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.

ing elements have different shapes and sizes and, therefore, exhibit different measurement efficiencies with respect to droplet size and water phase (liquid, frozen, or mixed). Three of the hot-wire sensing elements are oriented across the airflow so as to intercept incoming cloud water. For each of these elements, the LWC or TWC affects the power required to maintain a constant temperature in the presence of cloud water.

Each of these three elements is considered to be subject to two forms of heat loss. The first form consists primarily of convective loss attributable to the flow of air past the element. This form is sometimes termed the "dry" loss because it excludes the cooling effect of the impinging water. The second form of heat loss is the cooling effect of impinging water. When the element intercepts liquid cloud water, energy is lost from the element in heating the water from ambient temperature to the equilibrium temperature for evaporation, and further energy is lost as latent heat of vaporization. When the element intercepts cloud ice crystals, there is an additional loss consisting of the latent heat of fusion for melting the ice. In operation, each element is maintained at a temperature of 140 °C by a digital electronic feedback control subsystem. The power expended in maintaining this constant temperature is the measurement datum associated with the element.

The fourth hot-wire sensing element, denoted the reference element, is oriented along the direction of airflow so that it does not intercept cloud water but is still subject to convective cooling. Like the other three elements, the reference element is maintained at constant temperature. In the case of this element, the power needed to maintain the constant temperature is a measure of the dry heat loss and is thus termed the "dry" power. The cloud water content is estimated in a first-principles computation based on known relationships among the cloud water content, the hot-wire power levels, the dimensions of the sensor wires, ambient temperature, and true airspeed.

The measurements and computations needed to quantify cloud IWC (glaciation) and droplet size are more complex. It has long been known that the response of a hot-wire sensor to water droplets decreases with increasing droplet diameter. The response of a wider element is similar to that of a narrower element, except that the onset of the decrease occurs at a larger drop size. Although this droplet-size dependence is not fully theoretically understood, it is empirically known to be highly repeatable and to be useful as a means of inferring droplet diameter: Specifically, measurement data acquired under known conditions in a wind tunnel can be used to calibrate an instrumentation system like this one to enable determination of the median volume diameter of cloud water droplets, given the differences among the responses of the hot-wire sensing elements.

This work was done by Lyle Lilie, Dan Bouley, and Chris Sivo of Science Engineering Associates, Inc. for **Glenn Research Center**.

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-18029-1.

Advances in Measurement of Skin Friction in Airflow

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

Ames Research Center, Moffett Field, California

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 oil flow and produce chalk streaks that mark the streamlines.

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.

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 >2.22×10^5 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.

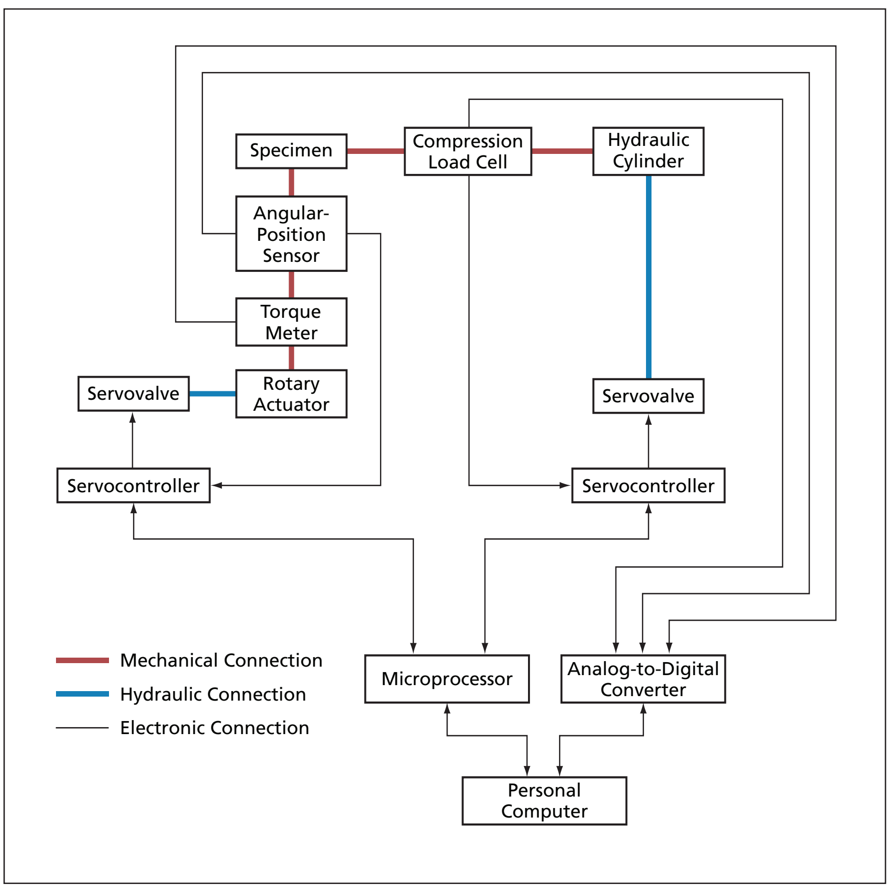

Figure 2. The **Data-Acquisition-and-Control System** of the testing apparatus automates all aspects of testing and processing of test data, once a human operator has initiated a test.

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.