Particle Image Velocimetry

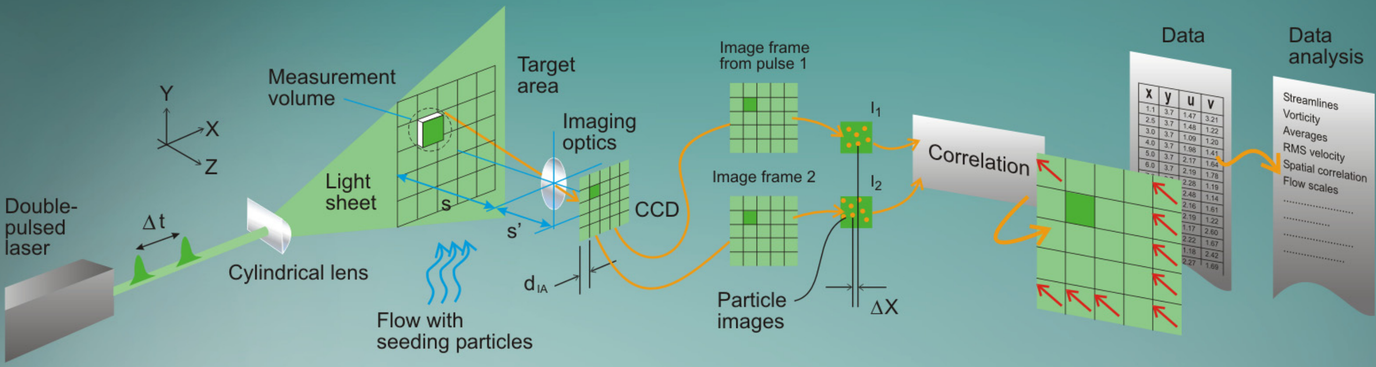
Introduction

Particle Image Velocimetry (PIV) is a whole-flow-field technique providing instantaneous velocity vector measurements in a cross-section of a flow. Two velocity components are measured, but use of a stereoscopic approach permits all three velocity components to be recorded, resulting in instantaneous 3D velocity vectors for the whole area. The use of CCD or CMOS cameras and dedicated software, results in real-time velocity maps.

Features

- The technique is non-intrusive and measures the velocities of micron-sized particles following the flow.
- Velocity range from zero to supersonic.
- Provides instantaneous velocity vector maps in a cross-section of the flow.
- All three components may be obtained with the use of a stereoscopic arrangement.
- With sequences of velocity vector maps, statistics, spatial correlations and other relevant data are available.
- With fast CMOS technology and powerful lasers, measurements in the kHz range can be made.

Results are similar to computational fluid dynamics, i.e. large eddy simulations, and real-time velocity maps are an invaluable tool for fluid dynamics

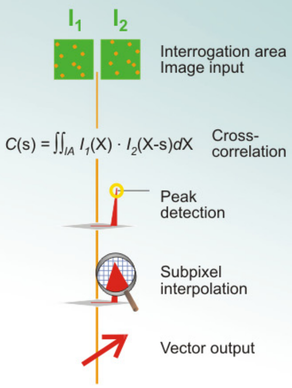


Principles

In PIV the velocity vectors are derived from sub-sections of the target area by measuring the movement of particles between two light pulses:

$$\bar{V} = \frac{\Delta \bar{X}}{\Delta t}$$

The particle seeded flow is illuminated in the target area with a light sheet. The camera lens images the target area onto the sensor array of a digital camera. The camera sensor is able to capture each light pulse in separate image frames. Once a sequence of two light pulses is recorded, the images are divided into small subsections called interrogation areas (IA). The interrogation areas from each image frame, I_1 and I_2, are cross-correlated with each other, pixel by pixel. The correlation produces a signal peak, identifying the average particle displacement, ΔX. An accurate measure of the displacement - and thus also the velocity - is achieved with sub-pixel interpolation. A velocity vector map over the whole target area is obtained by repeating the cross-correlation for each interrogation area over the two image frames captured by the CCD camera.



The correlation of the two interrogation areas, I_1 and I_2, results in the particle displacement ΔX, represented by a signal peak in the correlation C(ΔX).

PIV images are visual, just follow the seeding

In air flows, the seeding particles are typically oil drops in the range 1 μm to 5 μm. For water applications, the seeding is typically polystyrene, polyamide or hollow glass spheres in the range 5 μm to 100 μm. Any particle that follows the flow satisfactorily and scatters enough light to be captured by the camera can be used.

The number of particles in the flow is of some importance in obtaining a good signal peak in the cross-correlation. As a rule of thumb, 10 to 25 particle images should be seen in each interrogation area.

Recording several light pulses in the same image frame to track the movements of the particles gives a clear visual sense of the flow structure.

Spatial resolution and dynamic range

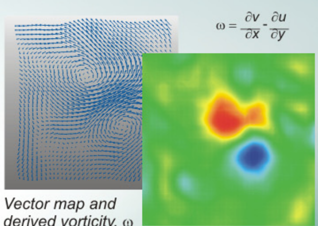
Setting up a PIV measurement, the side length of the interrogation area, d_{IA}, and the image magnification, s'/s are balanced against the size of the flow structures to be resolved. One way of expressing this is to require velocity gradients to be small within the interrogation area:

$$\frac{\frac{s'}{s} \cdot |v_{max} - v_{min}|_{IA} \cdot \Delta t}{d_{IA}} < 5\%$$

The highest measurable velocity is constrained by particles travelling further than the size of the interrogation area within the time, Δt. The result is lost correlation between the two image frames and thus loss of velocity information. As a rule of thumb:

$$\frac{\frac{s'}{s} \cdot v \cdot \Delta t}{d_{IA}} < 25\%$$

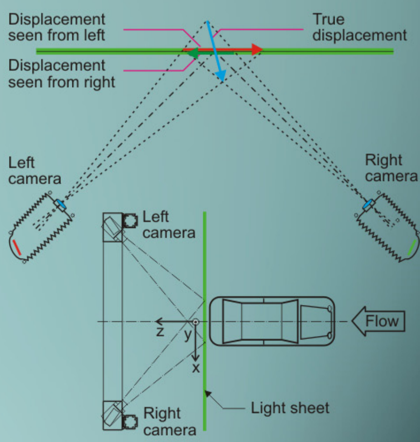
When the size of the interrogation area, the magnification of the imaging and the light-sheet thickness are known, the measurement volume can be determined.



Vector map and derived vorticity, ω

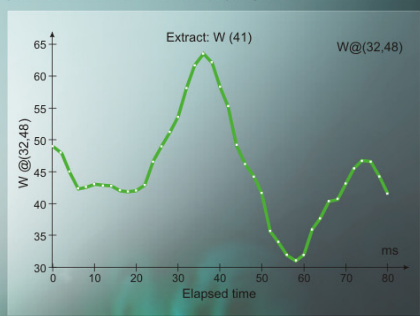
The third velocity component

In normal PIV systems, the third velocity component is "invisible" due to the geometry of the imaging. It can be derived by using two cameras in a stereoscopic arrangement.



Experimental set-up for stereoscopic PIV measurements of the flow behind a car model.

Time series of the 3rd velocity component in one of 91x68 points recorded at 500 Hz sampling rate.



DANTEC DYNAMICS

www.dantecdynamics.com