OPTICAL MEASUREMENT SYSTEMS

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ABSTRACT

This presentation describes some of the areas of research conducted at Lewis on optical measurement techniques. Two new laser anemometer systems developed at Lewis are used to illustrate the special instrumentation needs encountered in aeropropulsion research. Velocity measurements to be made through small viewing ports, close to surfaces within the propulsion system components, and in turbulent or highly-accelerating flows are some of the significant challenges. The application to research facilities of two advanced optical systems, the rainbow schlieren and the combustor viewing system, is presented. The calibration and verification of commercial optical measurement systems, such as droplet sizing systems, are also discussed. New calibration techniques capable of simulating moving droplets for flight-type sizing systems are being developed at Lewis. The presentation concludes with a brief look at the forces driving future research on optical instrumentation.

The goal of our research is to enhance the capabilities of non-intrusive research instrumentation used in aeropropulsion research. This instrumentation is needed to validate analytical codes and to verify the performance of aeropropulsion components and systems. Listed here are the primary areas of current research, together with two recently completed efforts. I will describe several of the areas in more detail in this presentation to illustrate the aeropropulsion instrumentation needs we are trying to fill. The fluid and structural parameters measured by the measurement techniques are also shown.

NON-INTRUSIVE RESEARCH INSTRUMENTATION FOR AEROPROPULSION SYSTEMS

- **LASER ANEMOMETRY**
  - **FOR AVERAGE FLOW VELOCITY, FLOW ANGLE, TURBULENCE INTENSITY**
- **HOLOGRAPHIC INTERFEROMETRY**
  - **FOR GAS DENSITY CHANGES, SURFACE DISPLACEMENTS**
- **LASER SPECTROSCOPY**
  - **FOR GAS TEMPERATURE, CONSTITUENTS, VELOCITY, PRESSURE**
- **PARTICLE SIZING**
  - **FOR FUEL SPRAY AND CLOUD DROPLET DIAMETERS**
- **LASER SPECKLE SYSTEMS**
  - **FOR SURFACE STRAIN**
- **RAINBOW SCHLIEREN**
  - **FOR FLOW VISUALIZATION**
- **HOT SECTION VIEWING SYSTEM**
  - **MONITORING HOT SECTION PHENOMENA**

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ADVANCES IN LASER ANEMOMETRY FOR AEROPROPULSION RESEARCH

Applying laser anemometry to aeropropulsion research facilities presents many challenges for the instrumentation researcher. Desired characteristics include the ability to measure flow in three axes through a very limited viewport, to make velocity measurements near surfaces, and to efficiently make measurements in a turbulent or highly accelerating flow. Two systems developed to meet these special needs will be described. The use of fiber-optics in laser anemometry systems is currently being investigated to meet the problem of high vibration and acoustic noise levels.

ADVANCES IN LASER ANEMOMETRY FOR AEROPROPULSION RESEARCH

- **THREE-AXIS LA FOR LIMITED VIEW APPLICATIONS**
- **FOUR-SPOT LASER-TRANSIT-ANEMOMETER FOR NEAR-SURFACE TURBULENT FLOWS**
- **FIBER-OPTIC LA FOR HIGH-VIBRATION ENVIRONMENTS**

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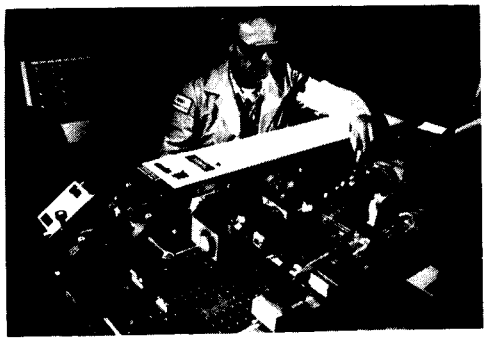
THREE COMPONENT LASER ANEMOMETRY SYSTEM

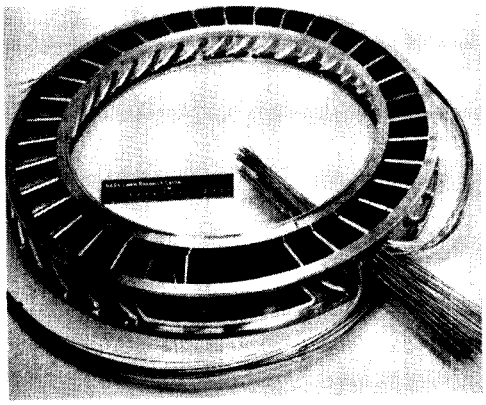
The system was developed at Lewis to measure the radial component of flow in addition to the axial and circumferential components in a turbine stator cascade facility, through a single optical viewing port. The system uses a Fabry-Perot interferometer technique in conjunction with the more common dual-beam fringe configuration. The annular vane ring shown has a contoured hub to enhance the radial velocity component. Velocity data for each axis and total velocity are shown in the figure and compared with the predicted values obtained with a computer code.

THREE COMPONENT LASER ANEMOMETRY SYSTEM

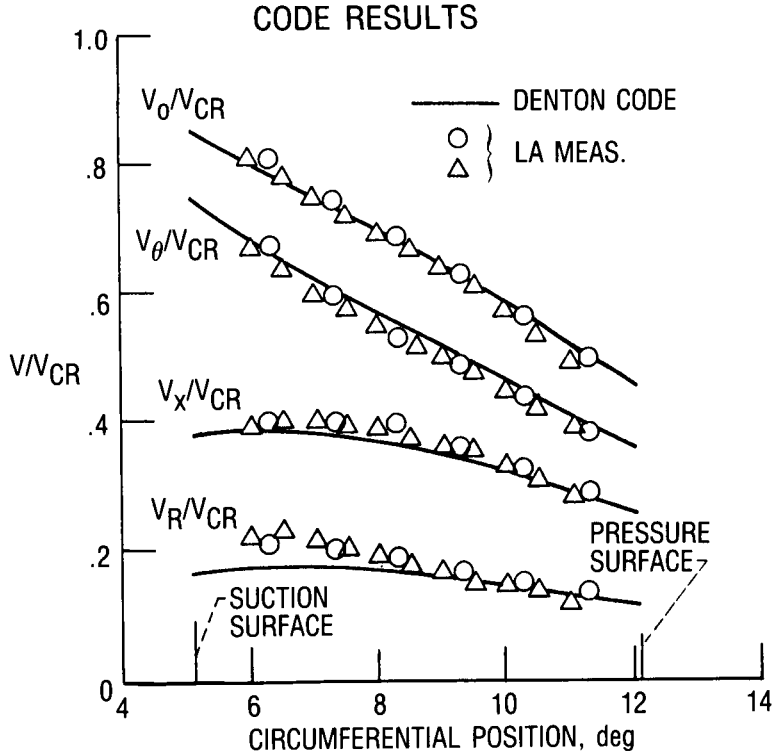
THREE COMPONENT LASER ANEMOMETER



ANNULAR VANE RING



LA SURVEY DATA AND DENTON CODE RESULTS



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FOUR-SPOT LASER ANEMOMETER

This system was developed at Lewis in conjunction with Case Western Reserve University. It is a laser transit anemometer (LTA) wherein velocity is determined by measuring the time it takes for seed particles to cross the gap between closely-spaced laser beams. The four-spot system has the feature of wide flow acceptance angle (necessary for measurements in turbulent flows) while retaining the LTA advantages of close-to-wall and small seed particle compatibility.

FOUR-SPOT LASER ANEMOMETER

- **FEATURES**

  WIDE FLOW ACCEPTANCE ANGLE NECESSARY FOR MEASUREMENTS IN TURBULENT FLOWS

  HIGH SPATIAL SELECTIVITY FOR MEASUREMENTS CLOSE TO SURFACES AND WITH SMALL SEED PARTICLES NECESSARY TO FOLLOW HIGH VELOCITY/HIGHLY ACCELERATING FLOWS

- **TEST RESULTS**

  VELOCITY SURVEYS OBTAINED TO WITHIN 200 MICROMETERS OF SURFACE IN 700 °C FLOW

  VELOCITIES TO MACH 1.3 MEASURED WITH 0.5 MICROMETER SEED PARTICLES

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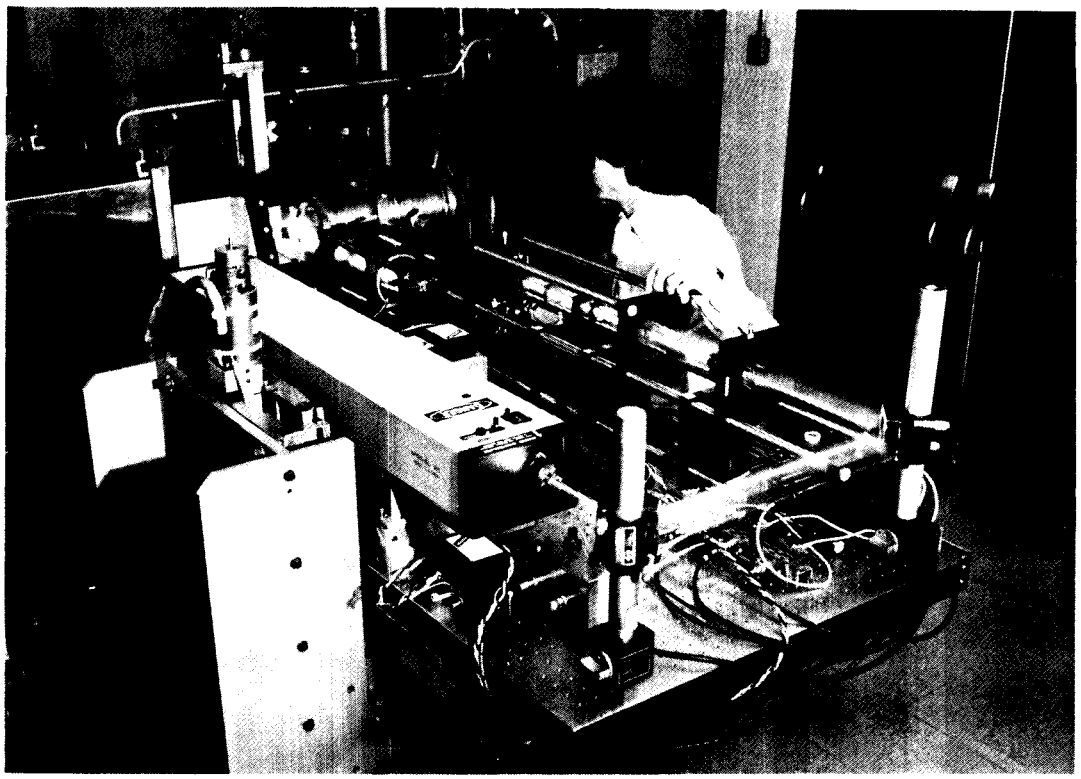
TESTING OF FOUR-SPOT LASER ANEMOMETER IN OPEN JET BURNER FACILITY

The four-spot LA was tested in a facility capable of generating hot (700 °C) turbulent flows. Velocity surveys were obtained to within 200 micrometers of a turbine vane surface inserted into the test flow. Other tests demonstrated velocity measurements to Mach 1.3 with 0.5 micrometer seed particles.

TESTING OF FOUR-SPOT LASER ANEMOMETER IN OPEN JET BURNER FACILITY



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RAINBOW SCHLIEREN

The rainbow schlieren system, developed at Lewis, uses a bull's-eye color filter to add a continuous color spectrum to the classical flow visualization technique for enhancing index-of-refraction gradients such as those accompanying supersonic shock waves. Not only does the color aid the eye's sensitivity in perceiving minor flow features, it adds a potential for quantitative flow analysis by coding the magnitude of refractive index changes in those flows exhibiting simple geometries.

RAINBOW SCHLIEREN

- **BULL'S-EYE FILTER ADDS CONTINUOUS COLOR SPECTRUM TO CLASSICAL FLOW VISUALIZATION TECHNIQUES**
- **POTENTIAL FOR QUANTITATIVE INFORMATION ON FLOW DENSITY GRADIENTS**
- **SYSTEM INSTALLED IN LEWIS WIND TUNNELS AND COMPONENT FACILITIES**

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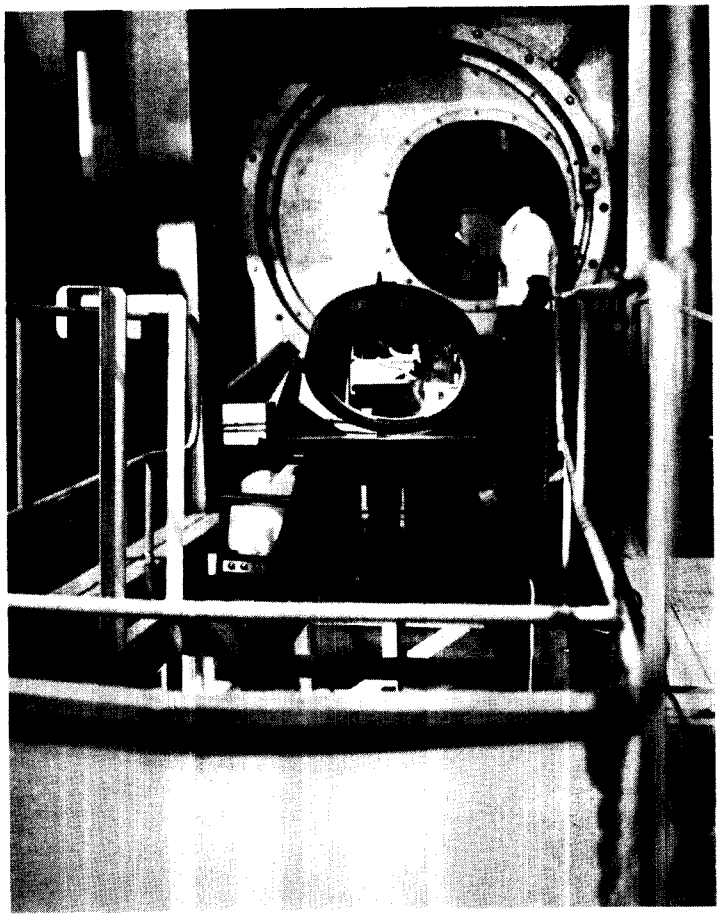
RAINBOW SCHLIEREN SYSTEM IN THE 10 x 10 WIND TUNNEL AT LEWIS

A technician is shown aligning the rainbow schlieren system in the 10 x 10 Wind Tunnel.

RAINBOW SCHLIEREN SYSTEM IN THE 10×10 WIND TUNNEL AT LEWIS



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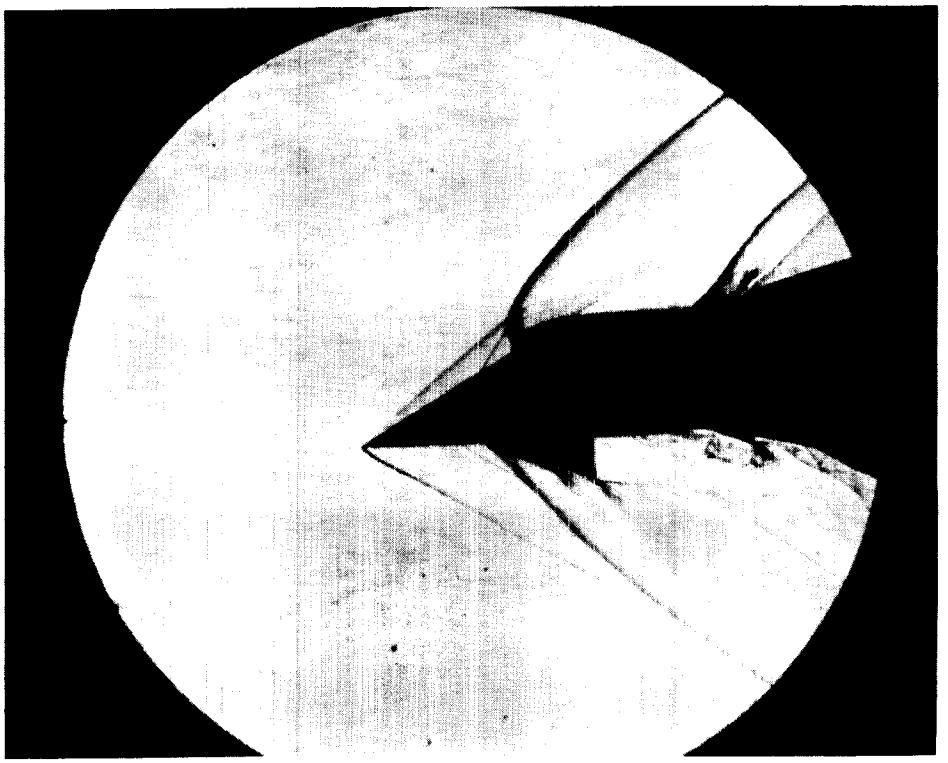
RAINBOW SCHLIEREN PHOTOGRAPH OF A SUPERSONIC INLET TESTED
IN THE 10 x 10 WIND TUNNEL AT LEWIS

This color photograph illustrates the flow visualization enhancement achieved with the rainbow schlieren system. It shows a top view of a supersonic side inlet (wherein flow features to the bottom of the photo are artifacts of the lack of a mounting body). The red color indicates maximum index-of-refraction changes.

RAINBOW SCHLIEREN PHOTOGRAPH OF A SUPERSONIC INLET TESTED IN THE 10×10 WIND TUNNEL AT LEWIS



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COMBUSTOR VIEWING SYSTEM

The combustor viewing system was designed as a diagnostic tool for use in studying internal processes in high temperature, high pressure combustors. One of the primary goals was to study the onset of combustor liner failures such as cracking. The images of the combustor interior are transmitted to a photographic or video camera through a coherent bundle of 75,000, 10-micrometer fibers. Also included are two 1-mm fibers to provide illumination from a laser or arc lamp. The rotatable, retractable probe is purged with N_2 to keep the tip clean and water cooled to allow operation at environmental temperatures above 2000 K.

COMBUSTOR VIEWING SYSTEM

- AN OPTICAL SYSTEM TO VIEW THE INTERIOR OF HIGH PRESSURE COMBUSTORS TO STUDY COMBUSTION PROCESSES TO RECORD LINER FAILURE MECHANISMS
- USES COHERENT IMAGE BUNDLE OF 75,000 10-MICROMETER FIBERS TOGETHER WITH TWO 1-MM FIBERS FOR ILLUMINATION
- ROTATABLE PROBE PURGED WITH N_2 AND COOLED WITH WATER FOR OPERATION IN ENVIRONMENTS AT 2000 K
- OPERATING EXPERIENCE AT PRATT & WHITNEY ON PW 2037 ENGINE, AT LEWIS IN HIGH PRESSURE FACILITY, AND AT NAPC IN HOT GAS FACILITY

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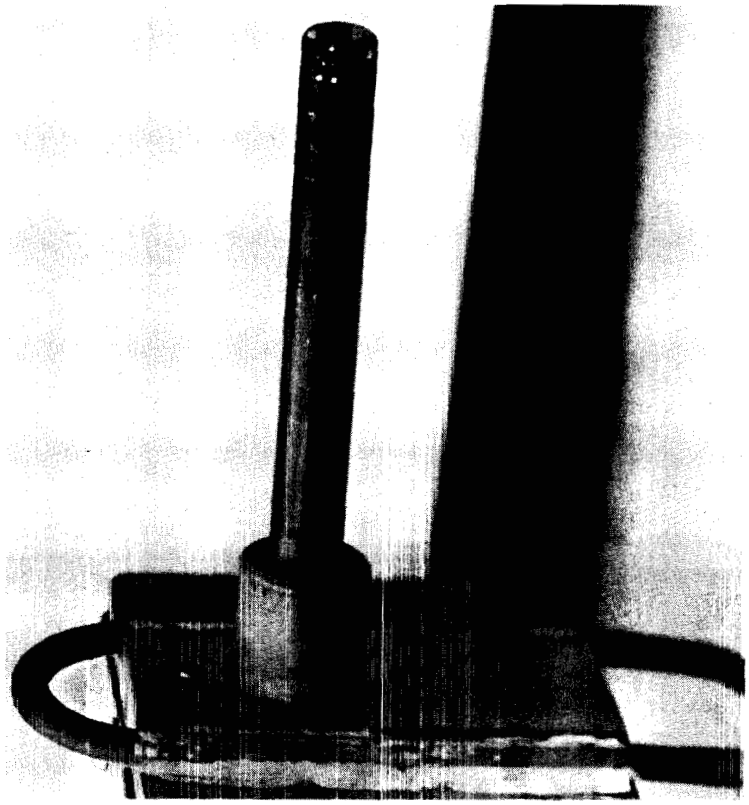
COMBUSTOR VIEWING SYSTEM PROBE

In this photograph of the combustor viewing system probe, the two illumination-carrying fibers and the angled tip of the imaging bundle can be identified by the backlighting.

COMBUSTOR VIEWING SYSTEM PROBE



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PW 2037 ENGINE FUEL NOZZLE AT FULL POWER

This photograph of a combustor fuel nozzle in a PW 2037 engine was recorded through the combustor viewing system while the engine was operating at full power.

PW 2037 ENGINE FUEL NOZZLE AT FULL POWER

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VERIFICATION OF OPTICAL DROPLET SIZING SYSTEMS' ACCURACY

In many areas of measurement technology, the available commercial instrument systems satisfy research needs. Optical droplet sizing systems appear to be adequate for most aeropropulsion-related applications such as fuel-spray and icing research. But important questions remain on the proper use and calibration of these instruments. We are conducting comparison tests on the most useful systems to better define their operating regimes (droplet size, droplet concentration, droplet velocity, etc.) and are also developing adequate calibration tools and techniques.

VERIFICATION OF OPTICAL DROPLET SIZING SYSTEMS' ACCURACY

- **AEROPROPULSION-RELATED APPLICATIONS**
  - **FUEL-SPRAY MEASUREMENTS**
  - **ICING CLOUD AND SPRAY MEASUREMENTS**
- **MENU OF COMMERCIAL INSTRUMENTS APPEARS TO SATISFY NEEDS OF RESEARCHERS**
- **THERE ARE IMPORTANT QUESTIONS OF PROPER USE AND CALIBRATION OF THESE INSTRUMENTS**
- **WE ARE CONDUCTING COMPARISON TESTS ON THESE INSTRUMENTS TO DEFINE OPERATING REGIMES**
- **WE ARE DEVELOPING NEW CALIBRATION TOOLS**

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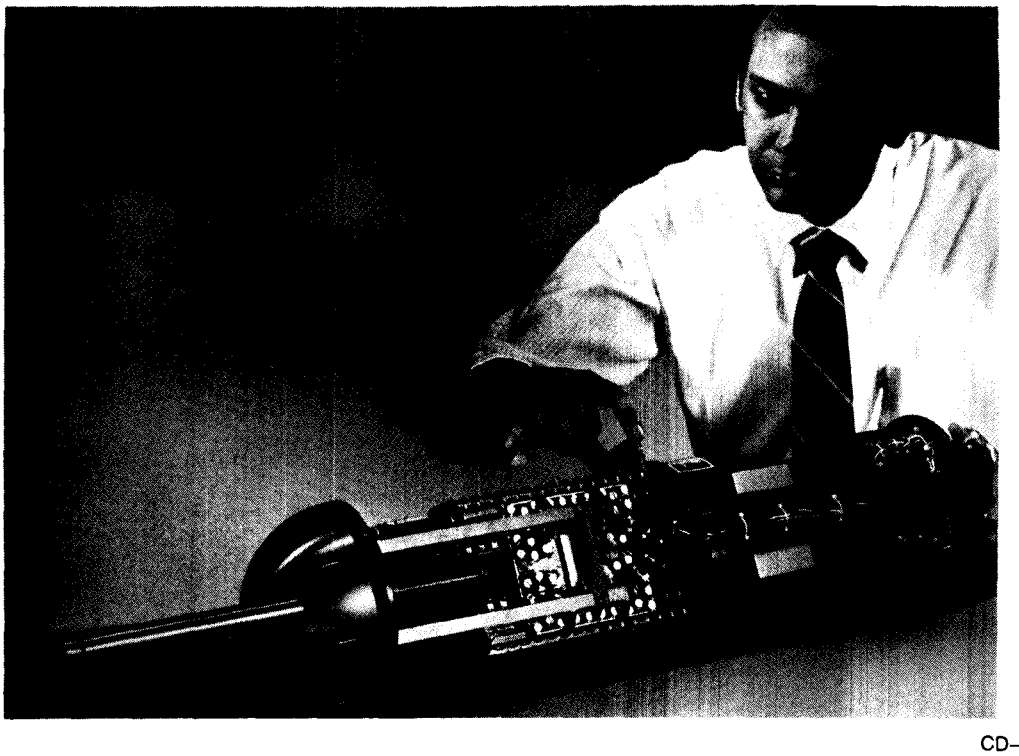
DROPLET SIZING INSTRUMENT USED IN THE ICING FLIGHT RESEARCH PROGRAM

Shown is a cloud droplet sizing instrument used on the Lewis Twin Otter aircraft during icing research. Techniques to better calibrate this instrument are being developed and evaluated.

DROPLET SIZING INSTRUMENT USED IN THE ICING FLIGHT RESEARCH PROGRAM



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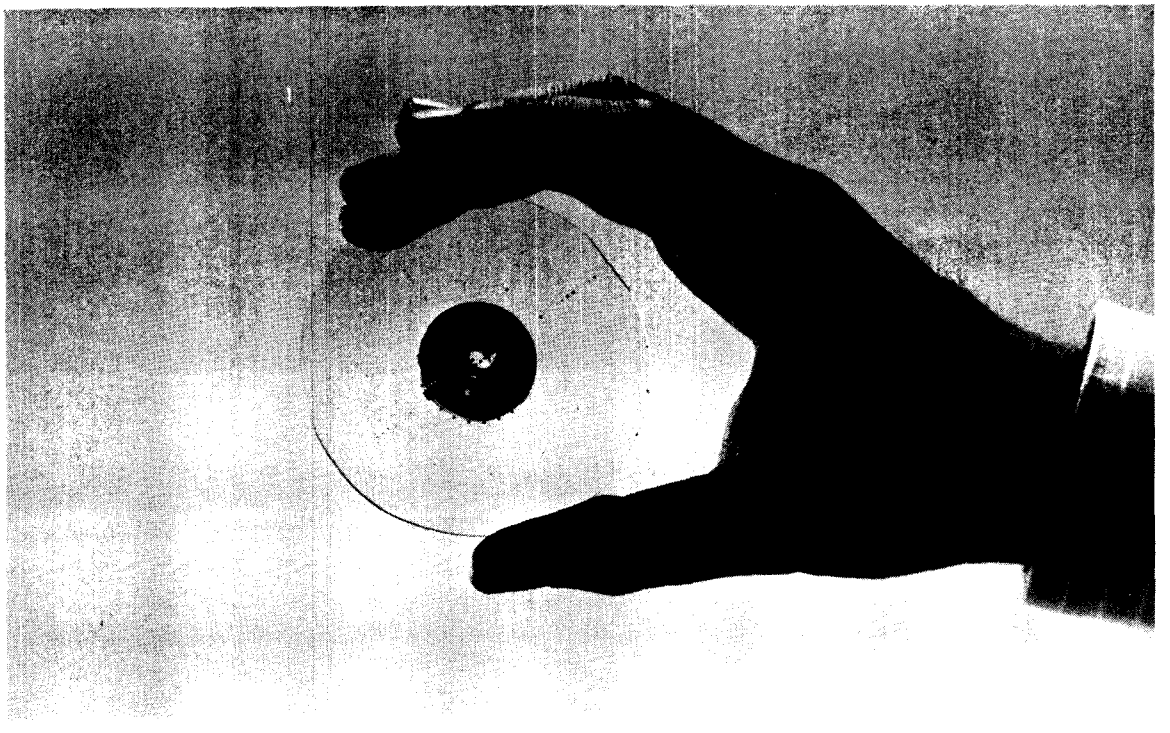
CALIBRATION RETICLE FOR DROPLET SIZING INSTRUMENTS

Shown is a rotatable calibration reticle with precisely-sized spots used to simulate droplets passing through the probe volume of a flight-type droplet sizing instrument.

CALIBRATION RETICLE FOR DROPLET SIZING INSTRUMENTS



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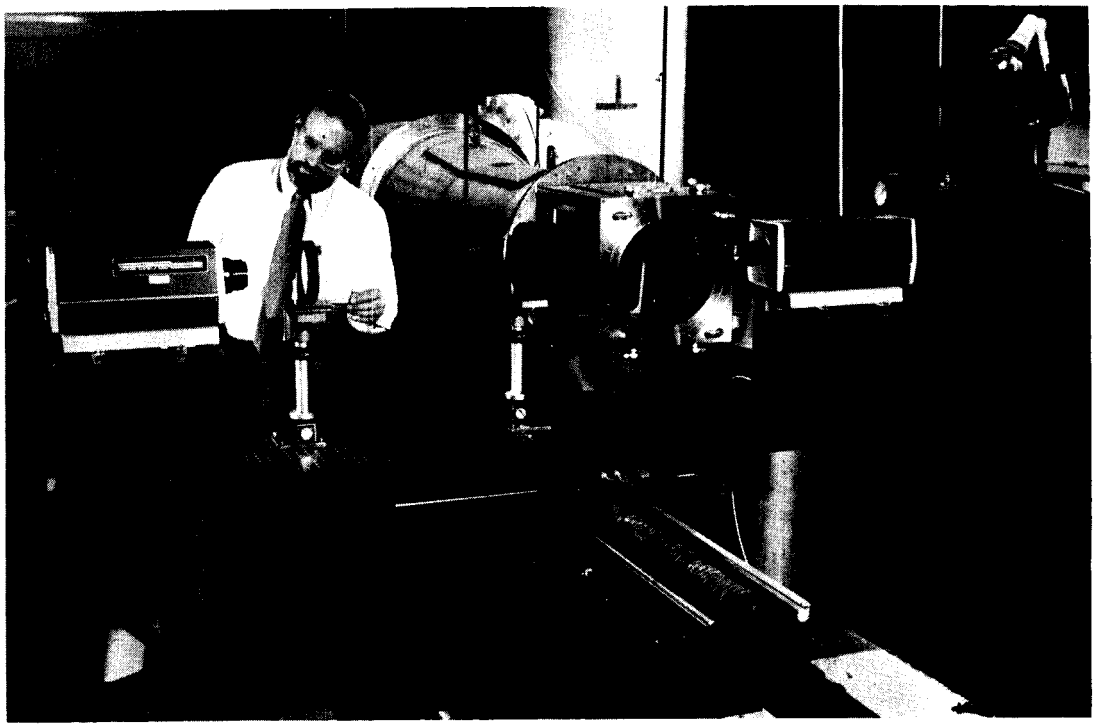
OPTICAL DIFFRACTION-BASED DROPLET SIZING SYSTEM
IN AN AEROPROPULSION FACILITY

A commercial diffraction-based multiple droplet sizing system has been adapted through the use of additional optics to meet the research needs of a hypersonic-related research facility.

OPTICAL DIFFRACTION-BASED DROPLET SIZING SYSTEM
IN AN AEROPROPULSION FACILITY



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FUTURE RESEARCH IN OPTICAL MEASUREMENT SYSTEMS

Our present program in optical instrumentation research is driven by the needs of the aeropropulsion researcher and aided by the advances in optical and electronic technology. Prevalent needs are dynamic data, including the time correlation between two or more parameters, and rapidly acquired whole-field data maps. Fiber optics and new solid-state lasers are two of the important ingredients for rugged diagnostic systems to be used in aeropropulsion facilities.

FUTURE RESEARCH IN OPTICAL MEASUREMENT SYSTEMS

- NEED FOR DYNAMIC DATA
- ADVANTAGES OF WHOLE-FIELD DATA ACQUISITION (VERSUS POINT-BY-POINT)
- ADVANCES IN FIBER OPTICS
- DEVELOPMENTS IN RUGGED, EFFICIENT SOLID-STATE LASERS
- MATURING OF LASER SPECTROSCOPY FROM LAB TO FACILITY ENVIRONMENTS
- POTENTIAL FOR APPLICATION OF ARTIFICIAL INTELLIGENCE

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