Second Comet Visit is a First

by Bob Silberg

On January 15, 2006, the Stardust spacecraft completed one history-making mission and began another. Returning from a rendezvous with comet Wild (pronounced "Vilt") 2, the spacecraft approached Earth and jettisoned the capsule containing particles from the comet and interstellar dust. The capsule landed safely and on-target, southwest of Salt Lake City, Utah, completing the world's first sample return from a comet. The spacecraft, responding to commands from the mission's navigators, flew past Earth and began an orbit around the sun that would bring it near the planet every 3 years.

Now this spacecraft is on a new record-setting mission: a visit to Tempel 1, the comet that was the target of the Deep Impact mission. It's the first-ever follow-up mission to a comet. And since NASA has already built, tested, and launched the spacecraft, the new mission (called "Stardust-NExT" for New Exploration of Tempel 1) will cost less than 10 percent of what a mission like this would normally cost. That's a saving of hundreds of millions of dollars.

NASA plans to revisit Tempel 1 in 2011 to finish the investigation begun in 2005 when the Deep Impact mission blasted a crater into the comet. "The crater's there," said Joseph Veverka, Professor of Astronomy at Cornell University and Principal Investigator of Stardust-NExT, "but we've never seen it." That's because the cloud of material ejected from the crater obscured the Deep Impact spacecraft's view. By the time the particles slowly settled back down to the comet's surface, the spacecraft, traveling at about 10 km (about 6 miles) per second, was gone.

Looking into the crater with Stardust-NExT will provide mankind's first view of a comet's internal structure, information that is not only scientifically interesting, but vital to our future ability to keep a comet from hitting the Earth. Even the size of the crater will be revealing. "That will tell us the mechanical properties of the subsurface of the comet," Veverka said. "In other words, how does the comet respond to impacts? And that's one of the fundamental things that you'd need to know if you were trying to blow up a comet or push it out of the way."

In order to examine the crater, the mission's scientists and engineers will have to time the encounter with extraordinary precision, so that the crater side of the rotating comet will face the spacecraft as it zips by at around 11 km (nearly 7 miles) per second. "That's by far the most challenging part of the mission," Veverka said.

"The good news," said Allan Cheuvront, the mission's Spacecraft Engineer and Program Manager, "is we have enough fuel that, a year before our encounter date, we can change our time of arrival up to 20 hours. And that's significant because the rotational period of Tempel 1 is a little over 40 hours. So we improve our chances tremendously of arriving with the crater on the right side, in the field of view."

Why perform this maneuver a year before the encounter? Because that's the most efficient time to use the relatively small amount of fuel that will be left over from the original Stardust mission and a maneuver in January 2009 in which the spacecraft will position itself to use Earth's gravity to change trajectory and increase speed.

After the Earth flyby, the spacecraft will be able to increase its speed a little further by firing its thrusters behind it, or slow down a bit by firing the thrusters ahead of it. Performing this maneuver in February 2010 allows a year of traveling time for that small change in velocity to build up into a change in arrival time of up to 20 hours. (If this maneuver were performed 30 days before the encounter with the same amount of fuel, it would result in only a 15-minute change in arrival time.) The tricky part, of course, is that the scientists will have to decide a year before arrival exactly how much the spacecraft's speed needs to be changed in order to see the crater in 2011. And if they make a small error in calculating the comet's rotational rate, that error will also have a year to compound.

Stardust-NExT will encounter Tempel 1 at about the same point in the comet's orbit where Deep Impact met up with it six years earlier—a couple of weeks after the comet's perihelion, its closest approach to the Sun. This provides an opportunity for what Veverka says may be the most important part of the mission: "to do something that's never been done before, and that is to see how much comets change each time they go by the Sun. We've never to this date seen a comet once and then again after it goes through perihelion to see how much things have changed," he said. Thanks to Deep Impact and Stardust-NExT, scientists will have before-and-after pictures of Tempel 1.

The comet's orbit never takes it much closer to the Sun than Mars gets (about 1.5 times Earth's distance from the Sun), but that's close enough to vaporize some of the comet's frozen gas to form jets, a coma (the cloud around the nucleus) and tail. According to Tom Duxbury, the mission's Project Manager, those jets, along with tidal forces from the Sun's slightly uneven gravitational pull on the near and far sides of the comet, are likely to affect the comet's rotation, making it harder to time the encounter. Scientists will have to predict what effect those factors will have. "That's not the simplest of things to do," Duxbury said, "but they're going to take their best shot at it."

"We have a big effort to model the rotation rate going on at three different places," Veverka said. "We think we can do this successfully and accurately. And when we do, it will be the first time that somebody has actually predicted the rotation state of a comet a year ahead of time."

Stardust-NExT will also be one of the few spacecraft that have observed two different comets with the same set of instruments. "So if we see differences," Veverka said, "no one can claim that those differences are because there are different instruments that didn't quite work the same."

Veverka estimates that Deep Impact imaged about 40% of the comet. "We want to see new territory," Veverka said, noting that Deep Impact revealed some strange and

unexpected surface features. “But we also want to see some of the old territory to see the changes and see the crater. Of what our coverage is going to be in 2011, 40% will be stuff we’ve seen before, including the crater, and about 60% will be new stuff.”

A series of fortunate events during the original Stardust mission made it possible to give the spacecraft this new mission. First, the weight of the Stardust spacecraft left enough margin to enable the team to completely fill its fuel tanks. The launch went perfectly, requiring no corrective maneuver. Subsequent maneuvers, including a gravity assist at Earth in 2001 to target comet Wild 2, were similarly accurate. The result is that after completing its successful sample-return mission, the spacecraft still had enough fuel—if used cleverly—to conduct a new mission.

“We hit our targets,” Cheuvront said, “so we didn’t have to use a lot of extra fuel to correct for unknowns.” He added, “The spacecraft was a very, very well-behaved spacecraft. Its performance was outstanding and predictable, which let us save fuel.”

But given the amount of fuel remaining, could the spacecraft get to an interesting new target?

Knowing that Deep Impact had been unable to view the crater, Robert Farquhar, who had been Mission Director for NEAR, MESSENGER, and New Horizons among other missions, took it upon himself to see whether the Stardust spacecraft could get to Tempel 1. Working with his colleague, David Dunham, he discovered that the Earth flyby for which the spacecraft was headed in 2009 could be used to retarget it for Tempel 1. Farquhar proposed the idea to Veverka and became a co-investigator on the mission.

So, if all goes right, Stardust-NExT will approach Earth in January 2009 at exactly the right distance, speed, and angle to change its trajectory to one that will intercept Tempel 1 on February 14, 2011. And in February 2010, depending on the mission scientists’ calculations, it will fire its thrusters to speed up or slow down just enough so that, a year later, it will zoom by the comet just after the crater rolls into view. Sounds like a particularly difficult pool shot if all the balls were moving while you were shooting. “That’s right,” said Shyam Bhaskaran, a JPL spacecraft navigator, “except we know where the balls are going.”

“We’re able to take a spacecraft that everybody had given up on and basically do a first-class mission at 10 percent of the cost of a new mission,” Veverka said. “I think that’s very exciting.”