15p

NASA TECHNICAL
MEMORANDUM

NASA TM X- 62,254

NASA TM X- 62,254

# A TWO–COLOR, DUAL BEAM BACKSCATTER LASER DOPPLER VELOCIMETER

George R. Grant and Kenneth L. Orloff

Ames Research Center
Moffett Field, California 94035

March 1973

(NASA-TM-X-62254) A TWO COLOR, DUAL
BEAM BACKSCATTERING LASER DOPPLER
VELOCIMETER (NASA) 15 p HC $3.00
N73-21393
CSCL 14B
Unclas
G3/14 68834

# A Two-Color, Dual Beam Backscatter Laser Doppler Velocimeter

George R. Grant and Kenneth L. Orloff*
Ames Research Center, NASA
Moffett Field, California 94035

## ABSTRACT

A laser Doppler velocimeter has been developed which uses two of the colors emitted from an argon-ion laser for the simultaneous measurement of orthogonal velocities. Designed for use in a 2.13 m by 3.05 m wind tunnel, it is capable of traversing its focal volume across spatially unstable flows at scan speeds of up to 1.5 m/sec. Its optical layout and principles of operation are discussed and the data from a typical traversal of a trailing wing-tip vortex are presented.

## Introduction

Since the introduction of laser Doppler velocimetry (LDV) in 1964[1] utilizing a local oscillator geometry, the state of the art has advanced through the period of reference beam systems[2] to the now popular dual-scatter (differential-Doppler) configuration.[3] The latter dual-beam technique offers the advantages of high signal-to-noise ratios[4] and the opportunity to process the Doppler signals on either a multiple[5] (continuous wave) or single[6] particle (Doppler burst) basis. Similarly, the applications of LDV have ranged from measurements in simple liquid flows[7] to current requirements for

---

*National Research Council Associate

flow diagnostics in the atmosphere[8] and in subsonic[9,10] and supersonic wind tunnels.[11,12] While from a signal-to-noise and spatial resolution viewpoint, it is most desirable to use a forward scatter, off-axis arrangement, limitations imposed by current applications often dictate that one use a confocal backscatter, on-axis LDV, employing a common lens system for both the transmission of the output beams and collection of the scattered radiation.

Growing concern over the hazard resulting from the lift-generated vortices shed by large, heavy transport aircraft has led to the need for sophisticated instrumentation capable of detailing, in a wind tunnel environment, the velocity structure of such a swirling flow. The central filament of this vortex is observed to move (in a near-random manner) about some nominal position with respect to the wind tunnel coordinates.[9] In the following sections the principles of operation of a two-component backscatter laser velocimeter capable of obtaining data in the presence of this spatial instability will be discussed.

## Design Considerations

In order to examine effectively the character of flows which are essentially two-dimensional (e.g., the trailing vortex), it must be possible to detect simultaneously two orthogonal velocity components. A two-dimensional, dual scatter system which uses orthogonal polarization of a single wavelength for isolation of the two velocity components has been demonstrated by other investigators.[13] Another approach, again with a single color from the laser, uses a frequency shift by an acousto-optic modulator to separate the two Doppler frequencies.[14] However, for low signal level measurement situations, these methods may suffer as a result of having divided the available laser light between the two velocity components.

The above mentioned drawback is not present when two distinct colors (available from an argon laser) are used. Furthermore, by using two different colors for component separation, polarization isolation is still available for use in adapting the system for detection of a third, on-axis, dimension as demonstrated by Orloff and Logan.[15] We, therefore, chose to take advantage of these facts and to make a two-component system by using the 488.0 nm and 514.5 nm lines from an argon laser.

The basic configuration of the instrument is a dual-beam backscatter LDV, wherein scattered laser light is collected by the same optical system that was used to focus the laser beams. The optical configuration is such that there are essentially two dual scatter systems, each with its own wavelength, which permits simultaneous measurement of two orthogonal velocity components in a plane perpendicular to the optical axis of the system. These wavelengths can be effectively separated in the received light by optical filtering.

An additional design requirement imposed on the system by the requirement to measure the velocity components of trailing vortices is that of rapid spatial scanning. In order to depict accurately vortex velocity profiles, scan rates must be high enough to assure that the vortex moves an insignificant amount as the profile is being recorded. This spatial scanning of the focal volume along the optical axis of the velocimeter is accomplished by changing the effective focal length of the output optics; present design of the optics permits a maximum scan speed of 1.5 m/sec.

We thus have an instrument which will measure two components of velocity while making a linear scan across the tunnel test section. Moreover, the system has been designed so that a typical vortex cross-section can be scanned in a time span of from 1 to 3 sec, depending upon the degree of vortex motion and the vortex detail required.

In addition to the specific requirements needed to make an instrument suitable for rapid scanning of unstable flows, the velocimeter was designed to be portable. All of the components, including the laser, were securely mounted on the same rugged baseplate so that the instrument maintained its alignment even under severe ambient vibration conditions.

## System Components

The physical layout of the laser optics and detectors is shown in Fig. 1.

The baseplate, on which all of the components are mounted, is a 68 cm by 147 cm by 1.25 cm aluminum jig plate reinforced by a 7.6 cm by 7.6 cm aluminum "I" beam. Attached to the front of the 4-watt argon laser (A) is a dense flint prism (B) which disperses the laser output into six distinct laser lines. Mask (D) contains two holes, 15 mm apart, that allow only the 488.0 nm and the 514.5 nm lines to pass on to mirrors (E) and (F). Mirror (E) is located such that the 514.5 nm line is reflected from it and the 488.0 nm line passes by it to mirror (F). In order to have room for the beam splitters (G and H) and Bragg cells (I and J), the two laser beams are separated by about 7.5 cm after being reflected from mirrors E and F. The purpose of the Bragg cells will be discussed later.

The two beam splitters divide each beam into two parallel beams 5.06 cm. apart; the 488.0 nm line is split vertically and the 514.5 nm line horizontally. After reflection from mirrors K and L, the two sets of beams are recombined into a square pattern. This square pattern is adjusted until all four beams are parallel and the center of the square pattern is coincident with the optical axis of the output lens system. Mirrors M and N are part of the backscatter system and each has four holes to allow the four beams making up the square pattern to pass unimpeded.

The output optics are made up of two parts, a large lens, O, whose position is fixed, and a small movable lens, P, whose position along the optical axis is continuously monitored and recorded. By adjusting the relative position of these two lenses, the distance of the point of focus of the four laser beams from the output lens can be varied from 60 cm to infinity. In actual use, the focal volume is scanned from 60 cm to 200 cm at scan rates that are variable from less than one cm/sec to greater than 1.5 m/sec.

Backscattered light which contains Doppler information for both components is collected by this lens and returned into the system parallel to the outgoing laser beams. Except for the small amount of light that passes back through the holes, this light strikes the dichroic mirror N and is separated into the two original colors. The 488.0 nm light is reflected and focused onto photomultiplier T and the 514.5 nm light is transmitted to mirror M and reflected and focused onto photomultiplier W. Additional interference filters are required in front of the photomultiplier, since the dichroic filter is only about 85% efficient. Outputs from these two photomultipliers are fed into two separate spectrum analyzers.

When the Bragg cells are not utilized, the Doppler signal can yield only absolute values of velocity, so that negative velocities cannot be distinguished from positive ones. However, the frequency measured by the photomultiplier is the difference between the frequencies of the Doppler shifted incident beams. It can be shifted by using a Bragg cell to change the frequency of one of the outgoing laser beams. When the velocity of flow passes through a zero value, the difference frequency does not pass through zero, but instead passes through the Bragg cell frequency. As long as the difference between the Doppler shifted components does not exceed the offset frequency, any directional ambiguity of individual components is resolved. Since the beam is diffracted by the Bragg cell, an optical wedge made from a water cell was inserted into the beam and its angle adjusted until the beam returned parallel to its original direction.

## Signal Processing

To date, all Doppler signals have been processed with two spectrum analyzers whose outputs, along with the analog voltage giving a measure of the position of the scattering volume, have been recorded on a high speed Visicorder tape.

Doppler frequencies and position information were read directly from the tape and then punched onto IBM cards for computation; profiles were constructed of the axial and tangential velocities from the computer tabulated data.

## Experimental Results

Detailed reporting of the results obtained from using this instrument for the analysis of trailing vortices appears in Ref. 9. Figures 2 and 3 show typical vortex velocity distributions obtained simultaneously from a single vortex traversal at two chord lengths downstream and over the time spans indicated. Smoke was added to the flow to provide scattering. Figure 2 displays a "slow" scan in which the movement of the vortex results in an apparent scatter of the tangential velocity data outside of the vortex core. Faster scans (Fig. 3) have been made in which the same distance is covered in approximately 0.75 sec, resulting in very smooth data outside of the vortex core, but very little core detail. The scan rate was limited by the physical constraint of moving the small lens while the response of the oscillograph galvonometers, in combination with the sweep integrator time required for a 30 KHz bandwidth, limited the sweep rate of the analyzer to 20 sweeps per sec. Since the lens system used for these tests was not fully achromatic, the focal volumes from the two colors were not coincident, but this separation is easily accounted for in the data reduction. Furthermore, the small scanning lens was driven at a constant rate; hence the focal volume was moving nonlinearly, yielding a nonlinear temporal scan.

One result of continuous scanning rather than step scanning is that the volume being sampled is actually changing as the spectrum analyzer is processing the Doppler frequency. At the 20 sweep/sec rate, each sweep takes 50 msec. Since the 30 KHz bandwidth is 6% of the total scan width of 5 MHz, the time to record the Doppler signal is less than 3 msec. At the higher traversal speed employed here, the movement of the focal volume during recording is less than 3 mm.

## Summary

A two-dimensional scanning laser velocimeter has been constructed and tested to aid in wake turbulence alleviation research. The character of wake vortices from conventional wings, as well as those from new designs and wings whose characteristics have been altered, can be studied in detail with this instrument.

Present methods of analyzing the data, though effective, are laborious. A two-channel RF tracker is being incorporated and will furnish an analog voltage for on-line computing so that individual vortex profiles can be plotted in near real-time.

The authors gratefully acknowledge the aid of Jim Johnston of the Model and Instrument Machining Branch in the construction of this laser Doppler velocimeter.

## References

1. Y. Yeh and H. Z. Cummins, Appl. Phys. Lett. 4, 176 (1964).
2. R. J. Goldstein and W. F. Hagen, Phys. of Fluids 10, 1349 (1967).
3. M. K. Mazumder, A Symmetrical Laser Doppler Velocity Meter and its Application to Turbulence Characterization, NASA CR-2031, May 1972.
4. J. F. Meyers, "Investigation of Basic Parameters for the Application of a Laser Doppler Velocimeter"; AIAA 6th Aerodynamic Testing Conference, Paper No. 71-288, March 1971.
5. J. D. Fridman, R. M. Huffaker, and R. F. Kinnard, Laser Focus, (1968).
6. D. B. Brayton and W. H. Goethert, New Velocity Measuring Technique Using Dual-Scatter Laser Doppler Shift, AEDC-TR-70-205, November 1970.
7. H. H. Bossel and K. L. Orloff, J. Hydronautics 6, 101 (1972).
8. R. M. Huffaker, A. V. Jelatian, and W. H. Keene, Aircraft Wake Turbulence and its Detection; Ed. J. H. Olsen, et al., (Plenum Press, 1971), p. 113-124.
9. K. L. Orloff and G. R. Grant, The Application of Laser Doppler Velocimetry to Trailing Vortex Definition and Alleviation, NASA TM X-62,243, February 1973.
10. A. E. Lennert, D. B. Brayton, F. L. Crosswy, et al., Summary Report of the Development of a Laser Velocimeter to be Used in AEDC Wind Tunnels, AEDC-TR-70-101, July 1970.

11. G. R. Grant and R. W. Donaldson, A Laser Velocity Measurement System for High-Temperature Wind Tunnels, NASA TM X-1976, April 1970.

12. W. J. Yanta, D. F. Gates, and F. W. Brown, "The Use of a Laser Doppler Velocimeter in Supersonic Flow", AIAA 6th Aerodynamic Testing Conference, Paper No. 71-287, March 1971.

13. D. B. Brayton, H. T. Kalb, and F. L. Crosswy, A Two-Component Dual Scatter Laser Velocimeter with Frequency Burst Signal Readout, Workshop on Laser Doppler Velocimetry, Purdue University, 9-10 March, 1972.

14. F. L. Crosswy, J. O. Hornkohl, and A. E. Lennert, Signal Characteristics and Signal Conditioning Electronics for a Vector Velocity Laser Velocimeter, Workshop on Laser Doppler Velocimetry, Purdue University, 9-10 March, 1972.

15. K. L. Orloff and S. E. Logan, "Confocal Backscatter Laser Velocimeter with On-Axis Sensitivity", submitted for publication (January 1973).

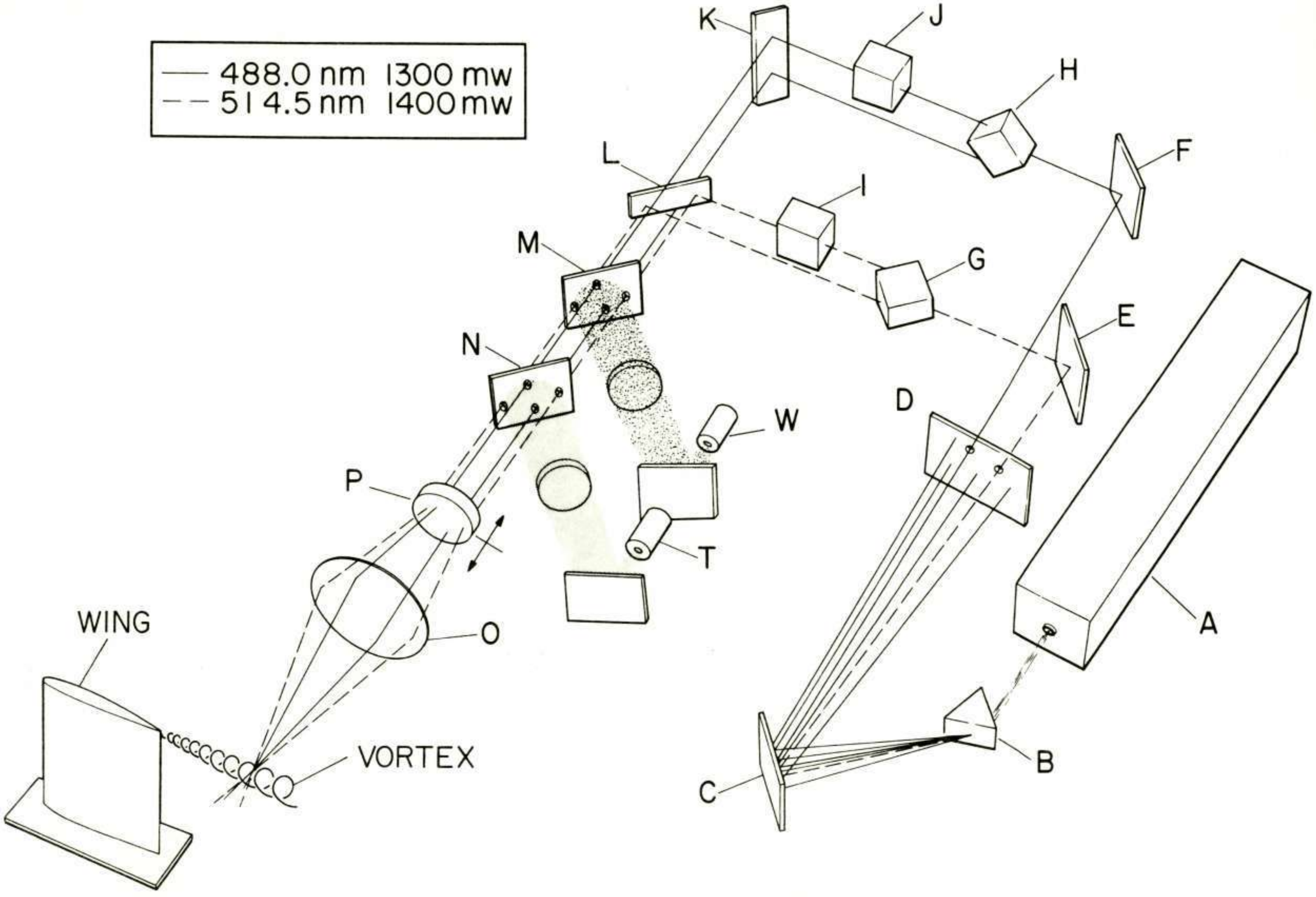

Fig. 1 Schematic diagram of two-color laser Doppler velocimeter

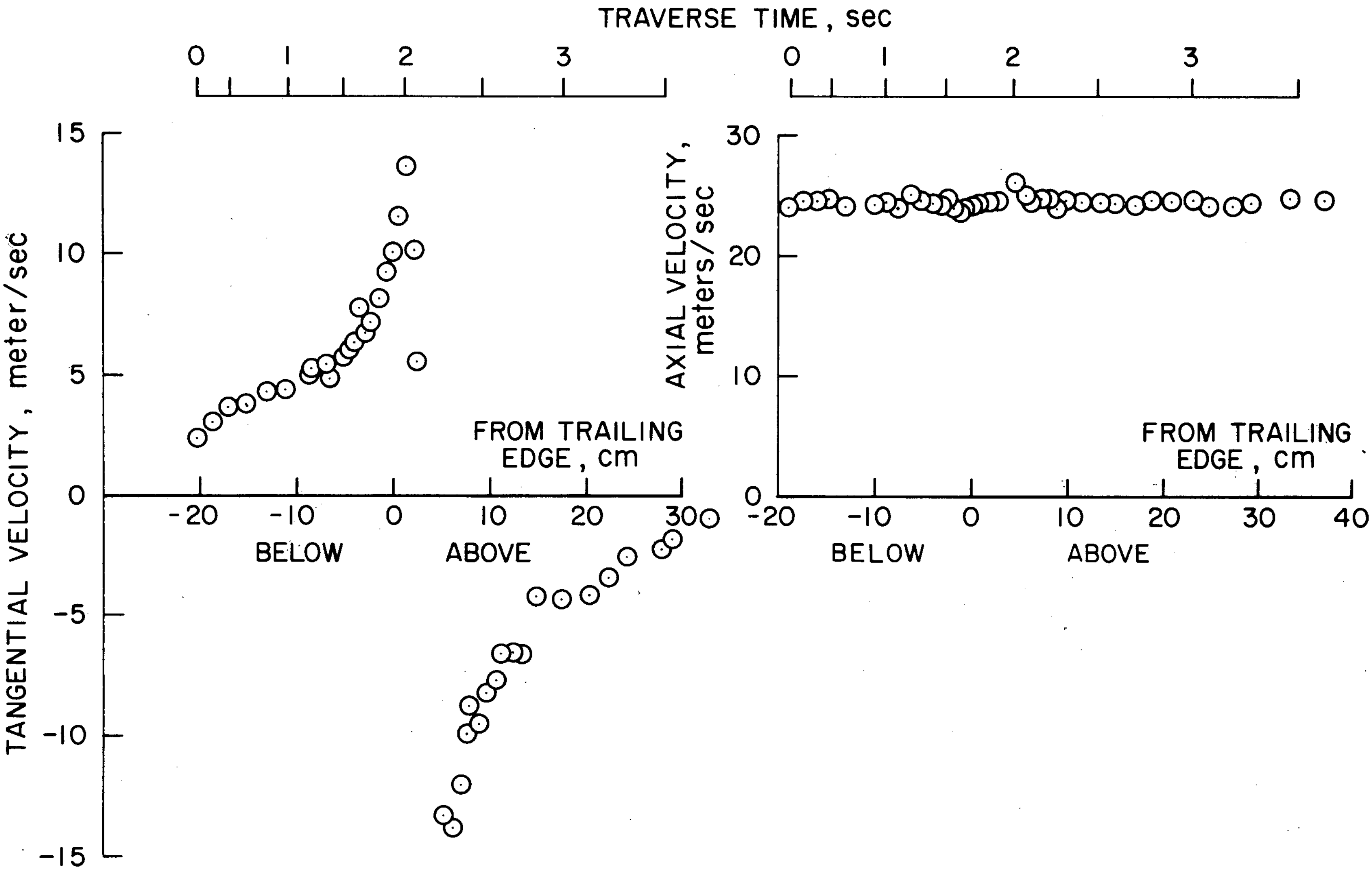

Fig. 2 Vortex velocity distributions - slow traversal.

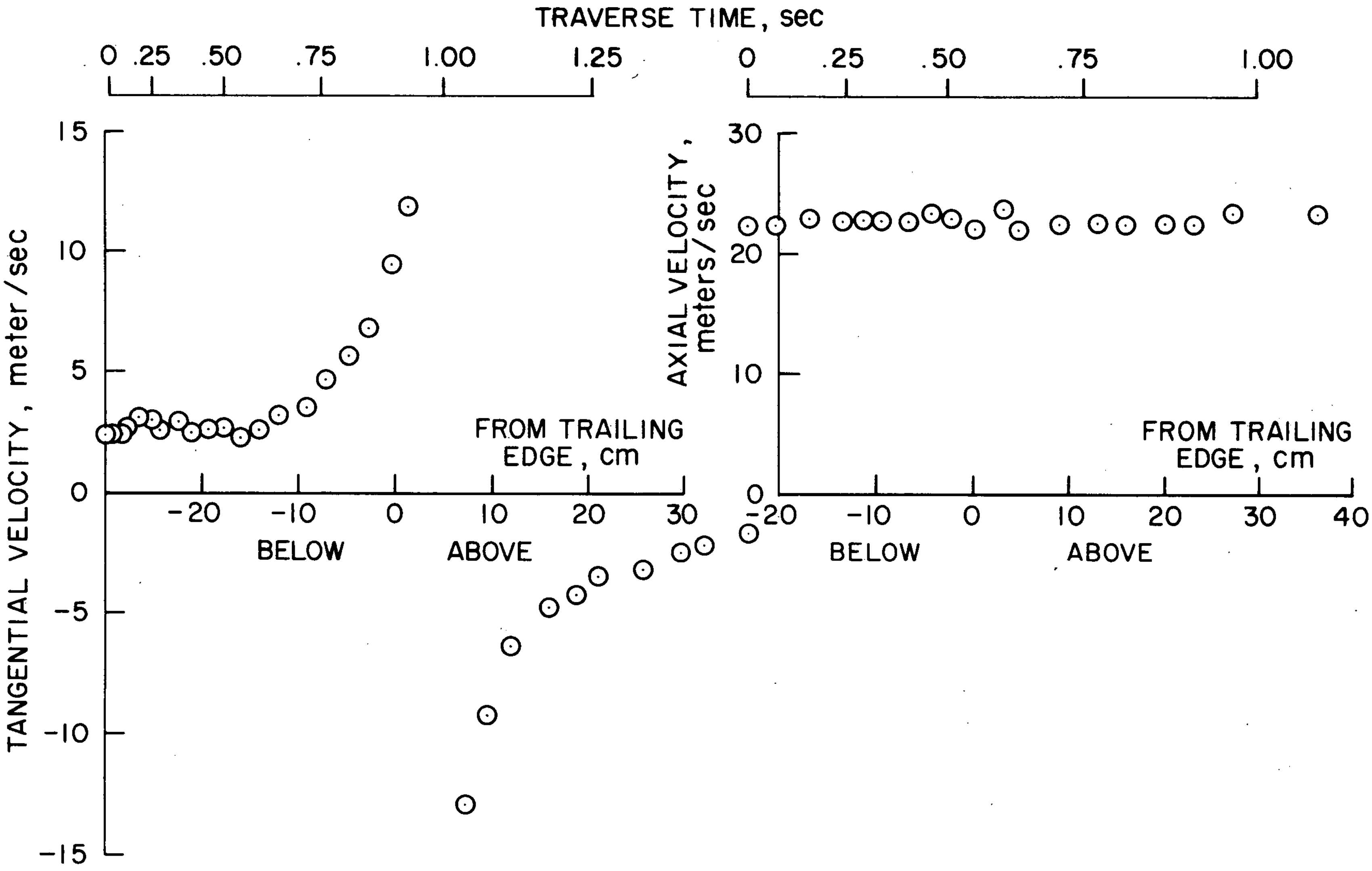

Fig. 3 Vortex velocity distributions - fast traversal.