

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, Terrence 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.

The figure shows a prototype assembly of conformal tanks. Each tank was fabricated by (1) copper plating a wax tank mandrel to form a liner and (2) wrapping and curing layers of graphite/epoxy composite to form a shell supporting the liner. In this case, the conformal tank surfaces are flat

ones where they come in contact with the adjacent tanks. A band of fibers around the outside binds the tanks together tightly in the assembly, which has a quasi-toroidal shape. For proper functioning, it would be necessary to maintain equal pressure in all the tanks.

This work was done by Tom DeLay of Marshall Space Flight Center.

This invention is owned by NASA, and a patent application has been filed. For further information, contact Sammy Nabors, MSFC Commercialization Assistance Lead, at sammy.a.nabors@nasa.gov. Refer to MFS-32015-1.

Microfluidic Pumps Containing Teflon® AF Diaphragms

Operational temperature ranges have been extended to lower and higher limits.

NASA's Jet Propulsion Laboratory, Pasadena, California

Microfluidic pumps and valves based on pneumatically actuated diaphragms made of Teflon® AF polymers are being developed for incorporation into laboratory-on-a-chip devices that must perform well over temperature ranges wider than those of prior diaphragm-based microfluidic pumps and valves. Other potential applications include implanted biomedical microfluidic devices, wherein the biocompatibility of Teflon® AF polymers would be highly advantageous. These pumps and valves have been demonstrated to function stably after cycling through temperatures from -125 to 120 °C.

These pumps and valves are intended to be successors to similar prior pumps and valves containing diaphragms made of polydimethylsiloxane (PDMS) [commonly known as silicone rubber]. The PDMS-containing valves are designed to function stably only within the temperature range from 5 to 80 °C. Undesirably, PDMS membranes are somewhat porous and retain water. PDMS is especially unsuitable for use at temperatures below 0 °C because the formation of ice crystals increases porosity and introduces microshear.

"Teflon® AF" is the trade name of family of fluoropolymers that are amorphous (in the sense of lacking crystalline structure). These polymers are less permeable and more thermally stable, relative to PDMS. These polymers are similar to other fluoropolymers in their mechanical and optical properties, in

being highly resistant to attack by many chemicals, and in retaining their desirable properties over wide temperature ranges. However, unlike other fluoropolymers, these are soluble in selected solvents; as such, they are amenable to spin coating to form membranes.

A typical microfluidic device of the type to which the present development applies includes one or more rigid glass substrate layers containing fluid-handling channels and chambers. Each pump or valve includes a polymer membrane diaphragm bonded to a glass layer or sandwiched between two glass layers, with one or more circular cutout(s) in each such glass layer to accommodate motion of the diaphragm and flows of fluids. The development effort thus far has included experiments to determine optimum combinations of ingredients and process conditions to form Teflon® AF membranes and incorporate them into pumps as diaphragms. It was found that structurally robust Teflon® AF 1600 membranes of acceptably high quality, about 50 µm thick, can be formed by means of a spin-coating process repeated at least five times and that adequate adhesion of the membranes to glass substrates could be ensured by coating the membrane-anchoring areas of the substrates by vapor deposition of chromium to a thickness of 50 Å. Chromium was removed from valve seats and other nearby substrate areas to which moving portions of diaphragms were required not to adhere.

Pumps fabricated according to the guidance provided by the experiments have been operated for more than 240 hours without delamination of membranes from substrates or any other failures. Diaphragms and valve seats of various sizes and shapes have been tested; the combination of circular diaphragms of 2 mm diameter with hemispherical valve seats was found to yield the best overall performance. Various combinations of opening and closing actuation pressures were also tested; a combination of 6 psi (41 kPa) closing pressure and -12 psi (-83 kPa) opening pressure was found to generate the highest rate of flow while preventing formation of bubbles in the pumped liquid.

Temperature-cycling tests have also been performed. The first test involved warming the pumps to 50 °C followed by cooling the pumps to -25 °C for 30 minutes. Next, the pumps were cooled to -80 °C and held there for 48 hours. Finally, the pumps were cycled from -125 to 120 °C four times over 24 hours. After each thermal cycle, pumping characteristics were measured. Interestingly, flow rates were found to be slightly increased after temperature cycling. No detrimental effects were noted after any of the temperature tests.

This work was done by Peter Willis, Victor White, Frank Grunthaler and Mike Ikeda of Caltech and Richard A. Mathies of the University of California, Berkeley, for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-44482