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Development of Point Doppler Velocimetry for Flow Field Investigations

Angelo A. Cavone[1], James F. Meyers[2], Joseph W. Lee[3]

1: Swales Aerospace, NASA Langley Research Center, Hampton, Virginia 23681, United States
A.A.Cavone@larc.nasa.gov
2: Distinguished Research Associate of NASA Langley Research Center, Hampton, Virginia 23681, United States
james.f.meyers@larc.nasa.gov
3: NASA Langley Research Center, Hampton, Virginia, 23681, United States
joseph.w.lee@nasa.gov

Abstract A Point Doppler Velocimeter (pDv) has been developed using a vapor-limited iodine cell as the sensing medium. The iodine cell is utilized to directly measure the Doppler shift frequency of laser light scattered from submicron particles suspended within a fluid flow. The measured Doppler shift can then be used to compute the velocity of the particles, and hence the fluid. Since this approach does not require resolution of scattered light from individual particles, the potential exists to obtain temporally continuous signals that could be uniformly sampled in the manner as a hot wire anemometer. This leads to the possibility of obtaining flow turbulence power spectra without the limitations of fringe-type laser velocimetry. The development program consisted of a methodical investigation of the technology coupled with the solution of practical engineering problems to produce a usable measurement system. The paper outlines this development along with the evaluation of the resulting system as compared to primary standards and other measurement technologies.

1. Introduction

Over the last 16 years, a new generation of laser-based diagnostic instruments based on the research of Komine, *et. al* (1991) have been introduced to the fluid mechanics research community. These techniques employ molecular iodine absorption filters as light frequency discriminators enabling flow fields to be characterized in a non-intrusive manner. To date several variations of the Doppler Global Velocimeter (DGV) (or Planar Doppler Velocimeter (PDV)) have been developed to characterize the movement of flow embedded particles. Taking advantage of the optical frequency shift observed when light is scattered by moving particles due to the Doppler effect, this technique exploits the light frequency-to-light absorption transfer function of iodine vapor to measure the directional velocity of particles passing through a single-frequency laser light sheet. The application of lessons learned and methodologies developed during DGV research has resulted in a spin-off technique referred to as point Doppler velocimetry (pDv).

pDv trades the spatial capabilities of DGV to make planar velocity measurements for the ability to make temporally continuous velocity measurements at a point by using photomultipliers in place of video cameras and a focused laser beam in place of a light sheet. This offers advantages over the more matured fringe-type Laser Doppler Velocimeter (LDV) because pDv measurements are obtained by detecting optical frequency variations in overall scattered light levels. Thus, the requirement of LDV to detect single particle passages through the sample volume is overcome. Consequently, smaller scattering particulates can be used eliminating concerns related to particle lag. The potential to make continuous velocity measurements overcomes the Poisson random sampling of LDV, the low frame rates of cameras used in DGV, and possibly improves the accuracy of temporal statistical measurements beyond that of LDV.

With sufficient scattering particles pDv offers the potential to make flow frequency measurements that are as accurate as those of hot-wire anemometry. In addition pDv measurements can be expanded to perform spatial cross correlations by replacing the single detector with a linear array and imaging a portion of the laser beam onto the array. The non-intrusive nature of pDv removes two limitations of the hot-wire which; (a) disturbs the investigated flow and (b) are not capable of measuring reverse flows. This offers the potential for improvements over hot-wire spatial cross correlation measurements which must be taken in a manner that insures that the wake of one probe does not influence the second probe.

2. Background

Non-intrusive, laser-based flow instruments are attractive to aerodynamicists since they do not disturb the flow. Further, global flow mapping techniques such as Particle Image Velocimetry (PIV) yield instantaneous flow maps and reduce facility run times and costs. Alternatively, Komine *et. al* (1991) proposed using molecular absorption filters together with video cameras to globally map velocity flow fields. Their DGV system overcame the requirement of fringe-based laser velocimetry and PIV to resolve single particle passages and increased the field of view over what PIV was capable of at that time.

Since the time of Komine's original work, a number of organizations have worked diligently to develop DGV systems that have proven to be reliable and robust enough to meet the demands of production flow research facilities. Several variations of DGV systems employing molecular iodine as an absorption medium have been developed that use either Argon-Ion or frequency doubled Nd:YAG lasers to illuminate particle laden flows. The geometry used in most of these systems is presented in Fig. 1.

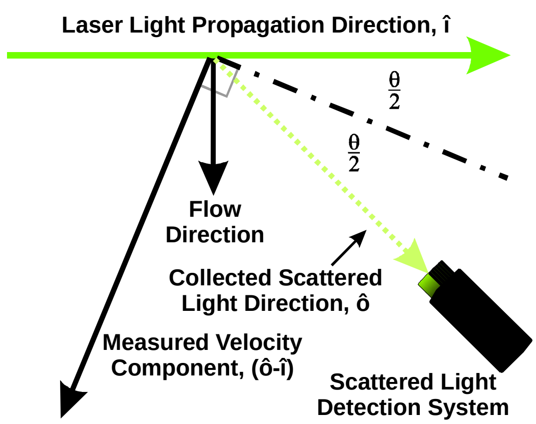

Fig. 1 DGV velocity measurement geometry.

In this arrangement, the Doppler frequency and hence the velocity component measured is dependent on the location of the laser light sheet with respect to the receiving optical system. The component of velocity measured, $\hat{o} - \hat{\imath}$, is the vector perpendicular to the bisector of the unit vector of the collected scattered light, $\hat{o}$, and the propagation direction of the input laser light, $\hat{\imath}$. For a given flow velocity vector V, the collected scattered laser light frequency shift, $\Delta\nu$, is dependent on the dot product between the velocity vector V, and the measurement vector $\hat{o} - \hat{\imath}$, (Equation 1), (Meyers, Komine (1991)), where c represents the speed of light and ν_o represents the laser light frequency. Thus, multiple detector systems and/or light sheets have been used to measure additional, non-orthogonal, velocity components. These non-orthogonal components can then be translated into standard orthogonal u, v, and w velocity components.

$$\Delta\nu = \frac{\nu_o\left(\hat{o} - \hat{\imath}\right) \bullet V}{c} \qquad [1]$$

Fig. 2 is a representative DGV system in which the absorption characteristics of iodine vapor acts as an optical frequency discriminator on the scattered laser light produced when particles pass through the illuminated region. The optical frequency difference between the output of a either a single-frequency Argon ion or frequency doubled Nd:YAG laser and the collected scattered light is the Doppler frequency induced by the motion of the particles. The light-frequency dependent optical