Determination of aerodynamic forces based on high-resolution PIV measurements

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Abstract

The knowledge of aerodynamic forces is a key to the design and improvement of many technical systems. Several measurement techniques have been developed to measure the aerodynamic loads acting on a body. They mainly use extrinsic methods, i.e. methods that are independent of fluid mechanics. Force balances are one example – although they are used to measure the influence of the flow on an object, they do not measure any physical quantity of the flow itself. Balances are widely used because of their accuracy, however, they come with two disadvantages: they can only measure the force acting on the *whole* body that they are connected to and they need a fixed reference. Pressure measurements are also commonly used to determine the aerodynamic forces on an object. However, their positions are usually fixed on the object. Additionally, unsteady pressure measurements require expensive sensors. An intrinsic measurement will permit to extract information from the flow field without any action on the studied object. Intrinsic methods could be used to measure the force on a specific cross-section of a wing or to measure forces on objects that are not easily instrumented.

Particle image velocimetry (PIV) is a non-intrusive flow measurement technique. To obtain the instantaneous velocity field in a 2D plane, the flow is seeded with tracer particles and illuminated with a light sheet generated by a pulsed laser. From the displacement of clusters of particles within a short time difference, the local flow velocity is calculated (*cf.* [1, 3]). Other quantities like vorticity can be calculated from the measured velocity field. Information on the flow around an obstacle can be used for an estimation of the resulting aerodynamic forces. Noca *et al.* [2] have developed the theoretical framework for the estimation of aerodynamic loads on a bluff body by integration of the velocity and vorticity fields on a control volume surrounding the object.

The topic of this study was to evaluate and further improve this technique by means of lift and drag determination on a NACA 4415 profile from high-resolution PIV data. The experiments were conducted in the open test section of the low speed wind tunnel at DLR Göttingen at a chord Reynolds number of $4 \cdot 10^5$ and Ma = 0.1 for angles of attack between -5° and 15°. The experimental setup consisted of two pulsed dual-cavity Nd:YAG lasers and four state-of-the-art high-resolution CCD

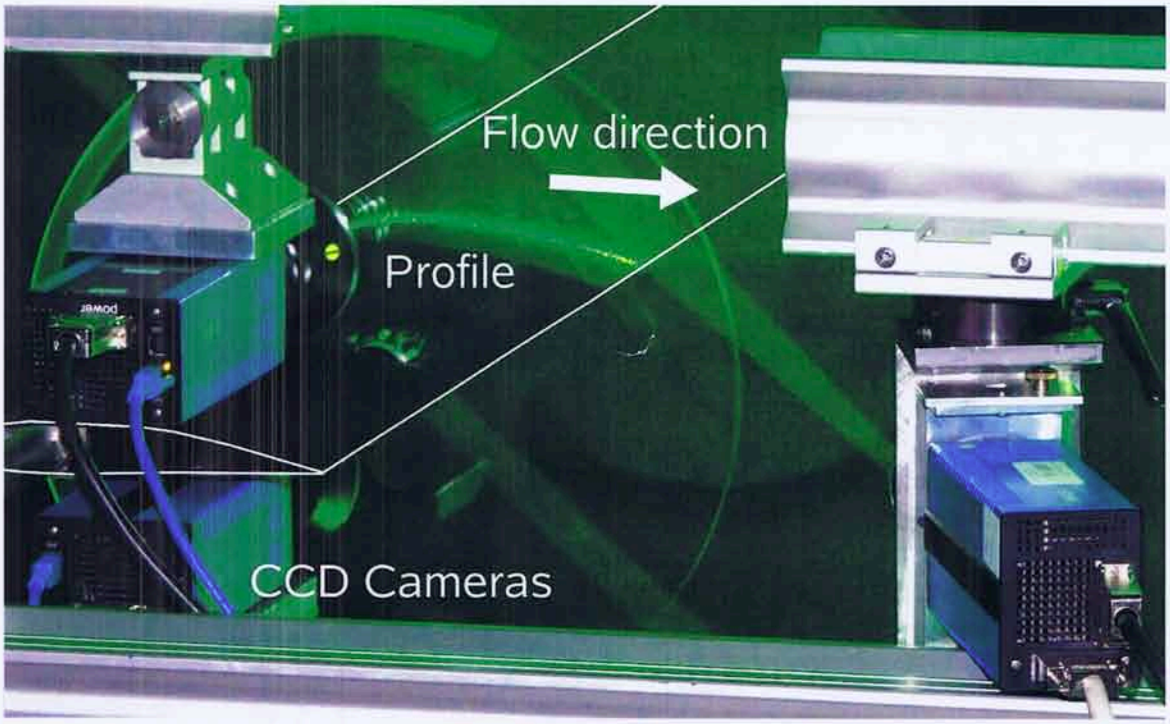

Figure 1: Experimental setup showing airfoil with laser light sheet and CCD cameras

cameras in a stereo configuration. The airfoil was instrumented with 28 pressure taps along the chord for reference lift calculations and correction of the aerodynamic angle of attack. For observation of the entire flow field around a cross-section of the model, the cameras were positioned around the airfoil and next to the test section in the configuration shown in Figure 1. The resulting two-dimensional velocity fields were corrected for geometrical distortion using pairs of cameras with overlapping fields of view.

Following the work of Noca *et al.* [2], an algorithm was developed for the calculation of aerodynamic forces from velocity data. CFD calculations of the test case were performed employing the DLR TAU code to solve the Reynolds-averaged Navier-Stokes (RANS) equations with the Spalart-Allmaras turbulence model. The accuracy of the algorithm was verified by calculating CFD-based lift coefficients, which showed good agreement with pressure-based lift coefficients. Calculation of force coefficients with PIV-based velocity data and simultaneously performed pressure measurements will be performed in the final paper. One example of the flow around the airfoil measured with PIV is given in Figure 2. The vector field was assembled from the instantaneous views of the four cameras shown in Figure 1.

The final paper will provide a detailed discussion of the experimental and computational issues in obtaining high accuracy force measurements from PIV data. An outlook is given for extending this method to time-resolved measurements and for its limitations towards lower resolution as well as noise of the PIV data. Future projects include unsteady measurements on oscillating airfoils under dynamic stall conditions and the extension of this method to compressible flows.

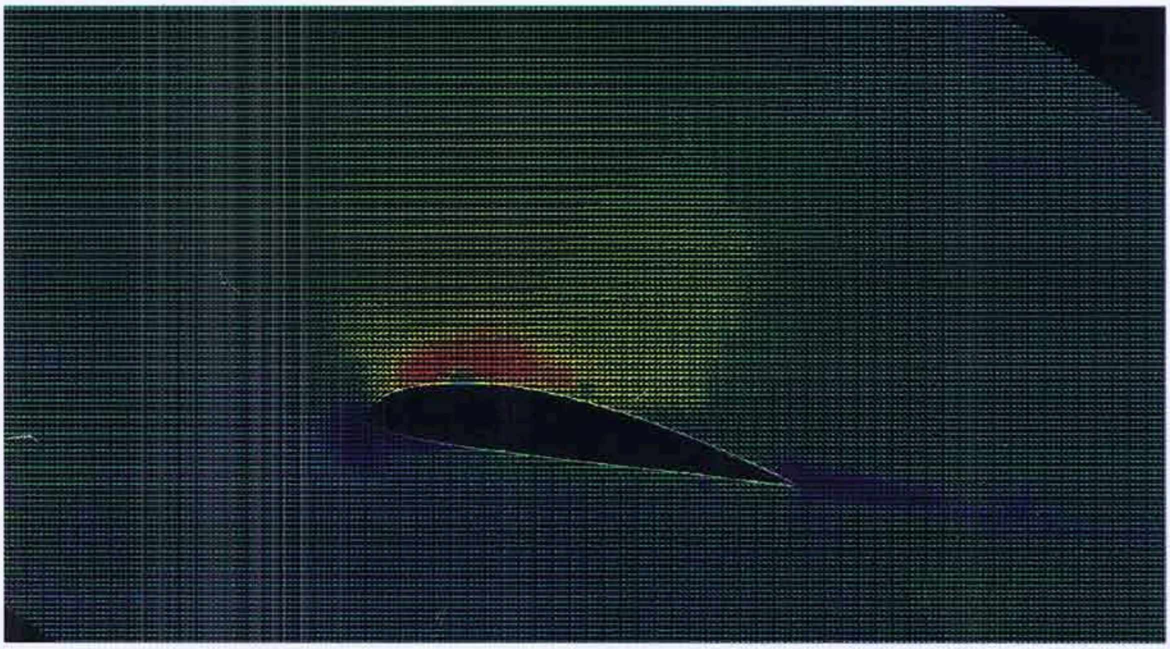

Figure 2: Exemplary high-resolution PIV results around the airfoil

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