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NPS Teams Up with NASA, Industry to Test Groundbreaking Maneuvers on Spacecraft in Orbit

Stein, Amanda D.

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SPACE HIGHLIGHTS

NPS TEAMS UP WITH NASA, INDUSTRY TO TEST GROUNDBREAKING MANEUVERS ON SPACECRAFT IN ORBIT

Amanda D. Stein Staff Writer, Naval Postgraduate School
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Dazzling sun spots and stunning solar flares were just another day in the life of the Transitional Regional and Coronal Explorer (TRACE) spacecraft for the past 12 years. Designed to record solar activity, TRACE captured images and data to transmit back to NASA until earlier this year when it was set to be shut down and replaced by a newer, more efficient craft.

Before shutting down a healthy spacecraft, though, NASA decided to give a team of scientists a shot at conducting their experiments on the fully operational vehicle in space. Handing over the keys to a multi-million dollar piece of equipment is not something that NASA takes lightly, and is no doubt, the opportunity of a lifetime for any scientist or engineer. That opportunity made its way to NPS when Professor Mike Ross and Researcher Mark Karpenko received a call, and an offer to man the spacecraft for four weeks of experiments that could transform industry standards.

―When do you ever get a chance to fly something on a satellite? "said Nazareth Bedrossian, Manned Space Systems Group Leader at Draper Laboratory. ―People like us who work in engineering usually don't get the chance to fly real things."

TRACE quickly went from being a quiet solar observation satellite to a slewing craft dancing in the sky. NPS joined forces with Draper Laboratory and NASA's Goddard Space Flight Center to give new life to the craft, and push the limits of what TRACE was designed to do. They hoped to prove their groundbreaking ideas – an alternative method for reorienting spacecrafts using maneuvers that reduce both time and fuel consumption.

―The right people were excited about the kinds of work we had been doing, and they thought it was a great opportunity to give us the keys to a spacecraft to see what we could do, "said Karpenko ―Although the intent of TRACE was not to do these kinds of maneuvers, we were able to figure out how to make the spacecraft execute our ideas, and really show how they work."

The idea for the TRACE experiments was a joint effort that Ross and Bedrossian had believed in for many years. TRACE was their chance to relive the successes they had seen when utilizing Zero Propellant Maneuvers (ZPM) on the International Space Station (ISS) in 2006. Bedrossian used his ZPM concept, and the support of DIDO software developed by Ross to execute the ISS maneuvers, which proved successful when, as the name implies, they were executed without using a single drop of propellant. Because of Bedrossian's experience in designing the ISS maneuvers, Ross and Karpenko knew that his involvement would be key to the success of the experiments on TRACE. This time, however, their objective would be to save time, not fuel.

"In doing these experiments, they determined that they could use less energy and therefore [less] power," said NASA Mission Director, Osvaldo Cuevas. "They also found that they could do it in a shorter amount of time. The maneuvers they are proposing are more efficient."

The team hoped to perform a series of slew maneuvers that would reorient the spacecraft by taking advantage of the physics of the craft as it orbits. The craft would appear to be "dancing" around before ultimately zeroing in on its end point. This winding path would, according to their theory, allow the craft to slew more quickly than if it was maneuvered along a straight path.

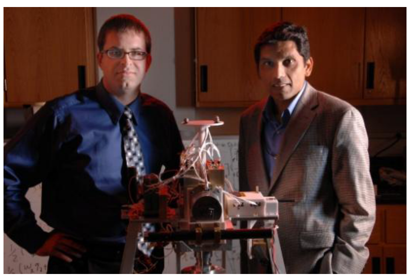
"It was a very tense time for NASA because in its entire history, the vehicle had only slewed once, to 15 degrees, "said Karpenko. "These were completely unprecedented maneuvers for the vehicle. "

This concept of the shortest path not necessarily being the fastest has been around for centuries, originally proposed by Swiss mathematician Johann Bernoulli in the 1700s. Through their research, however, the NPS and Draper team developed the means to utilize the same principle in space. TRACE then gave them the platform to demonstrate their new ideas to the greater scientific community.

"Until this opportunity came up, we hadn't even thought about doing these experiments on a reaction wheel spacecraft like TRACE," said Karpenko. "We had been focusing our efforts on other kinds of actuation systems like control moment gyros. So getting to the point of a successful flight test by the beginning of August was a real challenge."

Preparing for the experiments was an exhausting process for the team, all operating from different locations around the country. Bedrossian and his associate, Sagar Bhatt worked on developing the trajectories for the spacecraft, a monumental feat given the time crunch they were working under. Back at NPS, Ross and Karpenko were busy ironing out other details of the experiments, refining the trajectories and developing a series of simulation models to test the maneuvers in order to determine what potential problems might arise once they were operating the real spacecraft.

"Part of the difficulty of getting the spacecraft is it is already in orbit, and we have to really understand how it works in order to figure out whether or not we can do what we are proposing with that architecture," explained Ross. "Because TRACE was not designed to do anything like this. So we had to kind of turn back the clock 10 years and start picking peoples' brains about how to make this work."



NPS Research Associate Mark Karpenko, left, and Professor Mike Ross, right, teamed up with Draper Laboratory and NASA to test their time-optimal control maneuvers on the to-be-decommissioned TRACE spacecraft. The team ran a series of tests over four weeks that demonstrated their highly efficient maneuvers for slewing a spacecraft in orbit. (U.S. Navy Photo by Javier Chagoya)

All of their hard work paid off on August 10, when Ross, Karpenko, and several others from NASA all gathered at Goddard Space Flight Center in Maryland to execute the first test maneuver. The four week testing period included two tests a day, three days a week, during which the optimal maneuver commands were transmitted to the satellite, and then executed.

―We wanted to start off small and move the vehicle only by about 10 degrees to make sure that things were working correctly, "said Karpenko ―After our success on the first day, we decided to go for it and do our big test the next day. If we were only going to get one shot at this, this was the test that we really wanted to do."

That test, a 50 degree slew that took the spacecraft off of the sun line, and then back negative 50 degrees, proved to be a success. The tests that followed would slew the spacecraft up to 90 degrees off the sun line before returning back again to its starting point. Given the success of the experiments, there is hope of future opportunities to demonstrate the optimal control maneuvers on other satellites in orbit.

From an industry perspective, the maneuvers could improve the capabilities of satellites tasked with gathering information quickly. Maneuvering satellites in a way that best utilizes the physics of the spacecraft would allow imaging telescopes to capture images more quickly. In terms of military applications, Bedrossian noted, maneuvers like those performed on the TRACE spacecraft can prove invaluable for timely information gathering. Satellites are key to communications and information for the U.S. military, and are instrumental in gaining access to restricted territory. Quicker maneuvers could mean more information gathered in a shorter period of time.

―A single second could make a huge difference in terms of seeing something in time and responding to it, or being too late, "explained Bedrossian. ―The maneuver potentially enhances national security because it essentially improves the agility of your existing assets without touching the flight software. It's simply a matter of uploading commands."

While the team is still reveling in the success of the TRACE experiments, they haven't lost sight of the long-term goals. Given more opportunities to test on different types of spacecrafts, Karpenko expects their maneuvers will continue to yield positive results. Depending on the spacecraft characteristics, the team estimates that their maneuvers can yield performance improvements of up to 70 percent. Whether for NASA or the Department of Defense, their groundbreaking maneuvers have the potential to change the standard on how satellites are reoriented in orbit.

―The interesting thing about working with TRACE is that if you look at the physics of that particular spacecraft, it's not the best configuration to show that we can save a lot of time, "said Karpenko. ―But if we marry the ideas we demonstrated on TRACE with the correct spacecraft configuration, then we can see real savings. We will be able to exploit the available control efforts, together with unique configurations in order to really blow the doors off of what can currently be done using industry standard maneuvers."

Naval Nanos

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Launched from Cape Canaveral Air Force Station, December 8, 2010, as secondary payloads on a Space Exploration (SpaceX) Technologies, Inc., Falcon 9 launch vehicle, two NRL Naval Center for Space Technology designed and built nano-satellites have been deployed to evaluate nano-satellites as a platform for experimentation and technology development.

Known as the CubeSat Experiment (QbX), the two 3U (30x10x10 cm) CubeSat buses were built by Pumpkin, Inc., San Francisco, Calif., and provided to the NRL by the National Reconnaissance Office's (NRO's) Colony Program Office. This is the first flight of the Pumpkin-built Colony I spacecraft bus and is being used to evaluate the performance of the vehicle as a platform for experimentation.

Engineers from the NRL Spacecraft Engineering Department are in the checkout phase of the 3U CubeSats, the NRL developed tracking, telemetry and command (TTC) radio is fully functional, providing reliable two-way data transfers and the flight software, ported from previous and ongoing NRL programs to the Pumpkin Colony I processor, is providing an onboard scheduler for routine vehicle control and operation. "Currently, the spacecraft are healthy and experimentation and checkout are continuing," said Dr. Stephen Arnold, electronics engineer, NRL Spacecraft Engineering Department. "Deployments, including arrays and antennas, were successful and verified shortly after launch."

Spacecraft attitude is controlled by, and operates in, a novel "Space Dart" mode. Due to the low orbit (300km) atmospheric drag provides a stabilization torque that, used with reaction wheels and torque coils, provides stable pointing to within five degrees of Nadir throughout the orbit. The system has been verified on both vehicles and is providing a stable platform for continued experimentation. "It is expected that the QbX vehicles will remain in orbit for approximately 30 days," said Arnold. "After which, they will succumb to the effects of atmospheric drag and be destroyed during re-entry to Earth's atmosphere."

The primary payload launched aboard the SpaceX Falcon 9 was the Dragon Module. Developed by SpaceX and sponsored by NASA's Commercial Orbital Transportation Services (COTS) program, the Dragon Module is an initiative to develop private spacecraft to ferry cargo to and from the International Space Station. Flight software, antennas, and the TTC radio were built and integrated by the NRL, as was the developmental communications payload. Environmental testing of the completed package was also performed at NRL. Ground stations on the east and west coasts provide coverage for command loads and data collection.

NRL Researchers View the Sun in 3-D

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Beginning on February 6, 2011, the two STEREO spacecraft are 180 degrees apart providing Naval Research Laboratory scientists with a 360-degree view of the Sun. NASA's STEREO (Solar Terrestrial Relations Observatory) spacecraft were launched on October 25, 2006, and have been gathering spectacular images of solar activity, especially solar storms, since the mission began.

A key component of the STEREO mission is NRL's Sun Earth Connection Coronal and Heliospheric Investigation (SECCHI), a suite of five scientific telescopes that observe the solar corona and inner heliosphere from the surface of the Sun to the orbit of Earth. These unique observations are made in "stereo" by the two nearly identical solar-powered STEREO observatories with one observatory ahead of Earth in its orbit and the other trailing behind. The two observatories trace the flow of energy and matter from the Sun to Earth. The instruments aboard STEREO reveal the three-dimensional structure of coronal mass ejections, the powerful eruptions of plasma and magnetic energy from the Sun's outer atmosphere, or corona.

SECCHI Project Scientist and NRL researcher, Dr. Angelos Vourlidas, explains the significance of this opportunity for the 360-degree view of the Sun, "for the first time, we can take snapshots of the entire atmosphere of a star. To put it in perspective, before STEREO we were like a person trying to get the pulse of a city by watching through a half-open window - not an easy task. Now, STEREO has thrown wide open the window and we can watch the Sun and its activity in its full three-dimensional glory." Each STEREO telescope sees half the Sun at a time. By combining the two views, NRL researchers can map of the entire solar atmosphere continuously.

Before the three-dimensional view was available, researchers had to wait until an active region rotated across the visible-from-Earth disk in order to study the properties. The problem of having to wait for the proper views to appear is that the corona is highly variable, filled with regions that come and go in a matter of days and explosions that can alter the corona landscape in a matter of hours. With this capability of a three-dimensional view of the Sun, Vourlidas sees the potential for advances in the field of heliophysics. "We can solve the puzzles behind the evolution and structure of the solar atmosphere, including its violent eruptions, because we will be able to observe every feature and source of activity at the same time all over the Sun and follow their connections that can extend to large distances around the Sun," he explains. This opportunity for the STEREO spacecraft to view the Sun in three-dimension will be available for the next eight years.

STEREO is the third mission in NASA's Solar Terrestrial Probes Program. STEREO is sponsored by NASA's Science Mission Directorate, Washington, D.C. The Goddard Science and Exploration Directorate manages the mission, instruments, and science center. The Johns Hopkins University applied Physics Laboratory, Laurel, Md., designed and built the spacecraft and is operating them for NASA during the mission.