

Lawrence Berkeley National Laboratory

Recent Work

Title

MEASUREMENTS OF VELOCITY FLUCTUATION CORRELATIONS USING A SINGLE-COMPONENT LASER DOPPLER VELOCIMETRY SYSTEM

Permalink

<https://escholarship.org/uc/item/5z94x9fb>

Author

Ng, T.T.

Publication Date

1981-12-01



Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

RECEIVED
LAWRENCE

BERKELEY LABORATORY

ENERGY & ENVIRONMENT DIVISION

JAN 20 1982

LIBRARY AND
DOCUMENTS SECTION

Submitted to the American Institute of Aeronautics
and Astronautics Journal

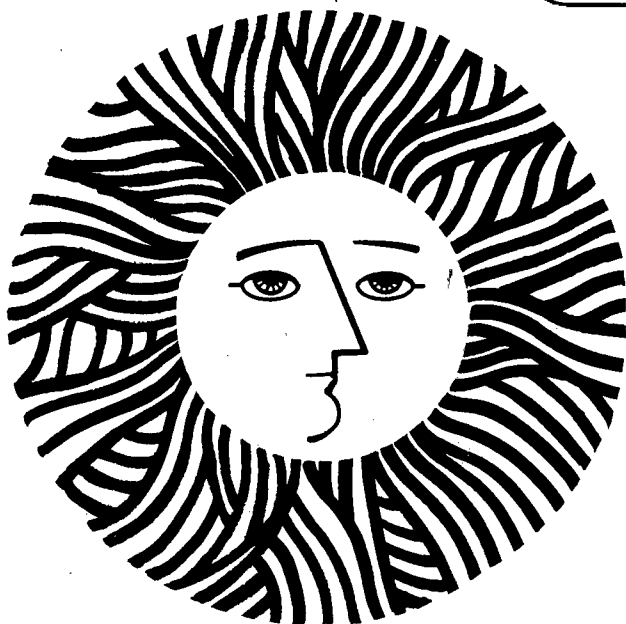
MEASUREMENTS OF VELOCITY FLUCTUATION CORRELATIONS
USING A SINGLE-COMPONENT LASER DOPPLER VELOCIMETRY
SYSTEM

T. T. Ng

December 1981

TWO-WEEK LOAN COPY

*This is a Library Circulating Copy
which may be borrowed for two weeks.
For a personal retention copy, call
Tech. Info. Division, Ext. 6782*



LBL-13702
22

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

Measurements of Velocity Fluctuation Correlations Using
a Single-Component Laser Doppler Velocimetry System

T. T. Ng

Lawrence Berkeley Laboratory
University of California - Berkeley
Berkeley, California 94720.

Abstract

Methods of measuring several velocity fluctuation correlations: $\overline{u'v'^2}$, $\overline{v'u'^2}$, $\overline{(u'v')^2}$, and $\overline{u'v'(u'^2 + v'^2)}$ using a single-component laser Doppler velocimetry (LDV) system were discussed. The methods offer an alternative to the more complex and costly two-component LDV system for many fluid mechanical measurements. Feasibility of the techniques is demonstrated by studying the turbulent boundary layers over a flat plate with no wall heating, strong stepwise wall heating, and exothermic chemical reaction.

Contents

Laser Doppler velocimetry has become one of the most widely used techniques in fluid mechanical and combustion experiments in recent years. However, its application has been limited mainly to measurements of the mean and the root-mean-square (rms) velocity distributions. In most situations, velocity fluctuations that are relevant to turbulent kinetic energy and momentum transports are valuable in characterizing the flows.

If both velocity components, u in the x -direction and v in the y -direction, are recorded simultaneously, all the correlations involving

the velocity fluctuations, u' and v' , can be evaluated. This would require a two-component optical system and two frequency measurement units to record two frequency readings simultaneously. The procedures and apparatus involved are a lot more complicated than single-component LDV measurements. By relatively simple methods, however, some important velocity fluctuation correlations can be derived from single-component measurements.

By measuring the velocity component u and two other components, u_1 and u_2 , at angles of $\pm \theta$ relative to the x-axis (Fig. 1), it can be shown that

$$u_1 = u \cos \theta + v \sin \theta \quad (1)$$

$$u_2 = u \cos \theta - v \sin \theta \quad (2)$$

Using the definition $u_i = \bar{u}_i + u_i'$, where superscript ' denotes fluctuation and $\bar{\quad}$ denotes the mean, the following equations can be derived:

$$\bar{u}_1 = \bar{u} \cos \theta + \bar{v} \sin \theta \quad (3)$$

$$\bar{u}_2 = \bar{u} \cos \theta - \bar{v} \sin \theta \quad (4)$$

$$u_1' = u' \cos \theta + v' \sin \theta \quad (5)$$

$$u_2' = u' \cos \theta - v' \sin \theta \quad (6)$$

The derivations of \bar{v} , $\overline{v'^2}$, and the Reynolds stress from the three velocity measurements, as described by Durrani and Greated¹, are summarized below:

$$\bar{v} = (\bar{u}_1 - \bar{u}_2)/2 \sin \theta \quad (7)$$

$$\overline{v'^2} = [(\overline{u_1'^2} + \overline{u_2'^2})/2 - \overline{u'^2} \cos^2 \theta] / \sin^2 \theta \quad (8)$$

$$\overline{u'v'} = (\overline{u_1'^2} - \overline{u_2'^2}) / 4 \cos \theta \sin \theta \quad (9)$$

These procedures are quite standard and have been used in many studies. Several additional higher order correlations, however, can also be derived from the same measurements.

Measurements of $\overline{u'v'^2}$ and $\overline{v'u'^2}$

For convenience of further discussion, define

$$k_1 = \overline{u'^2} + \overline{v'^2} \quad (10)$$

By evaluating $\overline{(1)^3}$ and $\overline{(2)^3}$, the following equations are obtained:

$$\begin{aligned} \overline{u_1'^3} = \overline{u'^3} \cos \theta + 3 \overline{u'v'^2} \cos \theta \sin^2 \theta + 3 \overline{u'^2 v'} \cos^2 \theta \sin \theta \\ + \overline{v'^3} \sin^3 \theta \end{aligned} \quad (11)$$

$$\begin{aligned} \overline{u_2'^3} = \overline{u'^3} \cos^3 \theta + 3 \overline{u'v'^2} \cos \theta \sin^2 \theta - 3 \overline{u'^2 v'} \cos^2 \theta \sin \theta \\ - \overline{v'^3} \sin^3 \theta \end{aligned} \quad (12)$$

Adding eq. (11) and (12),

$$\begin{aligned} \overline{u_1'^3} + \overline{u_2'^3} = 2 \overline{u'^3} \cos^3 \theta + 6 \overline{u'v'^2} \cos \theta \sin^2 \theta \\ \text{or} \quad \overline{u'v'^2} = (\overline{u_1'^3} + \overline{u_2'^3} - 2 \overline{u'^3} \cos^3 \theta) / 6 \cos \theta \sin^2 \theta \end{aligned} \quad (13)$$

Subtracting eq. (12) from (11),

$$\begin{aligned} \overline{u_1'^3} - \overline{u_2'^3} = 2 \overline{v'^3} \sin^3 \theta + 6 \overline{v'u'^2} \cos^2 \theta \sin \theta \\ \text{or} \quad \overline{v'u'^2} = (\overline{u_1'^3} - \overline{u_2'^3} - 2 \overline{v'^3} \sin^3 \theta) / (6 \cos^2 \theta \sin \theta) \end{aligned} \quad (14)$$

In some situations, it may be inconvenient to measure v directly. If θ is chosen to be 60° , the following can still be obtained:

$$\overline{v'k_1} = (\overline{u_1'^3} - \overline{u_2'^3}) / (3\sqrt{3}/4) \quad (\text{with } \theta = 60^\circ) \quad (15)$$

Measurements of $\overline{u'v'k_1}$ and $(\overline{u'v'})^2$

By evaluating $(1)^4$ and $(2)^4$, the followings are obtained:

$$\begin{aligned} \overline{u_1'^4} = & \overline{u'^4} \cos^4\theta + 4 \overline{u'v'^3} \cos\theta \sin^3\theta + 6 \overline{u'^2v'^2} \cos^2\theta \sin^2\theta \\ & + 4 \overline{u'^3v'} \cos^3\theta \sin\theta + \overline{v'^4} \sin^4\theta \end{aligned} \quad (16)$$

$$\begin{aligned} \overline{u_2'^4} = & \overline{u'^4} \cos^4\theta - 4 \overline{u'v'^3} \cos\theta \sin^3\theta + 6 \overline{u'^2v'^2} \cos^2\theta \sin^2\theta \\ & - 4 \overline{u'^3v'} \cos^3\theta \sin\theta + \overline{v'^4} \sin^4\theta \end{aligned} \quad (17)$$

Subtracting eq. 17 from eq. 16, one gets

$$\overline{u_1'^4} - \overline{u_2'^4} = 8(\overline{u'v'^3} \cos\theta \sin^3\theta + \overline{u'^3v'} \cos^3\theta \sin\theta)$$

If θ is chosen to be 45° , i.e., $\cos\theta = \sin\theta = \sqrt{2}/2$, it can be shown that

$$\overline{u'v'k_1} = (\overline{u_1'^4} - \overline{u_2'^4}) / 2 \quad (\text{with } \theta = 45^\circ) \quad (18)$$

Adding eqs. 16 and 17, one obtains

$$\begin{aligned} \overline{(v'u')^2} = & (\overline{u_1'^4} + \overline{u_2'^4} - 2 \overline{u'^4} \cos^4\theta - 2 \overline{v'^4} \sin^4\theta) \\ & / 12 \cos^2\theta \sin^2\theta \end{aligned} \quad (19)$$

Example of application

The techniques had been used in studying the boundary layers over a flat plate with no wall heating, strong stepwise heating, and exothermic chemical reaction². Reasonably satisfactory results were obtained. Some examples of the $\overline{u'v'^2}$ and $\overline{v'k_1}$ profiles of the isothermal boundary layer are shown in Fig. 2. More detailed results of the

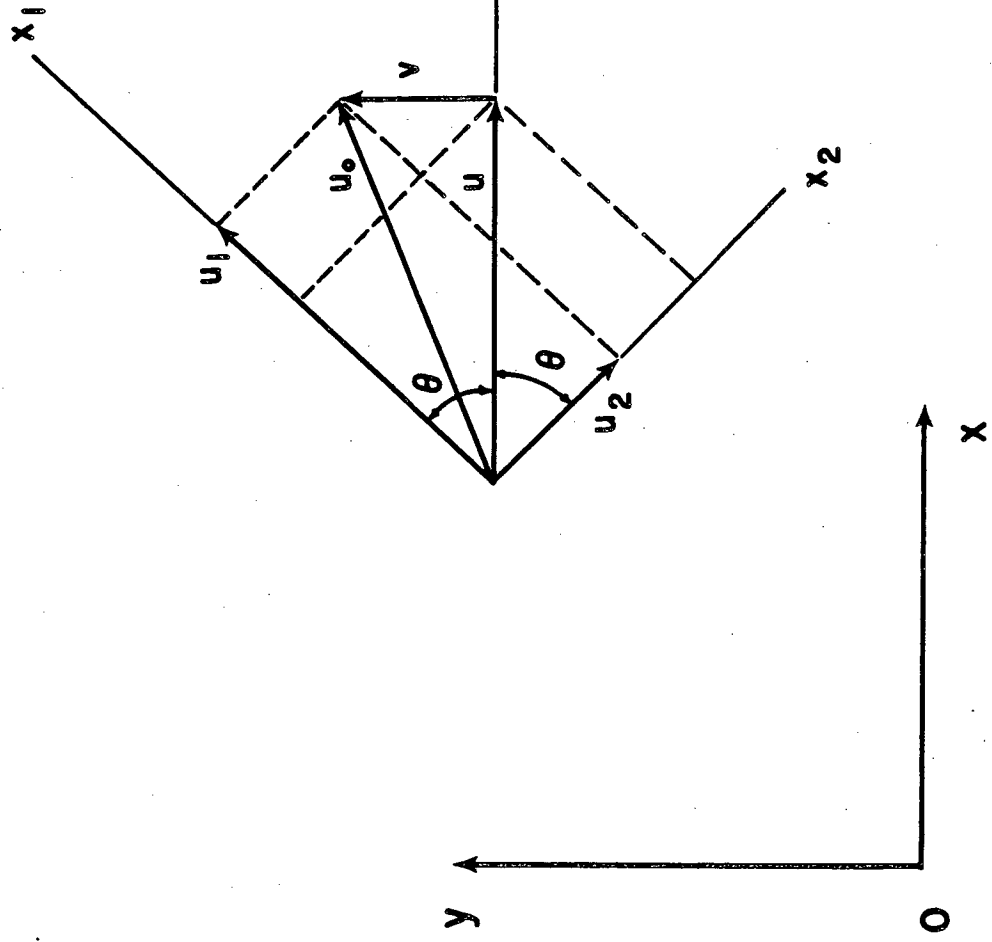
study will be presented in subsequent publications still under preparation.

Acknowledgement

This work was supported by the Assistant Secretary for Energy Research, Office of Basic Energy Sciences, Chemical Sciences Division of the U.S. Department of Energy under Contract W-7405-ENG-48.

References

1. Durrani, T. S. and Greated, C. A. (1977), Laser System in Flow Measurement, Plenum Press, New York.
2. Ng, T. T. (1981), Experimental Study of a Chemically Reacting Turbulent Boundary Layer, Ph.D. thesis, University of California, Berkeley, California.



u_0 = Instantaneous Velocity
 u_1 = Velocity component in x_1 -direction
 u_2 = Velocity component in x_2 -direction
 u = Velocity component in x -direction
 v = Velocity component in y -direction

Fig. 1 The velocity components

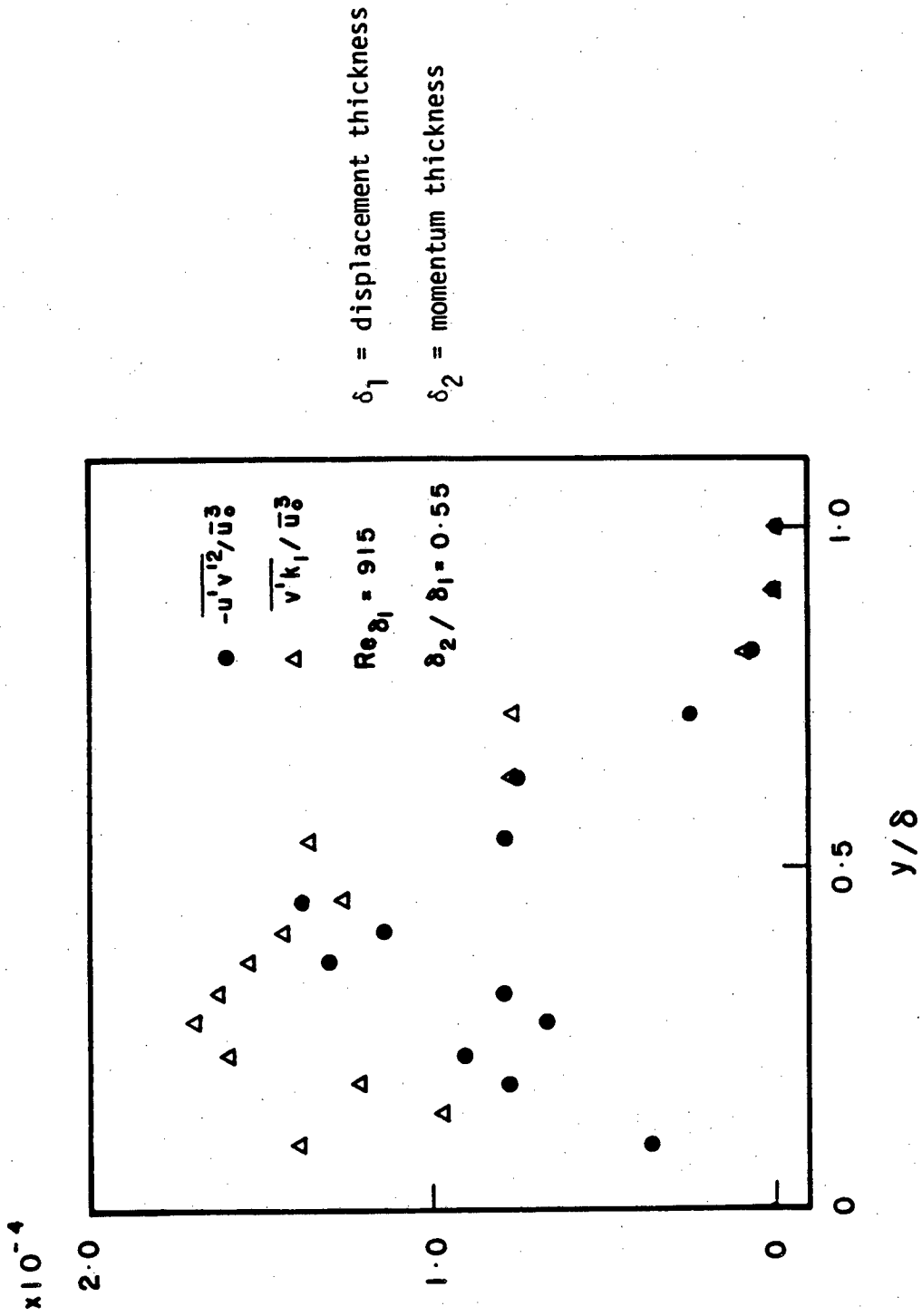


Fig. 2 Examples of $\overline{u'v'^2}$ and $\overline{v'k_1}$ profiles of an isothermal turbulent boundary layer over a flat plate.

This report was done with support from the Department of Energy. Any conclusions or opinions expressed in this report represent solely those of the author(s) and not necessarily those of The Regents of the University of California, the Lawrence Berkeley Laboratory or the Department of Energy.

Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Department of Energy to the exclusion of others that may be suitable.

TECHNICAL INFORMATION DEPARTMENT
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720