The sensor head (top) contains three hot-wire sensors oriented perpendicularly to the axis of the tube (across the flow) and one parallel to the axis of the tube (along the flow). The general views of the cockpit display and the sensor are shown, respectively, in the middle and bottom images.

**Advances in Measurement of Skin Friction in Airflow**

This system implements a combination of established experimental techniques and advanced image processing.

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The surface interferometric skin-friction (SISF) measurement system is an instrument for determining the distribution of surface shear stress (skin friction) on a wind-tunnel model. The SISF system utilizes the established oil-film interference method, along with advanced image-data-processing techniques and mathematical models that express the relationship between interferograms and skin friction, to determine the distribution of skin friction over an observed region of the surface of a model during a single wind-tunnel test.

In the oil-film interference method, a wind-tunnel model is coated with a thin film of oil of known viscosity and is illuminated with quasi-monochromatic, collimated light, typically from a mercury lamp. The light reflected from the outer surface of the oil film interferes with the light reflected from the oil-covered surface of the model. In the present version of the oil-film interference method, a camera captures an image of the illuminated model and the image in the camera is modulated by the interference pattern. The interference pattern depends on the oil-thickness distribution on the observed surface, and this distribution can be extracted through analysis of the image acquired by the camera.

The oil-film technique is augmented by a tracer technique for observing the streamline pattern. To make the streamlines visible, small dots of fluorescent chalk/oil mixture are placed on the model just before a test. During the test, the chalk particles are embedded in the
Improved Apparatus for Testing Monoball Bearings

Automated tests can be performed over wide ranges of conditions.

Marshall Space Flight Center, Alabama

A desk-sized apparatus for testing monoball bearings and their lubricants offers advantages, relative to prior such apparatuses, of (1) a greater degree of automation and (2) capability of operation under wider and more realistic ranges of test conditions. The ranges of attainable test conditions include load from 100 to >50,000 lb (445 to >2.22 × 10⁵ N), resisting torque up to 30,000 lb-in. (=3.390 N-m), oscillating rotation through an angle as large as 280°, and oscillation frequency from 0 to 6 Hz. With addition of some components and without major modification of the apparatus, it is also possible to perform tests under environmental conditions that include temperature from –320 to 1,000 °F (–196 to +538 °C), relative humidity from 0 to 100 percent, and either air at ambient pressure, high vacuum, or an atmosphere of monatomic oxygen.

In the apparatus (see Figure 1), a monoball bearing specimen is driven in oscillating rotation by a hydraulic rotary actuator through a series of shafts, one of which incorporates a torque meter and one of which is a flexible coupling. The torque meter measures the resisting torque; the flexible coupling accommodates misalignment, wear, and compression of the specimen and ensures equal loading on opposite sides of the monoball. Not shown in the figure is an angular-position sensor that is used for measuring the angle of rotation of the shafts.

The bearing surfaces that mate with the monoball are supported by an angle plate on one side of the monoball and a trolley on the opposite side. The trolley is supported by very-low-friction cam rollers on its bottom and sides to allow motion in the loading direction only. Rigid side supports absorb the side loads transmitted by the cam rollers. On the opposite end of the trolley from the specimen is a compression load cell, which measures the load, applied by a hydraulic cylinder via a piston that bears against the load cell.

The instantaneous rate of thinning of the oil film at a given position on the surface of the model can be expressed as a function of the instantaneous thickness, the skin-friction distribution on the surface, and the streamline pattern on the surface; the functional relationship is expressed by a mathematical model that is nonlinear in the oil-film thickness and is known simply as the thin-oil-film equation. From the image data acquired as described, the time-dependent oil-thickness distribution and streamline pattern are extracted and by inversion of the thin-oil-film equation it is then possible to determine the skin-friction distribution.

In addition to a quasi-monochromatic light source, the SISF system includes a beam splitter and two video cameras equipped with filters for observing the same area on a model in different wavelength ranges, plus a frame grabber and a computer for digitizing the video images and processing the image data. One video camera acquires the interference pattern in a narrow wavelength range of the quasi-monochromatic source. The other video camera acquires the streamline image of fluorescence from the chalk in a nearby but wider wavelength range. The interference-pattern and fluorescence images are digitized, and the resulting data are processed by an algorithm that inverts the thin-oil-film equation to find the skin-friction distribution.

This work was done by James L. Brown of Ames Research Center and Jonathan W. Naughton of MCAT, Inc. Further information is contained in a TSP (see page 1).

This invention has been patented by NASA (U.S. Patent No. 5,963,310). Inquiries concerning rights for the commercial use of this invention should be addressed to the Ames Technology Partnerships Division at (650) 604-2954. Refer to ARC-14189-1.