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Recent advancements towards large-scale flow diagnostics by robotic PIV

*Fulvio Scarano, Department of Aerospace Engineering, TU Delft, The Netherlands

*E-mail for correspondence: f.scarano@tudelft.nl

1 Introduction

The use of particle image velocimetry (PIV) among fluid dynamic research laboratories has become widespread due to its capabilities to render quantitative flow field data with high precision and spatial resolution. However, setting up the diagnostic system remains an often lengthy and procedure, requiring specialized skills in the domain of precision mechanics, optics, and digital image analysis. The latter is often reported as the main reason delaying the diffused use of PIV for industrial testing.

A second major obstacle pertains the domain of aerodynamics, where the physical limits of the technique are often reached when attempting large-scale experiments (in the order of a meter or more). The use of micron-size droplets typically limits the planar measurement domain to 40x30 cm^2 (Raffel et al. 2018).

Three-dimensional PIV measurements, for instance by tomographic PIV, have been limited to even smaller size (10 to 100 cm^3) due to the stringent requirements on camera aperture to achieve the necessary depth of focus (Scarano, 2013).

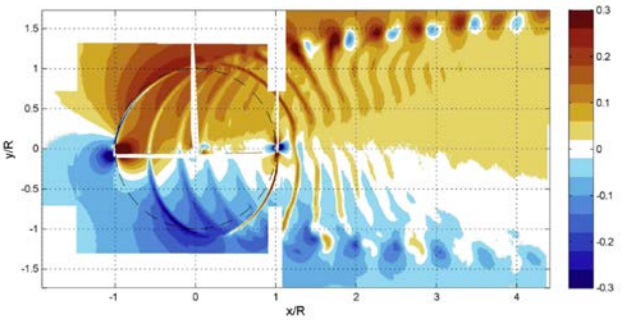

Fig. 1 Large scale stereo-PIV measurements around a vertical axis wind turbine (contours of phase averaged streamwise velocity component). Measurement patches of approximately 26 x 75 cm^2. (Repr. from Tescione et al. 2014).

2 Large-scale diagnostics

Experiments at large scale require that the measurement domain can be scaled up making use of seeding tracers that scatter light more effectively than the currently adopted micrometric droplets (e.g. fog or oil) by orders of magnitude. Helium-filled soap bubbles (HFSB) of sub-millimetre diameter have been proven to scatter $10^4 – 10^5$ more light than micron sized droplets (Caridi, 2017). At the same time HFSB tracers have also been demonstrated to trace the air flow with good fidelity up to flow velocity of 50 m/s and down to scales in the order of a centimeter (Engler Faleiros et al. 2018).

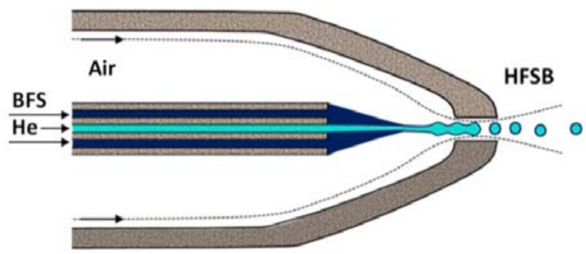

Fig. 2 Schematic description of HFSB generation from concentric ducts and air flow nozzle (repr. from Engler Faleiros et al. 2018).

The second requirement is a rapid adjustment of the measurement system when the domain of interest needs to be covered by several views. Three-dimensional techniques like tomographic PIV (Elsinga et al. 2006), 3D PTV (Murai et al. 2007) or scanning light sheet (Bruecker 1997) require a careful placement and calibration of the apparatus before measurements can be performed. It is commonly reported that the procedure takes from few hours to a day.

When a compact arrangement of imagers and illumination is achieved, the latter can be repositioned in physical space avoiding the lengthy procedures of alignment and calibration. This is achieved with the concept of Coaxial Volumetric Velocimetry (Schneiders et al. 2018, Figure 3) whereby a low-aperture tomographic system is coupled with conical illumination from the same direction as the lines of sight. The data analysis is accelerated making use of the Shake-the-Box algorithm (Schanz et al. 2016) that circumvents the computationally intensive tomographic reconstruction and 3D cross-correlation analysis.

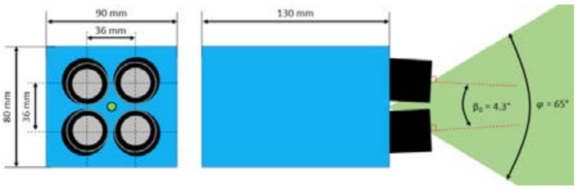

Fig. 3 Schematic configuration of a coaxial volumetric velocimeter.

Finally, the practical, yet not less important, task of maneuvering the measurement system needs to be accomplished by an automated device. The use of collaborative robots has been demonstrated in the recent work of Jux et al. (2018). Manipulation by robotic arm (Figure 4) allows expanding the reach of the measurement system within typically a sphere of 2 meters diameter.

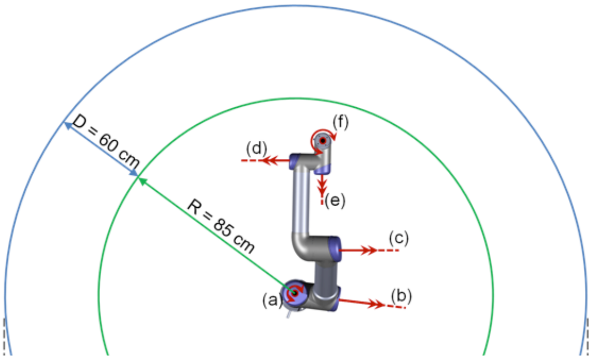

Fig. 4 Measurement range of coaxial volumetric velocimeter, operated from UR5 robotic arm.

3 Applications

The use of robotic PIV for large scale measurements has been demonstrated in several areas, from aeronautics to ground vehicle aerodynamics and speed sports.

The flow around a turboprop aircraft has been investigated in a large industrial wind tunnel (DNW-LST of 3 x 2.25 m^2 test section). The flow exhibits complex three-dimensional features (wing tip, flaps, propellers and engine nacelles) from the interaction between the propeller slipstream and the wing flow.

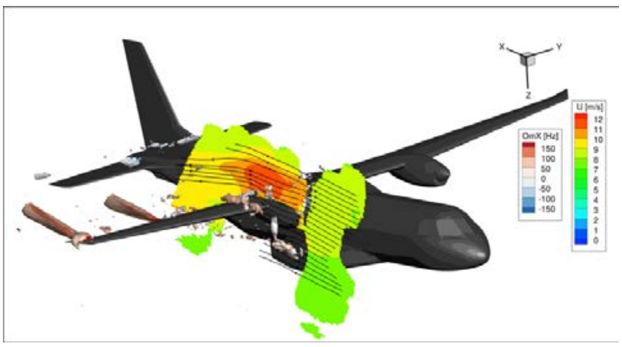

Fig. 5 Time averaged velocity and streamwise vorticity field around a scaled model of transport aircraft (Repr. from Sciacchitano et al. 2018).

Tests are performed at a velocity up to 50 m/s and the flow around fuselage, wing and propeller is characterized with robotic PIV measurements spanning a volume of approximately 1.5 x 1.0 x 0.5 m^3 with mesh points in the order of 10^6 (Figure 5).

The complex flow around a full-scale replica of the cycling "Giro d'Italia" champion Tom Dumoulin has been mapped making use of robotic PIV. The experiments are performed in the TU Delft Open Jet Facility at air speed of 14 m/s. The measurement is built from more than 400 independent views taken at a rate of approximately 2 minutes each (Jux et al. 2018). The measurements comprise approximately 20 x 10^6 grid points distributed over a domain of 2.0 x 1.6 x 0.7 m^3. Three-dimensional time averaged velocity and vorticity field around the athlete enable the detailed analysis of aerodynamic drag sources.

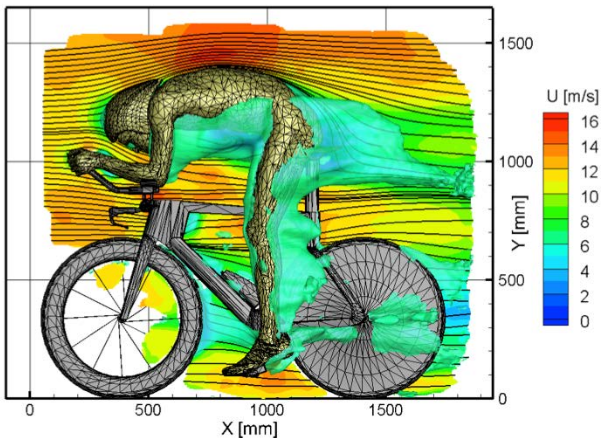

Fig. 6 Time averaged velocity field around a full-scale cyclist model (repr. from Jux et al. 2018).

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