



## Mechanics/Machinery

### Microgravity, Mesh-Crawling Legged Robots

**These relatively inexpensive robots may be used in search and rescue operations.**

*NASA's Jet Propulsion Laboratory, Pasadena, California*

The design, fabrication, and microgravity flight-testing are part of a continuing development of palm-sized mobile robots that resemble spiders (except that they have six legs apiece, whereas a spider has eight legs). Denoted SpiderBots (see figure), they are prototypes of proposed product line of relatively inexpensive walking robots that could be deployed in large numbers to function cooperatively in construction, repair, exploration, search, and rescue activities in connection with exploration of outer space and remote planets.

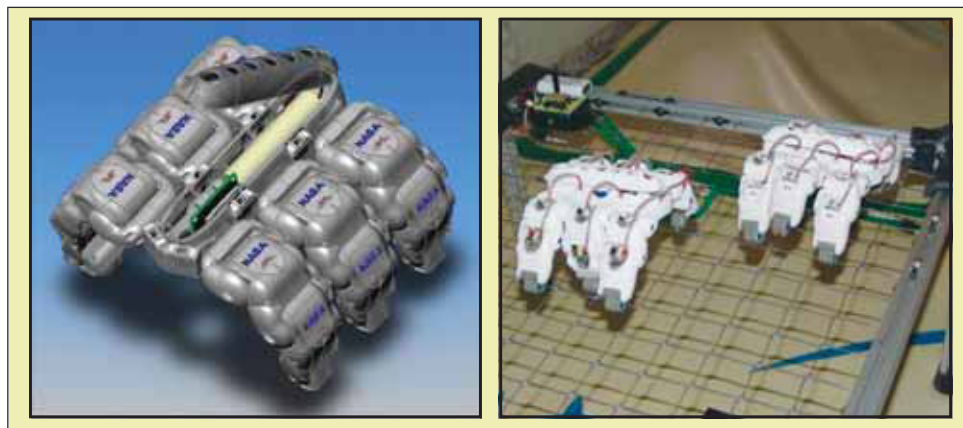
Relative to other legged robots, including ones reported in previous *NASA Tech Briefs* articles, SpiderBots are smaller, less power-hungry, and more specialized. A SpiderBot at the present stage of development is designed primarily to demonstrate that it can crawl on a flexible rectangular mesh (in micro-gravity) and secondarily that it can walk on flat surfaces and assemble simple structures. Each leg includes two spring-compliant joints and a

gripping actuator. The SpiderBot moves in a hard-coded set of tripod gaits involving alternating motions of legs variously anchored or not anchored to a mesh.

The robots were recently tested on a reduced gravity aircraft and were able to demonstrate crawling along the mesh during the microgravity portion of the parabolic flight. In one contemplated improvement, feedback from sensors on the feet would provide indications of success or the lack

thereof in gripping a mesh, thereby contributing to robust, fault-tolerant operation.

*This work was done by Alberto Behar, Neville Marzwell, Jaret Matthews, and Krandalyn Richardson of Caltech; Jonathan Wall and Michael Poole of Blue Sky Robotics; David Foor of Texas A&M University; and Damian Rodgers of ISU (International Space University) for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-42672*



Photos of SpiderBots show a prototype and one crawling on a mesh.

### Advanced Active-Magnetic-Bearing Thrust-Measurement System

**Automatic multipoint calibration and a fringing model are used to increase accuracy.**

*Stennis Space Center, Mississippi*

An advanced thrust-measurement system utilizes active magnetic bearings to both (1) levitate a floating frame in all six degrees of freedom and (2) measure the levitation forces between the floating frame and a grounded frame. This system was developed for original use in measuring the thrust exerted by a rocket engine mounted on the floating frame, but can just as well be used in other force-measurement applications.

This system offers several advantages over prior thrust-measurement systems

based on mechanical support by flexures and/or load cells:

- The system includes multiple active magnetic bearings for each degree of freedom, so that by selective use of one, some, or all of these bearings, it is possible to test a given article over a wide force range in the same fixture, eliminating the need to transfer the article to different test fixtures to obtain the benefit of full-scale accuracy of different force-measurement devices for different force ranges.

- Like other active magnetic bearings, the active magnetic bearings of this system include closed-loop control subsystems, through which the stiffness and damping characteristics of the magnetic bearings can be modified electronically.
- The design of the system minimizes or eliminates cross-axis force-measurement errors. The active magnetic bearings are configured to provide support against movement along all three orthogonal Cartesian axes, and such that the support along a given axis does not

produce force along any other axis. Moreover, by eliminating the need for such mechanical connections as flexures used in prior thrust-measurement systems, magnetic levitation of the floating frame eliminates what would otherwise be major sources of cross-axis forces and the associated measurement errors.

Overall, relative to prior mechanical-support thrust-measurement systems, this system offers greater versatility for adaptation to a variety of test conditions and requirements.

The basic idea of most prior active-magnetic-bearing force-measurement systems is to calculate levitation forces on the basis of simple proportionalities between changes in those forces and changes in feedback-controlled currents

applied to levitating electromagnetic coils. In the prior systems, the effects of gap lengths on fringing magnetic fields and the concomitant effects on magnetic forces were neglected. In the present system, the control subsystems of the active magnetic bearings are coupled with a computer-based automatic calibration system running special-purpose software wherein gap-length-dependent fringing factors are applied to current- and magnetic-flux-based force equations and combined with a multipoint calibration method to obtain greater accuracy. All of the inputs required for calibration can be obtained from the control subsystems of the active magnetic bearings (and from magnetic-flux sensors if they are used). Tests have verified that force accuracies characterized by errors or <5

percent of full-scale readings are achievable when using current-based force equations or by errors <0.5 percent of full-scale readings when using flux-based equations.

*This work was done by Joseph Imlach of Innovative Concepts In Engineering LLC and Mary Kasarda and Eric Blumber of Virginia Polytechnic Institute and State University for Stennis Space Center.*

*Inquiries concerning rights for the commercial use of this invention should be addressed to:*

*Innovative Concepts In Engineering LLC  
2142 Tributary Circle  
Anchorage, AK 99516  
(907) 337-8954*

*Refer to SSC-00177-1/8-1, volume and number of this NASA Tech Briefs issue, and the page number.*

## ⚙️ Thermally Actuated Hydraulic Pumps

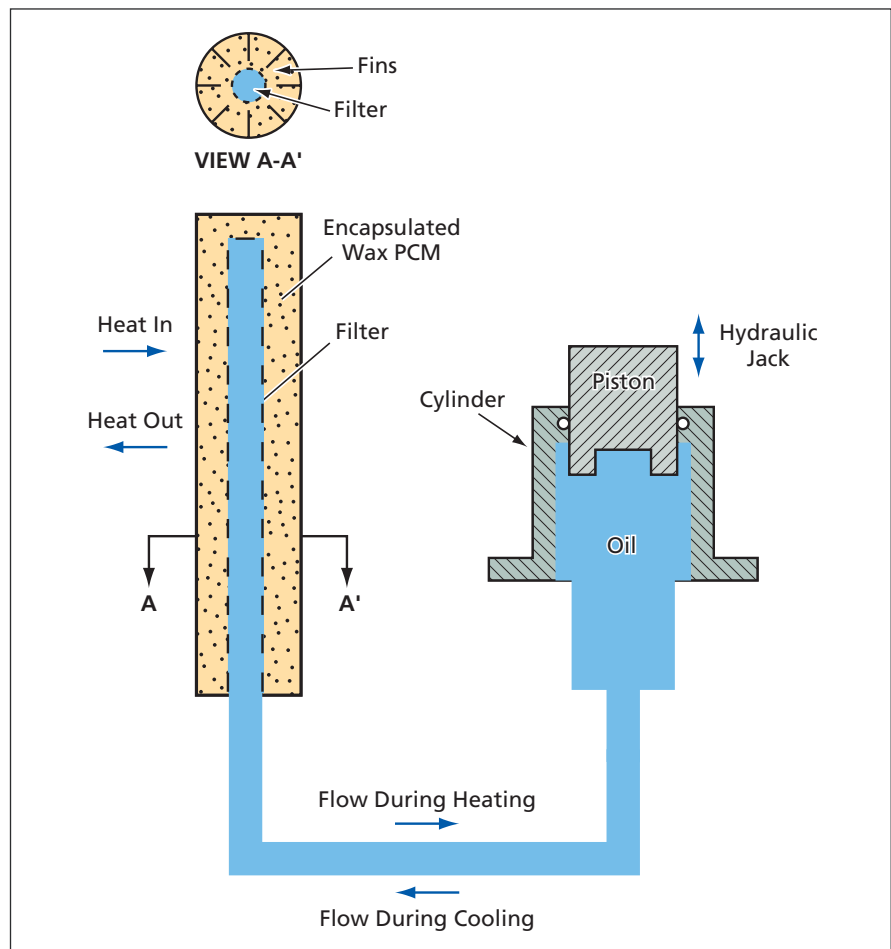
**These pumps would contain no sliding (wearing) parts.**

*NASA's Jet Propulsion Laboratory, Pasadena, California*

Thermally actuated hydraulic pumps have been proposed for diverse applications in which direct electrical or mechanical actuation is undesirable and the relative slowness of thermal actuation can be tolerated. The proposed pumps would not contain any sliding (wearing) parts in their compressors and, hence, could have long operational lifetimes.

The basic principle of a pump according to the proposal is to utilize the thermal expansion and contraction of a wax or other phase-change material in contact with a hydraulic fluid in a rigid chamber. Heating the chamber and its contents from below to above the melting temperature of the phase-change material would cause the material to expand significantly, thus causing a substantial increase in hydraulic pressure and/or a substantial displacement of hydraulic fluid out of the chamber. Similarly, cooling the chamber and its contents from above to below the melting temperature of the phase-change material would cause the material to contract significantly, thus causing a substantial decrease in hydraulic pressure and/or a substantial displacement of hydraulic fluid into the chamber. The displacement of the hydraulic fluid could be used to drive a piston.

The figure illustrates a simple example of a hydraulic jack driven by a thermally actuated hydraulic pump. The pump chamber would be a cylinder con-



A Thermally Actuated Hydraulic Pump would displace oil, which would displace a piston in a hydraulic jack.