# THREE-COMPONENT LASER DOPPLER VELOCIMETER MEASUREMENTS IN A JUNCTURE FLOW

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## INTRODUCTION

In a wing-fuselage juncture the oncoming turbulent boundary layer on the fuselage surface experiences steep adverse pressure gradients as it approaches the wing leading edge. These gradients cause the boundary layer to separate ahead of the leading edge, resulting in a vortex which rolls up and trails downstream in the juncture. The use of laser velocimetry facilitated making detailed measurements near the non-planar surfaces forming the juncture, and within near-separating flows close to the trailing edge of the wing (refs. 12, 13, and 14).

The experiment was carried out in the Low-Turbulence Pressure Tunnel (LTPT) at the NASA Langley Research Center. The LTPT is a single return, closed-circuit wind tunnel which can be operated at pressures from 0.1 to 10 atmospheres. It is capable of operating at Mach numbers from 0.05 to 0.50, and unit Reynolds numbers from 300,000 to 49,000,000/m. The turbulence level is very low because of the nine turbulence reduction screens and because of the 17.6:1 contraction ratio. The test section is 0.91 m (3 ft) wide, 2.29 m (7.5 ft) high, and 2.29 m (7.5 ft) long. Figure 1 gives the details of the experimental setup.
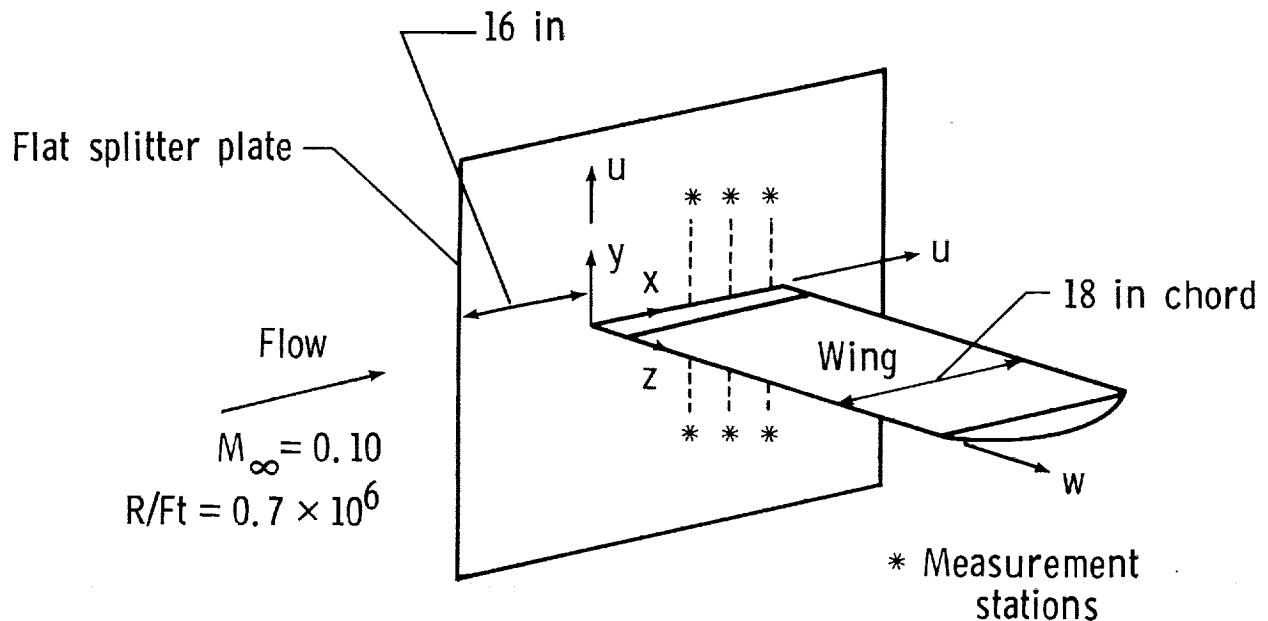


Figure 1

## THREE-COMPONENT LDV SYSTEM USED IN LTPT

The single-axis, five beam optical configuration uses the standard two-color, two-component beam pattern with the two green beams arranged in the horizontal plane and the blue beams arranged in the vertical plane (ref. 12). The green beams are used to measure the U component and the blue beams to measure the V component. A third green beam is placed along the optical axis bisecting the angles between the original two green beams. The addition of this beam creates two additional fringe patterns, from which the W component is obtained. Bragg cells are used in the two outer green beams to separate the three signals obtained from the three green fringe patterns. (Fig. 2.)
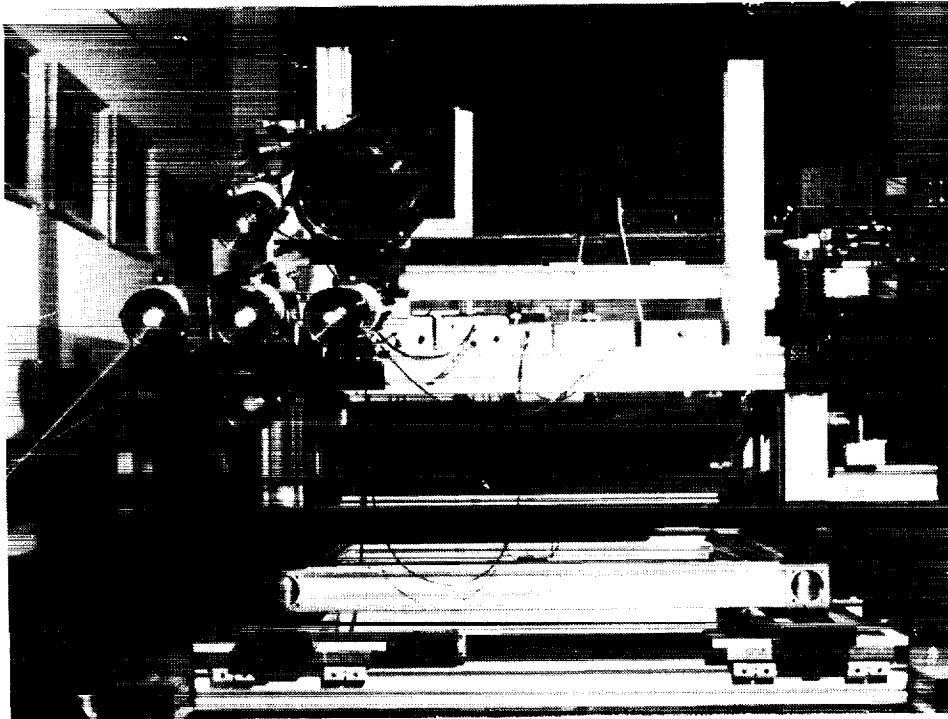
Figure 2

## OPTICAL ACCESS THROUGH SIDEWALL WINDOW

  The optical access to the model was limited to a single window of diameter 0.75 m. This window was surrounded by a drum 0.978 m in diameter by 0.711 m in depth. This further complicated the design of the laser velocimeter (LV) system, resulting in a reduced cross-beam angle. Also, an off-axis backscatter collection mode had to be used in order to reduce the effect of background reflections from the splitter plate. (Fig. 3.)
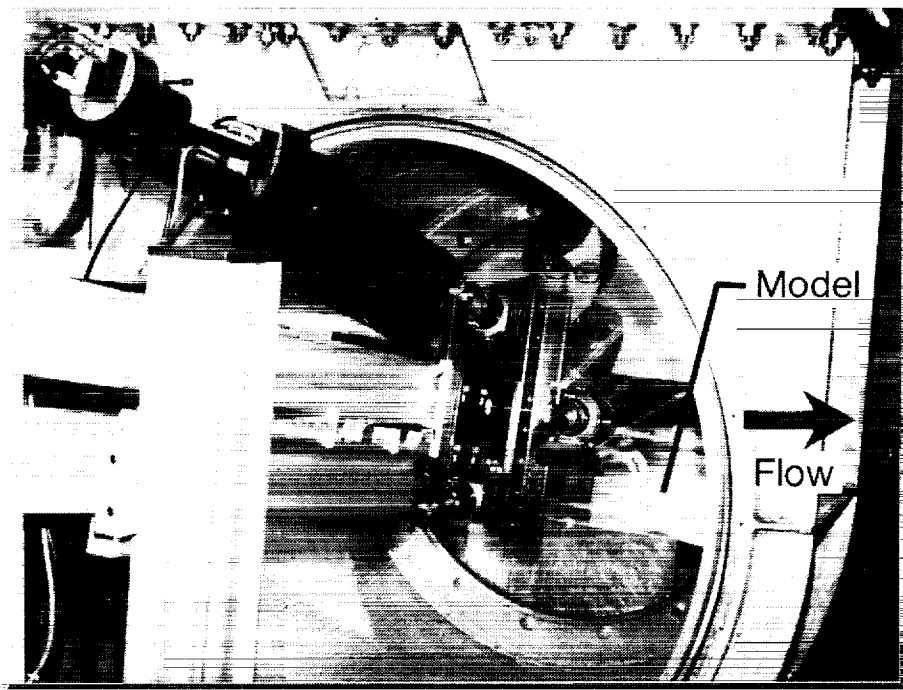


Figure 3

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## MODEL MOUNTED IN TEST SECTION

The LV system described here resulted in a sample volume of diameter 80 micrometers and a length of 120 micrometers. In order to make measurements very close to the juncture, the LV beam system was oriented at an angle of 11 degrees with respect to the horizontal wing. Flare from the juncture surfaces restricted the closest measurement distance to 3.5 mm from the vertical splitter plate, and to 1.0 mm from the horizontal wing. Tridecane, a kerosene derivative, was successfully used as the seeding material in this experiment (ref. 14). (Fig. 4.)
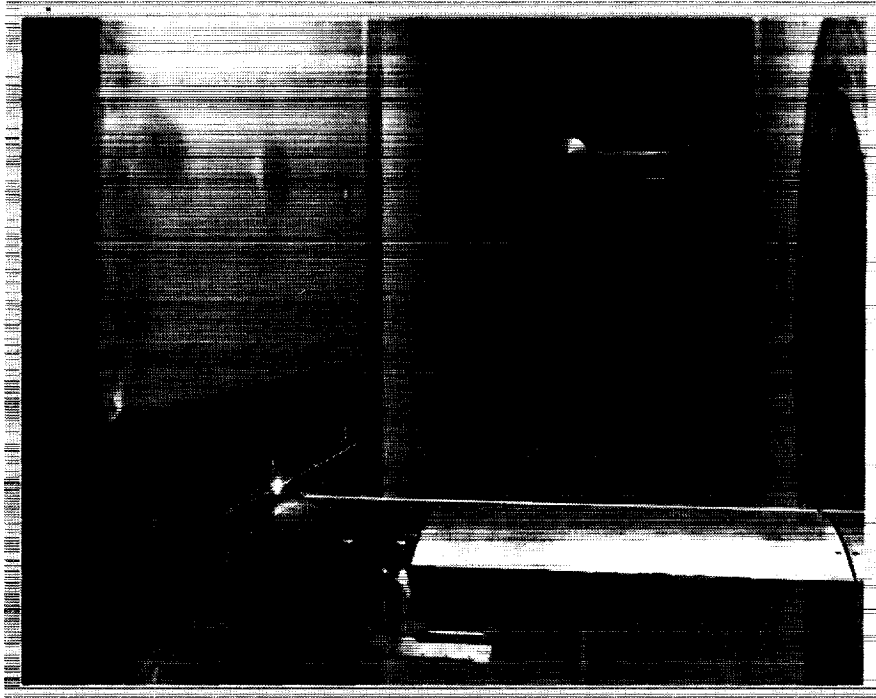


Figure 4

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# COMPARISON OF LV DATA WITH HOT-WIRE RESULTS

In order to determine the accuracy of the LV data, measurements made at stations located farthest from the juncture have been compared here with the two-dimensional turbulent boundary layer results from Klebanoff's hot-wire measurements over a flat plate with zero pressure gradient (ref. 34). Even though these stations were chosen to minimize the influence of the juncture, some three-dimensional effects are expected to be present in the LV data. The mean velocity component U shown in figure 5 compares very well with the hot-wire results.
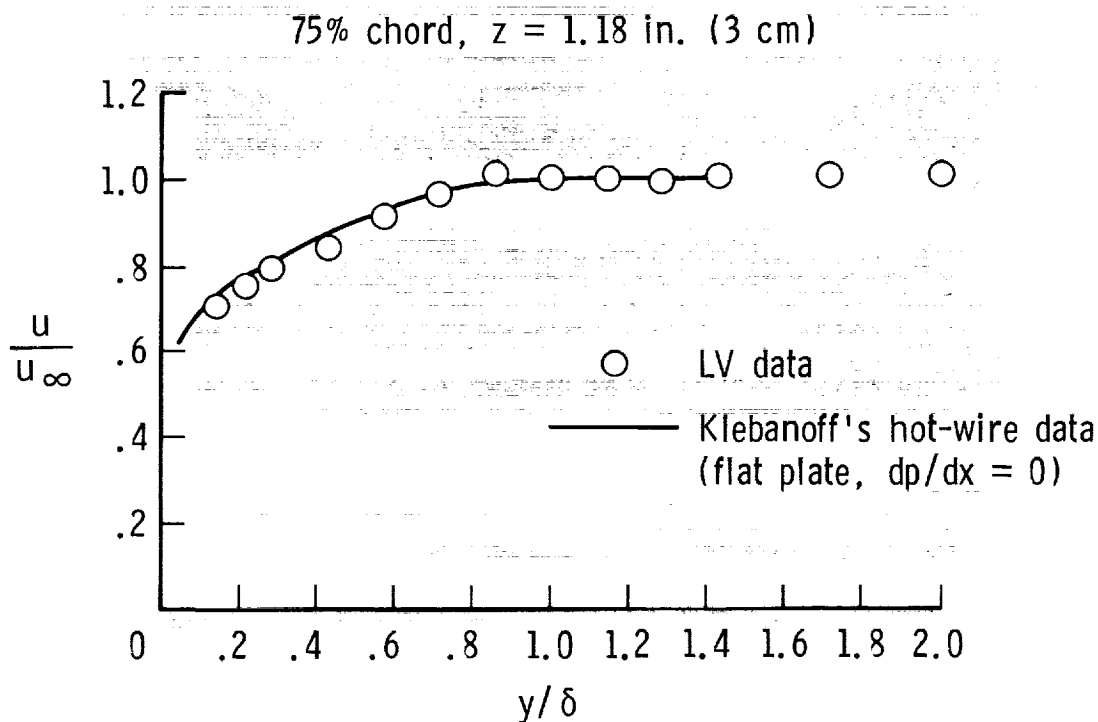


Figure 5

## MEAN VERTICAL VELOCITY

In a flat plate boundary layer, the mean velocity component V is non-zero because of the displacement effect of the boundary-layer growth; it is directed away from the plate and has small magnitude. The values of mean velocity component V measured by the LV system satisfy this criterion. (Fig. 6.)
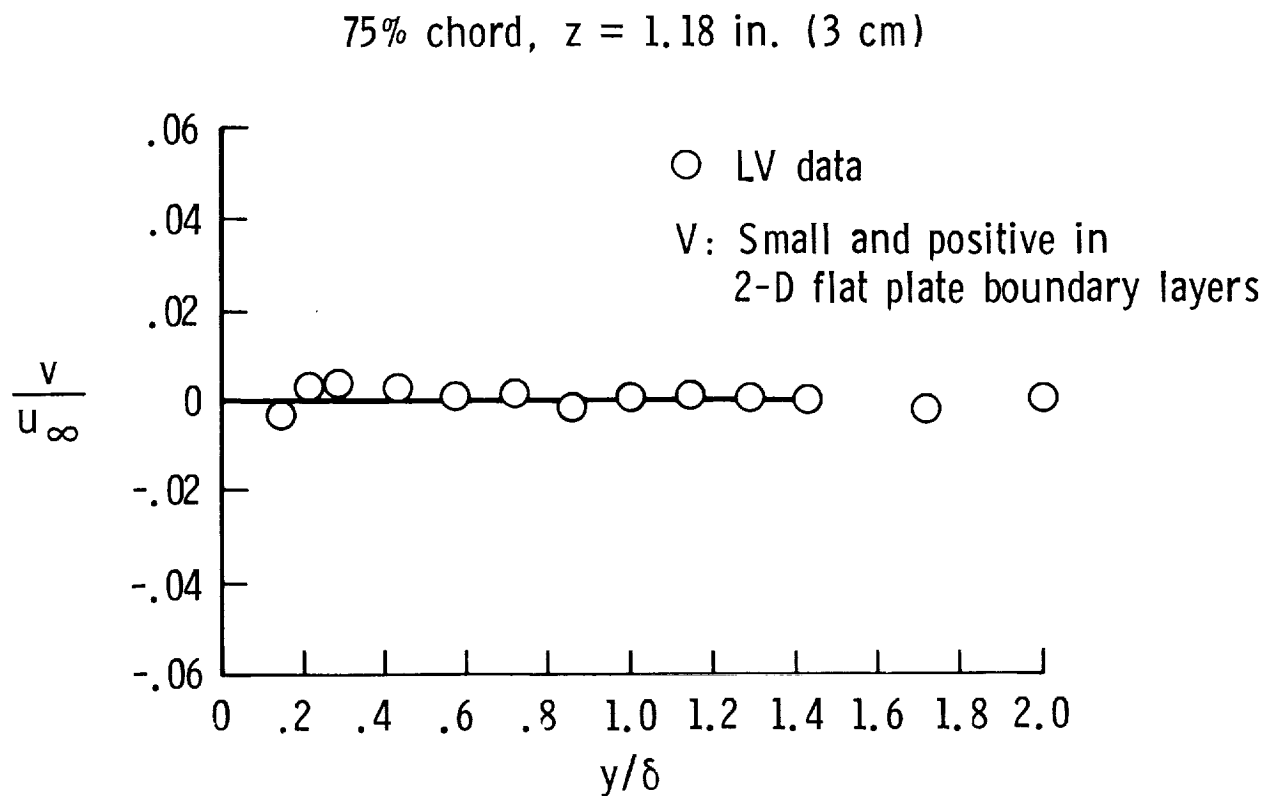
### 75% chord, z = 1.18 in. (3 cm)



Figure 6

The mean velocity component W is expected to be zero in a two-dimensional flow. But the flow in the juncture can still influence the measurements at the location where the data are being compared (fig. 7). This can partially explain the non-zero distribution of the W component.
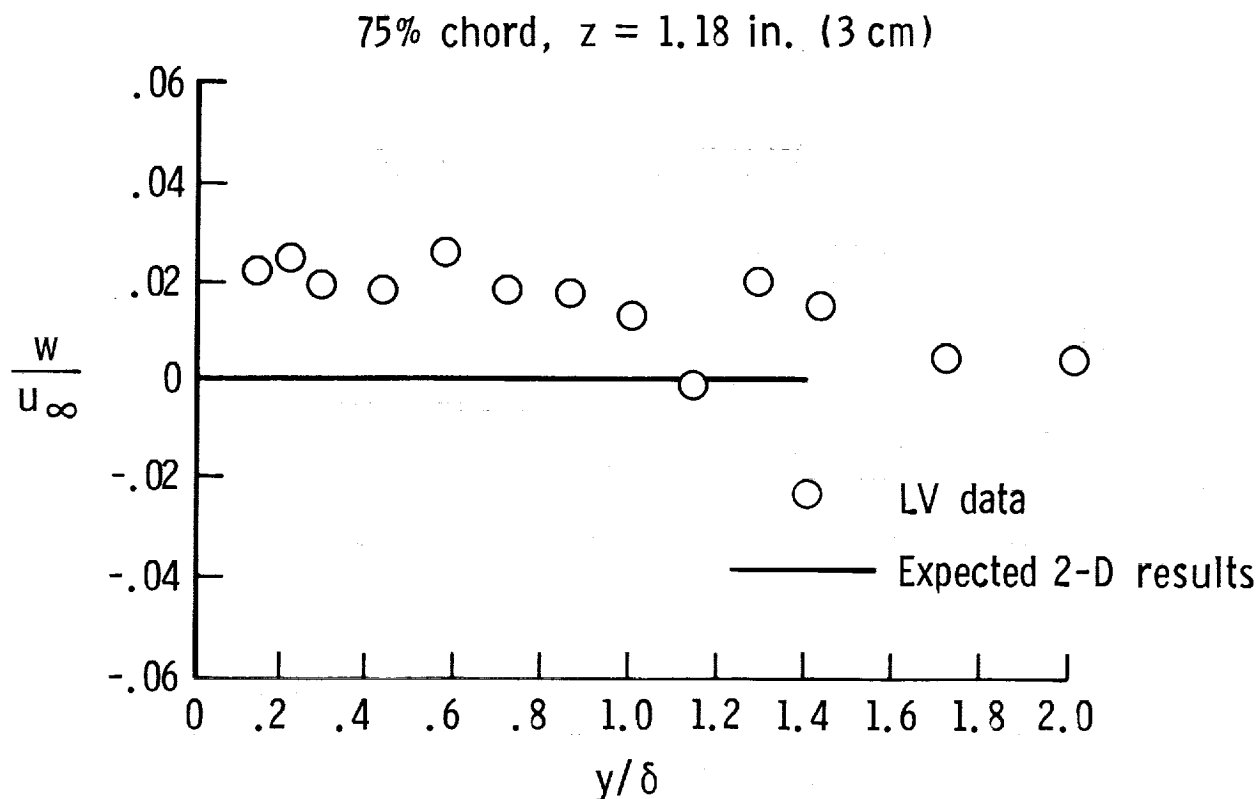


Figure 7

## CHORDWISE VELOCITY FLUCTUATIONS

In the case of the turbulence intensity, $\tilde{u}/u_\infty$ (where $\tilde{u}$ is the RMS fluctuating component of velocity in the x direction), the LV data obtained inside the boundary layer compare well with Klebanoff's hot-wire results (ref. 34). The value outside of the boundary layer is higher than the freestream turbulence intensity of 0.04 percent, obtained from hot-wire measurements made in the same facility. The value is also higher than the LV resolution limit of 1 percent. This can be due to the following reason: hot-wire measurements normally filter out the very low frequency tunnel oscillations (< 2 Hz) whereas in the case of LV measurements, no such filtering is carried out. This will result in the higher-than-normal distribution of turbulence intensity u' as measured by the LV system. (Fig. 8.)
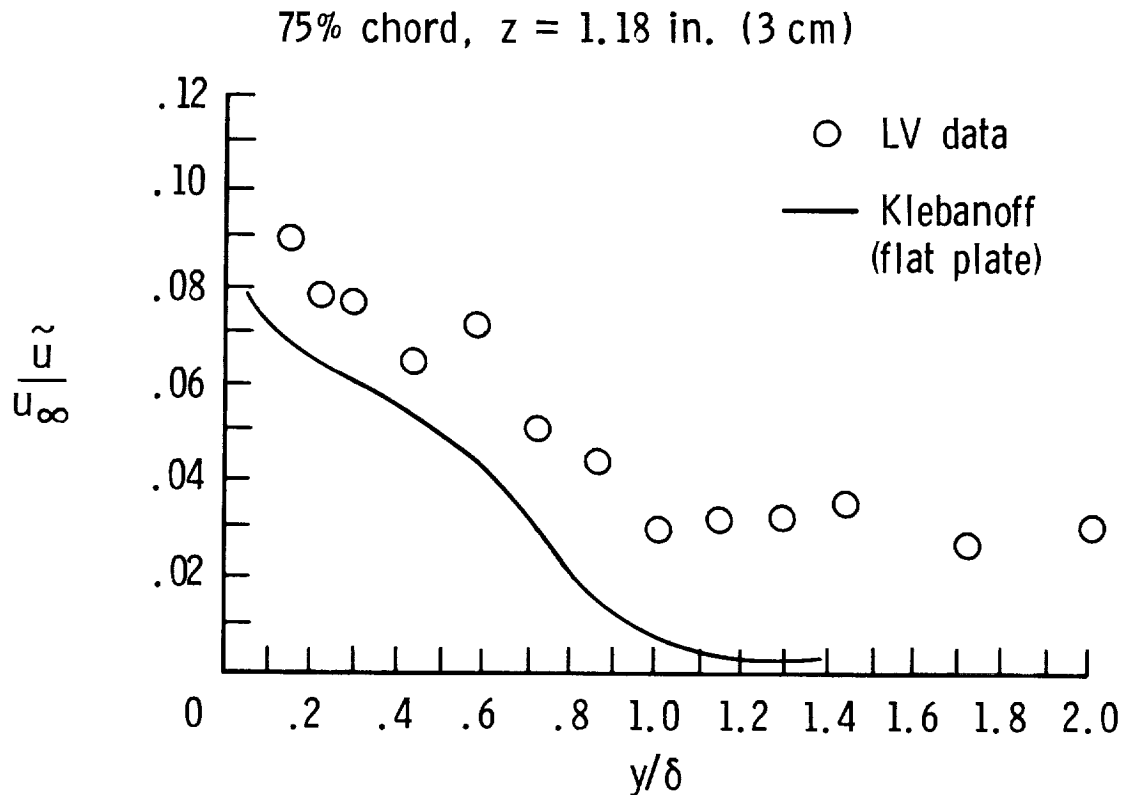


Figure 8

Comparison of the turbulence intensity, $\tilde{v}/u_\infty$ (where $\tilde{v}$ is the RMS fluctuating component of velocity in the y direction), with Klebanoff's results (ref. 34) within the boundary layer is very good, but outside of the boundary layer the turbulence level is high. This is due to the fact that the lowest turbulence level that could be measured with the present LV system (or any other LV systems) is about 1 percent. (Fig. 9.)
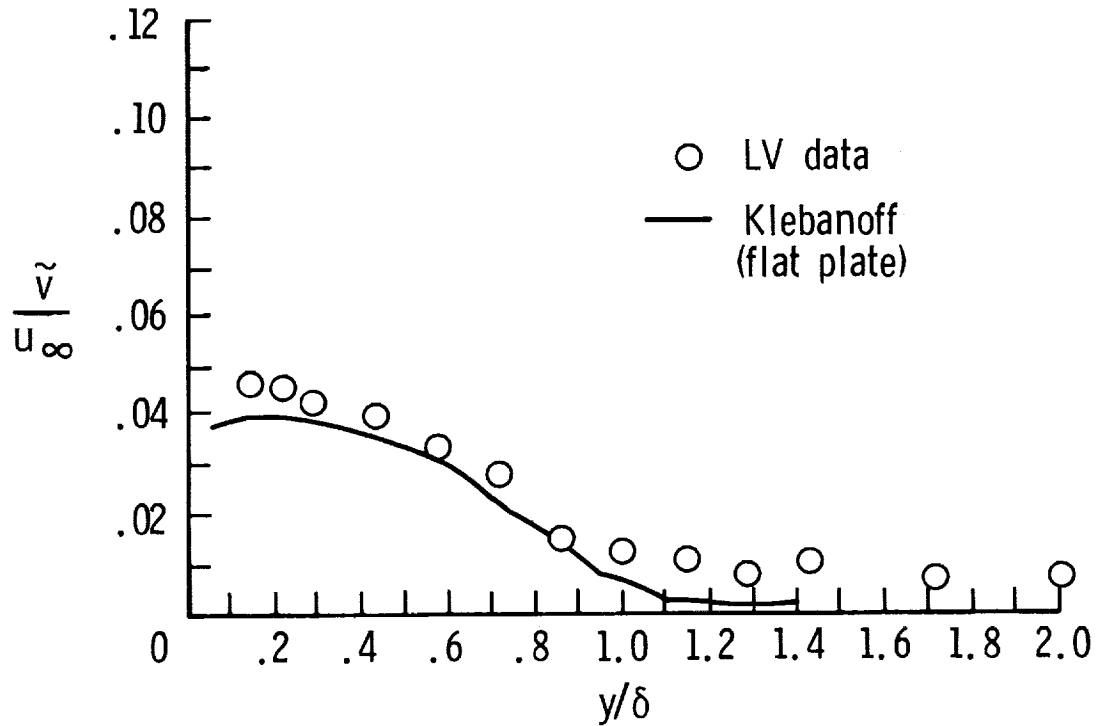
## 75% chord, z = 1.18 in. (3 cm)



Figure 9

# SPANWISE VELOCITY FLUCTUATIONS

The overall distribution of the turbulence intensity, $\tilde{w}/u_\infty$ (where $\tilde{w}$ is the RMS fluctuating component of velocity in the z direction), is much higher than Klebanoff's reference profile (Ref. 34). Part of it can be attributed to the three-dimensional effects of the juncture. Also, the narrow cross-beam angle between the laser beams that were used to obtain w-related components resulted in lower signal-to-noise ratio; this could have introduced some inaccuracies in this and other w-related components (fig. 10).
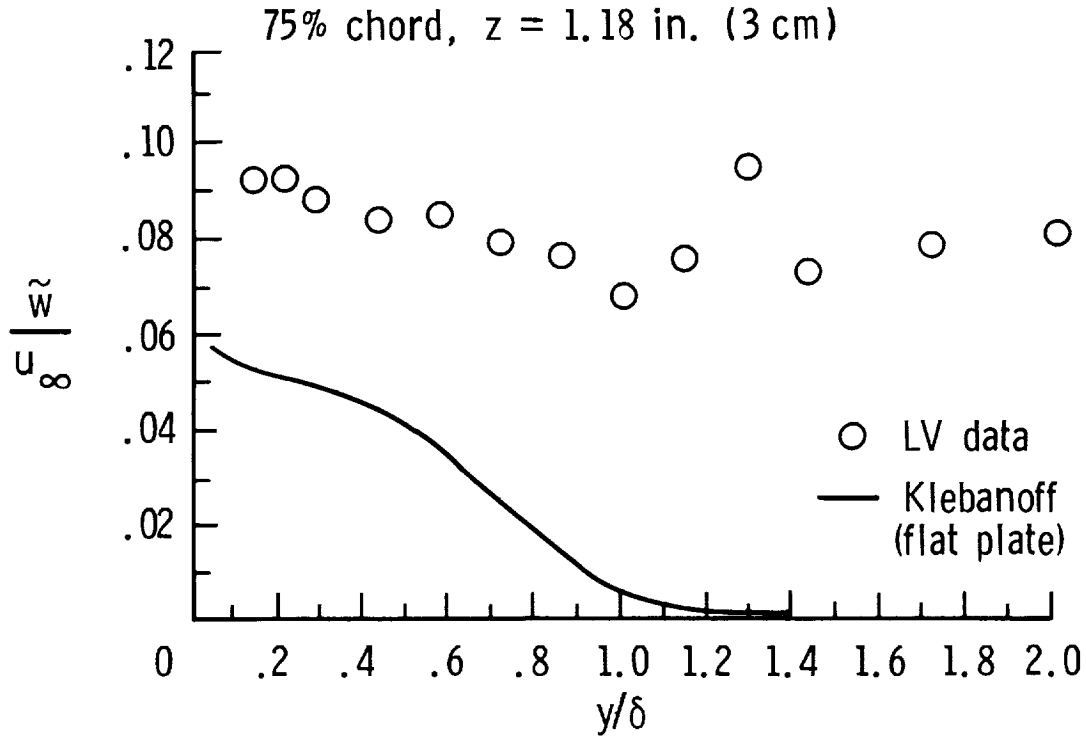
75% chord, z = 1.18 in. (3 cm)

○ LV data

—— Klebanoff (flat plate)

$\dfrac{\tilde{w}}{u_\infty}$    y/δ

Figure 10

There is excellent agreement between LV measurements of the Reynolds stress $\overline{uv}$ and Klebanoff's hot-wire results (Ref. 34). The accuracy of w-related Reynolds stresses $\overline{uw}$ and vw was not as good because of the reasons detailed earlier.

In conclusion, a single-axis, five-beam, three-component laser velocimeter system has been used in a major experiment. Satisfactory results have been obtained with the LV system in the juncture flow. Limited optical access to the tunnel proved to be a problem for a three component LV system in determining the third component (W). (Fig. 11.)
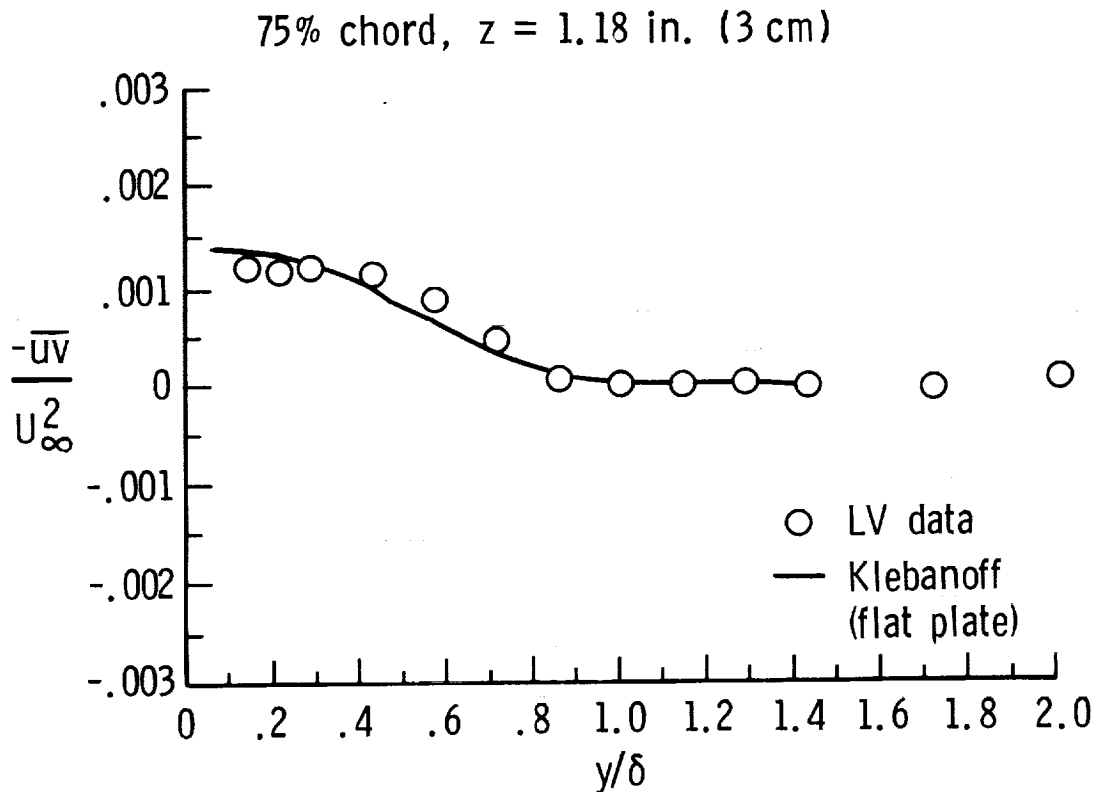
## 75% chord, z = 1.18 in. (3 cm)



Figure 11