the bottom of a rocket's upper stage. The cubes are compressed into the P-POD on a metal coil, so that when the door is opened they are automatically ejected. A single pod can carry up to three cubes, or one 30-cm-long satellite 10 cm on a side.

Precision pointing

Given the growing interest of ,government customers, Wassom and Young have their sights set on key upgrades that would keep the facility up to date with anticipated advances in CubeSat designs.

"One of the things that really differentiates the university-based CubeSats from what we call military grade is the ability to point," Wassom explains. "Pointing is usually critical to mission capability, and so that's where we're headed." Because CubeSats are so small, imaging is not typically a focus of their missions, but accurate pointing is nevertheless important for precisely mapping magnetic fields or the directions of space weather phenomena.

To improve pointing, engineers are starting to look into installing star-tracking cameras on their CubeSats. Sensing a star pattern gives better attitude knowledge than mathematically combining the Sun angle with the orientation of the cube relative to Earth's magnetosphere. A star-tracking CubeSat would have a control accuracy of ±0.02 deg compared to an error of 0.2 deg for one with a Sun-sensor/magnetometer system. When a CubeSat is stabilized by spinning, the attitude control error averages about 5 deg.

Once a CubeSat's computer knows where it is, the satellite can adjust its attitude, firing up torque coils—electromagnets whose magnetic fields interact with Earth's—or, in the case of PEARL, by combining the force from torque coils with the inertia from spinning reaction wheels.

The CubeSat standard does not provide for thrusters or other kinds of propulsion, and in any case, a launch provider would have to provide a waiver, due to the real or perceived threat the propulsion system could pose to the main payload, Young says.

A miniature version of much larger, costlier facilities, NOVA enables small satellites to be tested affordably and with greater precision.

New tools, new attitude

To test the new breed of CubeSats, Young and Wassom plan to add a star-field simulator and a Stewart platform, a table that would swivel with the satellite attached to it to mimic changes in attitude relative to the stars.

The combination of those tools and the specialized mass table is a powerful one, the two say. Engineers of more complex missions need to be confident that their spacecraft can cope with orbital forces. "A satellite will naturally rotate based on perturbations based on drag in the atmosphere, or other things like that. There are gravity gradients that you get from Earth, so it will drift. And so the satellite has to be designed to correct for that drift in order to stay pointing in the direction it wants to point. And all of that requires you to know where the center of gravity is," Young says.

But for many CubeSats, the availability of a Sun simulator and Helmholtz cage was breakthrough enough. Spinning versions can be suspended by thread inside the cage or set on an air bearing atop a nonmagnetic pedestal. Electric coils generate a magnetic field to simulate conditions in space.

"The unique thing we believe we have in that Helmholtz cage is that it's a fully dynamic unit," Young explains. "Most of the coils we've read about in literature are just static magnetic fields. We have the controls and the electronics to rotate the magnetic field any way that's needed," he explains. "You can put the satellite in there on a stable, nonmagnetic platform and hold it really still and move the magnetic field around it."

The Helmholtz cage is particularly valuable for testing the performance of torque coils, which are the electromagnets that CubeSat operators rely on to change a satellite's attitude or prevent it from tumbling. "You run a current through the coil and it creates a magnetic field, and that field interacts with the magnetic field around the Earth," Young says. CubeSat operators "use that in order to have the forces that cause the rotation of the satellite."

Once the satellite is in the Helmholtz cage, the craft's onboard control algorithms can be tested. When things go well, the tests provide confidence that the craft's magnetometer is measuring Earth's magnetic field correctly and that the torque coils are receiving the proper commands, which might be to counteract or augment the force imparted by the surrounding magnetic field. "In addition to validating the performance of the components, you are validating the full, end-to-end system capabilities to make sure everything is working the way it's supposed to prior to launch. That philosophy is actually the reason we built the facility," Young says.

As for testing power systems, engineers can do a lot better than carrying the craft outside or putting it on a car dashboard. NOVA includes a test cell specifically for verifying the power output of CubeSat solar arrays, which are typically mounted flush on the satellite's surfaces. To simulate solar illumination, lamps are shone on the arrays, either separately or after they are installed on the CubeSat. That way, they can validate the entire electrical power assembly. The intensity of the illumination is measured by a pyranometer built to National Institute of Standards and Technology standards.

"You generate power from the light, then charge the batteries, run the system, and validate that everything in that system—all the algorithms, all the software, all the connections—are working. It's a similar concept to the attitude control, where we're validating the end-to-end system, or the individual components," says Young.

NOVA is a miniature version of the test facilities available for multibillion-dollar satellites, and one with a built-in growth plan. Says Young, "There's some infrastructure you need to have, and we haven't had it until NOVA."

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