

LASER DOPPLER VELOCIMETRY APPLICATION
IN THE
LANGLEY 0.3-METER TRANSONIC CRYOGENIC TUNNEL

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INTRODUCTION

The discussion given herein describes the work done in the Langley 0.3-Meter Transonic Cryogenic Tunnel (TCT), i.e., the beginning efforts toward fulfilling the flow velocity instrumentation requirement. A diagram illustrating the flow of events for accomplishing this task is given in figure 1. The purpose of the initial tunnel tests was to investigate the problems and the potential use of a nonintrusive flow velocity measuring technique in this facility. The approach used was the laser velocimeter (LV), a well-known method that has become widely used by researchers as a supplementary flow diagnostic tool (refs. 1 and 2). Some of the main features of the LV are as follows:

(1) It can obtain, nonintrusively, flow velocities directly without the need for calibrations or the knowledge of other flow parameters such as temperature and pressure.

(2) It has good spatial resolution and local-flow velocity response for turbulence intensity studies.

Some of the anticipated problems were maintaining optical alignment due to inherent vibration effects, preventing the test section window from frosting during the cold temperature runs, and detecting enough natural occurring particulates present in the flow to make a velocity measurement. Tests were conducted for the tunnel condition as given without a model. After the completion of these tests, a faulty liquid nitrogen (LN₂) injector was found. As a result of this finding, it was suspected that the particulates detected were primarily due to the malfunctioning LN₂ injector. A second test was conducted in the tunnel to investigate the presence of particles in the flow and measure their velocity after the LN₂ injector had been corrected.

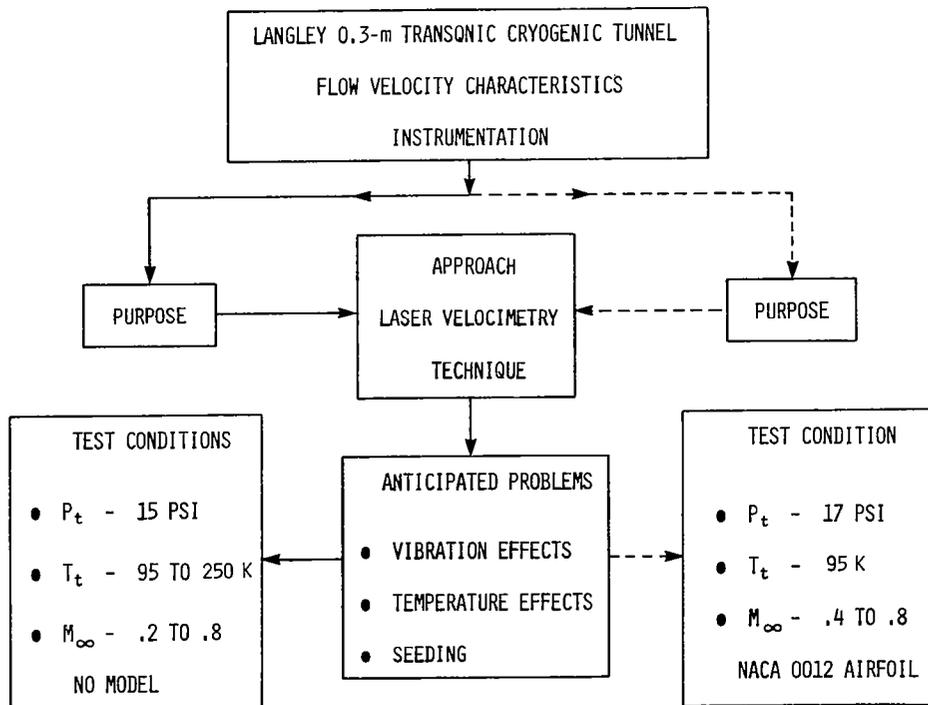


Figure 1

LASER VELOCIMETER SYSTEM CHARACTERISTICS

The LV system used in these tests (fig. 2) was configured to operate in the forward-scatter mode and to measure the axial component of the flow velocity. It uses a He-Ne laser operating in the TEM_{00} mode and providing 15 mW of continuous power at a wavelength of 632.8 nm. The laser beam is divided into two parts by a 50:50 beam splitter prism which yields a beam separation of 50 mm. The transmitter lens with focal length of 47.62 cm was used to focus the beams to a spot size (sample volume) 0.2 mm in diameter by 3 mm long. The fringe spacing was approximately 6 μm . The light scattered by particles in the sample volume is collected by an F1:2 lens and imaged on a high-gain, low-noise photomultiplier tube (PMT) with an S-20 wavelength response by a 10x (0.25 numerical aperture) microscope objective lens.

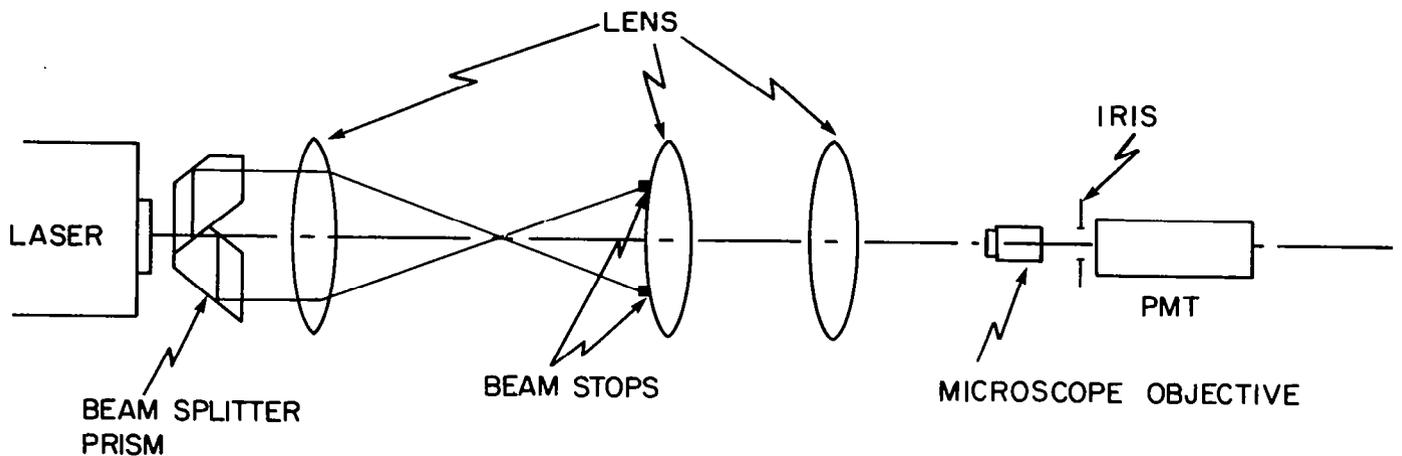


Figure 2

DATA ACQUISITION AND PROCESSING SYSTEM

The data acquisition and processing system (fig. 3) consisted of signal conditioning electronics (10-dB-gain wide-band amplifier/high-speed burst counter) and a 16-bit minicomputer with its peripheral devices. The processed data includes the basic statistical calculations for an ensemble of velocity measurements, i.e., events produced by particles moving through the sample volume.

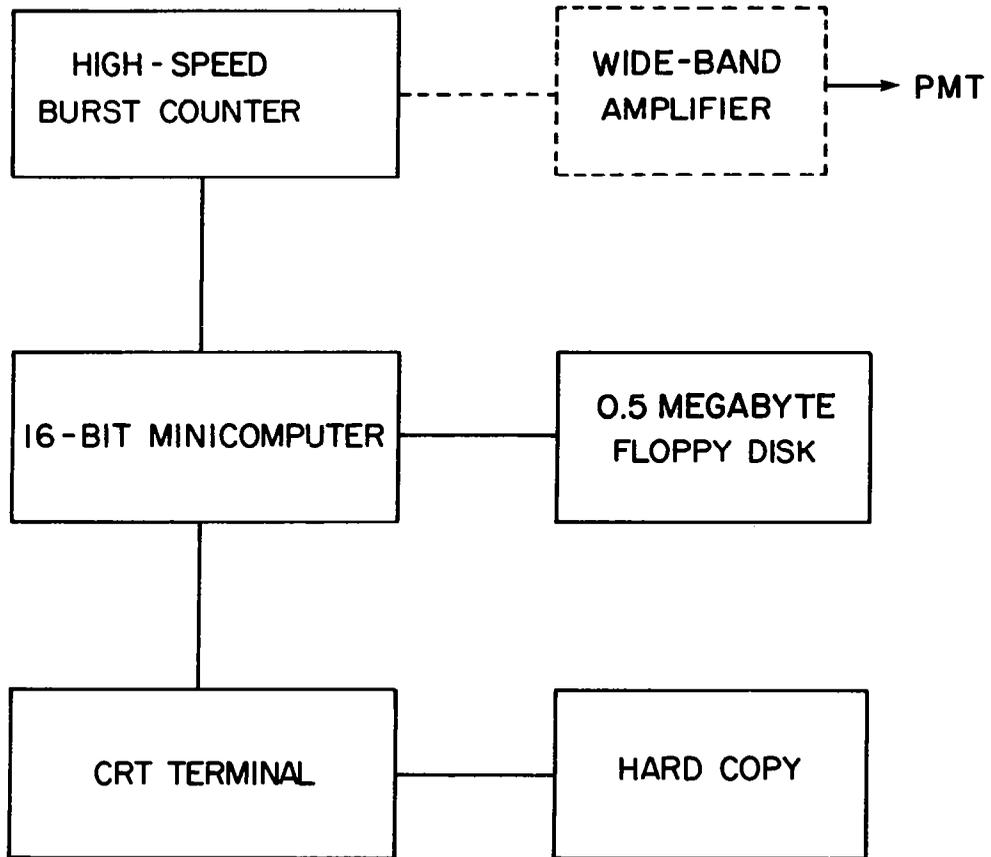


Figure 3

TEST PROCEDURE

The LV system is mounted in metal enclosures, originally used to house a schlieren system, and attached directly to the tunnel test section (fig. 4). These enclosures are purged with dry nitrogen to prevent the windows from frosting during the cold temperature runs. Accelerometers were mounted on the optics enclosures approximately 0.5 m from the test section wall to measure the inherent tunnel vibration levels. The tunnel is cooled prior to operation by running the drive motor and fan at a low speed and injecting LN₂ at a low rate. After reaching the desired operating temperature, the tunnel flow is brought to the desired Mach number and pressure. For the tests discussed herein, the nominal free-stream pressure was 18 psi, the temperature range from 95 to 250 K and free-stream Mach numbers from 0.2 to 0.8. Tests are made with and without an airfoil model. For the tunnel test conditions discussed herein, the inherent tunnel vibrations on the order of 0.3g at 100 Hz, had very little effect on the optical alignment. Dry nitrogen gas purged through the optics enclosures kept the viewing ports free of condensation.

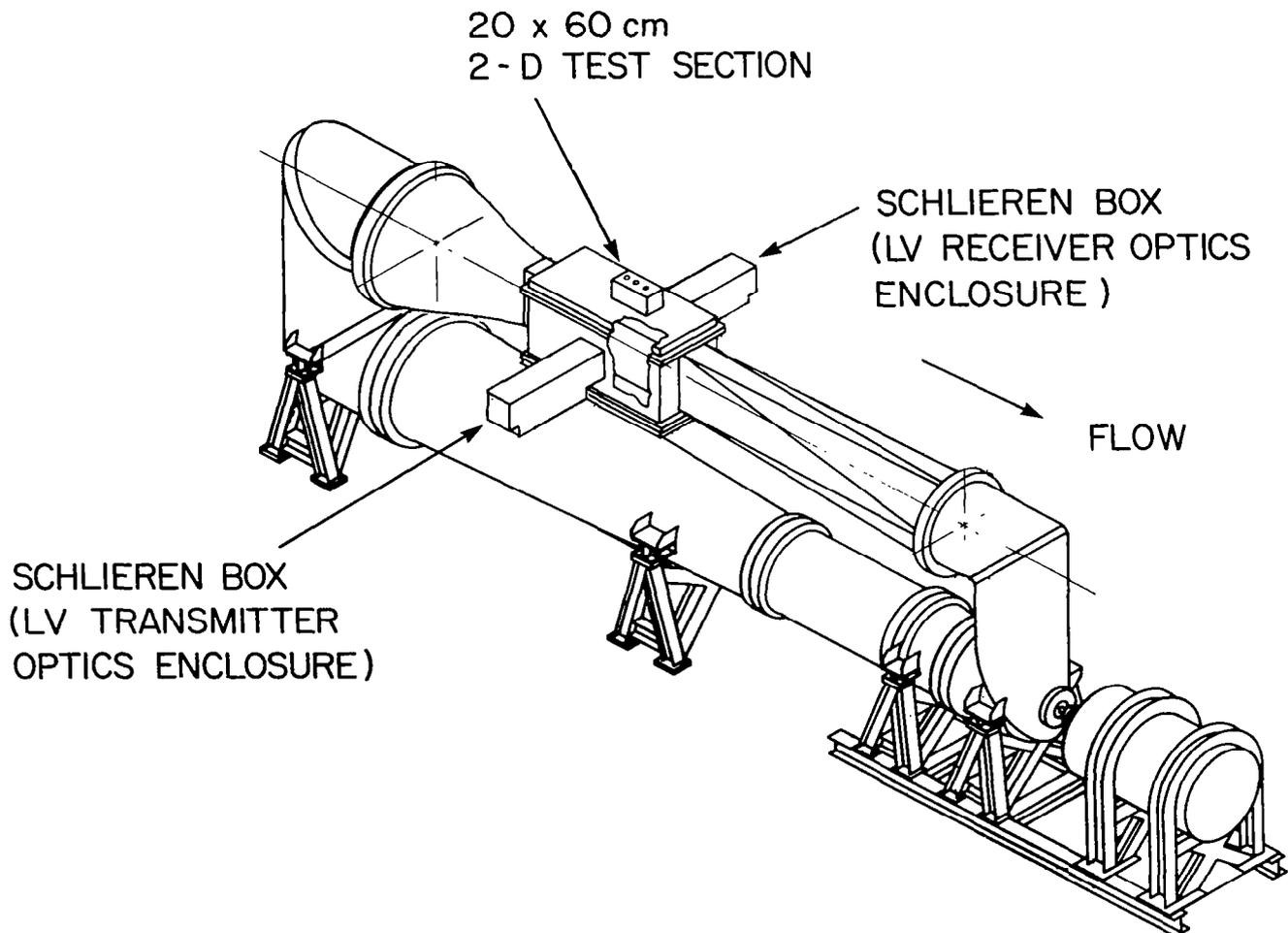


Figure 4

FREE-STREAM VELOCITY MEASUREMENT

Free-stream mean flow velocity as a function of Mach number and temperature are shown in figure 5. The most consistent measurements were below a temperature of 250 K and Mach numbers ranging from 0.3 to ~0.8.

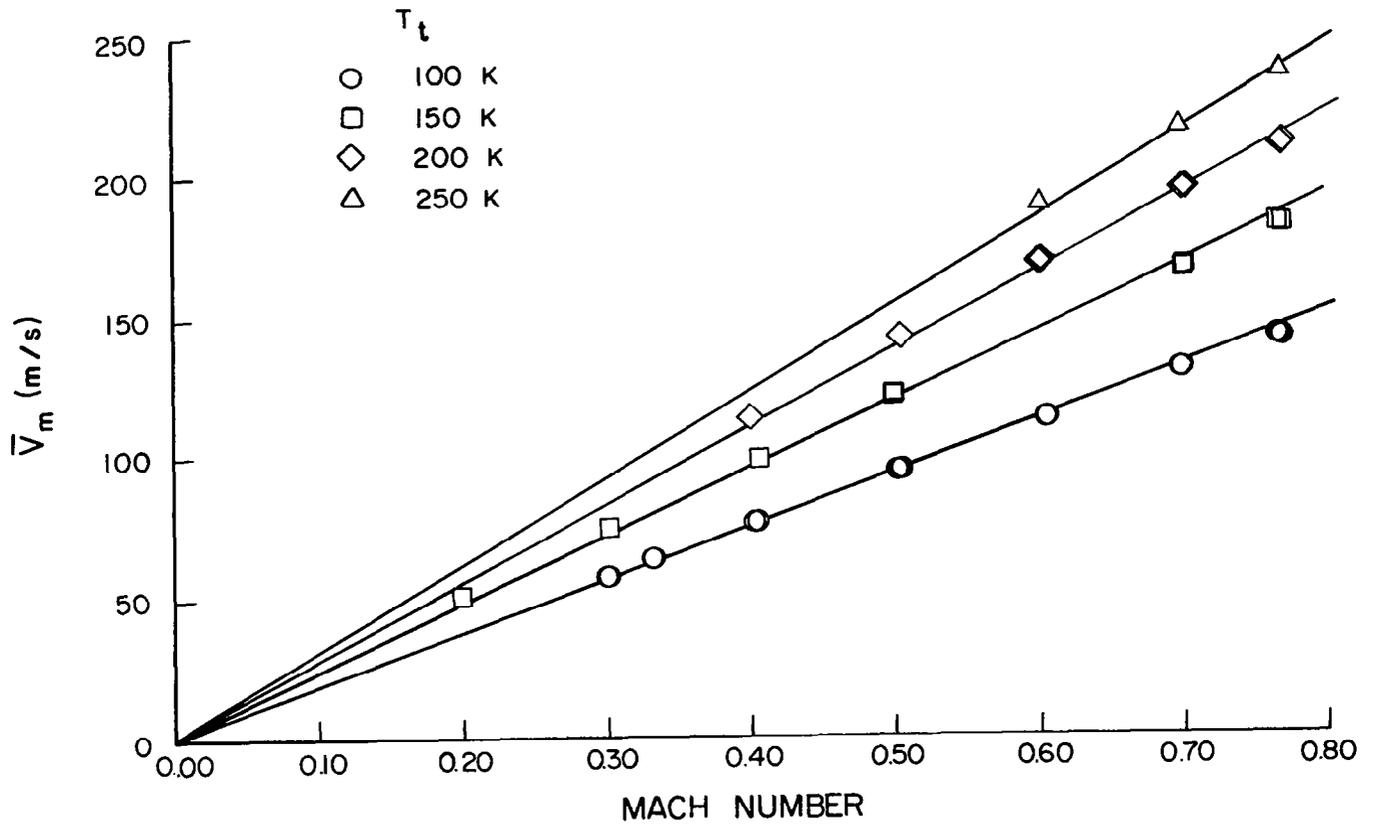


Figure 5

MEASURED MEAN VELOCITY VERSUS CALCULATED MEAN VELOCITY

In comparing these test results (fig. 5) to those calculated from tunnel parameters \bar{V}_c (shown in fig. 6), the agreement was typically better than 1 percent. The standard deviations for this plot cannot be shown because they would appear within the test-point symbols.

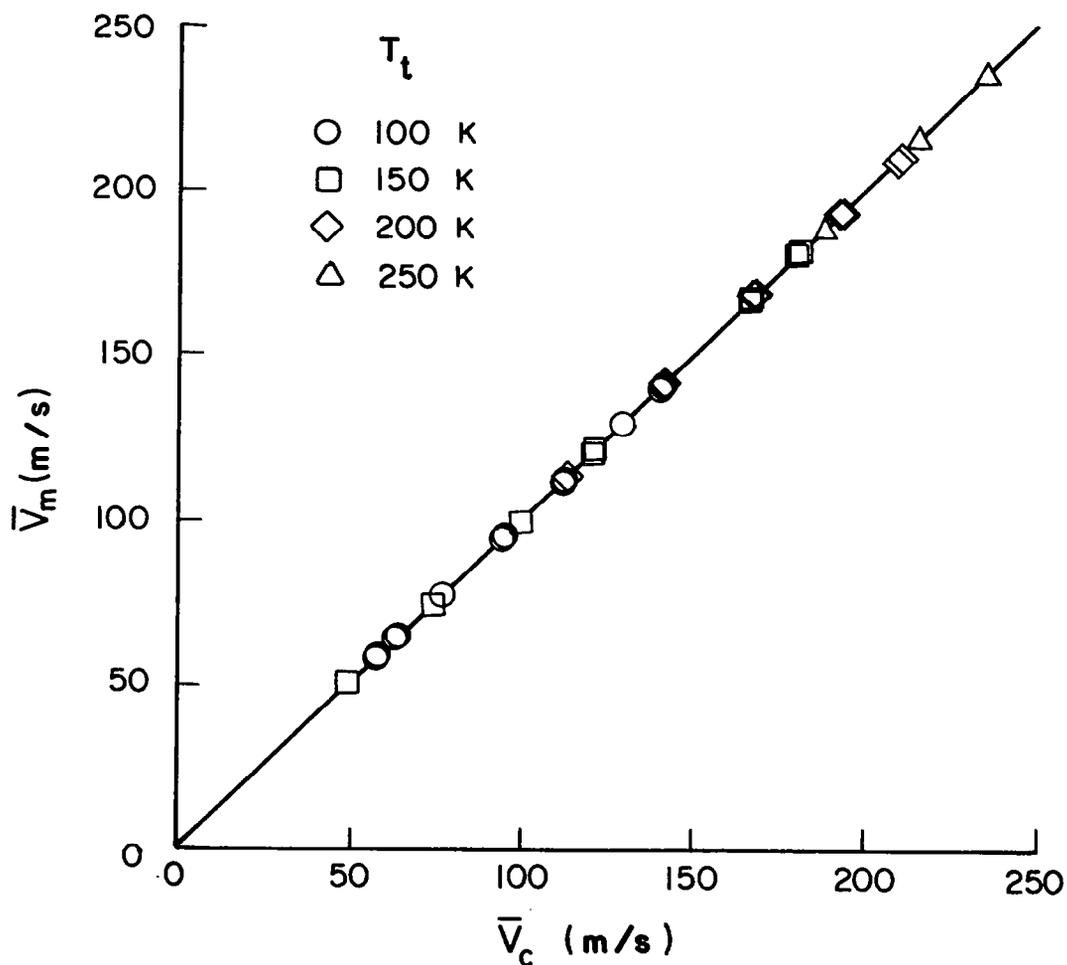


Figure 6

NORMALIZED STANDARD DEVIATION

A plot of the normalized standard deviation σ_m/V_m is shown in figure 7, where σ_m and V_m are the measured standard deviation and velocity, respectively. Over the test Mach number and temperature range, the normalized standard deviation was usually less than 1 percent.

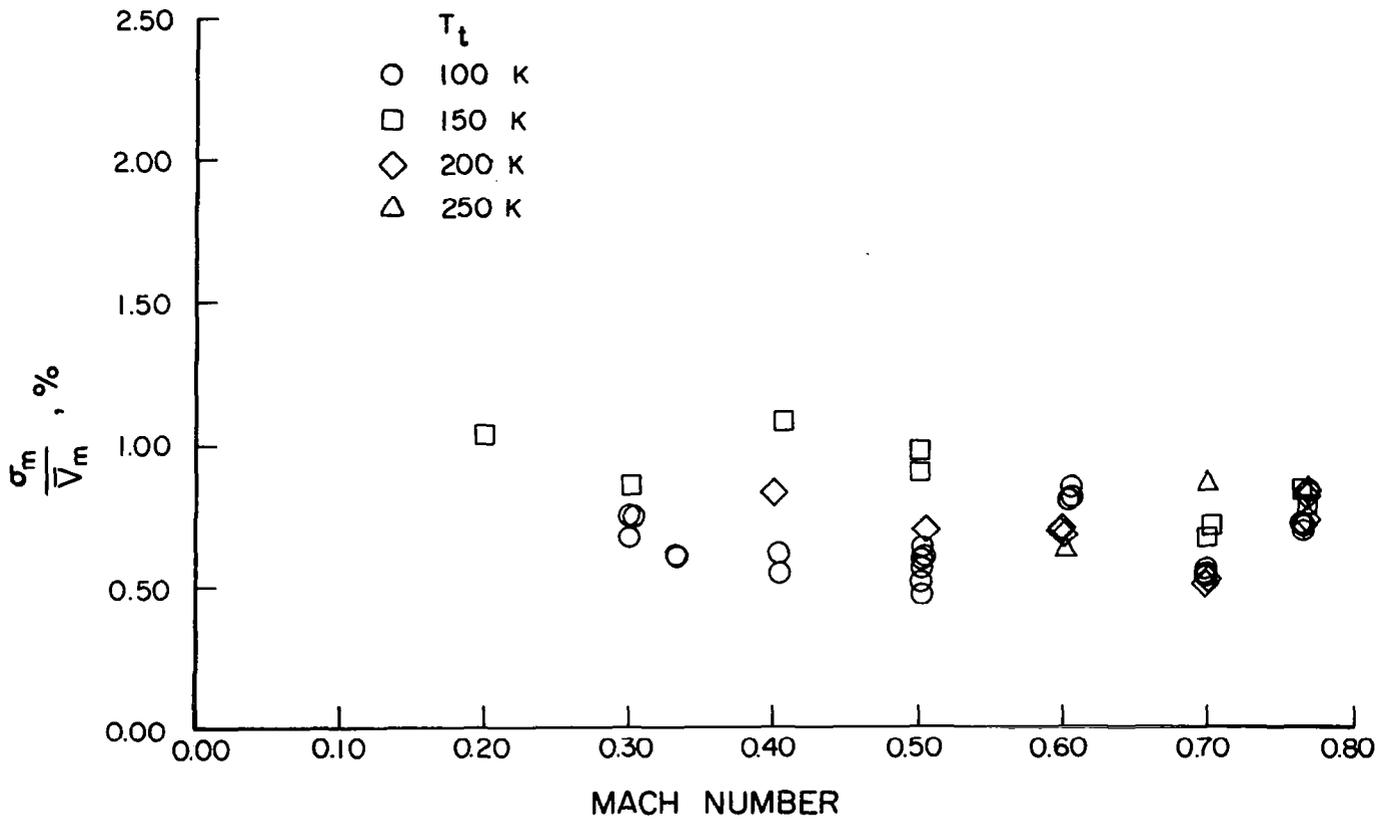


Figure 7

AIRFOIL MODEL VELOCITY MEASUREMENT

The test results for the velocity measurements at a point above an airfoil are shown in figure 8. At a Mach number of 0.8 the normal shock generated was located approximately 2 cm ahead of the measurement point (verified from flow visualization data). The corresponding velocity measured in the subsonic region was within a 10-percent agreement with the predicted value. The particle concentration based on the data rates shown was in the order of $10^6/m^3$.

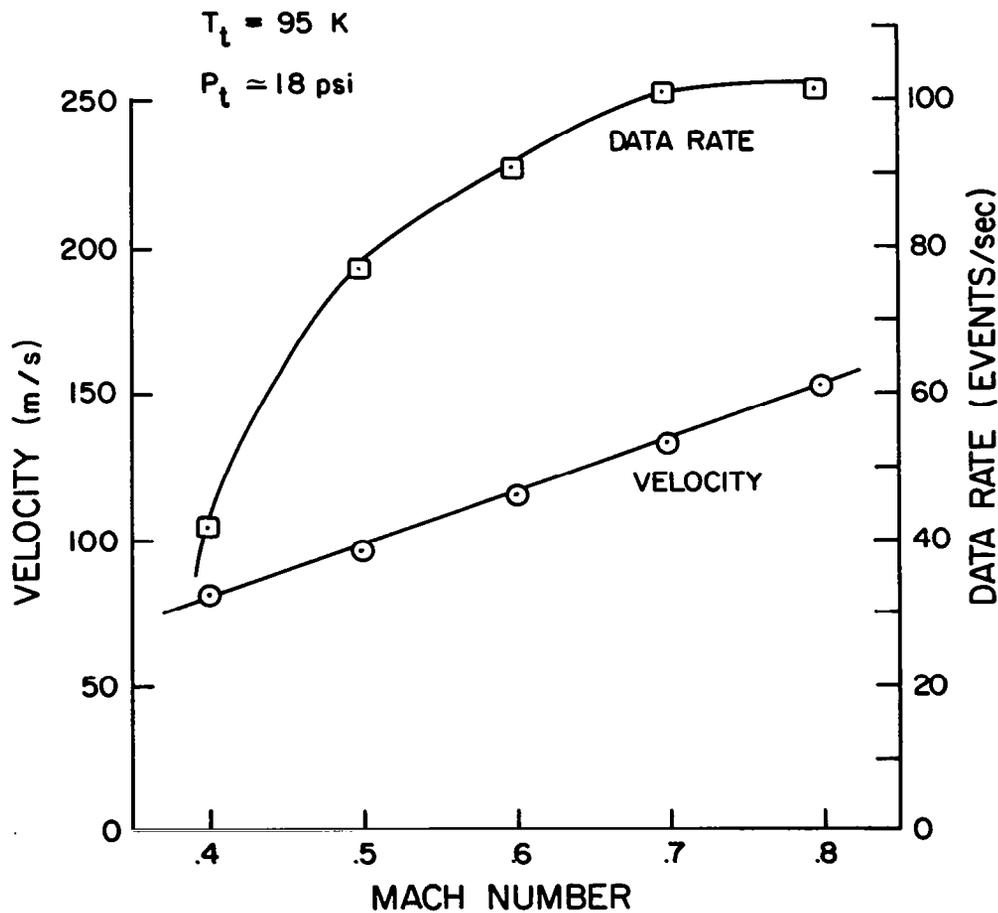
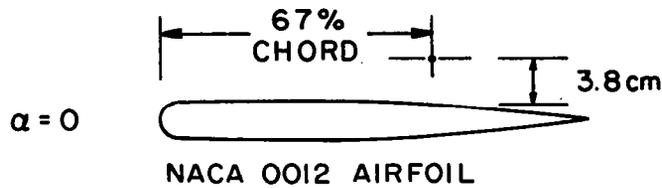


Figure 8

VELOCITY HISTOGRAM

A typical velocity histogram is shown in figure 9. Each velocity ensemble consisted of 1024 measurements and the average data acquisition time was approximately 15 seconds.

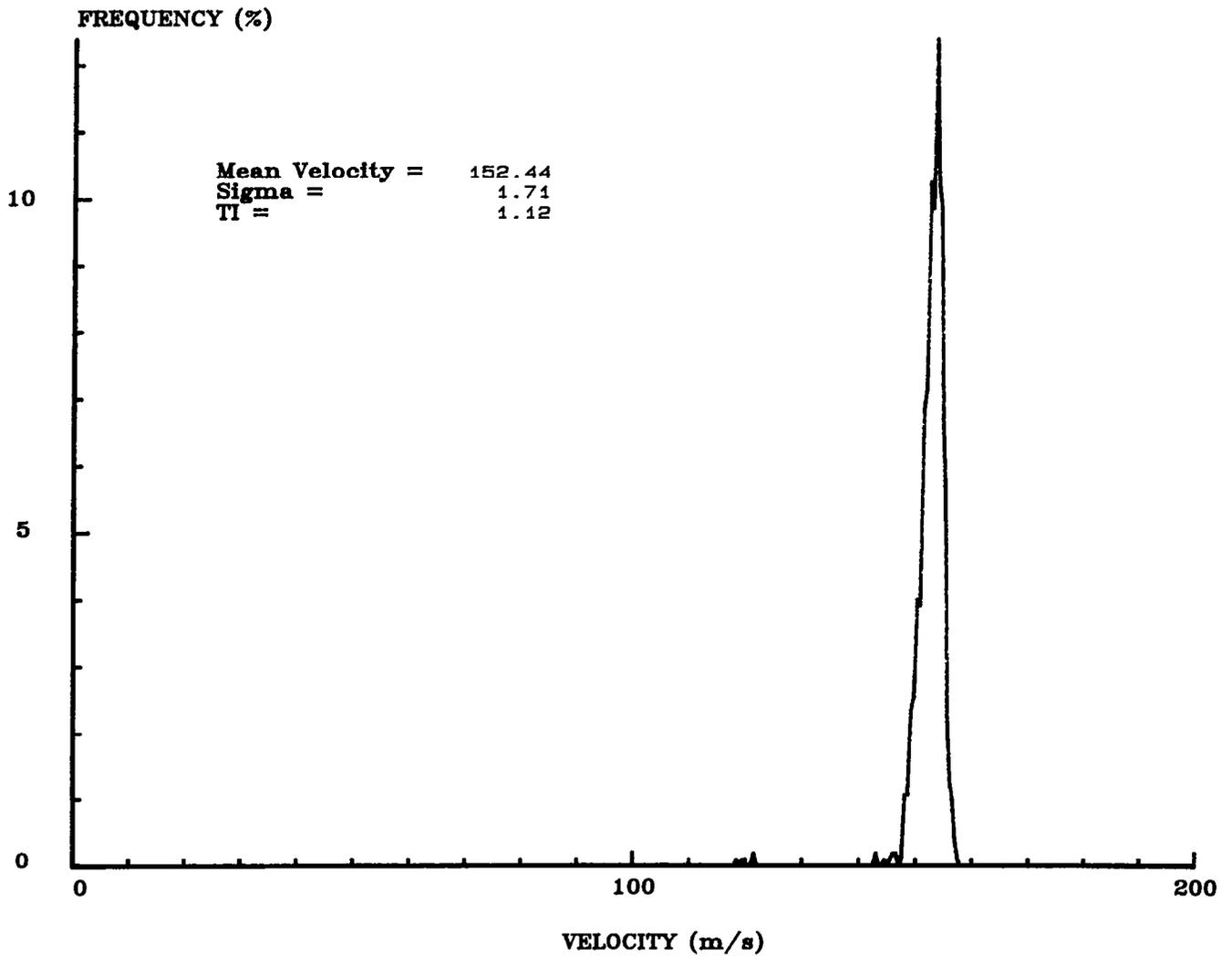


Figure 9

PARTICLE VELOCITY LAG VERSUS PARTICLE SIZE

At the present time, no quantitative data for particle size has been obtained. However in viewing the particle behavior in a moving fluid, the deceleration of a particle passing through a shock in a supersonic flow field is smaller than the deceleration of the fluid. Consequently, a finite relaxation distance behind the shock is traveled before the particle reaches the fluid velocity. This phenomenon depends on the particle size and velocity and the Reynolds number of the flow. Figure 10 (a severe gradient case) illustrates the particle velocity lag (percent) versus particle size at 2 cm behind a normal shock. This spline fitted curve is based on calculations given in reference 3 for a temperature of 95 K, a pressure of 18 psi, and a Mach number of 1.2 ahead of the normal shock. The symmetry of the velocity histogram (fig. 9) shows that the particle size could be in the order of 5 μm or less. In addition, observations of the Doppler burst pattern on an oscilloscope indicated that a majority of the particles (contributors to the flow velocity measurement) are smaller than the fringe spacing ($\approx 6 \mu\text{m}$) for the test conditions shown in figure 8. The velocity survey across the shock using a laser transient anemometer (LTA) revealed a 27-percent velocity change (within 3 percent of theoretical calculations). This measurement further indicates that the particles are probably small enough to track the flow reasonably well.

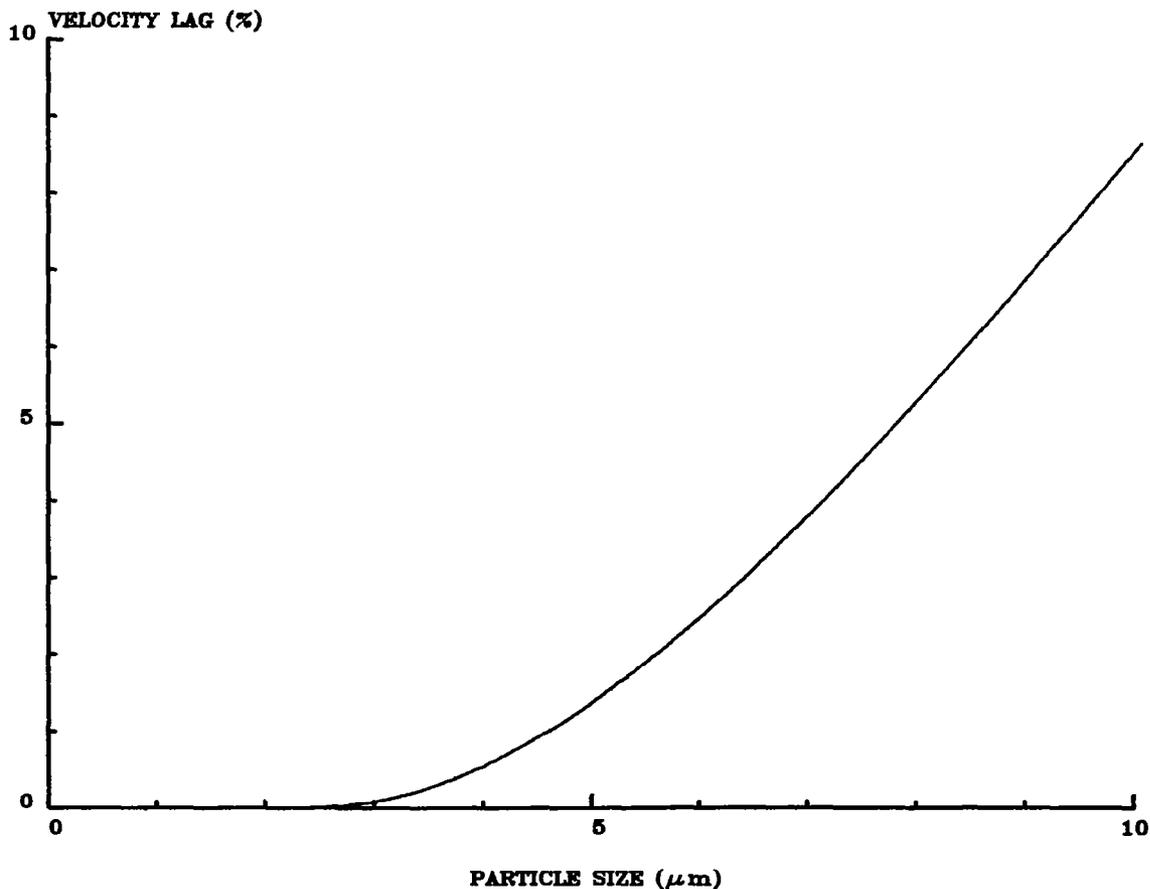


Figure 10

CONCLUSIONS

In view of the test results obtained, the following conclusions are made:

1. Free-stream velocity measurements can be successfully made in the Langley 0.3-m TCT using a low-power (15-mW) LV system.
2. The measured and calculated mean velocities typically agreed within 1-percent.
3. The overall normalized standard deviation (σ_m/V_m) was less than 1 percent.
4. The concentration of the detected particles were in the order of $10^6/m^3$.
5. Tunnel vibration and temperature had no detrimental effects on the optical system.
6. It is recommended that the LV work should be further investigated for future use in the Langley 0.3-m TCT.

REFERENCES

1. Eckert, E. R. G.; ed: Proceedings of the Minnesota Symposium on Laser Anemometry. Continuing Education and Extension, University of Minnesota, Jan. 1976.
2. Thompson, H. D.; and Stevenson, W. H., eds.: Laser Velocimetry and Particle Sizing. Hemisphere Publishing Corp., C. 1979.
3. Walsh, Michael J.: Influence of Drag Coefficient Equations on Particle Motion Calculations. Symposium on Laser Anemometry, University of Minnesota, October 22-24, 1975.