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LASER ANEMOMETERS OF HOT-SECTION APPLICATIONS

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INTRODUCTION

The objective of this in-house program is to develop laser anemometers (LA's) for use in the study of the hot-section components of turbomachinery. Specifically, laser anemometers are being developed for use in the turbine facilities at Lewis that are involved in the HOST program. In this paper a brief review of the status of the program is given along with some results of work accomplished since the report to the 1983 HOST Workshop (ref. 1).

SUMMARY OF ACCOMPLISHMENTS

The PDP 11/44 minicomputer acquired for the open-jet burner facility is fully operational. It is used both for the control of the three-axis traversing system and for data acquisition. In addition, it provides on-line graphics that allows the operator to monitor the data as it is acquired. Software was written for off-line data reduction. Mean velocity and turbulence intensity profiles are generated, and, for sufficiently high data rates, the autocorrelation of the velocity can be computed, which gives the turbulence scale.

A preprocessor was designed, fabricated, and tested; its function is to allow computer control of several previously manual controls of the counter processor.

The open-jet burner facility was used to test the LA system. An experiment was conducted that used the LA to measure the mean velocity and turbulence intensity near a cylinder located in the hot exhaust jet.

Analytical work done as part of the LA optimization was reported at the AIAA/SAE/ASME Joint Propulsion Conference (ref. 2). Computer programs were written to calculate Mie scattering from spheres with complex index of refraction.

The design for the housing, windows, and traversing system for the Lewis Warm Turbine Facility was completed.

The new design, four-spot, time-of-flight laser anemometer developed at Case Western Reserve University under a NASA grant is now operational.

APPROACH

The overall approach being followed in this program is outlined in figure 1. Based on an analysis of particle lag for the expected flow field, the required particle size is determined. A particle generator can then be selected (with additional size selection if required). A commercial particle sizing instrument (described in ref. 1) is used to evaluate particle generators. Mie scattering theory is used to evaluate the scattering cross sections of the particles, which are needed for the analysis of the optics design. Another important input needed for the system analysis is the reflectivity of surfaces located near the probe volume. Laser light scattered from these surfaces (flare) limits the proximity of measurement to surfaces. A model for the sig- nal processor completes the elements needed to define the system. Prediction analysis methods are then used to optimize the system design to achieve the desired accuracies of the flow parameters in the minimum run time.

MODELING OF FRINGE-TYPE LASER ANEMOMETER

The fringe-type LA (fig. 2) was analyzed using the Cramer-Rao bound for the variance of the estimate of the Doppler frequency as a figure of merit. Mie scattering theory was used to calculate the Doppler signal with both the amplitude and phase of the scattered light taken into account. The noise from wall scatter was calculated using the wall bidirectional reflectivity and the irradiance of the incident beams. A procedure was developed to determine the optimum mask for the probe volume located a given distance from a wall (fig. 3). The rapid decrease in the signal-to-noise ratio as the probe volume approaches a wall is shown in figure 4. A complete description of this work is given in reference 2.

MIE SCATTERING CALCULATIONS

Mie scattering algorithms for spheres with a complex refractive index were developed for both the IBM 370/TSS and PDP-11 computers. These are used both for the selection of seed material and to evaluate the effect of other particulates found in the flow (e.g., soot). They are also an integral part of the fringe-type LA modeling work. Figure 5 shows the differential cross section for aluminum oxide, one of the principal candidate seed materials for high-temperature flows. Note that the cross section decreases significantly as the scattering angle moves from direct backscatter. The complex behavior of the backscatter cross section as a function of particle size is shown in figure 6 for aluminum oxide and in figure 7 for silicon carbide. Note that silicon carbide, whose index of refraction is much larger than that of aluminum oxide, does not offer any advantage in scattering ability over aluminum oxide. Figure 8 shows the differential cross section of soot (an absorbing material with a complex refractive index). An important point shown by this figure is that the backscatter for soot is relatively small. Finally, it must be pointed out that these Mie calculations are only for spheres; indeed, the actual refractive seed materials usually have irregular shapes. We are assuming, for the purposes of our modeling work, that the scattering cross section for irregular shapes of a given aerodynamic size can be approximated by the results for spheres of the same aerodynamic size.

PREPROCESSOR FOR COUNTER

One limitation encountered when using counter-type burst processors in computer-based laser anemometer systems is that many of the counter controls must be set manually. Examples of these manual settings are the high- and low-pass filter cutoff frequencies and the threshold level. In many experiments it is necessary to change these settings frequently. This is a major impediment to the development of the automated data taking procedures needed to minimize experimental run time. To overcome this limitation, a separate preprocessor was developed (fig. 9). The preprocessor provides both local and computer control of the high- and low-pass filter selections (eight each), the system gain (controlled by means of an RF amplifier and programmable attenuator), and the PMT high voltage. Other functions of the counter can also be controlled, such as the resolution of the time between measurements and the number of words sent from the counter to the computer for each measurement. Finally, the preprocessor monitors the PMT average current, and, if it exceeds the maximum permitted value, sounds an alarm.

CYLINDER IN CROSS-FLOW MEASUREMENTS

One of the applications of the laser anemometer installed in the open-jet burner facility (fig. 10) was the measurement of the mean velocity and turbulence intensity distributions near a cylinder in cross flow (fig. 11). These measurements are being used for another HOST project, the development of advanced heat flux sensors. The cylinder had an diameter of 1.6 cm and was mounted 56 mm from the jet exit. An example of a survey of mean axial velocity and tubulence intensity with the cylinder removed from the flow is shown in figure 12. Figure 13 shows a survey taken about 1 mm upstream at the cylinder. Each survey consisted of measurements at 50 points and took about 2 minutes.

FOUR-SPOT TIME-OF-FLIGHT LASER ANEMOMETER

The four-spot, time-of-flight LA being developed at Case Western Reserve University under a NASA grant is now operational. A description of this new type of anemometer is given in references 3 to 5. A second version of that system, based on an argon-ion laser, has been designed for use in high-velocity gas flows. This system will be fabricated and tested in the open-jet burner facility to evaluate its suitability for use in hot-section flow experiments.

REFERENCES

1. Seasholtz, Richard G.; Oberle, Lawrence G.; and Weikle, Donald H.: Laser Anemometry for Hot Section Applications. Turbine Engine Hot Section Technology-1983, NASA CP-2289, 1983, pp. 57-68.

2. Seasholtz, R. G.; Oberle, L. G.; and Weikle, D. H.: Optimization of Fringe-Type Laser Anemometers for Turbine Engine Component Testing. AIAA Paper-84-1459, June 1984.

3. Edwards, R. V.: Laser Anemometer Optimization. Turbine Engine Hot Section Technology (HOST), NASA TM-83022, 1982, pp. 113-136.

4. Edwards, Robert V.: Time-of-Flight Anemometer for Hot Section Applications. Turbine Engine Hot Section Technology 1983, NASA CP-2289, 1983, pp. 69-72.

5. Lading, L.: Estimating Time and Time-Lag in Time-of-Flight Velocimetry. Appl. Opt., vol. 22, no. 22, Nov. 15, 1983, pp. 3637-3643.

LASER ANEMOMETER DEVELOPMENT

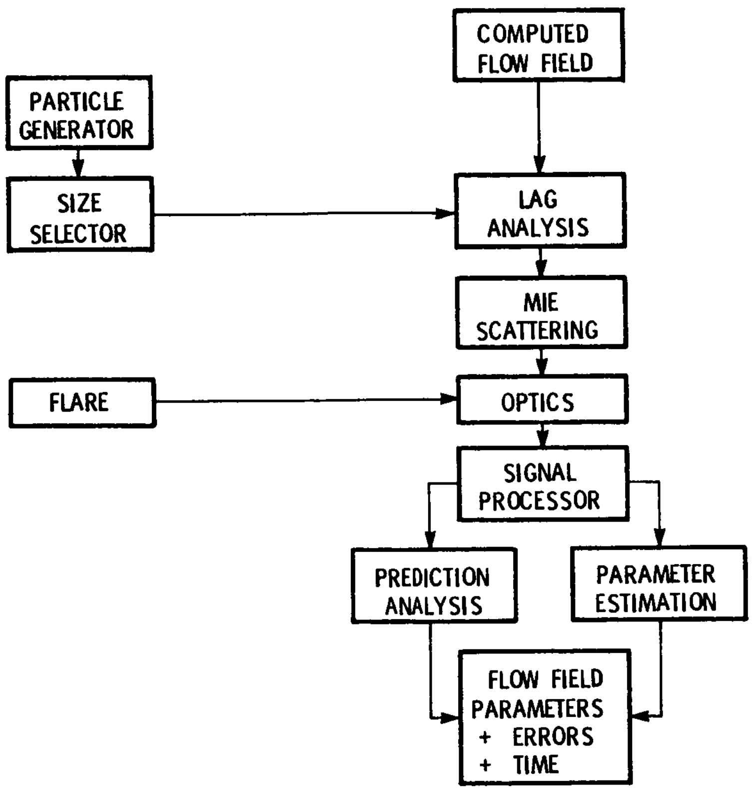

Figure 1

FRINGE-TYPE LASER ANEMOMETER

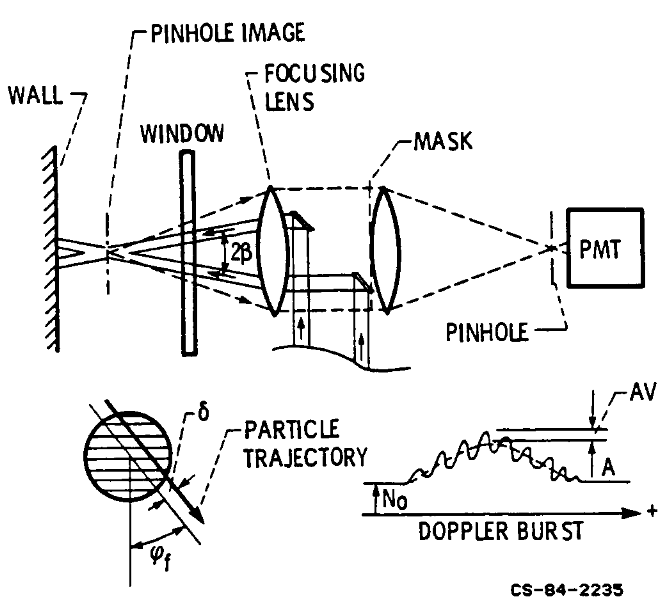

Figure 2

OPTIMUM APERTURE MASK FOR PROBE VOLUME 1 mm FROM WALL, f/4 SYSTEM

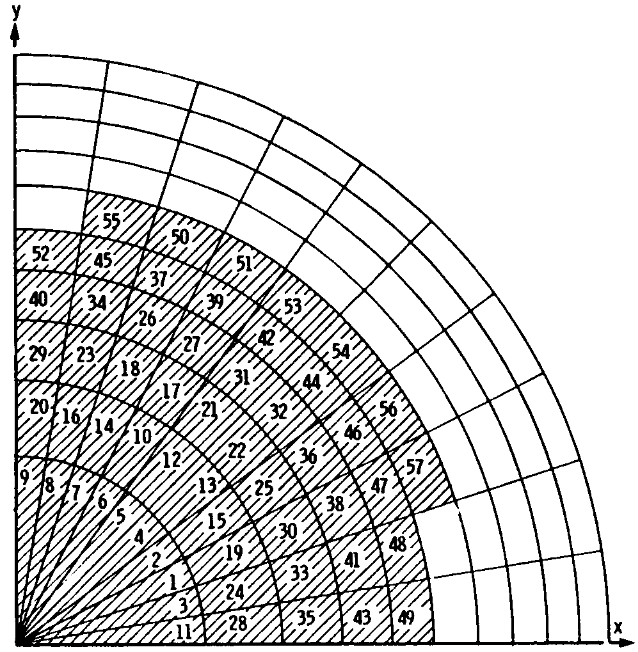

Figure 3 CS-84-2238

SNR VS. DISTANCE OF PROBE VOLUME FROM WALL, f/4 SYSTEM

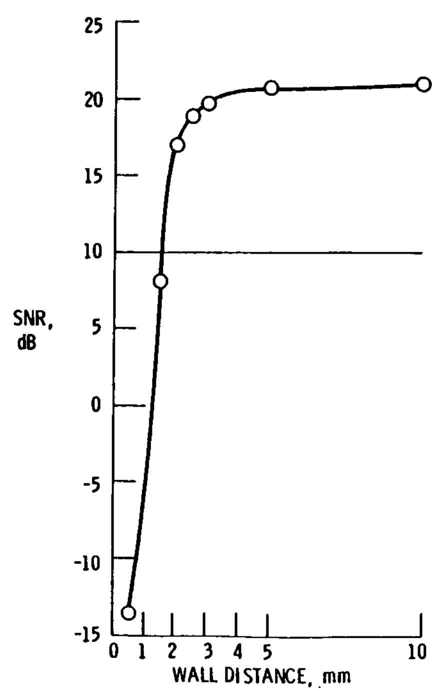

Figure 4 CS-84-2231

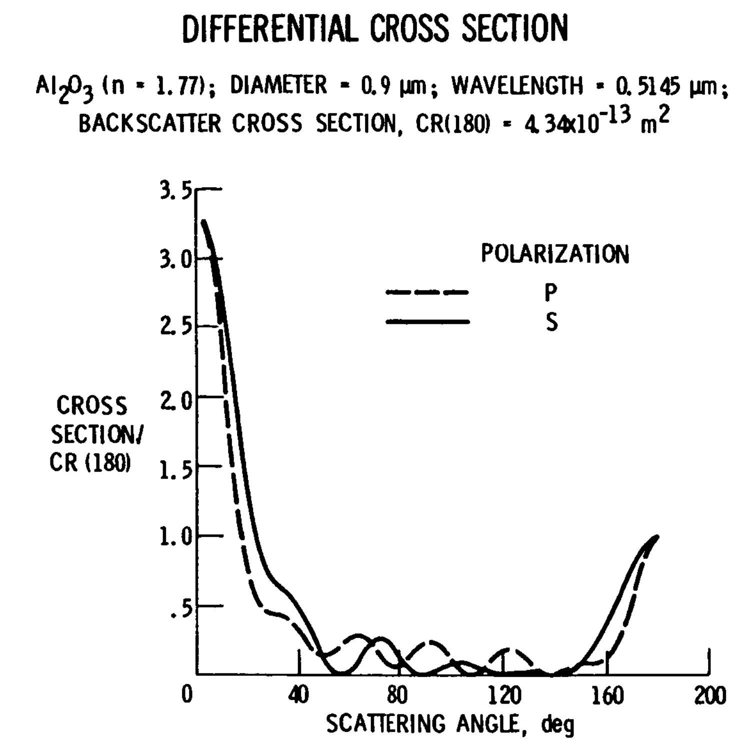

Figure 5

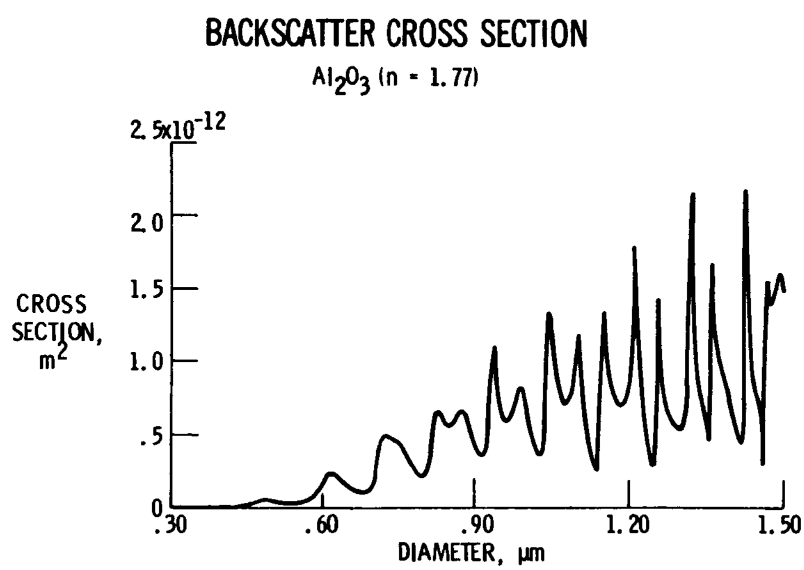

Figure 6

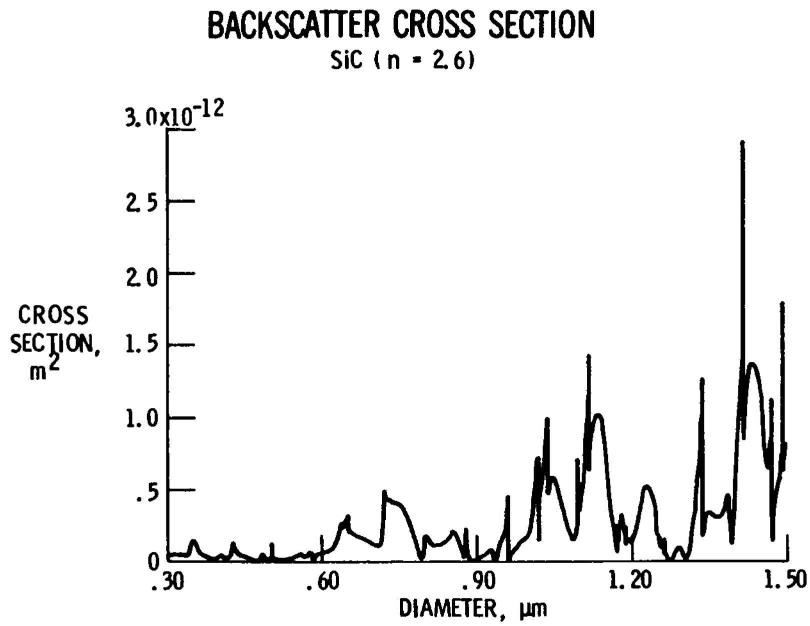

Figure 7

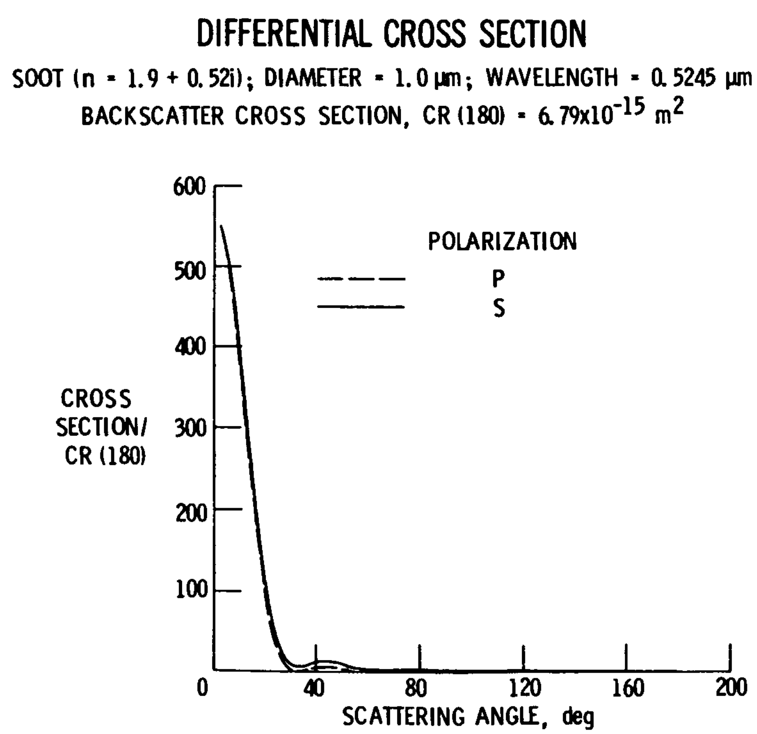

Figure 8

LASER ANEMOMETER PREPROCESSOR

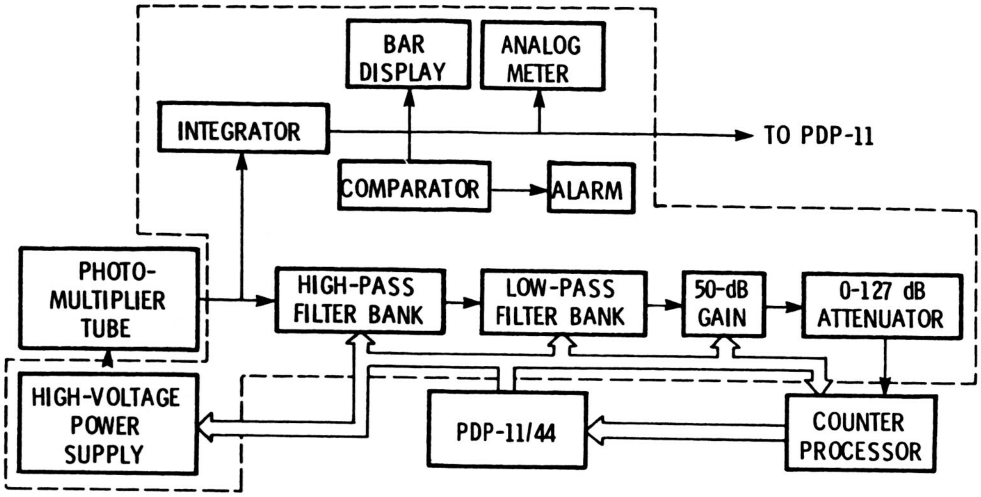

Figure 9

OPEN-JET BURNER AND LASER ANEMOMETER

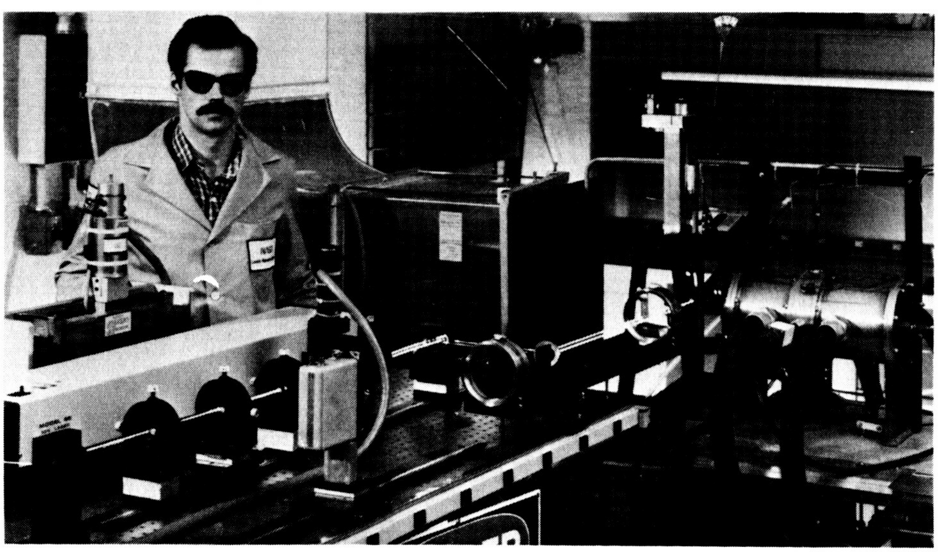

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Figure 10

CYLINDER IN CROSS FLOW EXPERIMENT

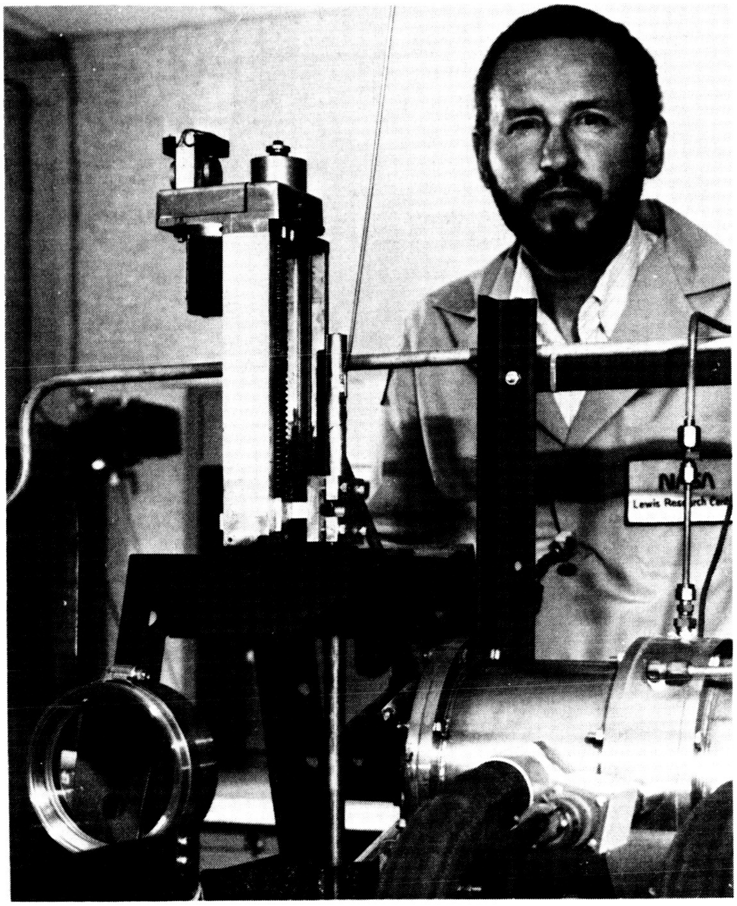

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Figure 11

AXIAL VELOCITY AND TURBULENCE INTENSITY

AXIAL POSITION, 51 cm; MACH 0.7; T = 800° C

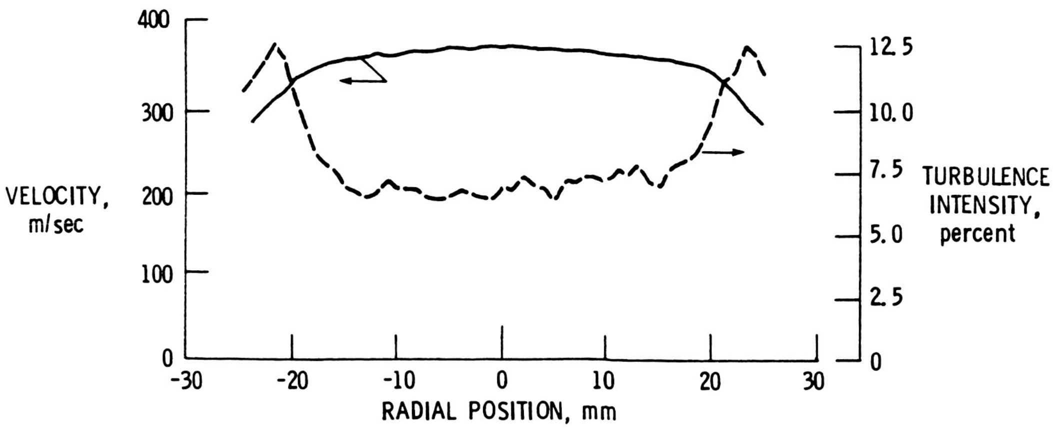
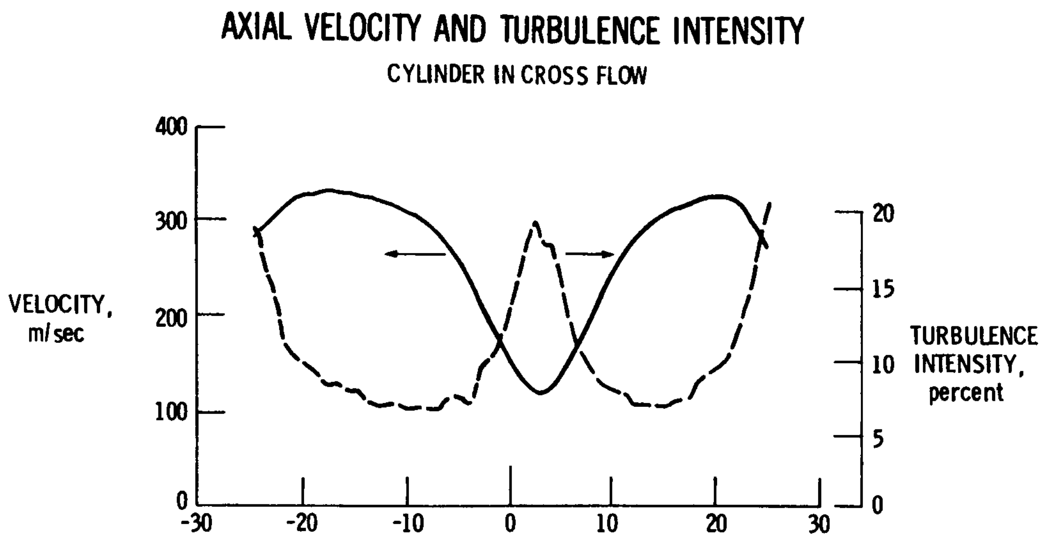


Figure 12



AXIAL VELOCITY AND TURBULENCE INTENSITY
CYLINDER IN CROSS FLOW
VELOCITY, m/sec
400
300
200
100
0
-30
-20
-10
0
10
20
30
RADIAL POSITION, mm
TURBULENCE INTENSITY, percent
20
15
10
5
0

Figure 13