Mechanics/Machinery

Ultra-Large Solar Sail

Marshall Space Flight Center, Alabama

UltraSail is a next-generation ultra-large (km^2 class) sail system. Analysis of the launch, deployment, stabilization, and control of these sails shows that high-payload-mass fractions for interplanetary and deep-space missions are possible. UltraSail combines propulsion and control systems developed for formation-flying microsatellites with a solar sail architecture to achieve controllable sail areas approaching 1 km^2. Electrically conductive CP-1 polyimide film results in sail subsystem area densities as low as 5 g/m^2. UltraSail produces thrust levels many times those of ion thrusters used for comparable deep-space missions.

The primary innovation involves the near-elimination of sail-supporting structures by attaching each blade tip to a formation-flying microsatellite, which deploys the sail and then articulates the sail to provide attitude control, including spin stabilization and precession of the spin axis. These microsatellite tips are controlled by microthrusters for sail-film deployment and mission operations.

UltraSail also avoids the problems inherent in folded sail film, namely stressing, yielding, or perforating, by storing the film in a roll for launch and deployment. A 5-km long by 2 micrometer thick film roll on a mandrel with a 1 m circumference (32 cm diameter) has a stored thickness of 5 cm. A 5 m-long mandrel can store a film area of 25,000 m^2, and a four-blade system has an area of 0.1 km^2.

This work was done by Rodney Burton and Victoria Coverstone of the University of Illinois Urbana-Champaign for Marshall Space Flight Center. For more information, contact Sammy Nabors, MSFC Commercialization Assistance Lead, at sammy.a.nabors@nasa.gov. Refer to MFS-32524-1

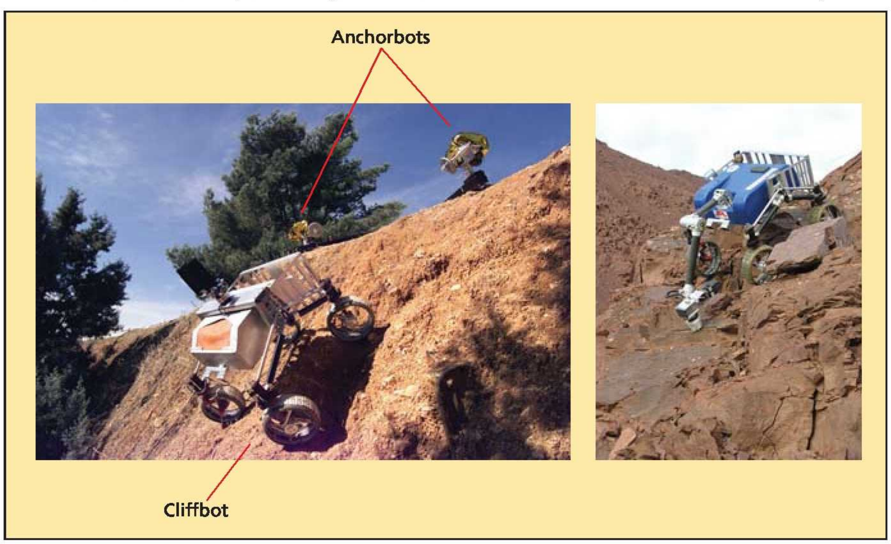
Cooperative Three-Robot System for Traversing Steep Slopes

This system is modeled on safe human climbing of steep slopes.

NASA's Jet Propulsion Laboratory, Pasadena, California

Teamed Robots for Exploration and Science in Steep Areas (TRESSA) is a system of three autonomous mobile robots that cooperate with each other to enable scientific exploration of steep terrain (slope angles up to 90°). Originally intended for use in exploring steep slopes on Mars that are not accessible to lone wheeled robots (Mars Exploration Rovers), TRESSA and systems like TRESSA could also be used on Earth for performing rescues on steep slopes and for exploring steep slopes that are too remote or too dangerous to be explored by humans.

TRESSA is modeled on safe human climbing of steep slopes, two key features of which are teamwork and safety tethers. Two of the autonomous robots, denoted Anchorbots, remain at the top of a slope; the third robot, denoted the Cliffbot, traverses the slope. The Cliffbot drives over the cliff edge supported by tethers, which are payed out from the Anchorbots (see figure). The Anchorbots autonomously control the tension in the tethers to counter the gravitational force on the Cliffbot. The tethers are payed out and reeled in as needed, keeping the body of the Cliffbot oriented approximately parallel to the local terrain surface and preventing wheel slip by controlling the speed of descent or ascent, thereby enabling the Cliffbot to drive freely up, down, or across the slope.



Left: The **Cliffbot Is Tethered to the Two Anchorbots** so that it can move on the steep slope. Right: The Cliffbot performs scientific studies of the cliff.

Due to the interactive nature of the three-robot system, the robots must be very tightly coupled. To provide for this tight coupling, the TRESSA software architecture is built on a combination of (1) the multi-robot layered behavior-coordination architecture reported in "An Architecture for Controlling Multiple Robots" (NPO-30345), *NASA Tech Briefs*, Vol. 28, No. 10 (October 2004), page 65, and (2) the real-time control architecture reported in "Robot Electronics Architecture" (NPO-41784), *NASA Tech*

Briefs, Vol. 32, No. 1 (January 2008), page 28. The combination architecture makes it possible to keep the three robots synchronized and coordinated, to use data from all three robots for decision-making at each step, and to control the physical connections among the robots. In addition, TRESSA (as in prior systems that have utilized this architecture), incorporates a capability for deterministic response to unanticipated situations from yet another architecture reported in "Control Architecture for Robotic Agent Command and Sensing" (NPO-43635), *NASA Tech Briefs*, Vol. 32, No. 10 (October 2008), page 40.

Tether tension control is a major consideration in the design and operation of TRESSA. Tension is measured by force sensors connected to each tether at the Cliffbot. The direction of the tension (both azimuth and elevation) is also measured. The tension controller combines a controller to counter gravitational force and an optional velocity controller that anticipates the motion of the Cliffbot. The gravity controller estimates the slope angle from the inclination of the tethers. This angle and the weight of the Cliffbot determine the total tension needed to counteract the weight of the Cliffbot. The total needed tension is broken into components for each Anchorbot. The difference between this needed tension and the tension measured at the Cliffbot constitutes an error signal that is provided to the gravity controller. The velocity controller computes the tether speed needed to produce the desired motion of the Cliffbot.

Another major consideration in the design and operation of TRESSA is detection of faults. Each robot in the TRESSA system monitors its own performance and the performance of its teammates in order to detect any system faults and prevent unsafe conditions. At startup, communication links are tested and if any robot is not communicating, the system refuses to execute any motion commands. Prior to motion, the Anchorbots attempt to set tensions in the tethers at optimal levels for counteracting the weight of the Cliffbot; if either Anchorbot fails to reach its optimal tension level within a specified time, it sends a message to the other robots and the commanded motion is not executed. If any mechanical error (e.g., stalling of a motor) is detected, the affected robot sends a message triggering stoppage of the current motion. Lastly, messages are passed among the robots at each time step (10 Hz) to share sensor information during operations. If messages from any robot cease for more than an allowable time interval, the other robots detect the communication loss and initiate stoppage.

This work was done by Ashley Stroupe, Terrance Huntsberger, Hrand Aghazarian, Paulo Younse, and Michael Garrett of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-44699

Assemblies of Conformal Tanks

Space is utilized efficiently and sloshing is reduced.

Marshall Space Flight Center, Alabama

Assemblies of tanks having shapes that conform to each other and/or conform to other proximate objects have been investigated for use in storing fuels and oxidizers in small available spaces in upper stages of spacecraft. Such assemblies might also prove useful in aircraft, automobiles, boats, and other terrestrial vehicles in which space available for tanks is limited.

The basic concept of using conformal tanks to maximize the utilization of limited space is not new in itself: for example, conformal tanks are used in some automobiles to store windshield-washer liquid and coolant that overflows from radiators. The novelty of the present development lies in the concept of an assembly of smaller conformal tanks, as distinguished from a single larger conformal tank. In an assembly of smaller tanks, it would be possible to store different liquids in different tanks. Even if the same liquid were stored in all the tanks, the assembly would offer an advantage by reducing the mechanical disturbance caused by sloshing of fuel in a single larger tank: indeed, the requirement to reduce sloshing is critical in some applications.

This **Prototype Assembly of Conformal Tanks** was built to demonstrate the feasibility of building such an assembly to fit an approximately toroidal available volume.