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DEMONSTRATION OF RAPID-SCAN TWO-DIMENSIONAL LASER
VELOCIMETRY IN THE LANGLEY VORTEX RESEARCH FACILITY
FOR RESEARCH IN AERIAL APPLICATIONS

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DEMONSTRATION OF RAPID-SCAN TWO-DIMENSIONAL LASER VELOCIMETRY IN THE LANGLEY VORTEX RESEARCH FACILITY FOR RESEARCH IN AERIAL APPLICATIONS

By

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SUMMARY

Tests have been conducted in the Langley Vortex Research Facility to demonstrate a rapid-scan two-dimensional laser velocimeter (LV) measurement technique for aerial applications research. The LV system is capable of simultaneously measuring both vertical and axial (along flight path) flow velocity components in a near or far-field vortex system. Velocity profiles were successfully measured in the wake vortex of a representative agricultural aircraft model, with the vortex system rapidly transporting in ground effect. Results indicate that the laser velocimetry technique can provide quantitative information of wake vortex characteristics in ground effect. Such quantitative wake measurements are expected to be important to an aerial applications research program in the Vortex Research Facility.

INTRODUCTION

With more than 65 million acres of farm land in the United States, aerial equipment has provided an extensive and timely application of chemical sprays and dry materials to crop areas (ref. 1). However, problems such as off-target contamination due to drift and a need for more efficient dispersion techniques are a growing concern. One contributing factor to the off-target drift problem is the interaction of the deployed chemical spray and wake vortices. The small particles are entrained into lingering wake vortices and carried into nontarget areas by cross winds.

A test program on aerodynamic modification of wake vortex systems in ground effect for aerial applications is being conducted in the Langley Vortex Research Facility. It is believed that judicious aerodynamic modification of the vortex wake may prevent some deposit entrainment. The investigation is part of a general research program to provide a technology base for the formulation and development of an improved aerial applications system. One current aspect of this test program is an exploratory investigation of wake vortex system transport in ground effect on a representative agricultural model, and a preliminary evaluation of the effectiveness of some candidate schemes for aerodynamic wake modification.

In the past, research efforts for a better understanding of the flow characteristics of wingtip vortices have been hindered by the lack of a suitable technique for measuring the velocity distribution in an environment where the vortex system is rapidly changing with time and in position. Stationary probes often cause disturbances which affect the flow characteristics, and data from nonstationary probes are difficult to interpret. Flow visualization techniques have allowed the investigator to observe the flow behavior but offer limited quantitative information.

With the development of a rapid scan nonintrusive two-dimensional laser velocimeter system, new opportunities for localized velocity measurements of vortex systems have been opened. This measurement technique has been demonstrated in the Langley Vortex Research Facility. The purpose of this paper is to describe briefly the laser velocimeter technique and the velocimeter system used in this work and to present representative velocity measurements made in the initial phase of an aerial applications test program.

SYMBOLS

b	model wing span, meters
f	Doppler frequency, hertz
S_f	fringe pattern spacing, meters
T	period
U	vertical or axial velocity component; positive vertical is up, positive axial is toward model, m/sec
U_∞	free-stream velocity, m/sec
y	spanwise distance from wingtip, positive outboard, meters
λ	wavelength of laser light, meters
θ	angle between intersecting laser beams, degrees

APPARATUS AND PROCEDURES

Laser Velocimetry Technique

The basic principle of the laser velocimeter (LV) is shown in figure 1. The laser beam is split into two parallel beams of equal intensity. A lens is used to direct these beams so that their wavefronts interact. Being coherent, the interacting beams form stationary interference fringes within an ellipsoidal sample volume at the focal plane. This fringe pattern is a combination of alternating light and dark regions of equal spacing. The spacing S_f, is given by

$$S_f = \frac{\lambda}{2 \sin \theta/2}$$

where λ is the wavelength of the laser light, θ is the angle between the intersecting beams. If a particle (~ 1 to 10 micron diameter) in the moving fluid passes through the fringes it will cause light to be scattered with a resultant burst signal whose period, T, is equal to the inverse Doppler frequency shift of the incident laser radiation. A photodetector is used to detect the scattered light with the Doppler frequency shift, f, given by

$$f = \frac{2|v| \sin \theta/2}{\lambda}$$

where $|v|$ is the absolute normal velocity component of the particle crossing the fringe pattern. Velocity directionality is obtained by using a Bragg cell to produce moving fringes proportional to a modulating frequency. Particles moving in the same direction of the moving fringes will provide a frequency shift lower than the modulating frequency. Conversely, particles moving in the opposite direction of the fringes will produce a frequency higher than the modulating frequency.

Test Apparatus

A sketch of the Langley Vortex Research Facility is shown in figure 2 (ref. 2). In this test facility the aircraft model is towed at constant velocity through stationary air by a powered carriage. Characteristics of the generated wake are then observed and recorded as a function of time at a ground-based station in the test section. The model carriage is shown on the 549 meter overhead track with a representative agricultural aircraft model mounted beneath from a thin support blade. The test section, which isolates the wake of the carriage from the model wake, is 91.37 meters long, 5.49 meters wide, and 5.18 meters high, with a 5-cm-wide opening in the ceiling to allow the model support blade to pass. The overhead track extends 304.8 meters ahead of the entrance to the covered areas to permit the carriage to accelerate to the test velocity. All test measurements are taken at a station 30 meters inside the test section, where smoke (vaporized kerosene) is injected for flow visualization.

The vortex-generating model was a 0.167-scale model of a representative agricultural aircraft. The model, shown in figure 3, has a wing span of 1.98 meters. Aerodynamic modification of the wake vortex system was achieved by deploying vortex attenuating devices at the wingtips. Such devices are known to attenuate the large swirl velocities close to the vortex core.

A ground plane was installed so that ground effects could be simulated. The vertical position of the model above the ground plane was changed by substituting various supporting strut lengths. For tests discussed herein, the model was mounted so that the wingtip was 0.34 meters above the ground plane.

The scanning laser velocimeter system basically consists of two parts, i.e., optics (ref. 3) and the data acquisition and processing electronics. A block diagram of the optics system is shown in figure 4. It is designed to permit the simultaneous measurement of vertical and axial velocity components. The system is operated in the backscattered mode to permit usage of common focusing optics and scanning mechanism. It provides a rapid scan rate, up to 30 times per second for simultaneous measurements of vertical and axial components at 16 different positions along the optical axis per scan. The total distance between extreme positions is approximately 0.35 m. The scan region absolute location along a 3 m optical axis was determined within ±7 mm. The 16 measurement positions within the scan region remain constant with respect to each other for each scan. This is due to the inherent features of the scan mechanism which is discussed in reference 3. The spatial resolution, determined at the $1/e^2$ relative beam intensity point, was typically 0.2 mm diameter by 1.4 cm long. Each measurement point is identified automatically by a digital position encoder so that the related velocity measurements in the flow can be cataloged by the data processing system.

A block diagram of the data acquisition and processing system is shown in figure 5. The axial and vertical velocity information are respectively separated by 15 MHz and 25 MHz Bragg cell frequencies which are separated by bandpass filters. Mixers are used to down shift the frequency spectrum for better operating efficiency of the digital frequency counters. The outputs from the counters and the position encoder are fed into an on-line minicomputer. The operation of the minicomputer is initiated by a photoelectric trip switch which is activated by the passage of the strut support for the vortex-generating model. It is located coincident with the plane of the scanned regions. Mean velocity and associated standard deviation data are computed, tabulated, and plotted.

The uncertainty in the velocity measurement due to systematic error depends basically on the determination of two factors, i.e., the cross beam angles and frequency. The cross beam angles, which ranged from 1.076° to

0.961°, were determined with an uncertainty of 0.6 percent (negligible effect on the measured velocity). The frequency resolution of the processing system was ±0.002 MHz, which corresponds to a velocity uncertainty less than ±0.1 m/sec.

Test Procedure

The vortex-generating model, positioned to produce vortices in ground effect, was towed through the test section at constant nominal velocity of approximately 30 m/sec. All test runs were made with the model at a constant representative lift coefficient. Kerosene vapors were deployed for flow field visualization and LV scattering centers. Flow visualization data was recorded on video tape. An illustration of the model above the ground plane in the test section and a designation of the scanned regions are shown in figure 6. The minimum distance between measurement points within the scan region is 0.1 b, where b is the length of the total wing span of the model. The vortex system moves laterally away from the wingtip along the optical axis. During this time, it is scanned at a rate of 20 times per second. Rapid scanning is needed because of the time dependency characteristics of the vortex.

RESULTS AND DISCUSSION

The wake vortex system in ground effects, both with and without vortex modification, is shown in the photographs in figures 7 and 8. A typical normalized vertical velocity distribution of the unmodified vortex system is shown in figure 9. The velocity distributions with both moderate and relatively large degrees of vortex modification are shown in figures 10 and 11, respectively. All velocity distribution lateral locations are measured with respect to the wingtip, and in figure 9 data from a second test run is presented with instrumentation adjusted for a more inboard scanning region in order to define the velocity field inboard of the wingtip. All velocity distributions presented were taken in the relatively near-field model wake.

Vortex System Core Size and Lateral Transport Characteristics

The main effect of ground plane on the vortex system transport is to restrict the normal vertical descent below the wingtip, and to cause a rapid outboard movement laterally across the ground plane (see visual data in figures 7 and 8). The predominately lateral movement results in the vortex system moving rapidly along the laser optical axis, the position of the vortex core within the scanning region changing appreciably during the time interval between each successive scan. Because the vortex system remains in the laser beam for a period of time as it moves across the ground plane, a time history of core location and velocity distribution is obtained.

Location of the core center is determined by the position of zero velocity between positive and negative vertical velocity peaks (see figure 9). For instance, the velocity distribution in figure 9 indicates that the vortex core is well outboard of the wingtips even in the reatively near-field model wake. The core diameter is determined by measuring lateral displacement between positive and negative vertical velocity peaks in each scan, and the rate of core growth is approximated by measuring the change in core diameter over several scans. For these tests, the core diameter and rate of growth were determined to be $\approx$ 0.02 b (0.04 m) and $\approx$ 7.1 cm per sec, respectively. Lateral transport velocity is calculated by measuring the shift of the zero crossings between peak velocity values for several successive scans and dividing by the corresponding time interval between scans. Using this method yield lateral velocities in the order of 0.56 m/sec.

Vortex System Velocity Field and Effect of Aerodynamic Modification

The measured peak vertical velocity of the basic vortex shown in figure 9 is nearly 30 percent of the free-stream velocity with standard deviations of the mean in the order of ±0.9 percent. The peak vertical velocities are relatively large at the core, a region where the vorticity is concentrated.

The substantial reduction in the peak vertical velocity near the vortex core shown in figures 10 and 11 is representative of the vortex modification that can be achieved through aerodynamic means. The standard deviation of the mean for the vertical (most occurring within symbols) and the axial velocity distribution are indicated. These measurements are typically based on 25 data points per measurement location per 2.5 milliseconds observation time. Although axial velocities were not measured for the basic vortex system (fig. 9), a comparison with moderate and relatively large degrees of modification, indicates a substantial increase in axial velocity with increasing attenuation. This result is probably related to the large profile drag associated with the method used to modify the vortex system.

CONCLUSIONS

Tests have been conducted in the Langley Vortex Research Facility to demonstrate a rapid-scan two-dimensional laser velocimeter (LV) measurement technique for aerial applications research. The LV system is capable of simultaneously measuring both vertical and axial (along flight path) flow velocity components in a near or far-field vortex system. Velocity profiles were successfully measured in the wake vortex of a representative agricultural aircraft model, with the vortex system rapidly transporting in ground effect. Results indicate that the laser velocimetry technique can provide quantitative information of wake vortex characteristics in ground effect. Such quantitative wake measurements are expected to be important to an aerial applications research program in the Vortex Research Facility.

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1. Warren, L. E.: Controlling Drift of Herbicides, The World of Agricultural Aviation, March 1976, pp. 30-39.

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3. Rhodes, David B.: Optical Scanning System for Laser Velocimeters, Proceedings of the Society of Photo-Optical Instrumentation Engineers, Vol. 84, Laser Scanning Components and Techniques, 1976, pp. 78-84.

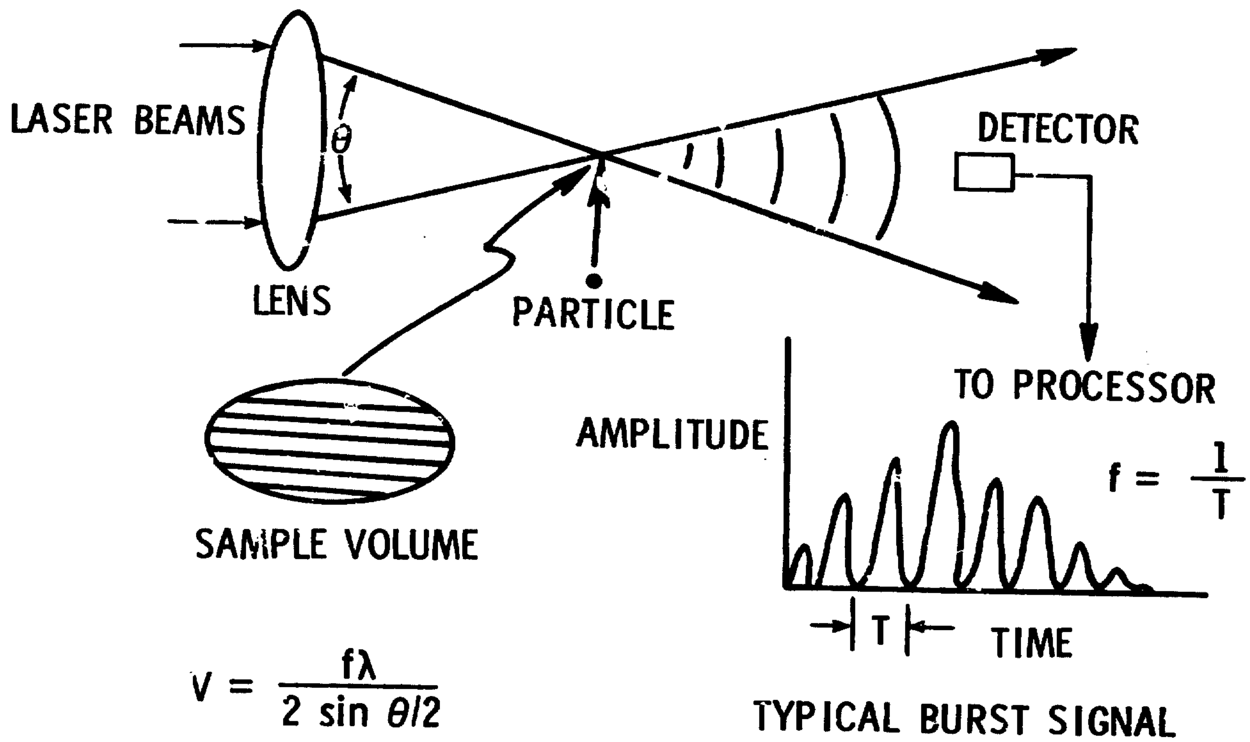

Figure 1. - Laser Velocimeter Technique.

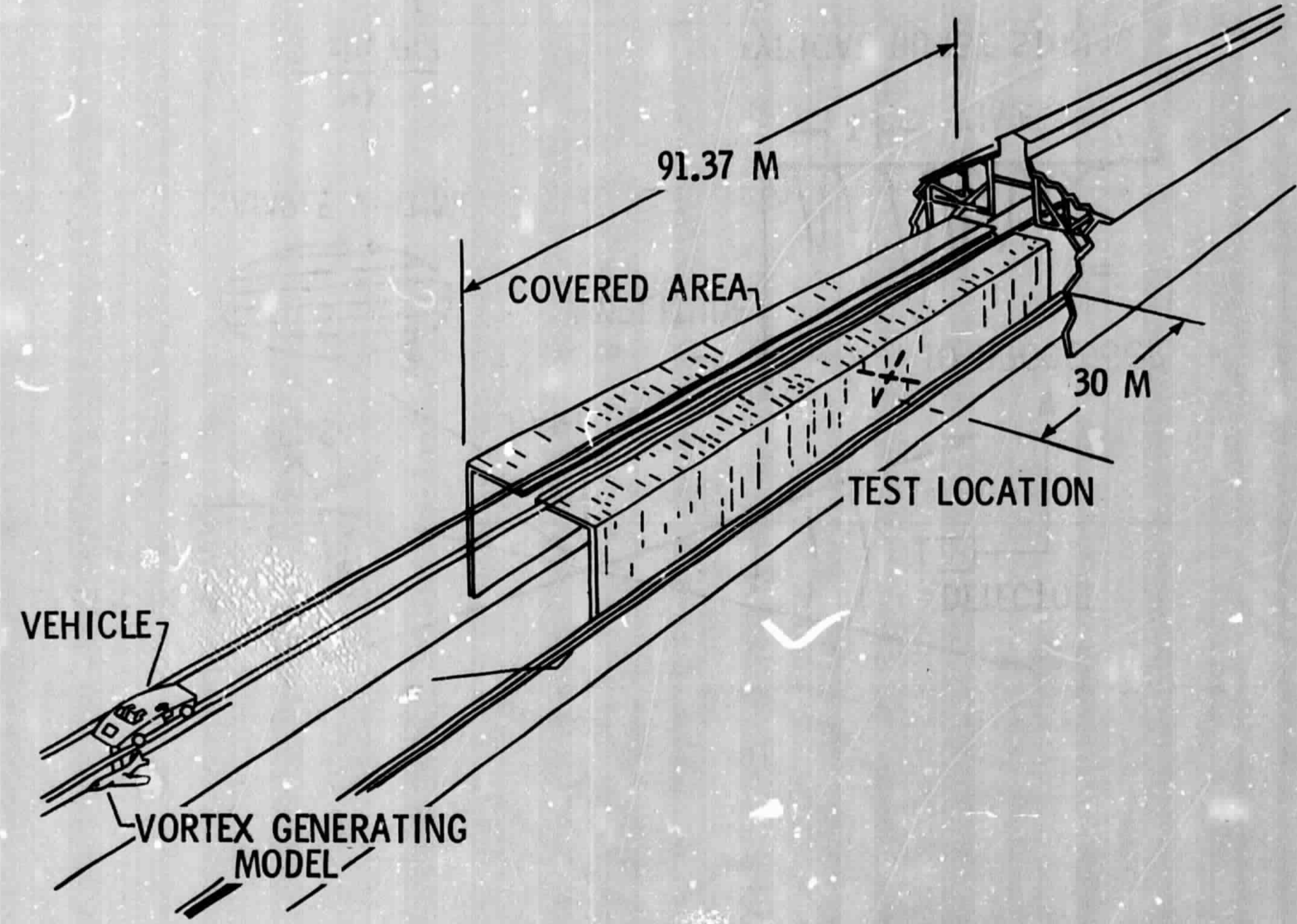

Figure 2. - A Sketch of the Langley Vortex Research Facility.

Figure 3. - The 0.167 Scale Model.

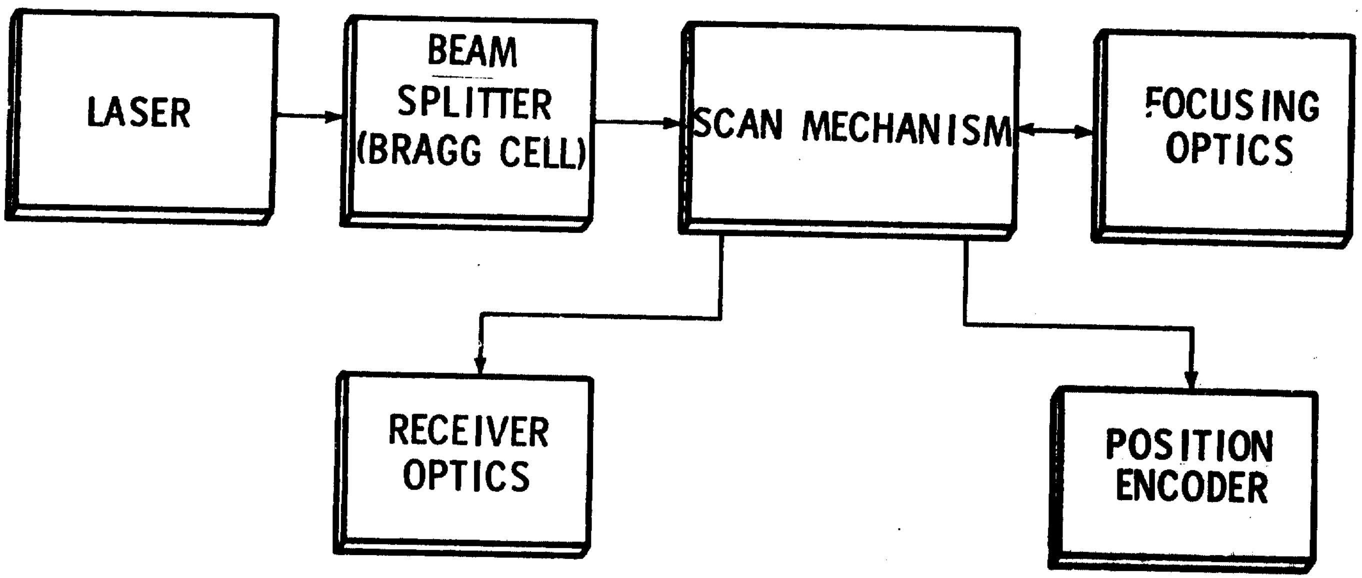

Figure 4. - A Block Diagram of the Optical System.

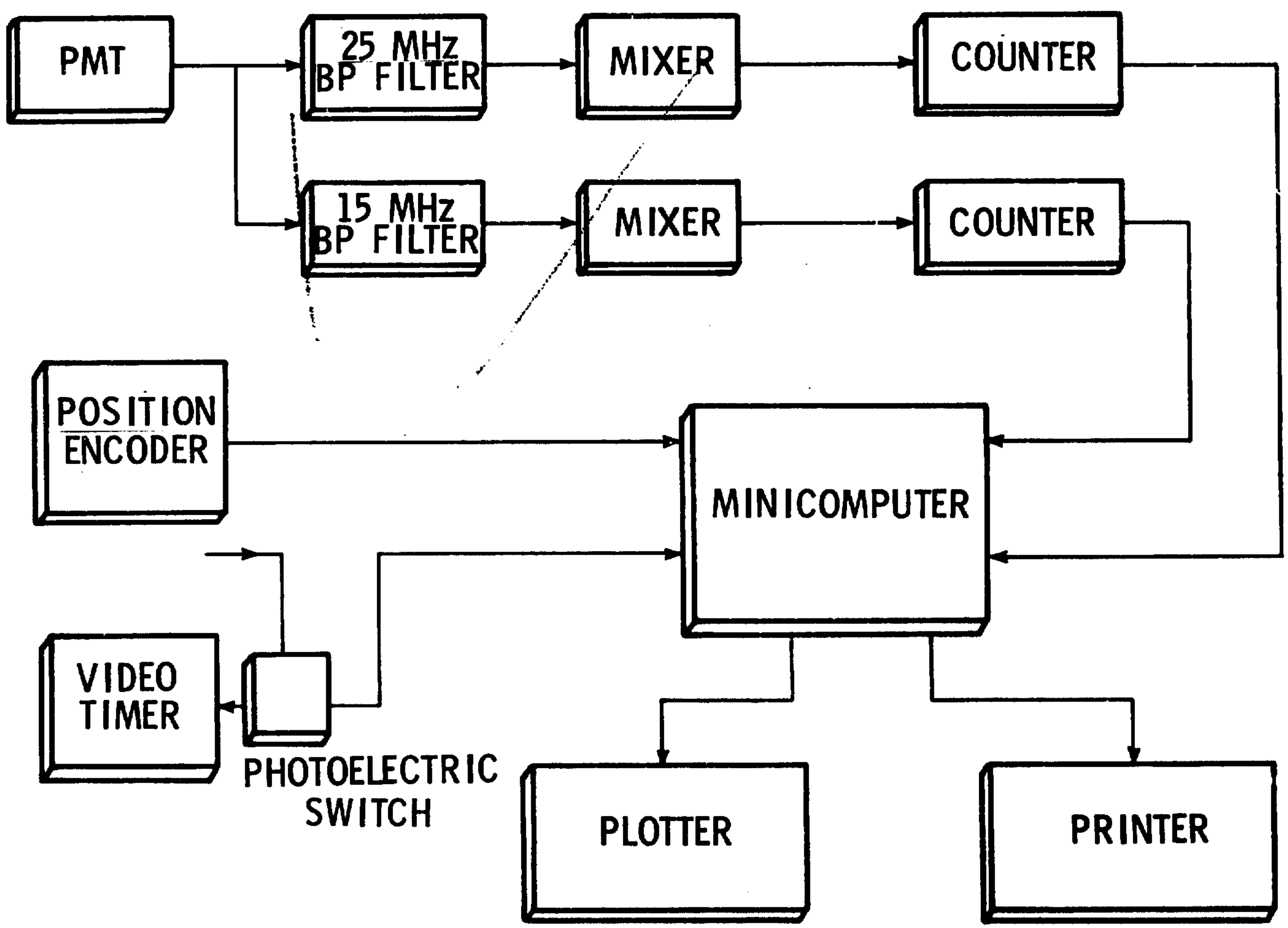

Figure 5. - A Block Diagram of the Data Acquisition and Processing System.

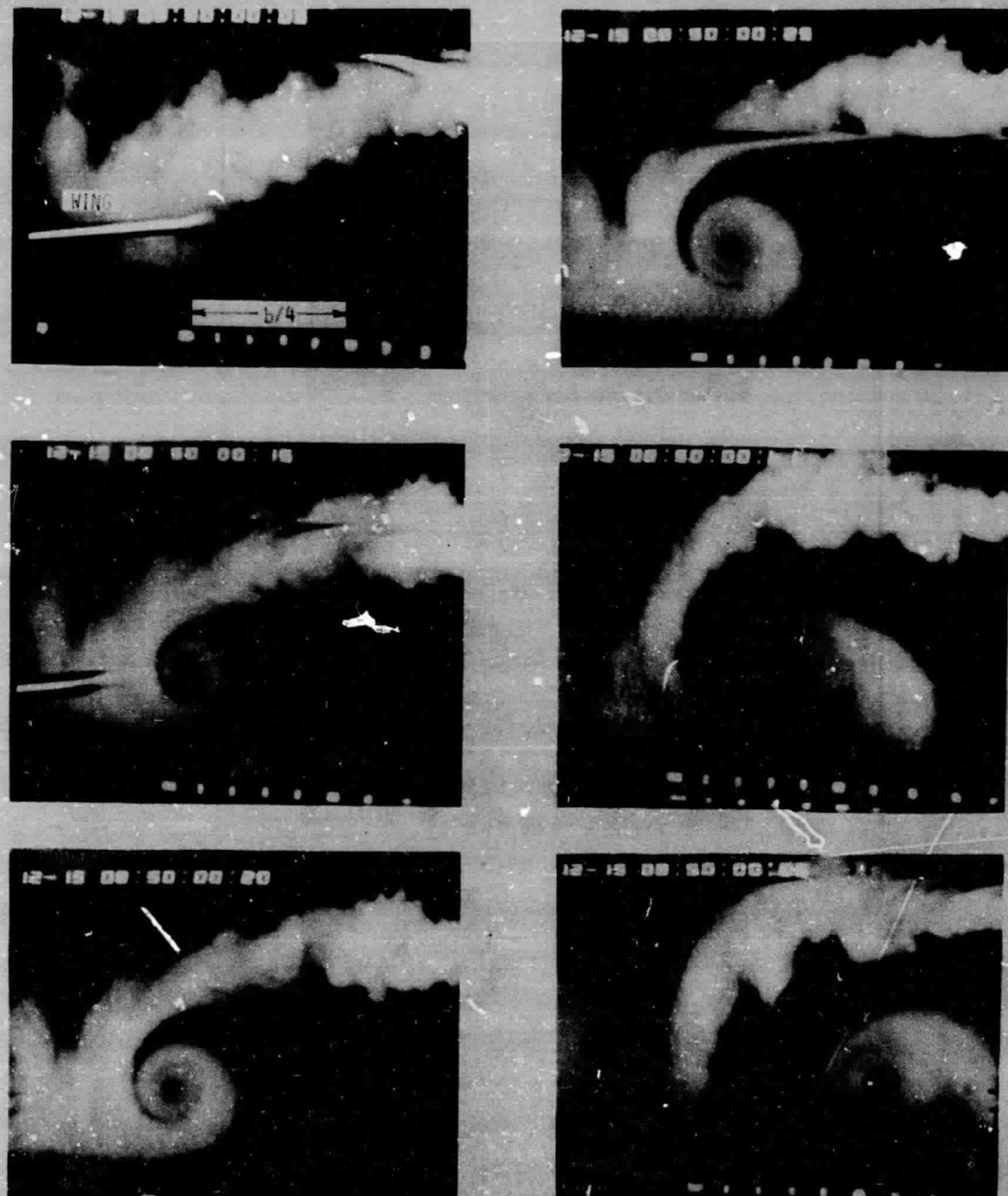

Figure 7. - Time History of the Basic Model Vortex System in Ground Effect.

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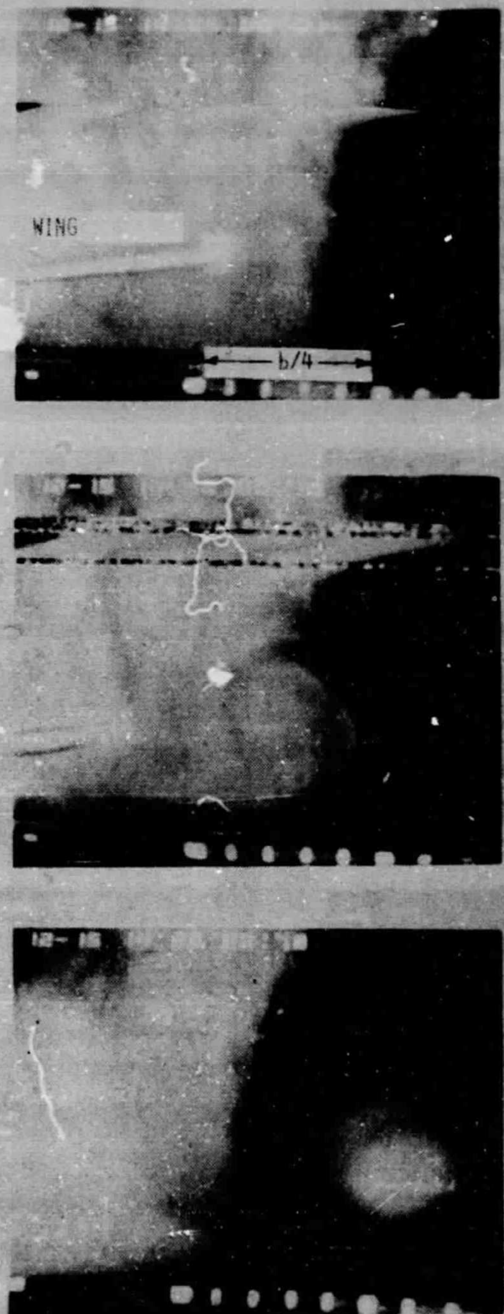

Figure 8. - Time History of Attenuated Vortex System in Ground Effect.

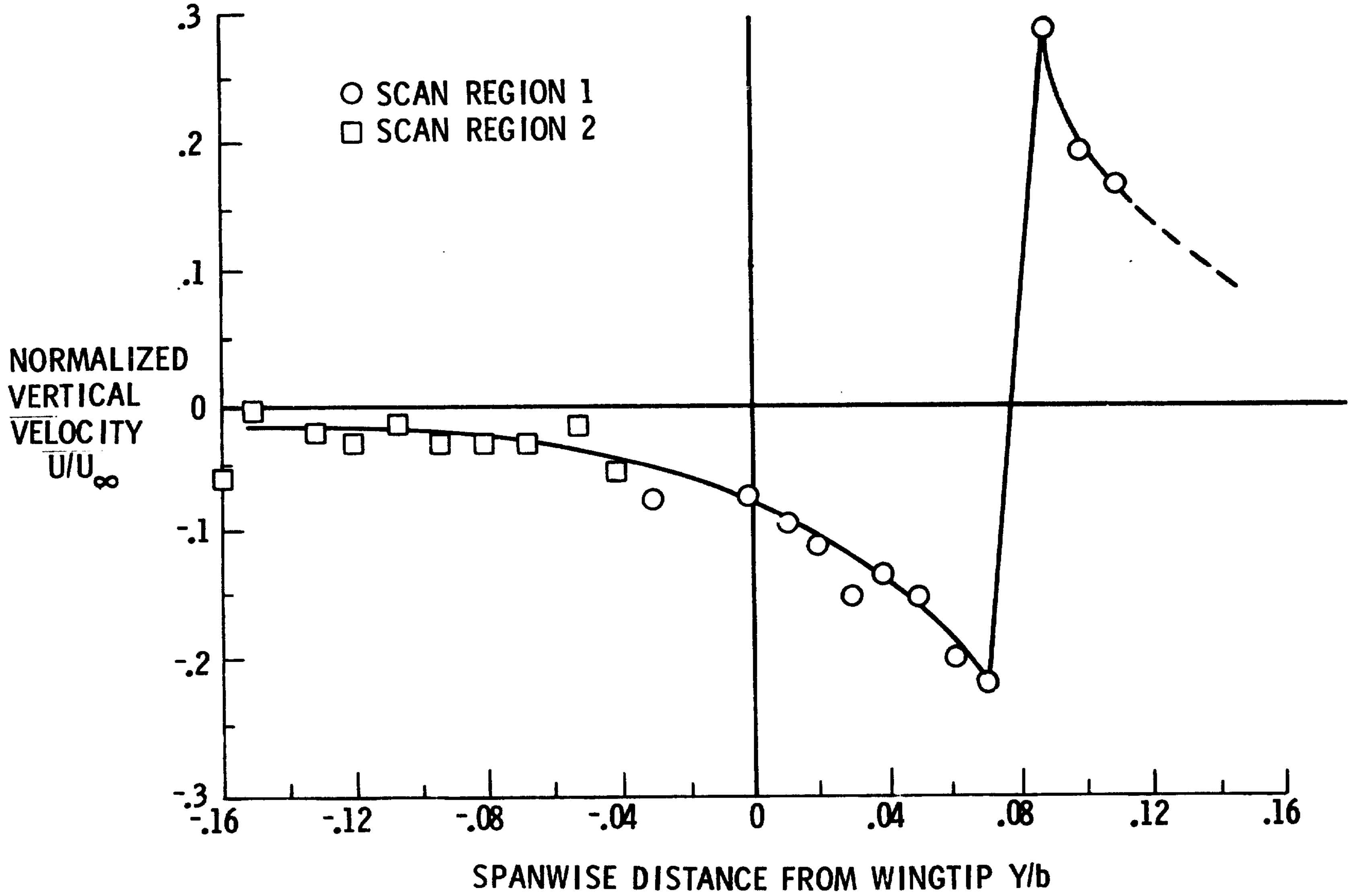

Figure 9. - The Vertical Velocity Distribution of the Basic Aircraft in Scan Regions 1 and 2. Downstream Separation Distance = 4.15b.

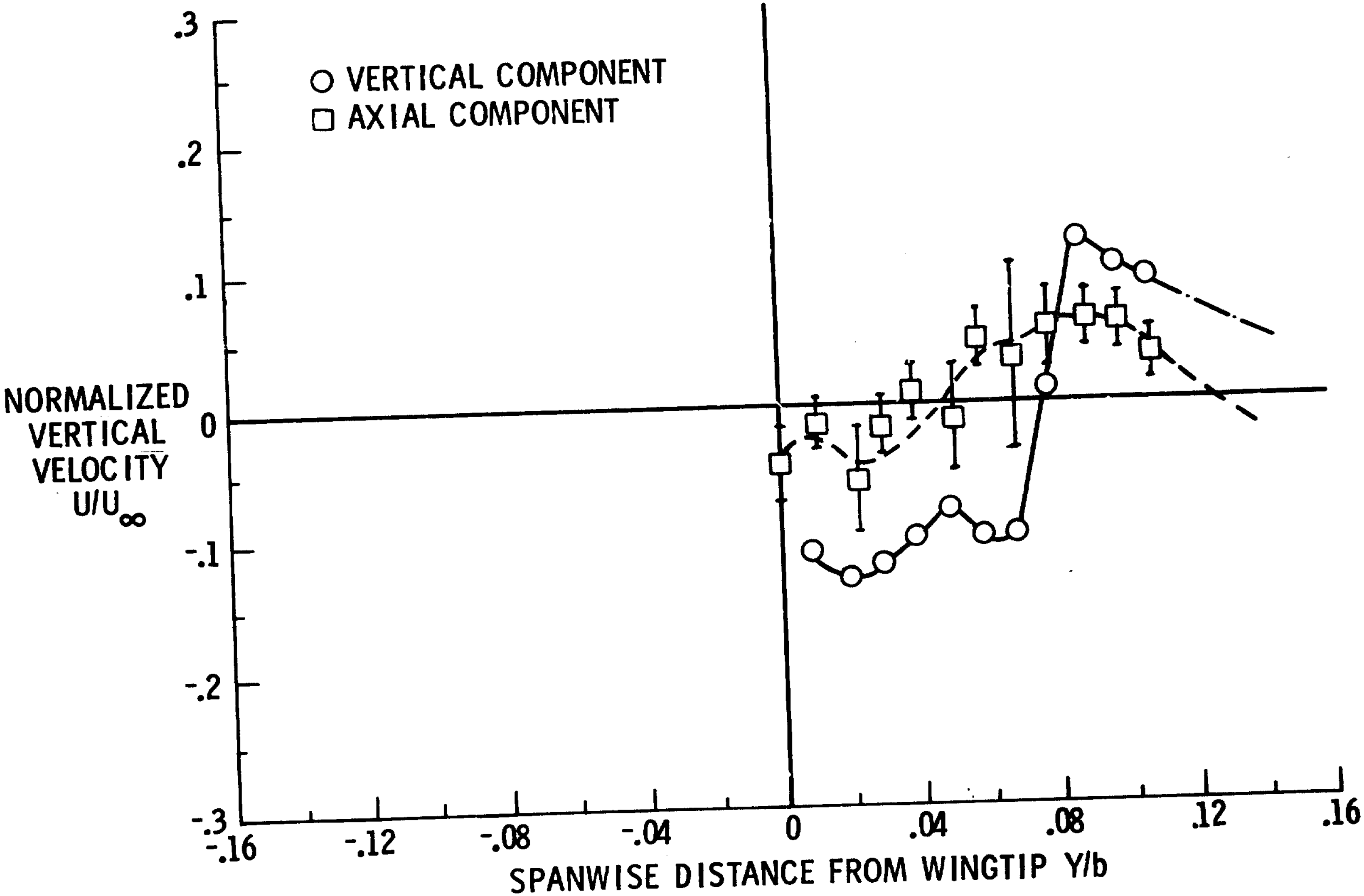

Figure 10. - The Axial and Vertical Velocity Distribution with Moderate Vortex Attenuation. Downstream Separation Distance = 4.24b.

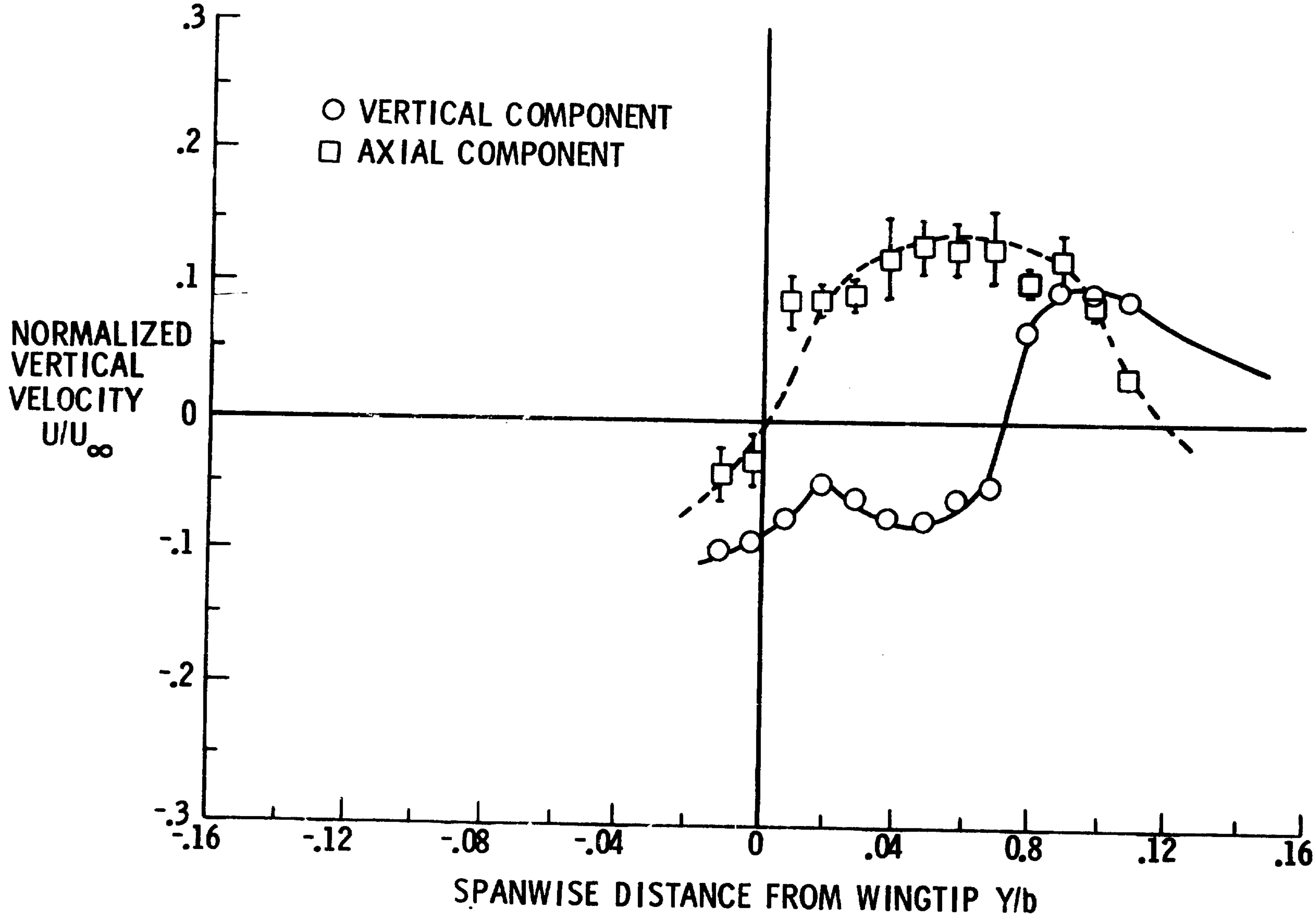

Figure 11. - The Axial and Vertical Velocity Distribution With Relatively Large Amount of Vortex Attenuation. Downstream Separation Distance = 3.90b.

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16. Abstract

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