Just beyond Earth's upper atmosphere, huge numbers of satellites and related "space junk" orbit about the planet. Their numbers will continue to grow as new launch vehicles bring about more routine and lower-cost access to space. Forecasts show that during the next decade, between one and two thousand new satellites will be put in orbit. Over time, some of them inevitably will begin to fail and will need to be inspected, monitored, repaired, or removed.

Lawrence Livermore is developing a very maneuverable microsatellite that can operate as a service vehicle in space for ailing satellites. The tiny, 40-kilogram vehicle, dubbed MicroSat, will be the first truly agile, small satellite. Once deployed, it will perform close-up inspections to determine the health and operational status of other satellites in orbit (Figure 1). Because the MicroSat can get close to other satellites, it can use new types of diagnostic sensing techniques to collect data unattainable from the ground. Active vibration sensing, for example, can yield specific information on moving parts that can be used to evaluate and characterize vehicle wear and performance degradation remotely. Thermal imaging can reveal surface features invisible to the eye, including leaks and nonuniformities that may result from changes in thermal insulation or structural fatigue.

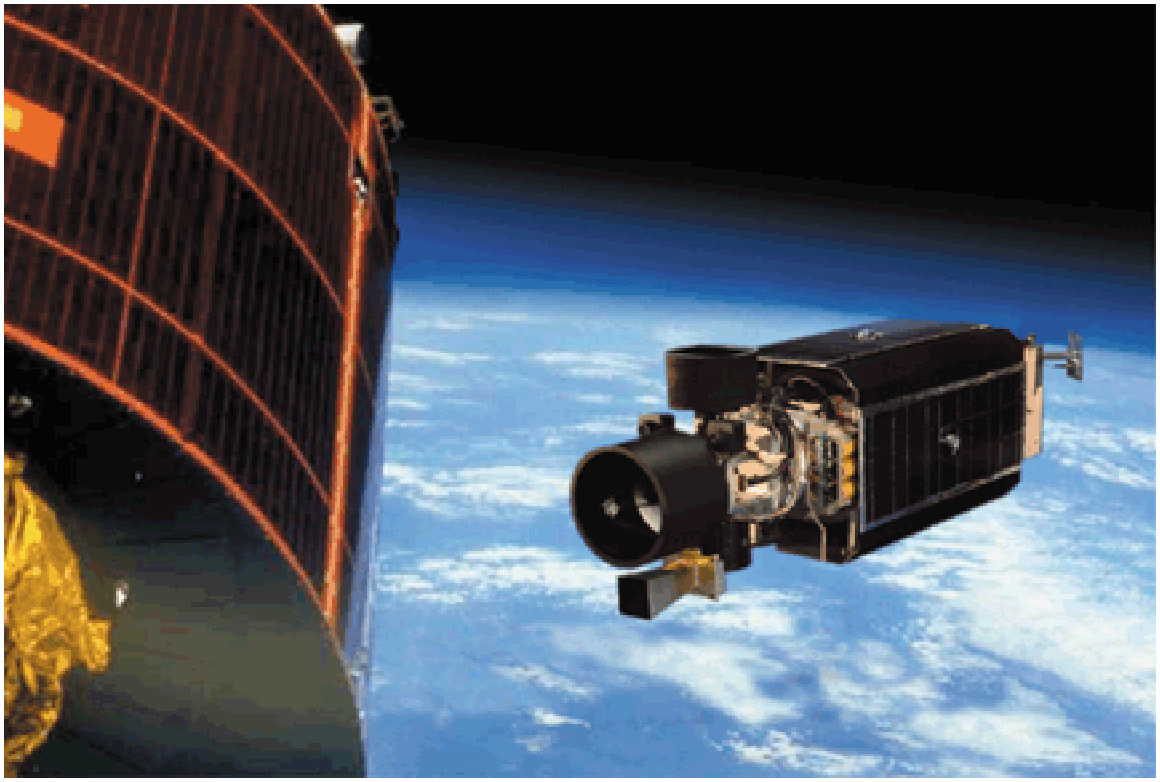


Figure 1. In this artist's rendering, a MicroSat gets a close look at a larger satellite. The goal is for the MicroSat to rendezvous with a satellite, inspect it, dock with it, service it, and verify its performance. It will look for signs of wear, including atomic oxygen and ultraviolet surface damage, micrometeoroid impacts, and debris cloud generation from leaks or other deterioration. These data can be stored on board or forwarded to ground control through an Ethernet connection.

These on-orbit measurements will offer early detection of potential failures and insight into events that might limit the life of the satellite. Periodic checks could allow preventive or corrective measures and avoid unexpected system breakdowns that lead to service outages, as occurred in 1997 to a communications satellite supporting a large paging system. The Livermore MicroSat is being designed to perform autonomous docking with ailing satellites and could eventually fly missions to repair or retrieve them. A docking maneuver is shown in Figure 2.

The Livermore team of 15 engineers and technicians is led by physicist Arno Ledebuhr; engineer Joe Kordas is the deputy project leader. The MicroSat program is funded by the U.S. Air Force Research Laboratory and is a spin-off from the Clementine II Program, which consisted of an asteroid fly-by and impact experiment. That earlier project was discontinued in 1997 and redirected by the Air Force to a series of MicroSat Earth-orbit demonstrations.

The team is working toward a date in 2002 when one of its MicroSats will be flown on either the space shuttle or an expendable launch vehicle. If flown on the shuttle, the Livermore MicroSat will ride on a National Aeronautics and Space Administration Spartan 251 "mothership carrier" spacecraft bus. The Livermore MicroSat will have to autonomously perform a series of complex tasks and conduct various close-in proximity maneuvers within a few meters of the Spartan carrier. It will collect stereo images and perform multiple autonomous dockings with the Spartan. Experiments will include the transfer of data and power between the two spacecraft. The Livermore MicroSat will then maneuver itself into its original deployment canister on board the Spartan mothership, which will be retrieved by the space shuttle and returned to Earth. Follow-on spacecraft experiments will examine autonomous docking onto a spinning satellite, propellant transfers, and towing experiments.

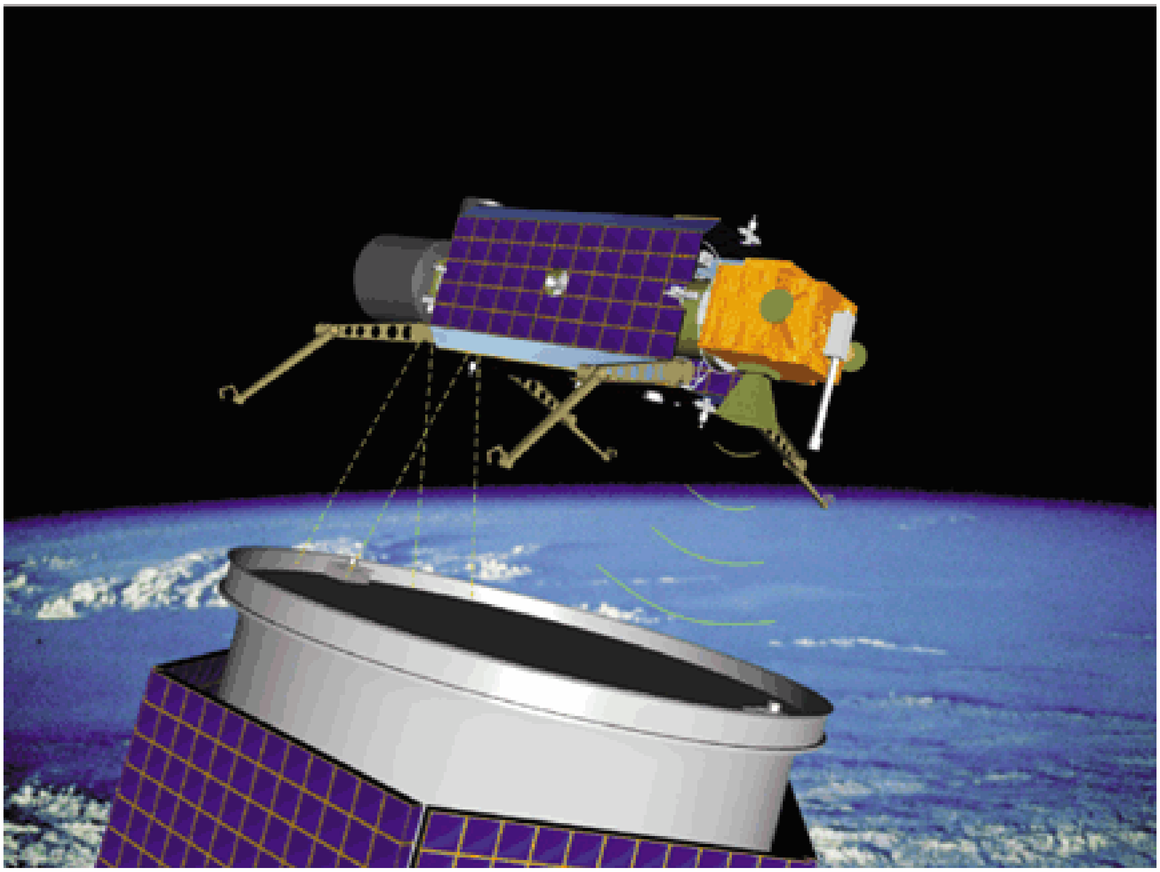


Figure 2. Active radar or lidar, augmented by stereo imaging, will be used for precision ranging during the final docking phase. Once docked, the MicroSat will be able to repair or replace subsystems, tow or push the satellite to a different orbit, and pull "space junk" out of orbit.

Old Hardware Put to New Use

The first prototype MicroSat was constructed in 1997 with spare hardware collected during earlier program efforts. It was operated on a new dynamic air-bearing table that enabled extensive and repeated ground testing of its guidance, navigation, and control software (see S&TR, September 1998, the article entitled Down to Earth Testing of Microsatellites). The next prototype was based on the Clementine II asteroid-impact probe vehicle and contained the first liquid propellant propulsion system. This MicroSat design was augmented with additional support subsystems to provide stand-alone operation in orbit, including solar arrays for battery recharging, thermal management, micropower impulse radar for docking, stereo cameras for passive ranging and telepresence, and a global positioning system receiver. The third vehicle incorporated improvements in propulsion, electronics, and sensors. For future vehicles, the team wants to add grappling and robotic arms for manipulation during docking and servicing missions.

The test vehicles combine the team's unique designs, other Livermore developments, and commercial systems. To date, three prototype vehicles have been ground tested on the air-bearing table, and the two most recent models have been tested outside on an air-bearing rail.

Darting about in Space

A critical aspect of the MicroSat design is its propulsion system, which must be able to move the vehicle about in orbit as well as control the satellite's attitude. There is no precedent for small, agile orbiting satellites with the large propulsion capability of the Livermore MicroSat designs. For maximum agility and range, the MicroSat must have the highest possible ratio of fuel capacity to overall mass. This goal is achieved by reducing the vehicle's dry weight and using miniaturized subsystems throughout.

Conventional spacecraft propulsion systems use high-pressure-fed toxic liquid fuels, but these systems cannot be miniaturized easily. Many small spacecraft use compressed gas such as nitrogen, which works well for attitude control but not for maneuvering. Compressed gas tanks also tend to be heavy. "Enabling agile maneuvering on a tiny scale requires fundamental advances," notes lead propulsion engineer John Whitehead.

Liquid can be stored more efficiently (that is, in lighter weight tanks), so MicroSat's innovative propulsion system relies on the concept of making gas as needed from liquid fuel. The system supplies tiny gas jets for vehicle attitude control and small precision maneuvers and fuels liquid thrusters for large orbital maneuvers.

Most rocket fuels are toxic, but Whitehead opted for nontoxic, high-concentration hydrogen peroxide (H_2O_2) to ease experimentation and development processes and thus reduce the cost of the project. Hydrogen peroxide was the first choice because of its proven track record. The U.S. space program used it in the past, and the Russians still fly their Soyuz vehicles with it.

For testing purposes, the Livermore team's first prototype MicroSats used compressed nitrogen (N_2) only. The next vehicle used N_2 for attitude control but added liquid H_2O_2 thrusters for directional maneuvering. The N_2 forced the H_2O_2 out of the liquid thrusters in a pressure-fed system.

The latest version, tested in October 1998, eliminated the N_2 system altogether, saving the weight of its relatively heavy storage tanks. A patented micropump designed by Whitehead is used to self-pressurize the liquid H_2O_2 tank, with oxygen and steam derived from the propellant itself. Shown in Figure 3, the system is lighter than its predecessors, although it still requires a higher-pressure liquid tank to operate. This self-pressurized system provides a constant system pressure as propellant is expended. It could be launched unpressurized or at low pressures, making launch safer as well.

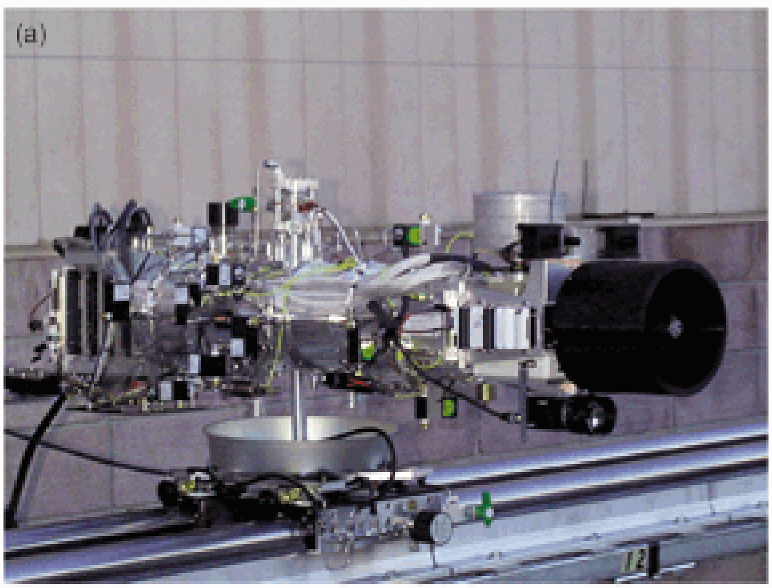
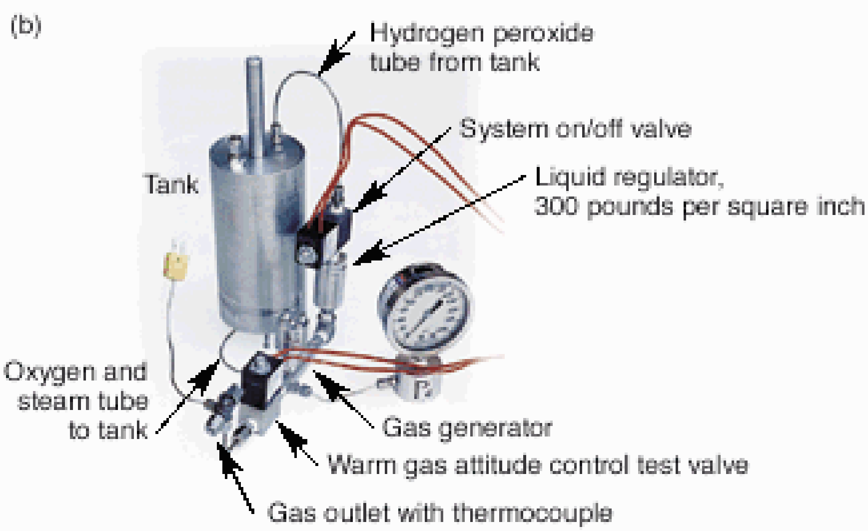


Figure 3. (a) The MicroSat tested in October 1998 is shown mounted on the air-bearing rail. (b) An early prototype for the self-pressurizing micropropulsion system.



The next step is to develop a slightly larger and more efficient pump that draws the liquid H_2O_2 out of its tank, making the satellite even more lightweight and agile. More of the system's total weight can be devoted to fuel and less to components.

Aside from the revolutionary propulsion system design, the Livermore MicroSat uses the latest generation of Power PC processors and compact PCI-format electronics. It also incorporates advanced active pixel sensors that, along with miniaturized laser ranging systems, will provide the necessary range and velocity data to allow autonomous docking by MicroSat. Figure 4 shows the team's vision for MicroSat's final design.

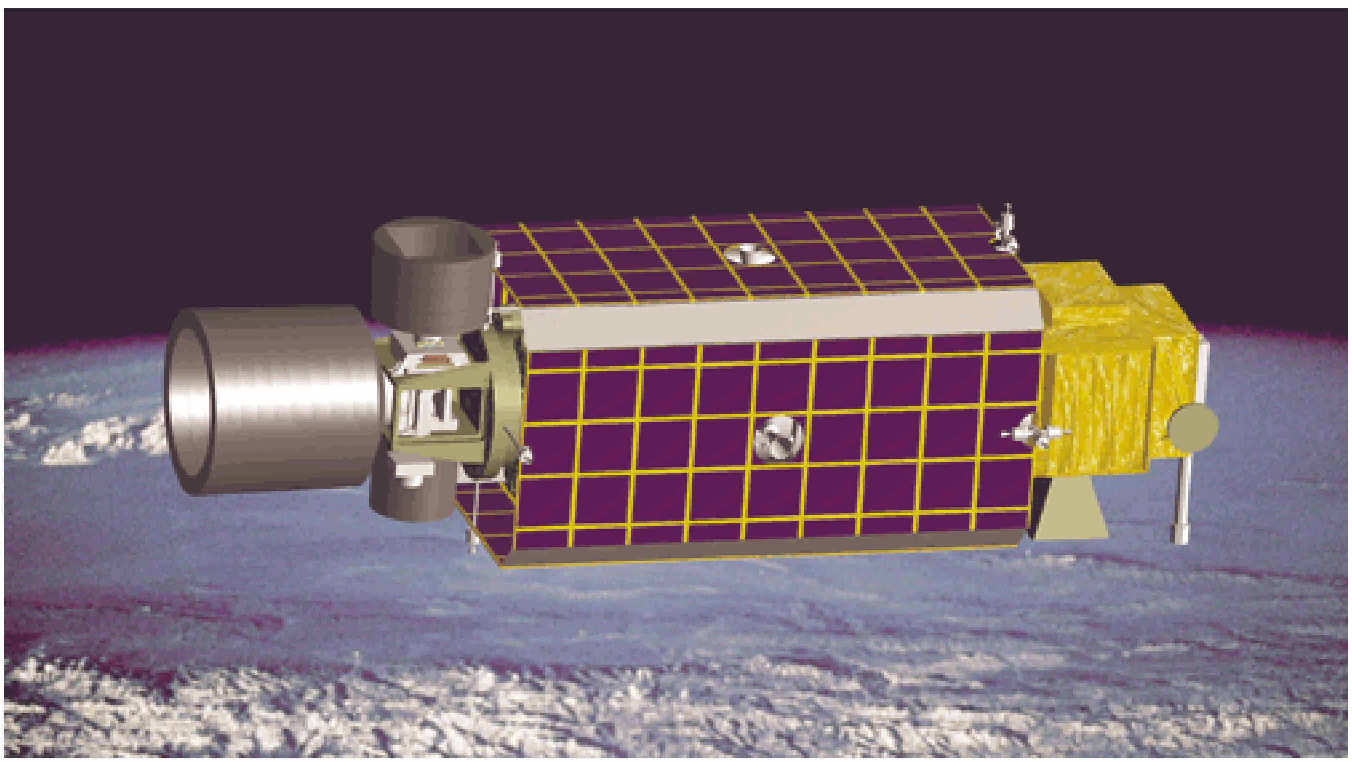


Figure 4. Artist's rendering of the MicroSat that will fly on the space shuttle.

Ledebuhr says, "The MicroSat will move like a hummingbird darting around." Some day, near-Earth space may be dotted with these autonomous, hummingbirdlike MicroSats. They won't change flat tires, but they will help other satellites stay healthy.
-Katie Walter

Reference:
1. "Testbeds Wring Out Technologies," Aviation Week & Space Technology, April 5, 1999, pp. 52-53.

Key Words: agile satellite, hydrogen peroxide propulsion, microsatellite (MicroSat).

For further information contact Arno Ledebuhr (925) 423-1184 (ledebuhr1@llnl.gov).

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