NASA Technical Memorandum 100588

LASER VELOCIMETER MEASUREMENTS IN A WING-FUSELAGE TYPE JUNCTURE

(NASA-TM-100588) LASER VELOCIMETER MEASUREMENTS IN A WING-FUSELAGE TYPE JUNCTURE (NASA) 9 p CSCL 01A

N88-22012

Unclas

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April 1988

NASA

National Aeronautics and Space Administration

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ABSTRACT

A single axis, five beam, three component laser velocimeter system has been used in a juncture flow experiment. A description of the seeding system developed for and used in this experiment is given. The performance of the LV system has been evaluated, and some of the problems associated with it have been identified. Satisfactory results have been obtained in the juncture flow experiment using this LV system.

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 (Fig. 1). The coupled effects of the separation vortex and the secondary flows that are present in any rectangular corner lead to a complex three-dimensional turbulent flow. This vortical flow can have significant effect on the juncture interference drag, and more importantly, it can adversely affect flow on the surfaces downstream of the wing.

Hot-wire measurements in simulated wing-fuselage junctures formed by a flat surface and a constant-thickness wing have been carried out by various investigators (e.g., Refs. 1, 2, and 3). These are simple streamwise juncture flows with no pressure gradients present along the juncture. The juncture flow experiment conducted at the NASA Langley Research Center had the following objectives: (1) to study the turbulent flow in a simulated wing-fuselage juncture with and without streamwise pressure gradients, and (2) to assess the effectiveness of juncture fairings in modifying the potential and viscous flows in the juncture.

The use of laser velocimetry will greatly facilitate making detailed measurements near the non-planar surfaces forming the juncture, and within near-separating flows close to trailing edge of the wing. Therefore, a three component laser velocimeter system was used toward achieving these objectives. Some of the relevant results have been published in Reference 4. This paper tries to evaluate the performance of this new laser velocimeter system in order to identify its merits as well as its shortcomings. An LV seeding system has also been developed to be used with this experiment; a brief description of the final seeding-system configuration and the results of the particle evaluation tests are included in the paper.

EXPERIMENTAL DETAILS

Wind Tunnel

The juncture flow 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 (Fig. 2). 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.

Experimental Model

The juncture flow was generated by a vertical splitter plate ("fuselage") with an unswept wing mounted perpendicular to it (Figs. 3 and 4). The wing had a chord length of 0.457 m (18 in.) and a thickness-to-chord ratio of 0.07. It had a curved surface (circular arc of radius of curvature 10 m) on one side and a flat surface on the other in order to simulate juncture flow with and without streamwise pressure gradients. The wing root was designed so as to accommodate corners with and without fillets (Fig. 4). The removable corner fillet used in this study had a radius of curvature of 25.4 mm (1.0 in.). The leading edge of the wing was located 0.406 m (16 in.) downstream of the plate leading edge. Trailing-edge flaps on the splitter plate and the wing were used to control the leading edge stagnation points.

LV MEASUREMENT SYSTEM

Details of the laser velocimeter system design and the data analysis are found in Reference 5; a brief description of the system is given here.

LV Configuration

The single axis, five beam optical configuration (Fig. 5) 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. 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.

The LV system described above resulted in a sample volume of diameter 80 micrometers and a length of 120 micrometers. An off-axis backscatter collection mode was used in order to reduce the effect of background reflections from the splitter plate. 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 (Fig. 3). 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.

Operating Conditions

The experiments were conducted at atmospheric pressure since the installation of LV optical system and traversing mechanism in the plenum chamber precluded any tunnel pressurization. The requirements of the three component LV system also limited the maximum tunnel speed to about 40 m/s. A nominal freestream velocity of 34.5 m/s corresponding to a Mach number of 0.1 and a unit Reynolds number of 2,300,000/m was used for making all of the measurements. A rectangular measurement grid of width 3 cm and height 3 cm was covered at each one of the measuring stations indicated in Figure 4. The instantaneous velocity information from ensemble measurement at each measurement location was processed in real time, and it was also stored permanently for later processing.

LV SEEDING SYSTEM

System Considerations

Since the laser velocimeter measures the velocity of seeding particles in the test medium, the fluid flow meassurements depend highly upon the generation of particles with known particulate characteristics. In the design of a system for artificial seeding, various requirements such as seeding rate, particle size, particle characteristics, and particle ejection point need to be considered. Many of these requirements are contradictory in nature. For example, insufficient seeding rate leads to long data acquisition time over which the test conditions could vary. But if the seeding rate is too high, the probability of having more than one particle inside the sample volume increases. The particles must be small enough to folow the flow stream, but large enough to be detected by the LV system. Another requirement is that the particles have small diameter variation (mono-dispersed). If the particles have too wide a dispersion, and if they are in a highly accelerating flow, the turbulence measurement may be due to the velocity variation of particles of different sizes rather than the turbulence level of the flow stream.

A primary requirement of the Langley Low-Turbulence Pressure Tunnel was that the seeding material did not deposit on or damage in any way the turbulence reduction screens located in the tunnel settling chamber. Both solid and liquid seeding systems were evaluated (Ref. 6), and some of the results are presented in the next two sections.

Solid Particle Seeding

A potential flow analysis of Kaolin particles of various sizes moving past a cylindrical wire (127 micrometers in diameter) indicated that the fraction of particles impacting on the cylinder increases with increasing particle size. The results led to the conclusion (Ref. 6) that the desired size of particles should be below one micrometer in diameter, in order to minimize particle build-up on the screens. A special experiment was set up to evaluate and gain insight into solid-particle seeding problems. Kaolin particles were injected into the flow stream in the diffuser (Fig. 2) between the test section and the drive fan, and the particle data rate was measured with the a laser transit anemometer. The particle data rate is shown in Fig. 6 as a function of time. A curve fit of the experimental data indicates that that there is a 15% loss of particles/minute at the operating Mach number of 0.1. Other evaluation tests indicated that the particle decay rate is proportional to tunnel speed, and that the gravitational settling rate is insignificant (Ref. 6). This implies that continuous tunnel operation will require continuous seeding, which will lead to undesirable accumulation of solid particles in a closed-circuit tunnel.

Liquid Particle Seeding

If the liquid particles are too large, then a large percentage of them will impact on the screens (Ref. 6). If the screen wetting rate is faster than the drying rate due to liquid evaporation, the liquid could collect dirt in the tunnel. Therefore, it is desirable to generate small particles and to use a liquid which is volatile enough that it will evaporate. Further, a safe and readily available liquid is desirable. Kerosene which satified most of the requirements left residues on a test screen, and therefore, it was not acceptable. However, kerosene is made up of a number of purer hydrocarbon components. Of these, dodecane and tridecane have droplet forming characteristics very nearly equal to that of kerosene. These hydrocarbon fluids can be obtained in a highly refined state, and they evaporated completely from the screens, at varying rates. Particle size evaluation tests indicated that dodecane and tridecane are very nearly mono-dispersed with very small mean particle diameter (Fig. 7). Therefore, dodecane and tridecane were chosen as the seeding particles for this experiment.

Particle Generator

The particle generator (Fig. 8) used in the present experiment operates on the principle of a shearing atomizer. Adequate air flow and pressure is supplied in order to have a shock wave at the exit of the nozzle. The low pressure at the exit sucks the liquid from the reservoir past an adjustable needle valve to the exit plane where the shock wave exists. The shock wave breaks up the jet into minute particles. The needle valve is used to control the seeding rate.

Successful LV measurements were obtained by injecting tridecane or dodecane through the atomizer. The same LV seeding system as well as the LV measurement system have been used in another major experiment carried out in the LTPT (Ref.7).

EVALUATION OF THE LV SYSTEM

In order to determine the accuracy of the LV data, measurements made at stations located farthest from the juncture were compared with the two-dimensional turbulent boundary layer results of Klebanoff (Ref. 8). Eventhough these stations were chosen to minimize the influence of the juncture, some three-dimensional effects are expected to be present in the LV data. Ideally, it is desirable to compare LV and hot-wire data taken under identical conditions; but, such experiments could not be carried out because of time limitations.

The comparisons presented in Fig. 9 are for the case of boundary layer on the flat surface of the wing at 75% chord streamwise measuring station, and at a lateral distance of 3 cm from the splitter plate ($z = 3$ cm).

The mean velocity components U and V, and the Reynolds Stress $\overline{uv}$ compare very well with the two-dimensional results (Figs. 9(a)-9(c)). Comparison of the turbulence intensity v' (Fig. 9(d)) 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%.

In the case of the turbulence intensity u' (Fig. 9(e)), the value outside of the boundary layer is higher than the freestream turbulence intensity of 0.04%, obtained from hot-wire measurements made in the same facility (Ref. 9). The value is also higher than the LV resolution limit of 1%. 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.

The accuracy of the mean velocity component W, and Reynolds stresses $\overline{uw}$ and $\overline{vw}$ are not as good as the other components (Figs. 9(f)-9(h)). The overall distribution of the turbulence intensity w' (Fig.9(i)) is much higher than the reference profile. 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 these components. This problem is being investigated by the Instrument Research Division at NASA-Langley, and the results are to be published soon (Ref. 10).

SAMPLE RESULTS

In order to get an idea about the type of data that were obtained in this experiment, some sample results are presented in Fig. 10. The contour plots of mean velocity U shown in this figure are for the 95% chord streamwise measuring station in the juncture formed by the curved surface of the wing and the splitter plate. The mean velocities encountered very near the juncture surfaces are relatively low. The presence of a low-momentum "bulge" (Fig. 10(a)) on the wing surface in the juncture without fillet can have adverse effects on the flow over the wing surface by accelerating trailing-edge separation at non-zero angles of attack. Fig. 10(b) indicates that the juncture fillet can be effective in removing this low-momentum region on the wing surface.

CONCLUDING REMARKS

A single axis, five beam, three component laser velocimeter system has been used for the first time in a major experiment. A seeding system which uses kerosene derivatives such as tridecane and dodecane as seeding materials has been developed and successfully used in the experiment. Satisfactory results have been obtained with the LV system in the juncture flow experiment. Inaccuracies in the w-related components can be due to the small cross-beam angle between the laser beams measuring these components. This implies that limited optical access to the tunnel is still a major problem for a three component LV system.

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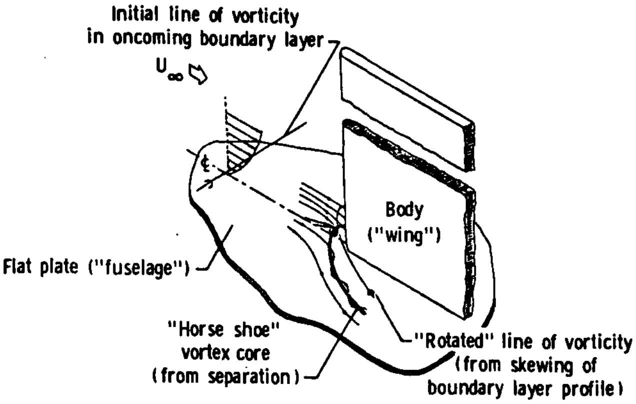

Figure 1.- Schematic of the flow in a juncture.

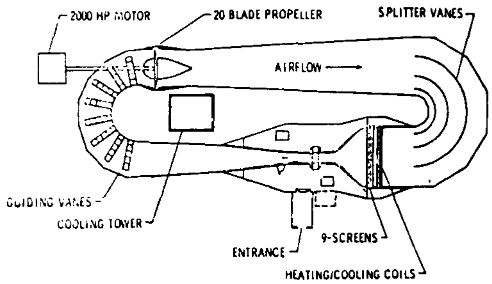

Figure 2.- Low-Turbulence Pressure Tunnel.

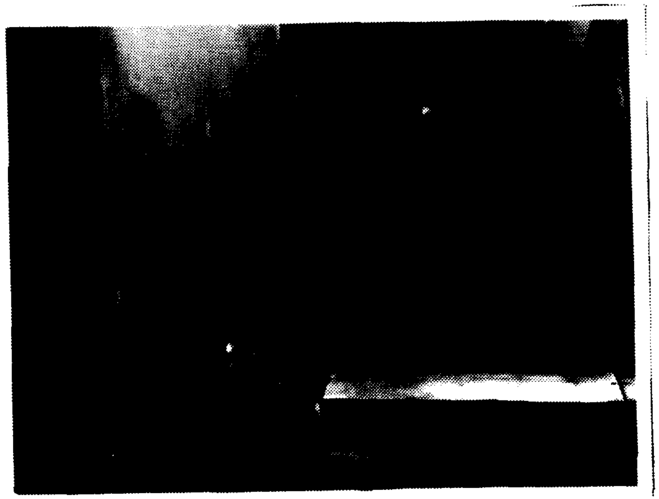

Figure 3.- Photograph of the set-up.

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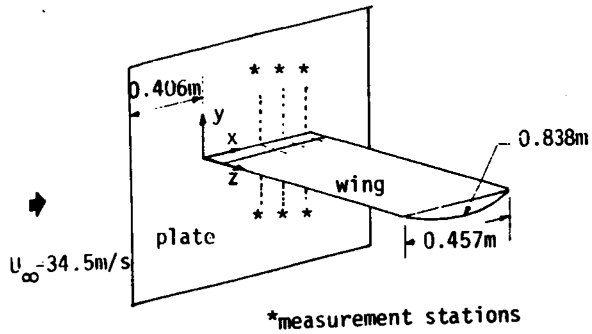
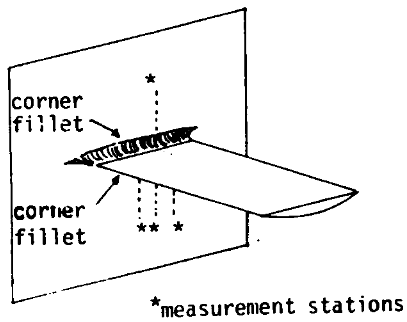


4(a) Square corner



4(b) With juncture fillet

Figure 4.- Experimental Model.

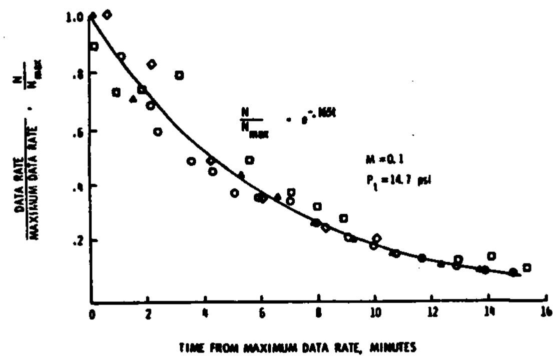


Figure 6.- Measured Kaolin particle data rate versus time from maximum data rate. Each symbol represents a different run.

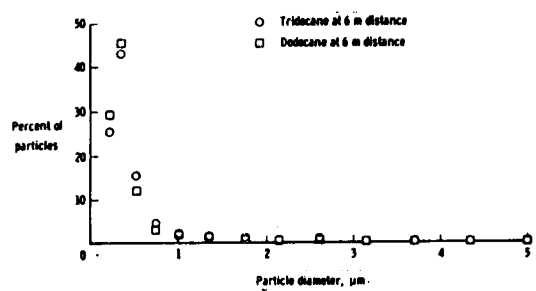


Figure 7.- Percentage of total number of particles counted versus particle diameter for tridecane and dodecane (measured at a distance of 6 m from the particle generator nozzle).

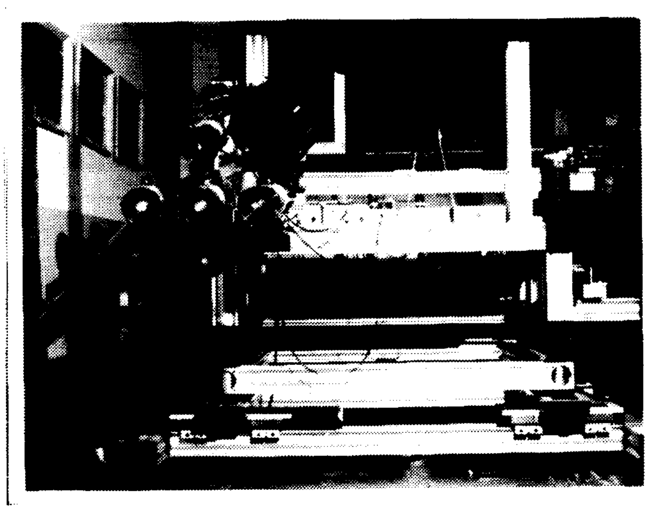


Figure 5.- Laser velocimeter system

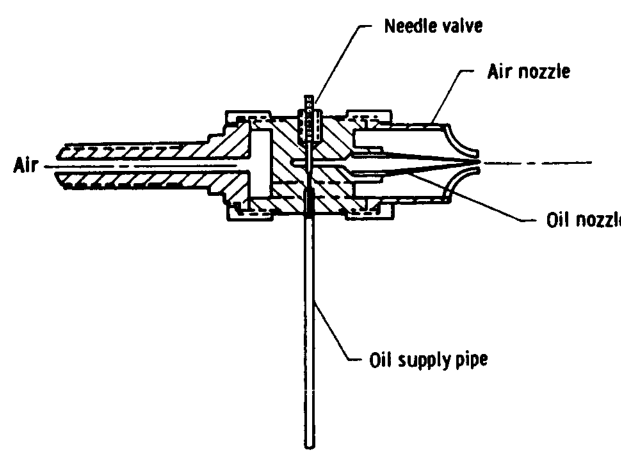
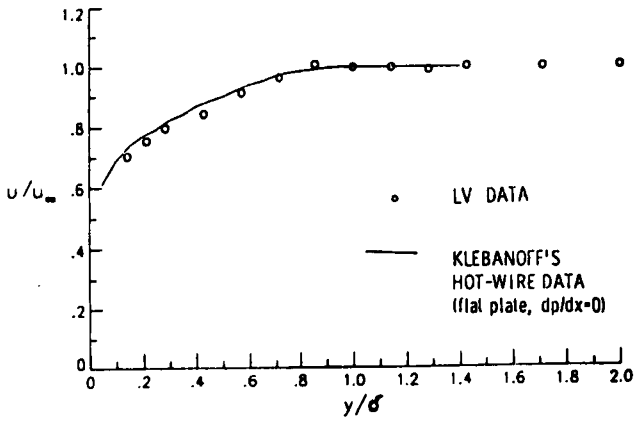
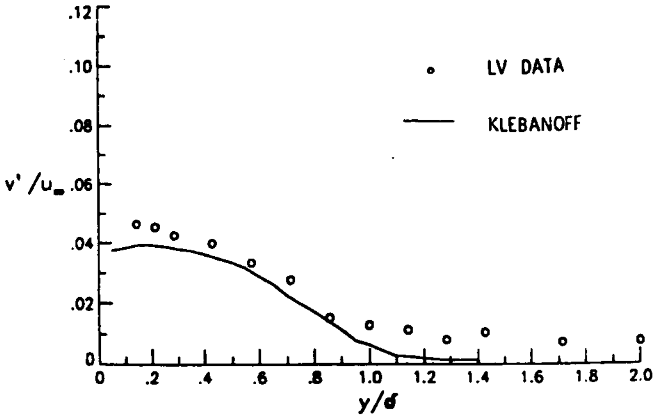


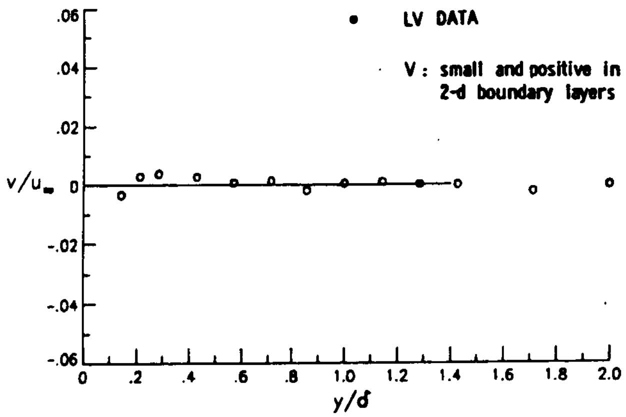
Figure 8.- Assembly cross-section of the particle generator developed for seeding of LDV.



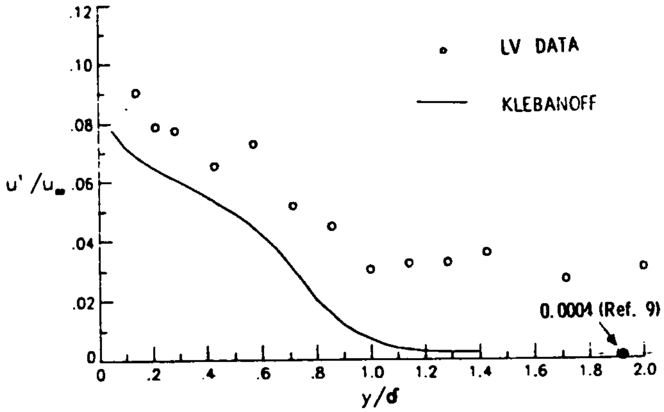
9(a) Mean velocity U



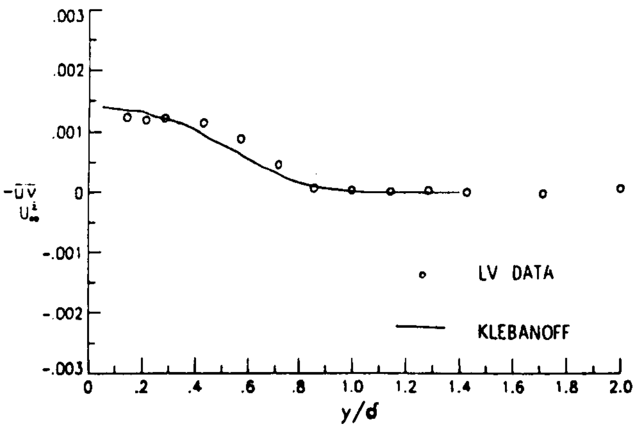
9(d) Turbulence intensity v´



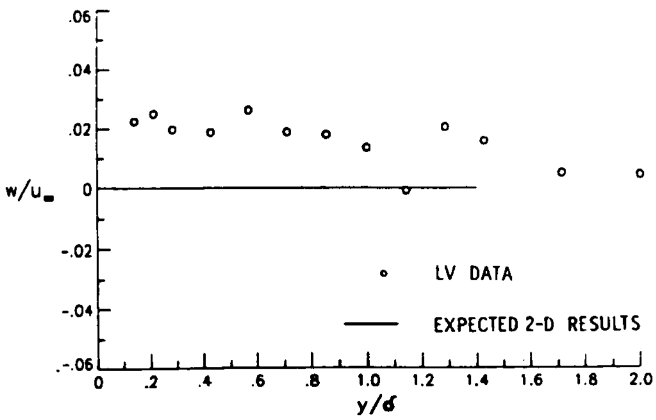
9(b) Mean velocity V



9(e) Turbulence intensity u´



9(c) Reynolds stress $\overline{uv}$



9(f) Mean velocity W

Figure 9.- Comparison of LV data with Klebanoff´s 2-D flat plate boundary layer results (x = 75% chord station on flat surface of the wing, z = 3 cm)

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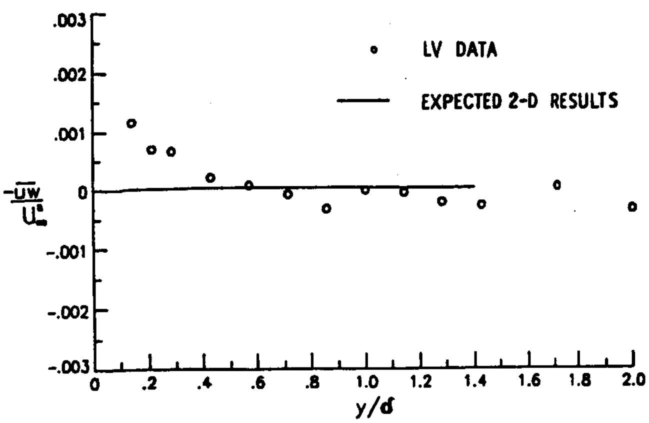
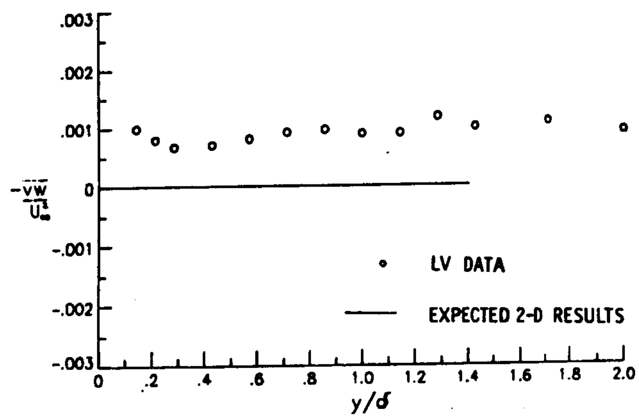
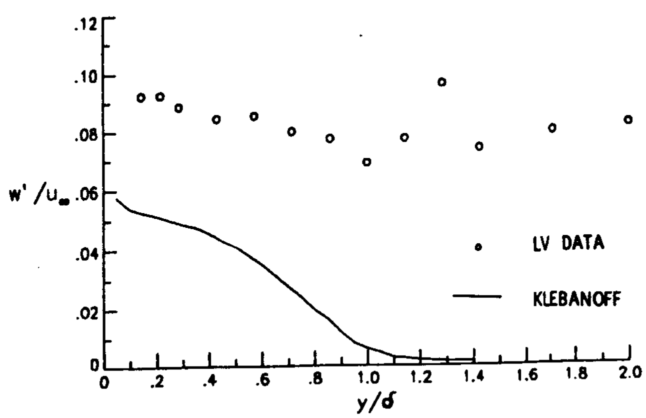


9(g) Reynolds stress $\overline{uw}$

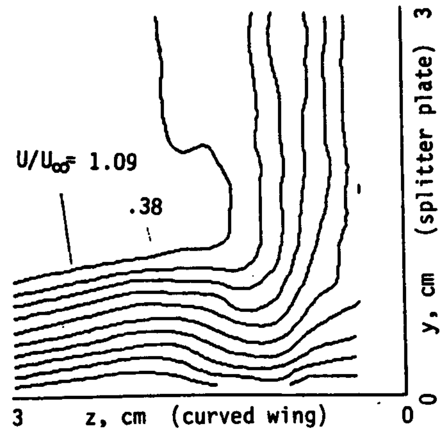


9(h) Reynolds stress $\overline{vw}$

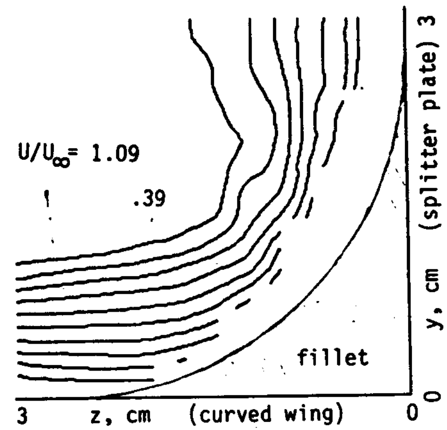


9(i) Turbulence intensity w'

Figure 9.- Concluded.



10(a) Square corner



10(b) With juncture fillet

Figure 10.- Contour plots of mean velocity U in the juncture formed by circular arc surface of the wing and the splitter plate (x = 95% chord station)

Report Documentation Page

National Aeronautics and Space Administration

1. Report No. NASA TM-100588	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle LASER VELOCIMETER MEASUREMENTS IN A WING-FUSELAGE TYPE JUNCTURE		5. Report Date April 1988
		6. Performing Organization Code
7. Author(s) J. Scheiman and L. R. Kubendran		8. Performing Organization Report No.
		10. Work Unit No. 505-60-21
9. Performing Organization Name and Address Langley Research Center National Aeronautics and Space Administration Washington, D.C. 23665-5225		11. Contract or Grant No.
		13. Type of Report and Period Covered Technical Memorandum
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546-0001		14. Sponsoring Agency Code

15. Supplementary Notes

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L. R. Kubendran, Analytical Services & Materials, Inc., Hampton, Virginia.
This paper was presented at the IEEE Eleventh International Congress on Instrumentation in Aerospace Simulation Facilities, August 26-28, 1985, Stanford University, Stanford, California.

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17. Key Words (Suggested by Author(s)) Juncture flow, Laser velocimeter, Fluid dynamics, Wing-fuselage	18. Distribution Statement Unclassified--unlimited Subject Category 02

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of pages	22. Price
Unclassified	Unclassified	8	A02

NASA FORM 1626 OCT 86