ed on the nacelle and aimed at reflective targets on the center body, which is part of the fan assembly.

The outputs of the laser displacement sensors are digitized and processed through a personal computer programmed with control software. The control output of the computer commands the servomotors to move the table as needed to restore concentricity. Numerous software and hardware travel limits and alarms are provided to maximize safety. A highly ablative rub strip in the nacelle minimizes the probability of damage in the event that a deviation from concentricity exceeds the radial clearance [<0.004 in. (<0.1 mm)] between the inner surface of the nacelle and the tips of the fan blades.

To be able to prevent an excursion in excess of the tip clearance, the system must be accurate enough to control X and Y displacements to within 0.001 in. (≈0.025 mm). One characteristic essential to such accuracy is sufficient rigidity in the mechanical components of the system to prevent excitation of vibrations in the strut/nacelle subsystem. The need for such a high degree of accuracy prompted a comprehensive analysis of sources of measurement and control errors, followed by rigorous design efforts to minimize these errors. As a result, the design of the system incorporates numerous improvements in hardware, software, and operational procedures.

This work was done by Cameron C. Cunningham, William K. Thompson, Christopher E. Hughes, and Tony D. Shook of **Glenn Research Center**. *Further information is contained in a TSP [see page 1].*

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Commercial Technology Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-17185.

Hopping Robot With Wheels

Hopping and wheeled motions complement each other.

NASA's Jet Propulsion Laboratory, Pasadena, California

A small prototype mobile robot is capable of (1) hopping to move rapidly or avoid obstacles and then (2) moving relatively slowly and precisely on the ground by use of wheels in the manner of previously reported exploratory robots of the "rover" type. This robot is a descendant of a more primitive hopping robot described in "Minimally Actuated Hopping Robot" (NPO-20911), *NASA Tech Briefs*, Vol. 26, No. 11 (November 2002), page 50. There are many potential applications for robots with hopping and wheeled-locomotion (roving) capabilities in diverse fields of endeavor, including agriculture, search-and-rescue operations, general military operations, removal or safe detonation of land mines, inspection, law enforcement, and scientific exploration on Earth and remote planets.

The combination of hopping and roving enables this robot to move rapidly over very rugged terrain, to overcome obstacles several times its height, and then to position itself precisely next to a desired target. Before a long hop, the robot aims itself in the desired hopping azimuth and at a desired takeoff angle above horizontal. The robot approaches the target through a series of hops and short driving operations utilizing the steering wheels for precise positioning.

Features of this robot include the following:

- An adaptive controlled nonlinear spring mechanism capable of delivering force of specified intensity for hopping;
- Three deployable wheels. Two in front are independently controlled for driving and steering. The third is passive and is located in the rear of the vehicle;
- An autonomous mechanism for self-righting after landing from a hop (described in more detail below);
- A digital camera for acquiring image data;
- Electronic hardware for processing acquired data, computing hopping and roving trajectories, and either wired or wireless communication with a host computer;
- Software for use in sensor-based navigation, trajectory computations, and adjustment of hopping parameters.

The robot has a mass of about 1.5 kg and a minimum volume of about 30 cm^3. It can jump about 1 m high and 2 m horizontally. After landing, the robot rights itself by a combination of actuation of side panels and shifting of its center of mass. The side panels also afford protection at landing and, in future versions, will carry photovoltaic panels for charging batteries.

Once in its upright position, the robot can sit still, move by use of its wheels, or prepare for another hop. The hopping distance can be adjusted by choosing an appropriate takeoff angle and controlling the spring loading. In the present version, images from the onboard camera are sent to a remote operator, who controls the operation of the robot; in future versions, the onboard software will enable autonomous navigation by the robot.

This work was done by Edward Barlow, Nevellie Marzwell, Sawyer Fuller, Paolo Fiorini, Andy Tretton, Joel Burdick, and Steve Schell of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP [see page 1].*
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