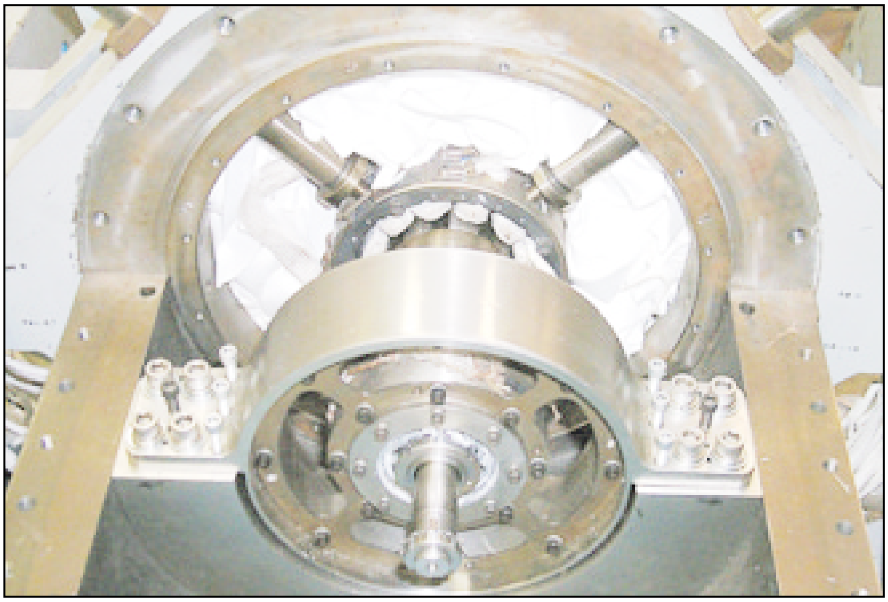
High-Temperature Switched-Reluctance Electric Motor

Motors like this one would be incorporated into gas turbines as starter/generators.

John H. Glenn Research Center, Cleveland, Ohio



The **High-Temperature Switched-Reluctance Electric Motor**, capable of operating at a speed of 8,000 rpm at a temperature of 1,000 °F (≈540 °C), is a modified version of a magnetic bearing capable of operating at 15,000 rpm at 1,000 °F (≈540 °C).

An eight-pole radial magnetic bearing has been modified into a switched-reluctance electric motor capable of operating at a speed as high as 8,000 rpm at a temperature as high as 1,000 °F (≈540 °C). The motor (see figure) is an experimental prototype of starter-motor/generator units that have been proposed to be incorporated into advanced gas turbine engines and that could operate without need for lubrication or active cooling.

The unique features of this motor are its electromagnet coils and, to some extent, its control software. Heretofore, there has been no commercial-off-the-shelf wire capable of satisfying all of the requirements for fabrication of electromagnet coils capable of operation at temperatures up to 1,000 °F (≈540 °C). The issues addressed in the development of these electromagnet coils included thermal expansion, oxidation, pliability to small bend radii, micro-fretting, dielectric breakdown, tensile strength, potting compound, thermal conduction, and packing factor.

For a test, the motor was supported, along with a rotor of 18 lb (≈8-kg) mass, 3-in. (≈7.6-cm) diameter, 21-in. (≈53-cm) length, on bearings packed with high-temperature grease. The motor was located at the mid span of the rotor and wrapped with heaters. The motor stator was instrumented with thermocouples. At the time of reporting the information for this article, the motor had undergone 14 thermal cycles between room temperature and 1,000 °F (≈540 °C) and had accumulated operating time >27.5 hours at 1,000 °F (≈540 °C).

The motor-controller hardware includes a personal computer equipped with analog-to-digital input and digital-to-analog output cards. The controller software is a C-language code that implements a switched-reluctance motor-control principle: that is, it causes the coils to be energized in a sequence timed to generate a rotating magnetic flux that creates a torque on a scalloped rotor. The controller can operate in an open- or closed-loop mode. In addition, the software has been modified to enable the simultaneous operation of the prototype motor or another, similar apparatus as both a motor and a magnetic bearing. Combined bearing/motor operation has been demonstrated at room temperature but had not yet been demonstrated at high temperature at the time of reporting the information for this article.

This work was done by Gerald Montague, Gerald Brown, Carlos Morrison, Andy Provenza, and Albert Kascak of **Glenn Research Center** *and Alan Palazzolo of Texas A&M University. 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-17287.

System for Centering a Turbofan in a Nacelle During Tests

The system helps to maintain safety and accuracy.

John H. Glenn Research Center, Cleveland, Ohio

A feedback position-control system has been developed for maintaining the concentricity of a turbofan with respect to a nacelle during acoustic and flow tests in a wind tunnel. The system is needed for the following reasons:

- Thermal and thrust loads can displace the fan relative to the nacelle;
- In the particular test apparatus (see Figure 1), denoted as a rotor-only nacelle (RAN), the struts, vanes, and other stator components of a turbofan engine that ordinarily maintain the required concentricity in the face of thermal and thrust loads are not present; and
- The struts and stator components are not present because it is necessary to provide a flow path that is acoustically "clean" in the sense that the measured noise can be attributed to the fan alone.

The system is depicted schematically in Figure 2. The nacelle is supported by two struts attached to a two-axis traverse table located outside the wind-tunnel wall. Two servomotors acting through 100:1 gearboxes drive the table along the Y and Z axes, which are perpendicular to the axis of rotation. The Y and Z components of the deviation from concentricity are measured by four laser displacement sensors mount-

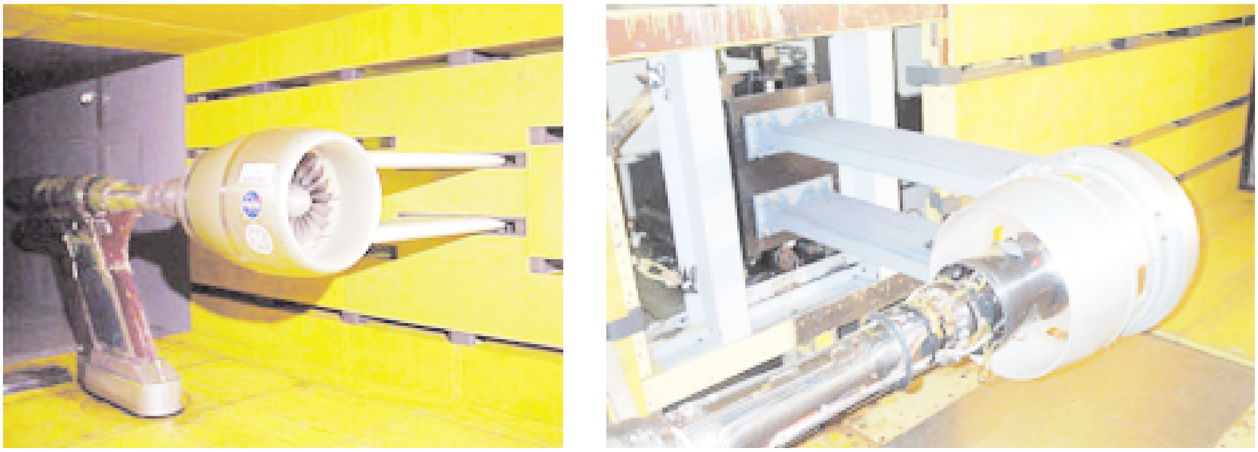


Figure 1. **RAN System in Test Configuration** is shown in (a), and (b) shows the installation of positioning table behind tunnel wall.

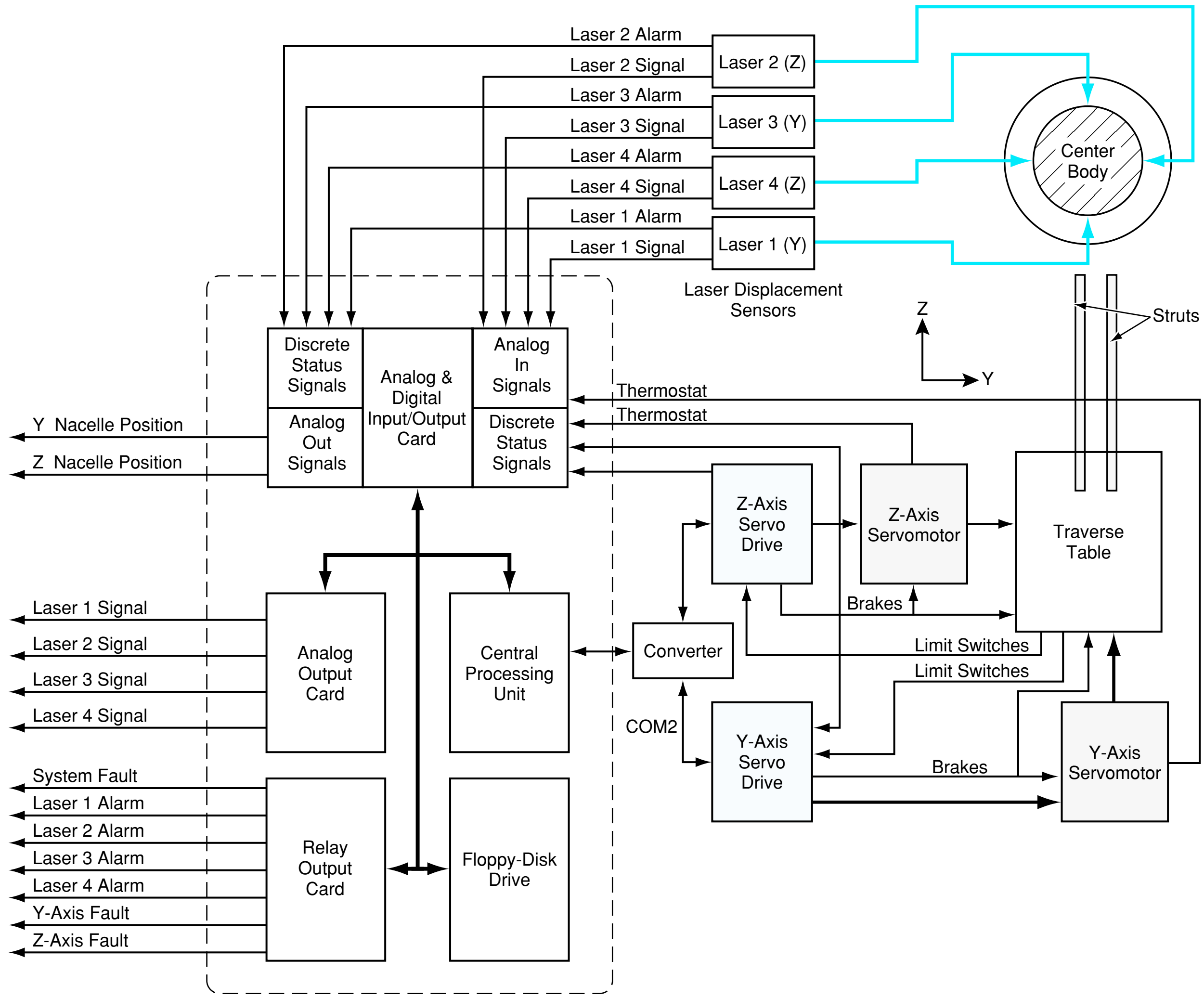


Figure 2. This **Control System** continually adjusts the Z and Y position of the nacelle to minimize eccentricity with respect to the center body.

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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