furnace, to the test position inside the furnace. On one side of the furnace there is another, relatively small opening on a direct line to the specimen. Once the specimen has become heated to the test temperature, the test is performed by using an instrumented external pressurized-gas-driven gun to shoot a projectile through the side opening at the specimen.

Advantageous features of the design and operation of this apparatus include the following:

- All parts of the retaining fixture are made of silicon carbide to withstand high test temperatures.
- The simplest version of the retaining fixture (see Figure 2) includes a tube, into which are machined tapered slots to accommodate a flat specimen and a side hole for admitting a projectile. (In a more complex version, there are slots for two specimens and two corresponding projectile holes at diametrically opposite locations.) The specimen is held in place by silicon carbide wedges inserted in the tapered gaps remaining between the specimen and the slots.
- Among the alternative versions of the retaining fixture are versions that offer a choice between full support or span support of the specimen. If full support is needed, then one can choose a version having slots wide enough to support not only the specimen but also a solid backing plate.
- To some extent, by partially enclosing the specimen, the retaining fixture provides some protection of the furnace insulation and heating elements against flying debris from a specimen and projectile. Shielding separate from the retaining fixture can added in cases in which more protection is needed.
- The rotational stage enables adjustment of the angle of impact — a feature that is desirable for impact testing of vanes under realistic conditions. Alternatively or in addition, if the retaining fixture is of the two-specimen type described above, then the rotational stage can be used to expose both specimens in succession without removing them from the furnace.
- The provision for inserting and removing specimens through the opening in the bottom of the furnace eliminates the need to cool and reheat the furnace between tests, thereby saving substantial amounts of test time.
- When multiple impacts at different positions along a lengthened specimen are required, the retaining fixture can be modified to lengthen the tapered slots and side holes at the additional impact positions, and the linear actuator can be used to place the specimen at the various impact positions. In such a case, the modifications can reduce the shielding effect of the retaining fixture, thereby making it desirable to add separate shielding as mentioned above.

This work was done by Ralph J. Pawlik and Sung R. Choi 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, Innovative Partnerships Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-17610-1.

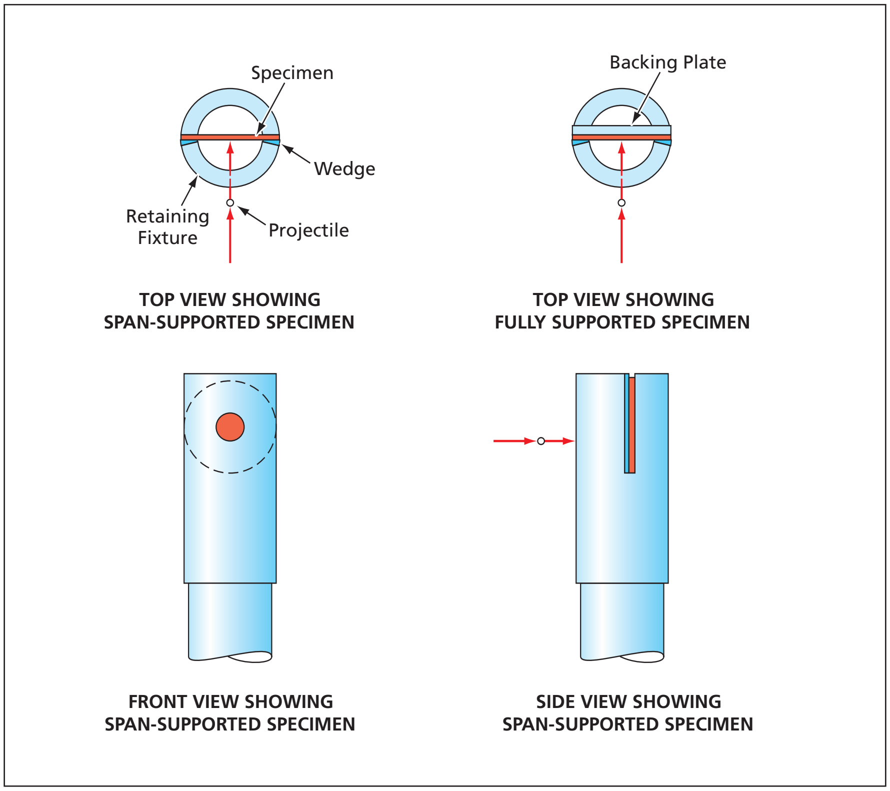

Figure 2. The **Specimen Is Held on the Retaining Fixture** by means of wedges in tapered slots. The slots can be dimensioned to provide span support of the specimen or to accommodate a backing plate for full support of the specimen.

Instrument for Aircraft-Icing and Cloud-Physics Measurements

Data on cloud water content are deduced from hot-wire power levels.

John H. Glenn Research Center, Cleveland, Ohio

The figure shows a compact, rugged, simple sensor head that is part of an instrumentation system for making measurements to characterize the severity of aircraft-icing conditions and/or to perform research on cloud physics. The quantities that are calculated from measurement data acquired by this system and that are used to quantify the severity of icing conditions include sizes of cloud water drops, cloud liquid water content (LWC), cloud ice water content (IWC), and cloud total water content (TWC).

The sensor head is mounted on the outside of an aircraft, positioned and oriented to intercept the ambient airflow. The sensor head consists of an open housing that is heated in a controlled manner to keep it free of ice and that contains four hot-wire elements. The hot-wire sens-

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