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On-orbit servicing: The new focus

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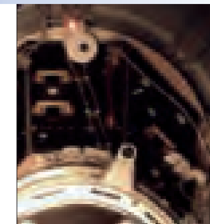


STORRM watch: Improving space navigation

Engineers from NASA, Ball Aerospace, and Lockheed Martin are using results from an experiment called STORRM (sensor test for Orion relative navigation risk mitigation) to make significant tweaks in the navigation system and operational simulations they are preparing for the Orion multipurpose crew vehicle.

NASA is also providing details on a technical glitch that prevented engineers from collecting as much video as they had wanted during the May 2011 mission of the space shuttle Endeavour. The problem could have had a far worse impact were it not for a rush workaround.

The experiment

The goal of STORRM was to test a high-definition video camera and a new type of laser range finder for Orion. The experimental instruments were installed on the orbiter's docking truss, and they fed their video and laser readings to STORRM's avionics box, which contained two data recorders, one for each instrument.

The centerpiece of the experiment was Ball Aerospace's laser range finding and imaging instrument, called the vision navigation sensor (VNS). Less technically challenging was the high-definition docking camera. Its role on Orion would be to provide situational awareness to the crew and reassurance that the VNS was accurately reporting the relative positions of Orion and the space station.

The plan was to operate the docking camera and VNS simultaneously with the shuttle's laser-based trajectory control system and cameras. For safety's sake, the VNS would shadow the trajectory control system, but its readings would not be used by the shuttle's navigation system.

Still, Ball engineers were anxious to prove the advantages of the VNS over the trajectory control system. "It's much lower power and mass than the current system, and it actually has no internal moving parts, which is also an improvement over the current system. That helps with reliability, of course," says Ball's Jeanette Domber, a systems engineer and the STORRM lead.

The trajectory control system consists of three mechanically scanning laser range finders, or lidars, that move back and forth over the field of view. VNS, by contrast, is a unitary sensor that sends pulses of light at the docking target 30 times a second. By measuring time of return from a set of reflectors installed on the target, the range and bearing can be determined.

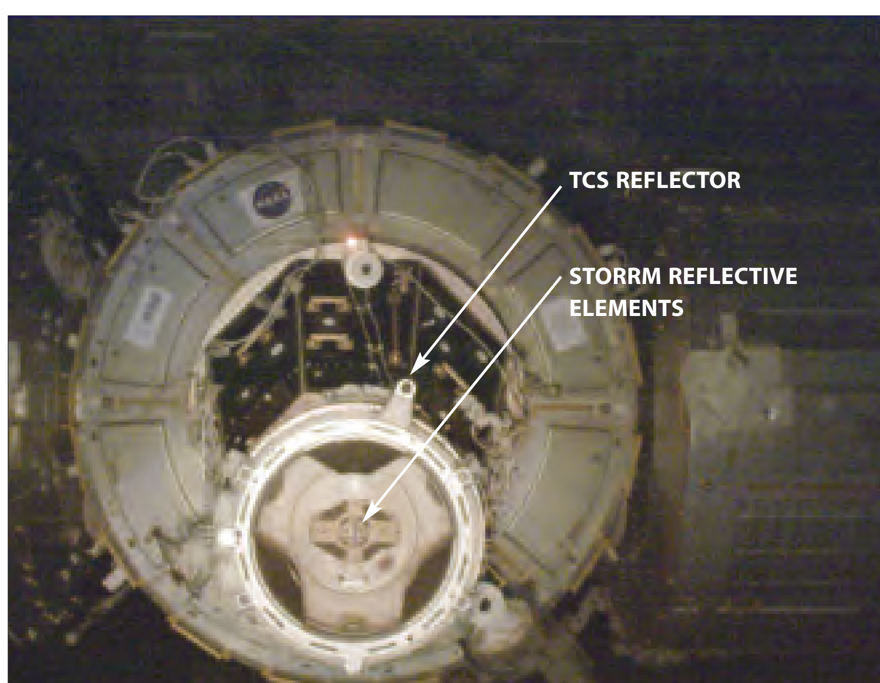
Only a space experiment could tell Ball engineers exactly what the complex surface of the ISS would look like in the particular wavelengths they had chosen for VNS. They needed to be sure their algorithms could find the docking targets from among those readings. The team would use the results to improve simulations at the Orion test chamber, built by Lockheed at its Waterton, Colorado, facility and unveiled last March.

Aboard Endeavour, the astronauts would view snippets of STORRM's video and laser range readings on a laptop computer. But for the most part, the data would be stored for processing and analysis after the mission.

Working around the clock

The STORRM equipment worked well on flight day three when Endeavour approached the ISS and docked with it. However, things would turn interesting on flight day 13, when astronaut Drew Feustel reported that the data recorder for STORRM's high-definition docking camera had failed to initialize properly.

In jeopardy was the plan to conduct a more elaborate STORRM test on flight day 15, the start of the orbiter's



STORRM's high definition docking camera captured the docking target as Endeavour approached the ISS in May 2011. As the shuttle neared, the individual reflectors on the docking target were resolved by the VNS and can be seen as five bright spots in the middle of the docking ring in the VNS intensity image.

trip home. After undocking, Commander Mark Kelly was to maneuver Endeavour away and reapproach the station to within 305 m on a trajectory mimicking the approach of an Orion crew vehicle. It would be an important test of VNS's ability to sense the relative positions of the spacecraft accurately during a docking approach.

The glitch never posed a safety issue for Endeavour, because STORRM's avionics box and sensors were separate from the shuttle's control system. But losing the day-15 data would have been a major blow for the engineers.

They spent the time between days 13 and 15 working "pretty much around the clock writing new procedures for Drew [Feustel]," says NASA engineer Heather Hinkel, the principal investigator for STORRM.

The fix would not be easy. Engineers had planned STORRM so that the docking camera and VNS would operate in tandem. A problem with either instrument would sound an alert. Feustel would have to load new procedures into the STORRM computer to quell the alerts. The docking camera could then be turned off and the VNS operated separately.

Running the docking camera without recording its images was not an option, because the recorder was also the command pathway to the camera.

"With that data recorder unit failing to initialize, there was no way to get commands from or to the docking camera anymore," says Hinkel.

The engineers managed to figure out how to shut off the docking camera without sounding alerts, and the VNS system operated as planned on flight day 15.

Surprising results

Thirty times a second, the VNS sent pulses of light at the ISS. These pulses bounced off the surface of the station and the five 1-in.-diam. reflectors that astronauts had installed on its docking target in 2010. If the VNS worked as hoped, it would acquire and start tracking the station from about three times farther away than the shuttle's trajectory control system could.

The two systems had radically different designs, starting with how they handled the varying light intensities. During docking, a laser system must be able to detect dim laser reflections at long ranges, as well as bright reflections at closer ranges, without becoming saturated by the light. The shuttle's trajectory control system consisted of three laser sensors for long, medium, and close-range sensing. The STORRM engineers wanted to prove they could accomplish the same thing with one sensor by toggling among different modes of gain, or sensitivity. If the strategy worked, it would reduce the mass and power of future navigation systems.

Ball engineers worked on the electronics in conjunction with Raytheon Vision Systems in Goleta, California, formerly Santa Barbara Research.

"In order to get that full range, we had three different modes built into the detector, which required two different electrical circuits on the back side. That was the innovation," explains Lisa Hardaway, lead engineer for Orion projects at Ball.

During the mission, engineers received some hints that the VNS was working well. Kelly had requested that the STORRM engineers display range estimates. The VNS was recording reflections 30 times a second, but without a powerful processing computer on board, range estimates could only be displayed once every 30 sec. Engineers were worried that bad luck might deliver 'noisy' range readings.

But, says Hinkel, Kelly "would look at that, and look at the other range information that was available, and it was matching up quite well."

After Endeavour landed, Ball engineers processed the VNS data and were happy with what they found. Before the mission, they had not been

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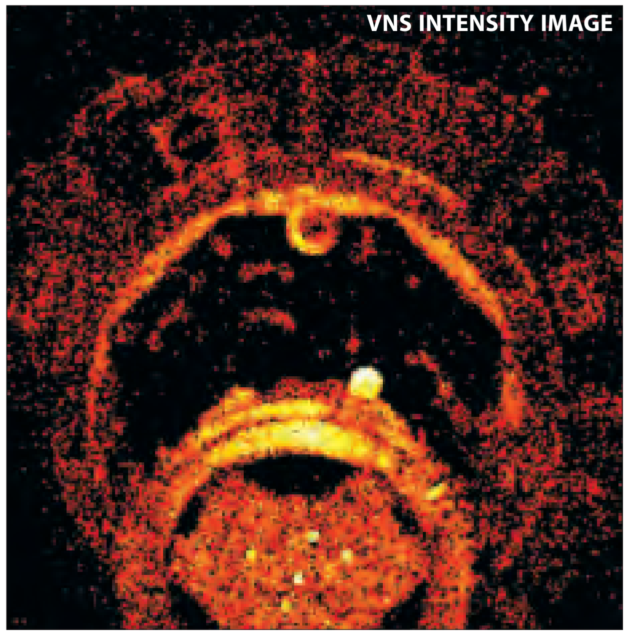

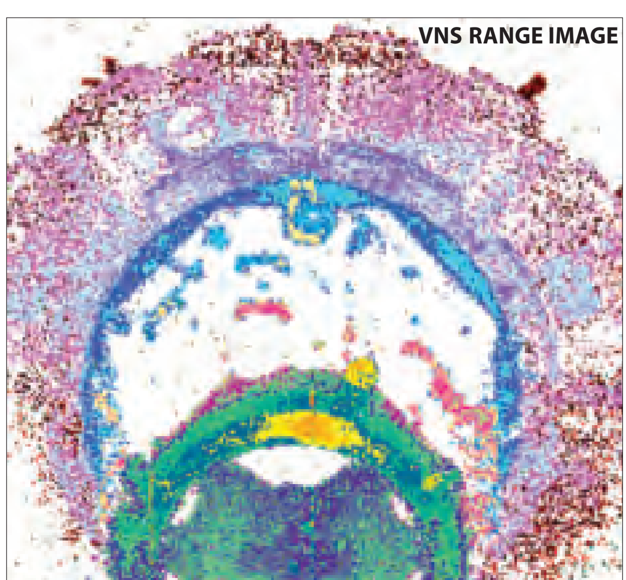

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completely confident that they could achieve tracking at a range of 5 km. They had tested the VNS by installing reflectors on a dorm at the University of Colorado in Boulder and at the National Center for Atmospheric Research. They made the reflectors a little larger than those on the ISS—2 in. in diameter compared to 1 in.—to compensate for atmospheric distortion. They then brought VNS to the roof of the Ball factory in Boulder and tested its ability to detect a reflection at 2.5 km and 5 km.

The engineers were anxious to have actual data from space because of the added complexities of the orbiter maneuvering relative to the station. The results were better than expected. "We acquired the space station at 5.7 km," says Hardaway. "Frankly, we were a little bit worried about acquisition at 5 km. That was the mode on the detector we were most worried about," she says. "We were so pleased."

The mission also provided unexpected challenges for VNS. "There was one time during the [day-3] rendezvous where the station actually had gone out of the field of view," says Hardaway. "You can see in the data exactly where that happens. And you can see the data come right back as soon as the station comes right back into view. The transition was perfect—[we] didn't expect that."

All the scurrying before day 15 paid off, too, because the engineers were able to push the sensitivity of the VNS's three modes.

"When we went in for the second dock, the 're-rendezvous,' we started off with long range. You could see station pretty far out; basically it was a dot. It turned out our midrange worked so well that when we switched to midrange, you could see the outline of the station," Hardaway says. "Now, it was noisier at the long ranges. Originally we thought it would be too noisy to use at 5 km, but it turned out we could see the station."

After the mission, the engineers gathered the data and tested the ability of STORRM's algorithms to process it rapidly and depict the relative positions of Endeavour and the station.

The mission also proved that the VNS's data can be turned into stunningly detailed images of a space object, because light from raised surfaces arrives back at the detector slightly earlier than light from the surrounding surfaces.

Ball engineers showed images of the space station to the astronauts after the mission. "You can see a handrail. You can see a NASA logo. It was just really amazing," says Hinkel. "If you don't have a camera, it's bringing you a three-dimensional picture. You can rotate it, you can look at it from the side, from above, from any direction you want, because it's got all that information right in the image. It's very powerful."

Hinkel says the technology could be valuable for asteroid rendezvous missions or satellite servicing.

Significant tweaks

The Orion team has installed the VNS and docking camera in the Space Operations Simulation Center at Waterton, the chamber that Lockheed built specifically for Orion.

"We'll try to duplicate the conditions we saw in orbit, and then see what the performance of the sensors on the ground looks like compared to flight. We'll see if we can't get them to match pretty closely," Hinkel says.

They've done just that for the station's docking ring. "When we first ran the VNS in the ground facility, the docking ring didn't look anything like the flight data," notes Hinkel. "We ended up taking some aluminum and scrubbing it with steel wool. That seemed to give us the type of reflective properties that we saw in the space station docking ring."

The STORRM data are "really helping to upgrade the fidelity of that facility," she says.

Already, the data have prompted engineers to change the algorithms that Orion would rely on to identify reflectors on the docking target. Before the mission, NASA Johnson and Ball each had written rival sets of algorithms for this purpose.

"Basically you take this bright-intensity pixel, or it might be a grouping of pixels that are very, very intense in your raw data, and you run it through a series of tests to see: Is this really a reflector, or is it just some spurious bright spot?" says Hinkel.

Engineers are pretty sure, for example, that one particularly bright spot in the data was the window of a Soyuz capsule rather than a reflector.

"Both of us [NASA Johnson and Ball] have had to make quite significant tweaks to our algorithms to make them work with what we actually saw," Hinkel explains. "When you get close in, there are all these different station structures that appear like reflectors. So we're having to do some things with algorithms to not identify those as reflectors. We've taken huge steps in the quality of those algorithms already."

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