Simple Method for Determining the Laser-Velocimeter Focal Point with the Aid of a Hot-Wire Anemometer

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Introduction

LASER velocimetry has long been recognized as a powerful tool for wind-tunnel measurements, primarily because of its nonintrusive nature. A particularly troublesome aspect of this technique, however, is the exact determination of the laser-velocimeter focal point, especially along the beam axis. Although this determination is of paramount concern to all experimental measurements, the published literature provides very little discussion of this issue, despite its importance. A technique is proposed herein that employs a hot-wire anemometer to determine the exact focal-point location. The details of this method are described in this Note.

Physical Principle

The thermal energy balance for a conventional hot-wire anemometer heated by a current i, in still air, may be written as

$$i^2R_w = c(T_w - T_a) \tag{1}$$

where c is a constant, R_w the hot-wire operating resistance, and T_w and T_a the temperatures of the hot wire and the surrounding air, respectively. If a hot wire in still air intercepts a laser beam, the hot wire receives thermal energy from the intercepted laser beam. If the hot wire is operated in a constant-temperature bridge, the heating current i will decrease to maintain the thermal balance in accordance with Eq. (1). As a consequence, the hot-wire bridge output $E = (iR_w)$ decreases. Therefore the location where the maximum reduction in hot-wire bridge output is observed determines the focal point of the laser beam. This technique may also be used in place of constant-current resistance thermometers or thermocouples to measure the distribution of laser beam intensity. Furthermore, since the wire resistance R_w is a constant, Eq. (1) indicates that the squared bridge output is also proportional to the mean value of the beam intensity incident on the hot-wire element.

Application to the Laser Transit Anemometer

Using a constant-temperature hot-wire bridge circuit, the proposed method was applied to determine focal-point locations for a laser-dual-focus velocimeter, also a laser transit anemometer (LTA). The LTA system consists of dual laser beams separated by some distance in the direction of the desired velocity, over which the time-of-flight for light scattering particles is measured. Precise knowledge of both the distance and the time permits accurate velocity determination. For two-dimensional measurements, the LTA system allows either standard single-color operation or multi-color operation. The single-color lenses for this application are mounted in the optical head, which is connected by optical fiber cables to a 3-W argon-ion laser source with a focal length of 500 mm. The basic concepts and detailed descriptions of both two- and three-dimensional measurements using the LTA system are given by Schodl.[1]

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The configuration of the dual beams (referred to as beam I and beam II) and the end-plated hot wire are shown in Fig. 1. The x axis is taken as the flow direction, the y axis is in the laser beam direction, and the z axis is along the hot-wire axis. Nominal dimensions of the beam diameter at the focal point, the beam separation (designated by S), and the hot-wire diameter are about 18, 265, and 5 μm, respectively.

An important parameter for measurements in highly turbulent flows is the focal depth, defined as the length of the measurement volume. For the measurements in this study, the focal depth (shown later in Fig. 3) was designed to be twice the length of the beam separation. Consequently, the measurement volume of each beam was cylindrical with an aspect ratio of about 30. Also the beam intensity for the focal-point detection was reduced to ensure that for the hot-wire bridge $T_w > T_a$, as required by Eq. (1). The total power for both beams was set at 70 mW, whereas values on the order of 250 mW are typically used for conventional LTA velocity measurements.

The first step in the focal-point determination procedure is the visualization of the dual beams using some light scattering particles (such as tobacco smoke), with the focal region roughly estimated by eye. Then the hot wire is traversed across the beam axis in this visible region. Figure 2 shows a typical beam-intensity profile across the dual beams near the focus. The dual Guassian-like distributions correspond to beam I and beam II, respectively, although some extraneous fluctuations due to air currents are superimposed on the distribution. Each

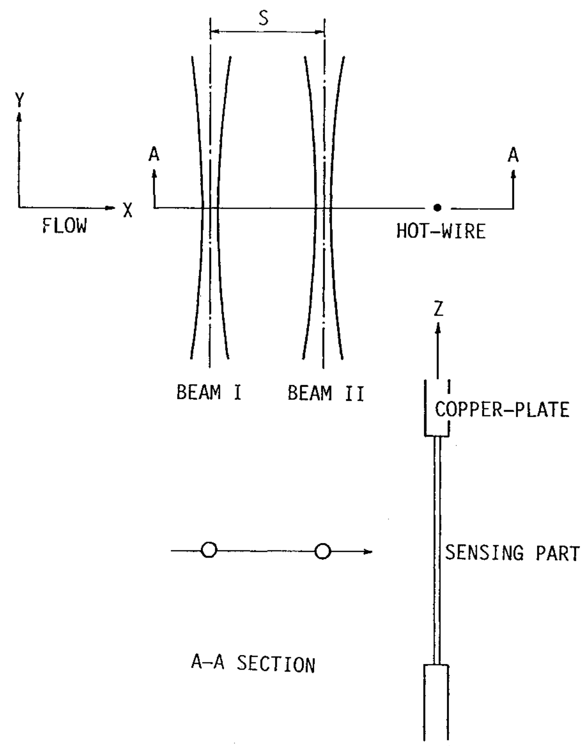

Fig. 1 Configuration of dual laser beams of the laser transit anemometer and hot-wire element with copper-plated ends.

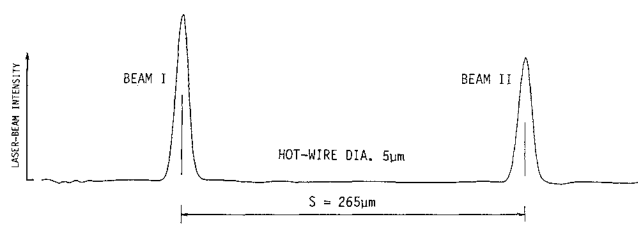

Fig. 2 Typical laser-beam intensity distribution across the dual beams of the LTA near the focus.

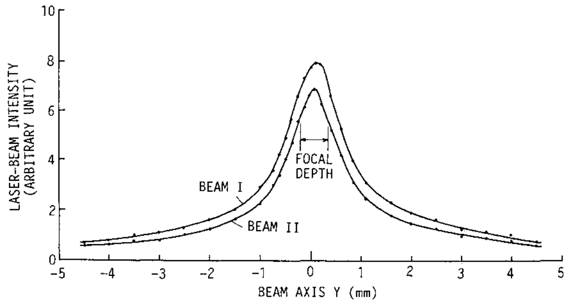

Fig. 3 Laser-beam intensity distribution along the beam axis. The focal depth is defined as the length of the measurement volume of the LTA along the beam.

peak amplitude indicates the beam intensity on the corresponding beam axis, and Fig. 2 clearly shows that beam I and beam II exhibit different intensities. The distance between the two peaks, however, represents the beam separation S, which is the critical parameter for velocity measurement with the LTA system. The accuracy with which this distance can be determined defines the accuracy of the overall measurement and is ultimately determined by the traversing mechanism precision. For this particular experiment, the traversing mechanism accuracy was ± 1 μm in the x axis and ± 5 μm in the y axis. These measurements are repeated at various beam-axis locations using an arbitrary origin, and peak amplitudes plotted against beam-axis location, as shown in Fig. 3. As indicated, each beam-intensity distribution is quite symmetrical about the peak position, and the peaks for each beam occur at exactly the same y location. This y location is the desired focal point for the LTA measurement. In the present application, the focal point is determined with an accuracy of about 0.1 mm in Fig. 3. If more accurate determination is desired, more data points near the peak in the distribution of Fig. 3 should be required, or rather, the focal point might be practically determined from the peak position on a spline joining the points of the distribution in Fig. 3.

Conclusions

A simple technique has been described for determining the exact focal point of a laser velocimeter, using only a hot-wire anemometer. To verify the proposed method, the focal-point separation of the two laser beams of an LTA system was measured. This example is only one potential application of the proposed technique, and others may include the laser Doppler velocimeter, or any laser measurement requiring exact knowledge of the focal-point location. Since hot-wire anemometers are extremely sensitive to thermal disturbances, the technique requires only modest laser beam power for the focal-point detection, as compared to that required for velocity measurement. Furthermore, since the squared bridge output of a constant-temperature anemometer indicates the mean value of the beam intensity intercepted by the hot-wire element, the method can be extended to evaluate other laser-beam parameters such as beam power, beam separation, beam diameter, relative beam intensity (e.g., between two laser beams), beam divergence, and cross-sectional beam-intensity distribution (Takagi[2]).

Acknowledgment

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References

[1]Schodl, R., "A Multi Colour Fiber Optic Laser Two Focus Velocimeter for Three-Dimensional Flow Analysis," AIAA Paper 88-3034, 1988.

[2]Takagi, S., "A Simple Method of Measuring Laser-Beam Properties Using a Hot-Wire Anemometer" (to be submitted).

New High Reynolds Number Mach 8 Capability

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Introduction

THE Naval Surface Warfare Center (NSWC) has an operational high Reynolds number Mach 8 leg in its Hypervelocity Wind Tunnel No. 9. This facility capability is unique and represents a benchmark in hypersonic aerodynamic ground testing. This Note highlights the facility development and summarizes its operational performance.

The NSWC Hypervelocity Wind Tunnel No. 9 is a blowdown facility that uses nitrogen as a working fluid. A test run is initiated by the rupture of two metal diaphragms that separate the high- and low-pressure sections of the wind tunnel. After initiation, the fixed volume of test gas, which is simultaneously heated and pressurized in the heater, expands through an axisymmetric contoured nozzle into the 5-ft-diam test section. Cold gas from pressurized storage vessels enters the heater base as the test gas exits, thereby maintaining a constant supply pressure throughout the wind-tunnel run. Run times, nominally 1 s in duration, are a function of the supply pressure and the fixed volume in the heater.

Tunnel 9 operates with interchangeable nozzles that expand the nitrogen to Mach numbers of 10, 14, and now 8. Reynolds numbers range from 0.5 to 20×10^6/ft at Mach 10 and 0.07 to 4×10^6/ft at Mach 14. Supply pressures range from 100 to 20,000 psia with supply temperatures up to 3400°R. Typical supply temperatures are chosen to operate the tunnel at a freestream temperature just above the nitrogen condensation temperature. More details on the operation of tunnel 9 can be found in Hill et al.,[1] Kavetsky,[2] Hedlund and Ragsdale,[3] and Ragsdale.[4]

Mach 8 Hardware Description

The Mach 8 development philosophy was to utilize as much existing hardware, including an auxiliary test cell, with no modifications to the high-pressure (heater and driver vessels) section of the tunnel. The existing Mach 10 heater assembly and thermal insulation package provided the supply gas to the Mach 8 nozzle. Figure 1 is a schematic layout of the tunnel components illustrating the hardware differences between the Mach 8 and 10 tunnel configurations. The Mach 8 nozzle is 20 ft long with an exit diameter of 33 in. Therefore, the facility operates in an open-jet fashion. More details on the design and fabrication of the hardware can be found in Hedlund et al.[5]

Calibration Tests

The Mach 8 calibration test included 10 flow survey runs and two verification data runs. The 10 flowfield survey runs were made with a 21-finger cruciform pitot rake. The rake

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