2D-LCA - AN ALTERNATIVE TO X-WIRES

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Abstract The 2d-Laser Cantilever Anemometer (2d-LCA) is an novel anemometer for two-dimensional velocity measurements in fluids. It uses a mico-structured cantilever with a specifically designed tip as a sensing element and is capable of performing measurements with extremely high temporal ($\approx$ 100kHz) and spatial ($\approx 140\mu$m) resolutions. Another big feature is a large angular range of 180° in total. The performance of the 2d-LCA has been verified by means of comparative measurements with commercial x-wires in laboratory-generated turbulent flow. We are able to show that both measurement techniques provide comparable statistics.

INTRODUCTION

Hot wires or x-wires are the standard and most popular anemometers used to perform highly-resolved measurements in turbulent flows. For hot wire anemometry a tiny tungsten or platinum wire is used as the sensing element. It is heated by means of electrical current and is brought into the flow where the circulation affects its temperature and thus changes the electrical resistance [1]. In CTA-mode (constant temperature anemometry), which is the standard mode for commercial hot wire systems, the current needed in order to maintain a constant temperature of the wire serves as the measuring signal. Standard hot wires reach temporal resolutions in the order of 50kHz and temporal resolutions of about 1mm. The working principle of hot wires is not suitable for measurements in certain domains, such as liquids or particle-ladden flows [5]. Moreover, the usage of hot wires for measurements of wall-bounded flows in wall proximity is compounded by heat reflections from the wall [3, 4]. These restrictions were part of our motivation to develop a new anemometer, namely the the 2d-LCA (2d-Laser Cantilever Anemometer). Another reason for the development originated from the fact that so far no alternative measurement technique has established for validation of hot wire data. Fig. 1 shows a photograph of the 2d-LCA with detailed view of the tip section where the sensing element (cantilever) is installed.

Figure 1. Illustration of the 2d-Laser Cantilever Anemometer with detailed view of the tip section and cantilever.

WORKING PRINCIPLE AND CALIBRATION

The underlying principle utilized in the 2d-LCA is the detection of the deformation of an one-sidedly fixed micro-structured cantilever that is exposed to a fluid flow [6, 5]. For a straight inflow, i.e. a flow direction perpendicular to the cantilever surface A, the deformation is a response to the drag force F_{drag}, that is given by:

$$F_{drag} = \frac{1}{2} c_d(v) \rho A v^2, \tag{1}$$

with the drag coefficient $c_d(v)$, the fluid density ρ and the velocity v. F_{drag} causes a simple bending of the cantilever. For an oblique flow, i.e. flow at an angle of attack $\alpha \neq 0$, the total deformation of the cantilever is observed to be a superposition of bending and twisting. The detection of the deformation is accomplished by means of the laser lever principle. For that purpose, a laser provided by a laser diode is focussed onto the tip of the cantilever. The resulting reflection beam is tracked using a 2d-position sensitive device (2d-PSD) with an active area of 4mm $\times$ 4mm. The deflection paths of the reflecting spot along the active area due to bending and twisitng are decoupled and follow two perpendicular directions. That way simultaneous measurements of two velocity components are possible. The cantilever is made of silicon and has dimensions of 140μm $\times$ 40μm $\times 1.6\mu$m (length $\times$ width $\times$ height). It features an additional vane made of SU-8 at its tip in order to increase the sensitivity towards cross-winds, thus increasing the angular resolution. The calibration of the 2d-LCA takes place in the wind tunnel. To do so, the 2d-LCA is mounted on a turning table in front of the wind tunnel outlet. A calibration plane is obtained by plotting the relative x- and y-coordinates of the reflecting spot along the 2d-PSD against the corresponding velocities and inflow angles. Appropriate interval steps for the calibrations are 1m/s and 5°. Figure 2 shows a typical section of a calibration plane for the 2d-LCA. The points indicate all collected data during calibration. Red and blue lines connect points that correspond to equal velocities and inflow angles, respectively.

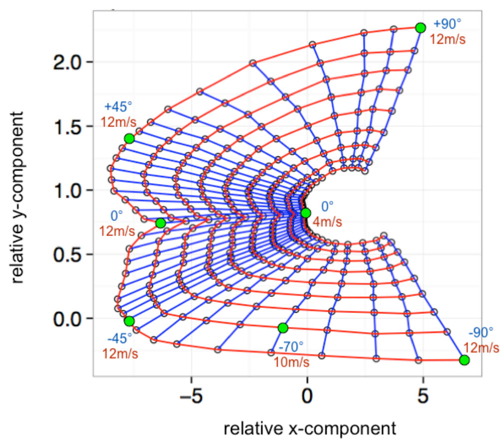

Figure 2. Calibration plane for the 2d-LCA in the range of $\pm 90^\circ$ and 4-12m/s.

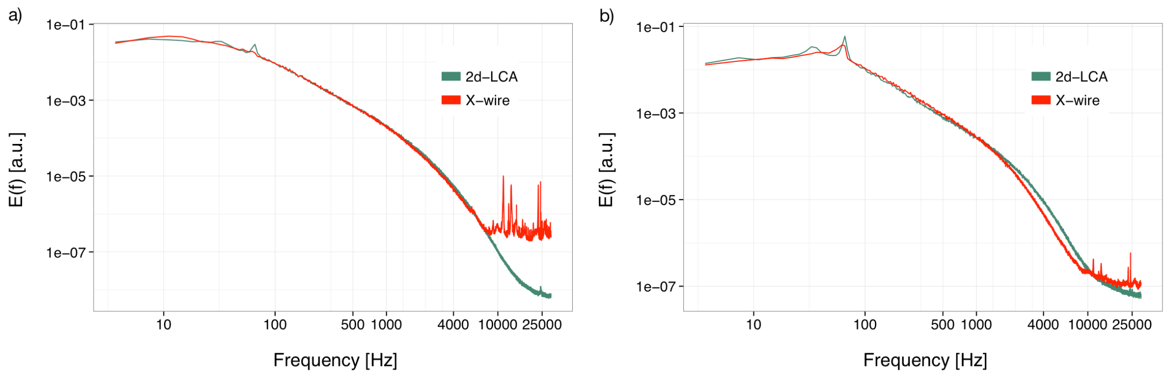

Figure 3. Power spectra for the longitudinal (a) and transverse (b) velocity components measured with the 2d-LCA (green) and a x-wire (red).

For reasons of clarity few points (highlighted in green) are labeled. The maximum angular and velocity ranges that can be covered with a cantilever of the above-mentioned dimensions are 1-50m/s and $\pm 90^\circ$. The limitation for the velocity range arises from the small area of the 2d-PSD and the stiffness of the cantilever. Larger velocity ranges can be achieved with different cantilever designs or larger detectors. The resolution power of the 2d-LCA increases towards higher velocities. This can be seen from eqn. 1 where $F_{drag} \propto c_d(v)v^2$ and $c_d(v) \approx$ const. for $v > 3$m/s. In comparison, the calibration of x-wires follows King's law and loses resolution power towards higher velocities. The angular range that can be achieved with standard x-wires is $\pm 45^\circ$ relative to the sensor.

MEASUREMENTS

Comparative measurements with the 2d-LCA and an x-wires of type Dantec 55p51 have been carried out in order to assess the performance of the new anemometer. The measurements were performed in wake flow that was generated using a cylinder (velocity = 12m/s, diameter = 4cm, Re = 33.800). Figure 3 a) and b) show the power spectra for the longitudinal and transverse velocity components, respectively. One can see that the spectra for the longitudinal component agree very well up to 10Khz. At this point the x-wire spectrum merges into noise. The spectra for the transverse velocity component agree within the inertial range and depart in the dissipation range. We believe that this deviation is caused by spatial averaging and differences in angular acceptance ranges. It is also worth mentioning that the 2d-LCA spectra show almost no noise in the high frequency region. This is due to the optical decoupling between the sensing element (cantilever) and the signal processing unit. Figure 4 shows the PDFs of increments for τ_1=0.167ms, τ_2=0.333ms, τ_3=1ms, τ_4=1.667ms and τ_5=16.667ms (from top to bottom) for the longitudinal velocity component. Both statistics agree well and show the increasingly intermittent character of turbulent flows towards smaller τ.

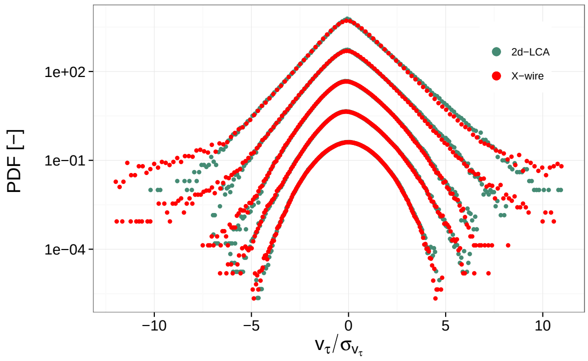

Figure 4. PDFs of increments measured with the 2d-LCA (green) and a x-wire (red) for different time lags τ ranging from 0.167ms to 16.667ms.

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