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Coming Soon: Swarms of Space Robots

The next generation of small spacecraft will travel in packs.

They may be small, but Cubesats launched by the dozen could tackle big jobs. (NASA)

By Kiona Smith-Strickland
airspacemag.com
May 6, 2016

In Earth orbit, a group of shoebox-size spacecraft swarms around the hull of a communication satellite, checking for damage. Further out in the solar system, a flock of glittering reflective spheres, each no bigger than a postage stamp, sweeps past an asteroid, measuring the pull of its gravity. A rain of wafer-thin circuit boards flutters down through the atmosphere of Titan, taking measurements as they fall.

Precursors of these future space "swarm" missions are scheduled to begin flying this year. They'll test basic functions like networking and communication; some will fly just to prove that extremely small, simple satellites can actually work in space.

In mid-May, the two CubeSats of NASA's Nodes mission will deploy from the space station into low Earth orbit, to became the agency's first free-flying, coordinated satellite swarm in space. The SPHERES satellites—three round, flying vehicles about the size of volleyballs—have been demonstrating formation flying inside the station since 2006. The SPHERES use ultrasound beacon and accelerometers to navigate, and cold carbon dioxide thrusters to propel themselves around the station, but they can't venture outside.

Nodes can, and the two CubeSats will collect data on charged particles in Earth's ionosphere as they drift apart. Scientists will get data from two locations at once, improving their understanding of spatial variation in the Earth's magnetosphere. The European Space Agency had similar goals in mind when it launched a constellation of three much larger satellites, called Swarm, in 2013. Swarm is more than halfway through its four-year mission and is still returning data from a more sophisticated instrument package than Nodes could carry.

The advantage of little satellites like Nodes is that they're cheap to build and launch, so they can fly in greater numbers to gather data over a wider area. Even with relatively simple sensors, large swarms could help map variations in Earth's magnetic field or pressure gradients in the atmospheres of other planets.

The two Nodes satellites will share their data, and one satellite will transmit both sets to Earth. In future large swarms, whichever satellite is best positioned to communicate with Earth will ping the others, one at a time, to request their data. This networking method was supposed to have been tested by an eight-CubeSat swarm called Edison Demonstration of SmallSat Networks, but EDSN was lost in a launch accident in November 2015. Nodes project manager John Hanson says the networking technique can easily scale up to tens of satellites.

With the ability to coordinate maneuvers and maintain a tight formation, swarms can potentially do even more. For instance, a swarm of small satellites could align their radio antennas to effectively work together as a single larger antenna. That requires that the satellites hold a very precise position relative to their neighbors, without colliding or drifting. The Defense Advanced Research Projects Agency (DARPA) had planned to launch a swarm of networked, formation-flying satellites called System F6 last year, but it cancelled the program in 2013 after six years of work. Reports at the time attributed the decision to management problems and a lack of interest from the Department of Defense.

This fall, two CubeSats will test formation flight in a NASA-funded experiment called CubeSat Proximity Operations Demonstration (CPOD). They'll use imaging sensors to keep track of each other while onboard software executes a pre-planned set of maneuvers, including having one CubeSat fly a circle around its partner, then dock with it. If successful, they'll be the first satellites to perform such maneuvers in open space, although SPHERES has done it onboard the space station.

"I think we're pretty close. I think in the next 5 to 10 years we should be able to successfully make use of these type of networks," says Andres Martinez, deputy program manager for NASA's Small Spacecraft Technology Program.

The European Space Agency has its own plans for a precision formation-flying mission, called Proba-3, in 2019. University researchers also are working on swarms of extremely small spacecraft, like the three-centimeter cubes that Jekan Thanga, head of the Space and Terrestrial Robotic Exploration (SpaceTREx) Laboratory at Arizona State University, calls FemtoSats. They resemble scaled-down versions of CubeSats, with miniaturized electronics. Thanga's team plans to launch a prototype next year, to make sure the mini-satellite's electronics can handle the harsh conditions of space. Next would come what Thenga calls a "rudimentary swarm" as a proof of concept, sometime in the next two years.

At Cornell University, aerospace engineering researcher (and former NASA chief technologist) Mason Peck and his team have been working on tiny satellites called Sprites. Weighing in at just 4 grams, the Sprites are basically flying, solar-powered circuit boards about the size of a Triscuit cracker, carrying a radio transceiver and small sensors.

Future missions could pack swarms of tiny spacecraft like FemtoSats and Sprites inside CubeSats, which in turn would ride to another planet along with a larger spacecraft. The idea may take off this year. In July, Peck's former grad student Zac Manchester, now a researcher at Harvard, hopes to launch a few hundred Sprites inside a CubeSat called KickSat 2. A communication protocol similar to one used by cell phones will allow the Sprites to share a frequency and communicate with Earth.

Eventually, similar swarms could become standard secondary payloads on science missions. "Some of those ideas are floating through our bigger missions," said Martinez.

“I think with such a small mass, it will become more and more difficult for folks to even avoid it or refuse to have them on larger missions,” said Thanga.

The consumer electronics industry has dramatically shrunk sensors and microcontrollers in the last decade, but propulsion has proven harder to miniaturize. Researchers at the University of Vermont are working on tiny chemical thrusters that could be small enough even for Peck’s 4g Sprites, but such thrusters aren’t on the market yet.

Meanwhile, tiny spacecraft might “live off the land,” as Peck puts it. Sprites are small enough to be pushed by the pressure of photons from the Sun, like leaves on the wind. Thanga’s group is working on harnessing solar power for the FemtoSats as well, using actuated solar panels for maneuvering.

Even without propulsion, fleets of tiny spacecraft could do some serious science. Justin Atchison at the Johns Hopkins University Applied Physics Laboratory envisions sending a dozen simple reflective spheres on a close flyby of an asteroid to map its gravitational field. A host spacecraft would launch them on trajectories passing close to the target asteroid, then track their reflected light against the background of stars. Measuring how their paths change as they pass the asteroid would reveal how much gravitational pull the asteroid exerts.

“The probes literally just have to be trackable for the camera, and have no intelligence or power or any actual capability in and of themselves,” says Atchison. He received a grant from NASA last year to develop the concept.

“There are missions that can be flown already with technology that we have now,” says Hanson. That could include an expanded version of Nodes, which would study how solar radiation interacts with Earth’s magnetic field. If CPOD works as well as its engineers hope, swarm radio telescopes could also be within reach.

By the 2020s, flying swarms could be incorporated into larger science missions. “We would like to be able to infuse these little guys into a bigger mission—to asteroids, comets, maybe Mars or the Moon—within a five-year timeframe,” says Thanga.

Peck says Sprites could be ready for missions to study Earth’s upper atmosphere within the next two years. And they’re probably three or four years away from a heliophysics mission, perhaps similar to Nodes, or a trip to an asteroid. “Primarily because we have to get a launch for that to happen,” he said, “but the actual technology to make it happen, again, is very near-term.”

And it all starts with two little satellites, ready to launch from the space station in the next couple of weeks.

This NASA video gives more detail about the coming Nodes mission:

About Kiona Smith-Strickland

Kiona Smith-Strickland is a freelance science journalist based in Kansas.