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VELOCITY MEASUREMENT ACCURACY IN LDV

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SUMMARY

A great number of parameters must be taken into account in order to insure a good confidence in the measurements; the accuracy is not given only by the resolution of the electronics; we shall discuss the influence of other parameters such as the calibration, the probe volume location and characteristics, the particle behavior in addition to the way of making the statistics.

1. INTRODUCTION

For any instrument, it is usual to give the user the accuracy with which measurements are performed. In laser velocimetry the same requirement appears; a good criterion is to consider the degree of confidence, due to statistics performed on many samples; but these uncertainty values are often optimistic and may mask larger errors if all precautions are not taken at different levels in the use of the apparatus. The geometry of the probe volume, its calibration, its location relative to the flow are important parameters, which must be looked at carefully; the influence of the particle behavior and of the data reduction and display are also mentioned, because conception errors (in the optics or in the electronics or in the choice of particles or in the way to generate them) often induce truncated information which are not obvious.

2. PROBE VOLUME INFLUENCE

The probe volume diameter in the vertical plane XZ is generally a few hundred µm; along the Y axis, when the receiving optics axis is inclined by about 10° relative to the emitting optics axis, the length seen extends on one mm; these dimensions characterize the spatial resolution of the instrument. If the angle between emitting and receiving optics is increased (until 90°), this length of the probe volume may be minimized, but the drawback comes from the fact that the collected scattered light is scattered in a part of the Mie diffusion diagram where the intensity is much lower. Therefore when reducing the probe length (which improves spatial resolution and leads to a reduced integration of velocity gradients in 3D flows), the intensity of scattered light is decreasing drastically, and the velocimeter becomes sensitive to bigger particles, which do not follow very well the flow fluctuations (then the velocity gradients) : compromises must be found !

When robust translation mechanisms are employed, as in ONERA set-ups, the displacement readings are done with an accuracy of 0.01 mm and emitting and receiving bench readings never deviate more than 0.03 mm. Nevertheless this optical probe volume must be located relative to the model placed inside the flow. Generally a hole, having a slightly larger diameter than the probe volume diameter, is done in a thin plate linked to the model and its position is perfectly known in the model frame. The probe volume is perfectly centered in this hole when the six laser beams of a 3D LV emerge from it, presenting diffraction rings observed on a screen; this way the uncertainty on the probe volume location relative to the model is less than 0.1 mm along the three axes. Normally this adjustment must be done during a wind-tunnel run in order to take into account eventual model displacements during tests.

It is very important to know with a high accuracy the probe volume location when making explorations in boundary layers near walls, because any uncertainty of this location relative to the wall drastically changes the data interpretation.

The size of the probe volume must be also minimized in order to improve the spatial resolution, which avoids integrating too much velocity gradients inside the probe volume. The spatial resolution of a laser velocimeter must not be greater than the dimension of the flow structures to be studied. Yet let us remember that decreasing the probe volume size induces small values of the fringe spacing i, therefore high frequencies to be processed at high velocities, which generally reduces the measurement accuracy: in laser velocimetry the user must always deal with this type of compromise. In fact in LV theory we assume that the particle has a constant velocity during its transit time across the probe volume (due to temporal velocity fluctuations at frequencies not so high, i.e. less than 1 MHz), but we also assume that it is a "local" measurement, which means that the velocity field is spatially constant across the probe volume: this last assumption may not be true in some flow regions having important velocity gradients. The influence of such a velocity gradient may be partially corrected by post-processing the data: along an exploration line z for instance, from the mean velocity evolution drawing, one may estimate the mean velocity gradient du_z across the probe volume at each measured location; this quantity may be deduced from the measured r.m.s. value $\overline{u'^2_m}$, assuming that the temporal velocity fluctuations $\overline{u'^2}$ are independent from this spatial mean velocity gradient, and then it comes:

$$\overline{u'^2} = \overline{u'^2_m} - \delta u_z{}^2$$

3. CALIBRATION

Let us remember that for one velocity component with a laser velocimeter two laser beams are crossed and focused inside a small probe volume, where a fixed (or mobile when using Bragg cells) fringe pattern is created. The velocity component is measured perpendicularly to the fringe planes (or to the interior bisector of the two crossed beams), through the well known relationship: