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Tracking cubesats

Students love their cubesats, except maybe when they lose contact with one in the first days after launch because the team hasn't yet nailed down its orbital track. Cubesats are often reacquired, but not without frayed nerves and lost experiment time. Amanda Miller spoke to researchers who think they can keep cubesat operators locked onto their satellites from the start.

BY AMANDA MILLER | agmiller@outlook.com

◀ **Two cubesats are** deployed from the Nanoracks cubesat deployer at the end of one of the International Space Station's robotic arms. To better help track cubesats, a team of researchers at the University of Colorado in Boulder has suggested adding cameras to the Nanoracks deployer.
Nanoracks

The first passes overhead by the Miniature X-ray Solar Spectrometer 2 cubesat were exhilarating to the students who built it. At each anticipated crossing time, a small crowd of students, professors and staff gathered around computers at the Laboratory for Atmospheric and Space Physics at the University of Colorado in Boulder. Signals raced from LASP's ground station toward the estimated track of MinXSS-2. The signals hit their mark and triggered MinXSS-2 to confirm that it was listening and to send a report about its well-being, including its temperature, position relative to the sun, and the performance of its solar panels, battery and science instrument.

Several ham radio operators in the U.S. and Japan were pulling in the information, too, aiding the students to predict the timing and path of MinXSS-2's orbit.

Then came the letdown. On one pass, no reply came back. That's not unusual, but soon it happened again. Matters turned tense. "You spent five years to build it, and not being able to talk to it is very excruciating," says Scott Palo, CU Boulder professor of aerospace engineering sciences and one of MinXSS-2's investigators.

If an equipment failure on the satellite were to blame, the spacecraft's mission to chronicle the X-ray intensities of solar flares might be over before much useful data was collected.

As it turned out, the culprit was a frustrating side effect of the most affordable way to get a cubesat into orbit. MinXSS-2 was dispensed from its launch vehicle with dozens of other cubesats, which meant that on its initial passes, the signal beam projected from LASP covered all or many of the satellites in this cluster. But as the satellites drifted apart due to atmospheric drag and differences in their masses, the job of estimating when and where to direct the signal became more challenging. At this point, MinXSS-2 was not yet in the catalog of satellite tracks published by the U.S. Air Force by parsing radar detections (a job now done by the U.S. Space Force).

MinXSS-2's operators scrambled during each eight-minute pass to figure out if they were missing the return signal perhaps by incorrectly anticipating the Doppler shift in the cubesat's radio frequency caused by the satellite's motion relative to LASP. "You're sitting there turning a bunch of knobs trying to dial it in," says Palo, making a figurative reference to the process that's actually commanded by software.

Enter Palo's colleagues at the university's Colorado Center for Astrodynamics Research. They have come up with a technique that could someday relieve cubesat operators from the prospect of temporarily losing contact with their satellites during the harrowing first weeks in orbit.

The problem

Our story starts in 2015, when then-doctoral candidate John Gaebler decided to take up the challenge of ending sagas like the one experienced by the MinXSS-2 team. He'd witnessed the advent of clustered deployments in his years as a flight dynamicist at NASA's Goddard Space Flight Center in Maryland, before he began his Ph.D. work.

Even then, "I couldn't envision that they would launch 100 cubesats in five minutes," he says.

Gaebler won a research grant from FAA, which, at the time, had been tasked with figuring out how to regulate space traffic.

His plan was to write software algorithms that would sort radar measurements gathered by the Air

“Not only does it take [the military] a long time to find the cubesats, once they find them, they don’t necessarily know whose is whose.”

— Penny Axelrad, University of Colorado in Boulder

Force before the service converted them to tracks of known and unknown objects in its Satellite Catalog. This would be done through a filtering process called finite set statistics.

If the approach worked, he could produce reliable tracks, comparable to the military’s, within a few days rather than the weeks it can take clustered satellites to show up in the catalog published on websites including CelesTrak.com and Space-Track.org.

By simulating a real deployment, he could create his own sets of simulated radar measurements to test the process, since he did not have that data from the Air Force.

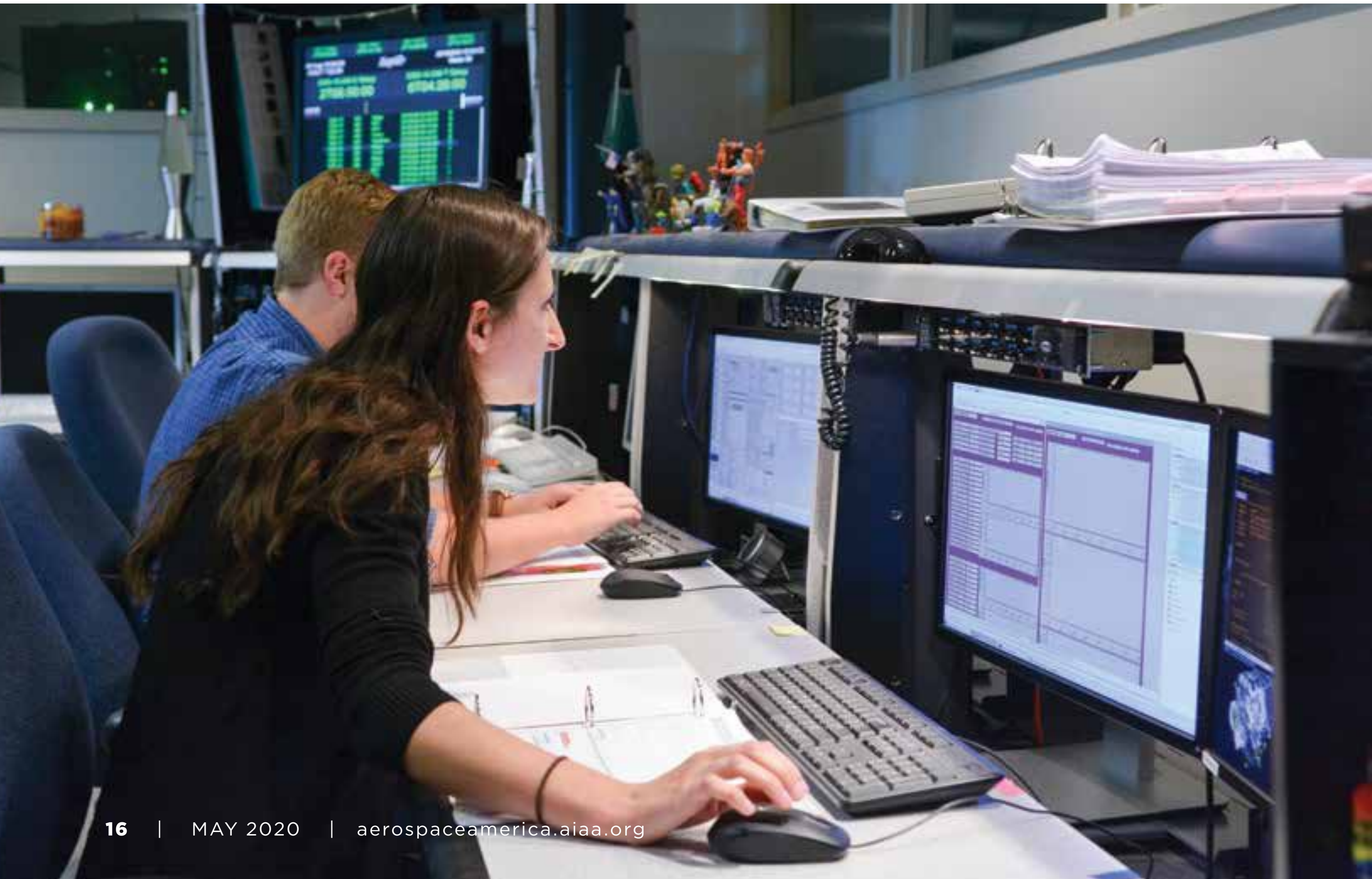
Gaebler’s project was no slight against the U.S. military’s space trackers. “What’s hard about it is cubesats are small. They have a low radar cross-section,” as Penny Axelrad, the project’s faculty adviser, explained during a public lecture last year.

When first dispensed, cubesats can be separated by as little as 5 meters, and Space Force trackers at first can’t sort out which radar measurements, such as the range, azimuth or direction of travel, and elevation, represent one orbit.

“Not only does it take [the military] a long time to find the cubesats, once they find them, they don’t necessarily know whose is whose,” Axelrad said.

Indeed, the Satellite Catalog lists unidentified satellites with a number. Once operators receive a signal confirming that one of these unidentified satellites is theirs, they report that to the Space Force’s 18th Space Control Squadron, which adds the identity to the catalog.

Back when just a cubesat or two reached space by riding along with bigger payloads, estimating the orbits according to the radar findings was “fairly obvious,” says Gaebler, who completed his doctorate this year. “What was plenty good enough before now isn’t so good.”



▼ **Then-graduate** students in the mission operations center at the Laboratory for Atmospheric and Space Physics in Colorado communicate with a satellite.

Glenn Asakawa/University of Colorado in Boulder

Building a simulation

To test his plan for quickly sorting radar measurements into satellite tracks, Gaebler first built a simulation of the 2017 deployment of 104 satellites from an Indian Space and Research Organization Polar Satellite Launch Vehicle rocket.

Plugging the cataloged radar tracks into NASA's open-source General Mission Analysis Tool showed him how the orbits spread apart over time. Next, he picked four of the military's radar sites around the world, and within the GMAT software he generated simulated measurements — range, azimuth and elevation — as though the satellites were being observed from those sites.

The 2017 launch afforded the added benefit that one company, Planet Labs of San Francisco (now simply Planet), owned 88 of the satellites. The company provided Gaebler with the only other information cubesat operators often have to go by upfront: prelaunch predictions of the satellites' positions.

"Now my simulation was that much more realistic," Gaebler says.

Running the algorithms

He went to work on the simulated radar measurements, before any had been matched as belonging to the same satellite.

After next defining the far outside limits of possible tracks for any satellite from the deployment of 104, he wrote algorithms to quickly pair up all the measurements one by one, calculating rough tracks and rejecting any combinations that exceeded his constraints.

To save time, Gaebler combined fewer data points at this stage than if he'd been trying to calculate precise tracks.

Once he'd narrowed down millions of possible measurement combinations into matches that could make realistic tracks, the algorithms set about doing the slower, more complex calculations of figuring precise orbits.

The process proved he could sort out the orbits of the 104 clustered cubesats "within days" with an uncertainty of about 50 meters.

Gaebler is continuing the research as a postdoctoral student, working on a proposal for an Air Force grant to figure out how few measurements he could get away with and still have the method work.

New data

Gaebler thinks radar might not be the only source of helpful information.

As the algorithm work progressed, Gaebler and Axelrad had a brainstorm when they recalled to each other how they had pored over the grainy black-and-white video taken from the launch vehicle as the 104 cubesats were dispensed, hoping for clues about the cubesat tracks.

One of the issues with cubesats is that they're dispensed by spring from their carriers. "There's a little bit of variability in how much oomph [each cubesat] goes out with," Gaebler explains. Accounting for that variability could make estimating the tracks more precise.

A more sophisticated camera system would be needed, one that measures the velocity of the departing cubesats.

Ten students in a yearlong senior design class mocked up a two-camera setup, thinking something like it might someday be mounted inside one dispensing tube of the Nanoracks cubesat carrier that dispenses up to six cubesats at a time from the International Space Station.

A time-of-flight camera would emit flashes of infrared light to bounce off the cubesats as they departed to calculate each cubesat's velocity during the deployment. Another camera would snap photos of each cubesat as it moved away.

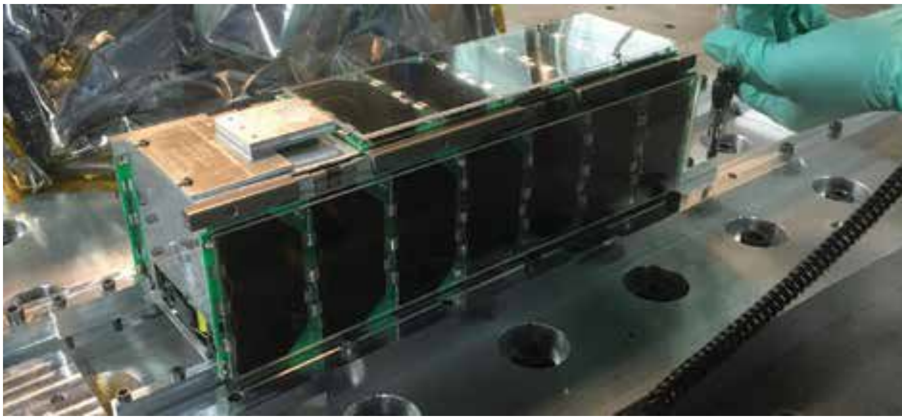
Now a new class of seniors has continued the research. Axelrad says she hopes the camera idea will prove worthy of a grant or other opportunity to do a flight experiment.

"We think these contributions are really going to be valuable for commercial space operations," she says.

As for MinXSS-2, the team reacquired it intermittently and finally nailed down the satellite's track after a month. Not long after, a computer card on the cubesat failed.

The cubesat is now considered a loss, but at the time, the team remained hopeful. The last MinXSS-2 post on the team's Twitter account was from Jan. 14, 2019:

"We think the MinXSS-2 is in a really slow tumble in an unusual software condition. At some point, the battery will trigger a system reset and beacons should begin again. #hamradio operators, please keep on tracking!" ★



▲ **Controllers lost track** of the Miniature X-ray Solar Spectrometer 2 cubesat, shown here during vibration testing, and were unsure whether they would be able to reconnect.
University of Colorado in Boulder