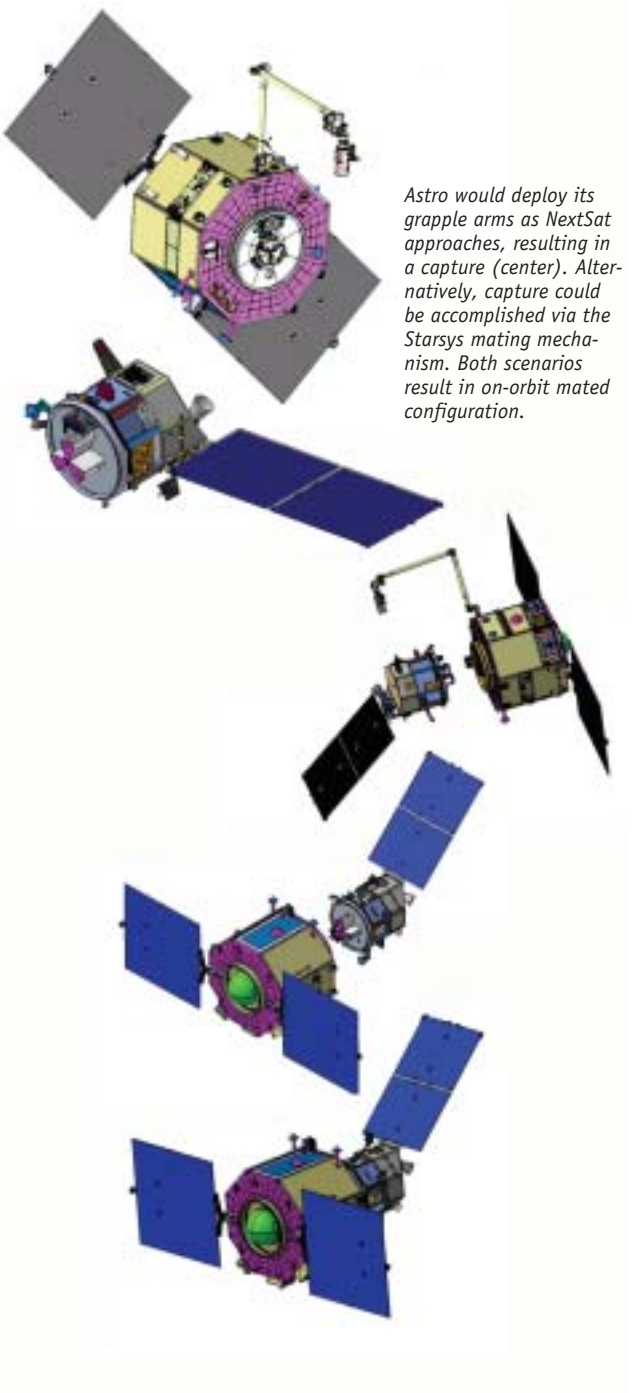
Satellite hopes ride on ORBITAL EXPRESS

DARPA is seeking to demonstrate the feasibility of extending the lives of spacecraft already in orbit by refueling or even upgrading them in space. The task will not be easy, which is why the agency took it on. But if successful, such technologies could lower costs and keep legacy satellites flying for 5, 10, or even 15 extra years. Convincing manufacturers and users of the advantages of this approach may be a bigger challenge.



Astro would deploy its grapple arms as NextSat approaches, resulting in a capture (center). Alternatively, capture could be accomplished via the Starsys mating mechanism. Both scenarios result in on-orbit mated configuration.

One of the early arguments for building the space shuttle was that it would provide less expensive ways to get satellites into space, taking them up in a reusable "truck" rather than launching with a throwaway rocket. While a number of factors kept the shuttle from fulfilling that promise, an ever-growing satellite user community has continued to seek ways of lowering costs.

One possibility would be to upgrade a satellite already in orbit, extending its operational life by giving it new technologies or capabilities. Another would be to reduce the weight of new satellites, thus allowing smaller launch vehicles or sharing of launch costs with other payloads.

The military, for example, sometimes needs to relocate surveillance satellites to fly over new areas of interest. Being able to extend that capability—which quickly depletes limited onboard fuel reserves—would not only save replacement costs, but would also maintain the ability to perform such maneuvers on short notice.

DARPA has taken the lead in addressing these issues and, under its mandate to take on difficult technology challenges even before there is a proven market, is looking at a single solution to accomplish all of the above tasks.

The first major step in that direction is the Orbital Express Advanced Technology Demonstration program. This is scheduled to begin this month with the twin launch of the Autonomous Space Transfer and Robotic Orbiter (ASTRO) and NextSat. The prime contractor for ASTRO is Boeing Advanced Systems in Huntington Beach, Calif. NextSat is produced by Ball Aerospace in Boulder, Colorado.

A hard task

"It definitely is a DARPA hard task—figuring out how to sidle up to vehicles, exchange propellant, put new hardware on board, and retrieve the old. That is hard enough to do with humans in spacesuits who are trained for the task; to do it autonomously is much more difficult," DARPA program manager Lt. Col. Fred Kennedy (USAF) tells *Aerospace America*. "DARPA wanted to use Moore's Law to our advantage and take the materials up to keep

by **J.R. Wilson**
Contributing writer

The two satellites were mated prior to the launch, which is scheduled for this month.

legacy birds flying for 5, 10, or 15 more years. And that is a laudable goal—but not an easy one, which is why DARPA took it on; we can do a demonstration of this type without being hamstrung by specific requirements.

"At the end of the day, I think a lot of people will see the utility and wish they had done this earlier. Unfortunately, you have to have the demonstration before people understand that. Will everyone glom onto it right away? Probably not. The Internet is a good example; it was not apparent right away what the utility of the concept was, but eventually people came to appreciate it and even forget that DARPA had anything to do with it."

A major roadblock, insofar as existing satellites are concerned, is that they were not designed for either refueling or parts replacement in space, although engineers are looking at whether some prelaunch ports might be of use.

"Every spacecraft has a standard set of disconnects with the launch tower, including fluids, that are accessible from the outside. Basically, if you can access it from the ground, you can access it from space," maintains Tom Kessler, Boeing's Orbital Express operational applications manager. "So some of those may be economically valuable to spacecraft operators.

"It's like a tow truck—AAA can't fix your engine, but they can tow you, fill your gas tank, recharge your battery, all valuable to saving your valuable asset. There is no AAA truck in the sky now, but Orbital Express technology can lead to one in fairly quick order if there is an economic demand."

Ball Aerospace will build the NextSat spacecraft for the Orbital Express on-orbit servicing demonstration.

A space revolution?

The capabilities that Orbital Express is designed to demonstrate could revolutionize satellite—and possibly some manned—operations in space for the next half century, not only in Earth orbit, but throughout the solar system. These capabilities range from servicing spacecraft to greatly reducing the need for human control, including autonomous rendezvous proximity operations (ARPO), where a spacecraft is given general directions, then uses onboard sensor updates to reach its target on its own.

"We've looked at key features of existing systems that we believe could be addressed—refueling, attaching as a space tug to go to a different orbit, or potentially some fairly rudimentary nonrefueling options, such as fixing a solar array, where you wouldn't need to have designed a satellite to be serviceable," says Boeing Orbital Express program manager Paul Geery. "I think we will see some pieces of that following on quickly, assuming we demonstrate everything as well as we expect. A follow-on based on serviceable operations may be farther out, but exploiting the various technologies we will be demonstrating should be fairly rapid."

ASTRO will be equipped with two methods to approach and mate with its target. It can use its small robotic arm to grab onto a special hook built into the NextSat, then guide itself to a precise mating using sensors and sensor targets, or it can rely entirely on the capture system provided by Starsys SpaceDev of Poway, Calif., both for making the approach and for mating.

"We're confident the approach we're using will support the same kind of solution for getting close to any given satellite, which we think we will demonstrate adequately. Then you get into where and how to attach, which will require looking at each satellite on a case-by-case basis. But we've looked at enough to know these are not technology hurdles we can't solve," Geery says.

"Once grappled, can you get to the refuel point or the battery compartment? The refuel we understand a bit better, but replacing a battery not made to be replaced robotically is a lot more complicated. Anything we can add on the outside, using existing electrical connections, may be possible, but is a nonstarter for now."

Dual role for NextSat

Ball's NextSat will play two roles in the Orbital Express effort—as the target satellite receiving fuel and as the commodities spacecraft, the "depot" from which ASTRO will acquire the fuel it will transfer to the target. Some of the NextSat architecture was adapted from Ball's Deep Impact Impactor (the first man-made object to collide with a comet), including software, command and data handling, and power control. Other elements were derived from the Ball Commercial Platform (BCP-2000), such as the narrow-band telecom architecture from NASA's CloudSat.

"There are some additional accommodations to make this happen, such as a data port that is mated when the two spacecraft are together so they can talk when docked and also with a cross-link when they are in close proximity but not attached," David Kaufman, Ball's NextSat program manager, points out. "Those are used to stage the next operation, with the ASTRO telling the NextSat what it needs to do to facilitate the next step.

"During the mission, we will be pointed in different directions so the ASTRO can approach us from different orientations—below, above, forward and back. So the client spacecraft does not have to have only one specific phase serviceable; there will be enough flexibility to be useful even for one with complex solar arrays or payloads."

Northrop Grumman in Redondo Beach, Calif., is providing the ASTRO hardware for autonomous transfer of hydrazine liquid rocket fuel to and from NextSat, as well as ASTRO's six-degree-of-freedom vehicle control propulsion system. The fluid-transfer system is designed to accommodate a variety of client configurations, which will be demonstrated during the multiple ASTRO/NextSat transfers.

> ***"Our focus is to provide a demonstrable system that shows the art of the possible—rather than focusing on a business case to make this a commercial venture—but that also gives a lot of people the opportunity to take advantage of this in their architectural solutions base."***
>
> **—Paul Geery,**
> Orbital Express program manager,
> Boeing Advanced Systems

The other Orbital Express team members are MDAssociates, British Columbia, and Draper Lab, Cambridge, Mass. The Canadian company is building ASTRO's robotic arm, and Draper is providing the mission-manager software.

The DARPA mission is expected to last three or four months, starting slowly with a few weeks of systems checks and some fluid transfers while the two satellites are still mated in their launch configuration.

"Then we will use the arm, starting slow and working up to more complicated operations, to detach NextSat from ASTRO and eject the separation ring that will help us during the launch. Then we reattach, do another set of fluid transfers, then some battery and computer component replacements (the computer will be on ASTRO, then taken off, then put back on ASTRO, but never switched to NextSat)," Geery says.

"Then we start unmated operations, again starting slow, backing away to 10 m, then remating, then gradually getting farther away, ultimately to a baseline of 7 km. But we have designed for cases up to 200 km, with autonomous guidance back to dock."

Making the business case

While Orbital Express is intended to demonstrate the technologies—the ability of one satellite to approach and dock with another already in orbit, refuel it, and even replace its batteries or upgrade electronic components—the ultimate goal is to convince the user community there is value in redesigning future satellites and in building the service satellites and even an orbiting depot prestocked with fuel and spare parts.

Northrop Grumman technicians conduct end-to-end fuel transfer tests on the Orbital Express Advanced Technology Demonstration program, designed to show capabilities needed for autonomous satellite servicing while on orbit.

"The economic perspective obviously is important: Is there a business case that can be built by generating a service-based architecture, or is it more cost-effective to use the traditional throw-away system?" says Geery. He acknowledges those who build satellites and launch vehicles—such as Boeing itself—will be guided primarily by customer demand. "This obviously is a different business model, and there are some internal conflicts. It has to make technological and economic sense and add value to the customer community. We think it is a capability that needs to be considered, but isn't necessary for everything you do.

"The first solution is for us to demonstrate success, the art of the possible, then show the satellite manufacturers how they can make minor modifications in their existing systems to allow for refuelability to extend their spacecraft. That doesn't cost much to make those serviceable. Then, instead of normal batteries, how to make it possible to remove and replace them. Then these things can be built into the design of satellites from the start and they can build it into their business cases going forward, to extend the constellation some number of years without a lot of extra money up front."

> ***"There is a real show-me mentality—until we go up and return video of NextSat and ASTRO mating and transferring propellant, batteries, and electronics, nobody is going to believe it."***
>
> **—Lt. Col. Fred Kennedy (USAF),**
> Orbital Express
> program manager, DARPA

Another factor that may spur such a decision is the ability to repair a newly launched satellite on which something has gone wrong or to make an orbit correction that is beyond the ability of onboard thrusters, which typically are limited to minor changes in attitude. If the satellite is designed with grappling points, a space tug could lock on and either take it to a different orbit or, in the case of a large decommissioned bird, reposition it for deorbit to ensure it will completely burn up on reentry.

SUMO becomes a FREND

That capability also is the goal of a separate DARPA effort that began as the Spacecraft for the Universal Modification of Orbits (SUMO), but recently was renamed the Front-end Robotics Enabling Near-term Demonstration (FREND). DARPA's overall vision is for SUMO/FREND to conduct spacecraft salvage, repair, rescue, reposition, and debris removal. (See "Sumo wrestles satellites into new orbits," Feb. 2006, page 26.)

"There is not a specific DARPA Orbital Express follow-on, but FREND, which is a robotic arm ground-based demonstration activity at NRL [Naval Research Lab], will allow us to grapple arbitrary spacecraft that do not have interfaces," says Kennedy, who also is DARPA's FREND program manager. "So there is a logical build on the Orbital Express concept.

"The name change was to clarify we are not pursuing a full-up space demonstration, but making sure we have a flight-qualified arm and payload we could eventually mate with a SUMO vehicle. SUMO's ability to grapple anything—including legacy systems—is an issue we faced on Orbital Express and determined we didn't have the resources to resolve, understanding the purpose line of SUMO is for spacecraft reboost and repositioning, where Orbital Express is for actual interfacing."

Before they can move from the ground-based FREND development to a space-based SUMO demonstrator, however, DARPA needs to find a transition partner to build the SUMO vehicle—and to share some of the costs, as Boeing and NASA are doing on Orbital Express. While no commercial partner has yet been found, the U.S. Space Command is seen as a probable government user community transition partner.

"We're looking into the 2008 time frame to establish a transition partner and work some of the preliminary studies on what kind of bus the SUMO payload will be useful for. We have some good folks at NRL thinking how issues with the SUMO/FREND payload will impact the bus and who will do what to whom," Kennedy says, adding he would like to move the demonstration to orbit as early as possible, but at this point cannot predict when that may happen.

"We're concentrating heavily on the idea of reboost and repositioning in GEO with SUMO; we haven't really looked at what else we might do with that suite of arms, but we're always open to a transition partner's interests."

The SUMO application would be far more robust and larger than Orbital Express' MDA arm. "The ASTRO arm is a fairly reasonable device and can do many of the things the FREND can do. It is specifically designed for the task of

grabbing an orbital replacement unit—flight computer or battery—and put it on the NextSat. So it isn't limited utility but specific utility to the Orbital Express mission," Kennedy explains. "We also have an extra degree of freedom on the SUMO arm.

"We eventually will ask for a multiarm paradigm for it; we're looking at a three-arm suite, which is a lot different from asking the Orbital Express arm to do its job alone. Grappling a vehicle in space with a single arm tends to introduce some interesting dynamics; additional arms provide greater stability and the ability to grab the right things with the right amount of force."

Before SUMO/FREND gets to orbit, however, the Air Force Space Command—and possibly others—may elect to do some additional experiments with Orbital Express.

"There are discussions at DARPA to look at government partners to do additional mission activities because we will not have used all the useful life of the spacecraft," Geery says. "That probably would involve only additional demonstrations with ASTRO and NextSat; we're not going to be in an appropriate orbit to interact with any other spacecraft, because we picked it to make sure we wouldn't be in the way of anybody else."

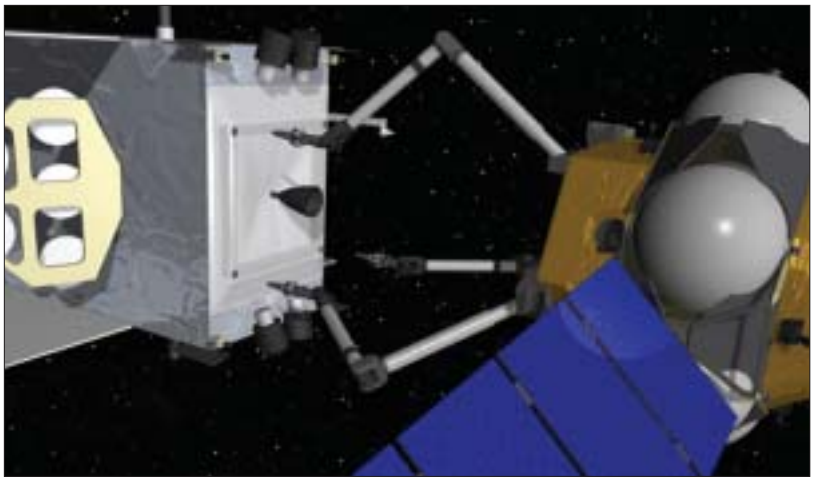
As DARPA programs, Orbital Express and SUMO/FREND are intended to demonstrate the potential for cutting-edge technologies; most DARPA efforts lead commercial or government applications by a decade or more. If they lead to a direct new evolution of orbital depots, deploying the space equivalent of tow trucks to refuel, recharge, upgrade, or even relocate satellites, the contractors involved expect their "niche" experience will provide a competitive advantage.

"We'd love to sell a bunch of satellites that could be repaired. And having done this, if the business opportunity presents itself, we certainly have the knowledge," Ball's Kaufman says. "But we need to find the right system before we start talking about a business plan for building fleets of these things. This demonstration is really designed to reduce the risk of a program office designing this into their constellation and then using it."

Other benefits

Not all DARPA research leads directly to a program, but even if on-orbit servicing does not catch on, the agency sees considerable value coming from Orbital Express.

"Even if we can't make folks buy into the central premise about servicing, upgrading electronics and batteries and refueling, we will get a lot out of this in terms of demonstrating to the space community what it means to have a truly situationally aware and agile spacecraft that can perform a lot of new missions," Kennedy says. "Having a spacecraft that can see its neighborhood, maneuver, and potentially change its orbit are all valuable. So there is a generic sense of utility that any of the major DOD space community members will find useful. It goes beyond DOD, of course, but that is where DARPA is obliged to care. NASA can decide if there is value in this for constructing large platforms on orbit, for example."



DARPA's SUMO program was renamed FREND, and the focus now is on a grapple arm.

There also is competitive value added for each of the contractors involved.

"We consider this the third spiral in the whole rendevous/proximity operations capability, taking the sensor package and guidance control software and applying autonomous, continuous guidance/navigation to the Air Force, NASA, and commercial architectures, showing how we can provide additional capability that may be required or make a system that is more affordable," Geery says. "The ARPO software was designed as a plug-and-play architecture for use with other spacecraft systems. Between it and the sensors—GPS, star-tracker, etc.—that is a product that can be adaptable to different kinds of spacecraft."

Just as Boeing builds aircraft, but does not run an airline, Geery says a fourth spiral, perhaps in the next decade, could see a Boeing-built orbital depot operated by NASA or Space Command—or even some commercial entity.

"We're following the government's lead on this more than leading the government," he concludes. "We think the involvement of many of the technologies we will demonstrate will have off-ramps into other space architectures, but we aren't going to step out in front of the government in saying we are going to service satellites as a business area at this time."