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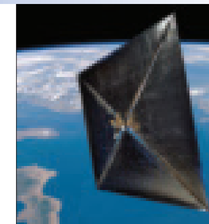


NanoSail-D2 breaks free

NASA ENGINEERS ARE PONDERING THE mystery of how the 10-m^2 plastic sail they launched into orbit in November somehow freed itself from its carrier spacecraft after refusing to deploy for five weeks. They are enjoying the new lease on life given to NanoSail-2D, which is now orbiting at an altitude of about 400 mi.

For several more months, they expect the kite-shaped sail to bring attention to the innovative concept of packing plastic sails into small units and attaching them to future satellites. The sails can then spring into action at the end of a mission to deorbit dying spacecraft through atmospheric friction. In other applications, they could catch photons the way sailboats catch the wind, providing an inexhaustible source of propulsion for satellites, or enabling them to circle over polar regions in non-Keplerian orbits.

While reveling in their good fortune, NanoSail-D2 team members say they are devising theories about how the sail became stuck. Although no one may ever know the answer with full confidence, the theories could help those planning to use the same deployment technique in the future. NanoSail-D2 was deployed using an eight-year-old design called a poly-picosat orbital deployer, or P-POD, which is counted as one of the great successes of the small satellite industry.

What's going on?

The mystery began when NanoSat-D was launched in a small NASA spacecraft called FASTSAT (Fast, Affordable Science and Technology Satellite) as one of six experiments on the spacecraft. On December 6, 2010, controllers opened a small door on FASTSAT to release the sail, which was supposed to spring into space and then unfurl. Instead, nothing happened.

"We spent the better part of the next month going through and trying to figure out what was going on," says electromechanical engineer Dean Alhorn, the NanoSail-D principal investigator at NASA Marshall. Because the sail was just one experiment aboard the craft, the FASTSAT managers had no choice but to shift their focus elsewhere. "It went from being first to last" in priority, Alhorn says.

The situation was frustrating for NanoSail-D engineers from Marshall and Ames. In just four months, they had figured out how to squeeze the sail, deployment booms, eight lithium ion batteries, and an antenna into the precise rectangular shape required for deployment from a P-POD. They had even posted a video on YouTube showing how the 10x10x30-cm package could transform itself into a kite-shaped spacecraft in just 5 sec. But their first attempt to test the approach had ended in disaster in 2008 when a SpaceX Falcon 1 rocket failed to reach orbit. Engineers had converted spare hardware into NanoSail-D2, but there were no spares left.

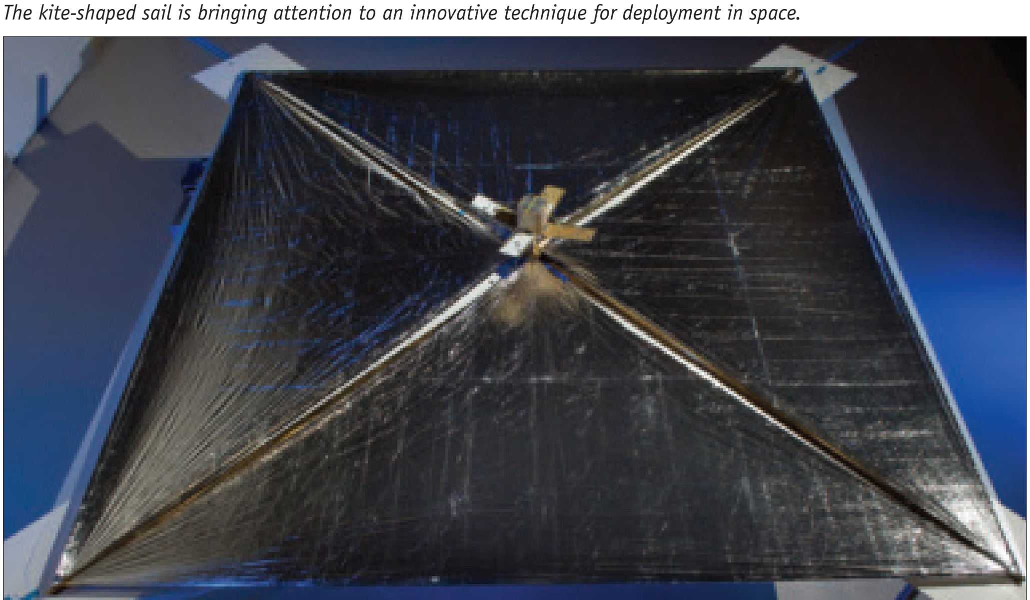
As for the P-POD approach, it appeared as if this mission could be a black mark in the series of missions that have been launched from Russian and U.S. rockets since 2003.

Then, on January 17, 2010, the outlook changed completely. Controllers in Huntsville, Alabama, detected a 3.5-deg rotation in FASTSAT, a torque that could come only from NanoSail-D2 ejecting from the spacecraft. There was no one to call immediately—it was a holiday, Alhorn notes. But on January 19, he was called to the mission operations center in Huntsville for the most pleasant surprise of his career.

"I'm looking on the white board and I see '3.5 degrees per second.' I said, 'Is this real?'" recalls Alhorn. Space surveillance tracking and, later, imagery, confirmed that NanoSail-D2 was indeed flying separately from FASTSAT.

Seventy-two hours after it

The kite-shaped sail is bringing attention to an innovative technique for deployment in space.



sprang free, the rectangular package transformed itself into the kite-shaped sail exactly as planned, beginning a 70-120-day mission.

Solving the mystery

NASA engineers are doing their best to untangle the mystery of the delayed ejection. "We probably will never know 100% why it got stuck," says Alhorn, "unless we go up there and get a 'CSI' satellite to take a look."

But coming up with plausible theories is not just an academic exercise. Engineers planning future P-POD missions might need to adjust their plans to avoid getting jammed the same way.

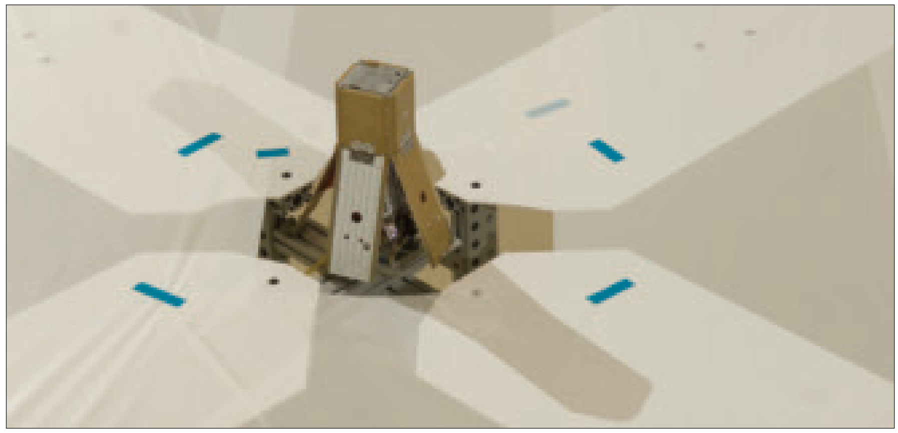
"When we heard we didn't come out, the team out at Ames Research Center cobbled together some old hardware that we had sent out there; some doors and a bus," Alhorn says. "They went through several iterations of trying to eject it in different configurations, and they sent us that data." That, coupled with on-orbit data "and what I know about operations of P-PODS," he recalls, "has led me to a theory that I think is true."

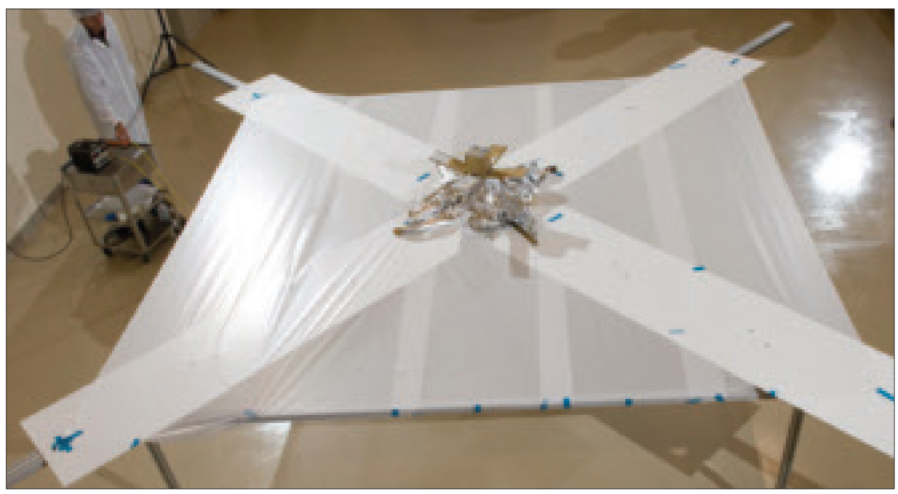
He says he will not discuss that theory until he presents a paper at the annual Small Satellite Conference, scheduled for August 8-11 in Logan, Utah.

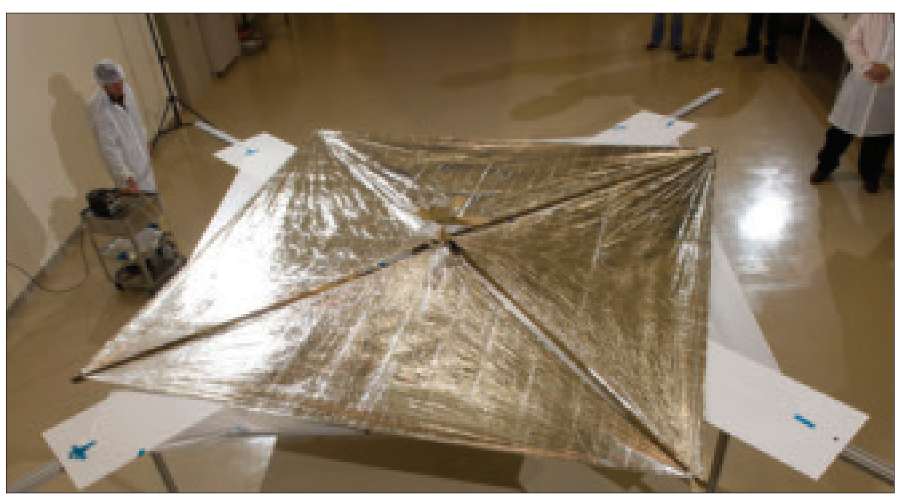
"It's such a simple system that if I were to say anything, you'd [think], 'oh, that's it,'" he says. "Suffice it to say that I have an idea of why it stuck and I'm in the process of verifying the analysis."

Other engineers involved with the project and with P-POD technology, however, were willing to offer some of their thoughts.

"Obviously, there was some friction somewhere in the system that prevented deployment," says aerospace engineer Jordi Puig-Suari, regarded as the grandfather of the P-POD mechanism. He is a professor at California Polytechnic State University (the poly in P-POD), San Luis Obispo. He suspects the attitude maneuver shifted the NanoSail package, or perhaps the canister, just enough to free it from FASTSAT.







(From the top) Three days into flight, the spacecraft would open four hinged doors, allowing the square sail to deploy.

The sail, made of extremely lightweight gossamer fabric, begins to unfurl, supported by rigid track booms provided by the Air Force Research Laboratory. The sail material is less than 1/16th the thickness of a human hair and is coated with an extremely thin layer of aluminum to enhance its ability to reflect solar energy. For this test engineers used rubber bands to secure the doors in the open position.

Fully deployed, the sail area measures 107 ft^2. It comprises four triangular membranes supported by thin metal tape booms. Full deployment takes just 5 sec. Image credit: NASA/MSFC/D. Higginbotham.

Friction is the enemy

But what caused the friction that kept the satellite in place? Puig-Suari remains somewhat confounded. "Everything is designed for the satellite to come out, which [the others] always have done," he says.

Friction was the enemy from the start. From 1999 through 2000, he and colleagues devised a concept for installing Teflon-coated aluminum rails inside storage containers and installing tabs on payloads to ride on those rails when the payload is ejected. They settled on a standard geometry and shared it with fellow small satellite enthusiasts, who have used the approach to launch up to three separate cubesats at a time. The strategy was a way to conduct several relatively low-cost experiments with one rocket launch.

Christopher Beasley, NASA Ames engineer, integrates NanoSail-D onto the ride share adapter, a piece of hardware that sits inside the shroud of the SpaceX Falcon 1 launch vehicle. Credit: NASA/ARC, Orlando Diaz.

A variety of cubesat experiments have flown, including NASA's 5-kg GeneSat in 2006. GeneSat carried a payload of bacteria and sensors to look for genetic variations caused by 0 *g*. GeneSat's bus, containing power and communications systems, became the foundation for NanoSail-D's bus design.

With the P-POD approach, engineers also have the option of ejecting single satellites filling the same volume. Small-sat engineers call these '3u' (three unit) satellites, and that is what NanoSail-D2 is.

When a payload is loaded into a P-POD, an off-the-shelf stainless steel spring is compressed, and the spring-loaded trap door is closed over it. Thin wires hold the door closed, but when a command is sent to put an electric charge through the wires, they dissolve and the door springs open. Without the pressure from the door, the stainless steel spring decompresses, ejecting the payload.

"It's basically a jack-in-the-box," Puig-Suari says.

It took Puig-Suari a while to convince NASA that a P-POD door would not fly open prematurely, damaging or destroying a rocket's multimillion-dollar primary payload. He says builders of multibillion-dollar geosynchronous communications satellites use the same technology to keep solar arrays in place until they are ready to deploy.

To keep the cubesats from getting stuck once the door opens, engineers must be careful to minimize friction between the canister and the payload. "The corners of the satellites have to be clean so the satellite can slide properly," Puig-Suari explains. Other, smaller, springs keep the payload properly positioned.

As with any technical mystery, engineers began by looking for ways that the NanoSail mission was different from other P-POD missions. One difference was that the NanoSail-D2 payload was mechanically complex, though designed not to shift within the aluminum panels that housed it before it was transformed. Compared to other instruments and what they do, says Puig-Suari, "it's a very complex, sophisticated spacecraft."

There was an even bigger difference. As Puig-Suari points out, in all P-POD flights to date the canisters were attached to the upper stages of their carrier rockets. This was the first time a P-POD was installed inside a satellite. In this case, a hole was cut into the lower deck of FASTSAT to accommodate the canister.

Puig-Suari mentions this disparity, but is still pondering whether it mattered: "There is no reason to think that should make a difference," he says.

Thermal challenge

NASA Ames engineer Bruce Yost, who helped coordinate the first NanoSail-D attempt, has an idea about why a P-POD vehicle might have reacted differently when launched from a free-flying satellite.

"Typically, as soon as the vehicle reaches orbit, it's deployed" from the P-POD, he says. "You want to get away from the rocket before it goes inert."

A P-POD ejection usually happens within 1.5 hr of reaching orbit, Puig-Suari notes. However, once FASTSAT separated from its Minotaur 4 rocket, no one expected controllers to deploy NanoSail-2D immediately. FASTSAT's attitude control and other systems had to be turned on and checked out. The spacecraft had to be oriented correctly to eject the sail into a safe zone, so that it would not slow down and fly back into FASTSAT.

"NanoSail-D was in the box for days," Puig-Suari says. The satellite was launched November 22 from Kodiak Island, Alaska. The door was opened on December 6.

There was plenty of time for 'thermal soak,' adds Yost. With parts of FASTSAT exposed to sunlight and others exposed to the cold of space, perhaps the thermal changes "were enough to change the geometry of the P-POD—or the spacecraft, for that matter," he says. That could have caused just enough friction to keep NanoSail-D2 from springing out until the attitude maneuver.

It is just a theory, but Yost has some concrete advice for anyone planning a similar mission. Before launch, "You could simply do a thermal test," he says. "You could cold soak the spacecraft" in a thermal chamber "for hours or days—however long it takes for the cold to have its effect—and then test" the deployment.

For the time being, he says, Ames plans to continue attaching its P-PODS to rockets.

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