Investigation of the evolution mechanisms of a propeller wake by Tomographic-PIV

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The experimental survey of the instantaneous 3D velocity field in a volumetric domain has a great interest in many branches of naval research and, in particular, in the propulsion field. The in-depth study of the propeller wake evolution, destabilization and breakdown mechanisms as well as the analysis of the correlated effects to the propeller noise and induced vibrations, concerns intrinsically unsteady and high turbulent phenomena which, in some situations, require to resolve the complete topology of the coherent flow structures at an instant. For example, this applies to the survey of the dynamics of the propeller wake structures (Okulov, 2007; Felli et al., 2011a; Felli et al., 2011b). In fact, in these applications, it is relevant to instantaneously capture the complete stress tensor and the vorticity vector for topological and modal analyses as well as to estimate important quantities for the analysis of the momentum and energy transfer in turbulent flows such as the divergence of the Lamb vector. Another example concerns the estimation of the non-linear terms in hydroacoustic research, underwater acoustic emission being strongly affected by the quadrupole source and, thus, by dynamical behaviour of large-scale flow structures and their interactions (Ianniello et al., 2013, Felli et al., 2015a). To this aim, time and space derivatives of the velocity field need to be calculated for the complete evaluation of the integrand terms whatever acoustic analogy is used for the estimation of the noise sources (e.g. Violato and Scarano, 2013). Moreover, the ability to extract instantaneous flow field information in a volumetric domain represents also an important requirement for the CFD modelling of complex flows. For example, the information of the three-dimensional topology of the largest relevant flow structures in such destabilized wake flows might provide with inputs to effectively define the size of computational domain in DES or LES simulations.

In the perspective of resolving the instantaneous 3D velocity field in a volume, the use of volumetric techniques represents the best suited approach in experimental fluid mechanics. As a matter of fact, traditional detailed flow measurement techniques, such as LDV, PIV and Stereo PIV, widely used for propeller flow analysis, are able to respectively extract at most three velocity components in a point or in a planar slice at a snapshot and, thus, they can provide only an on-average estimation about the topology of fluid structures. In this scenario, Tomographic PIV (Elsinga 2006) represents a potentially effective tool for the investigation of fully three dimensional turbulent and unsteady flows, such as the wake of a propeller, and represents a very attractive complementary approach to well assessed detailed flow measurement techniques for instant-flow-based analyses (see Felli et al., 2015b).

The present paper documents the application of Tomographic PIV to the analysis of a 7-bladed open water propeller wake in a cavitation tunnel (i.e. test section LxWxH=2.6x0.6x0.6m3). Measurements were performed over an axial extent of the near wake from the 0.1 to about 3 propeller diameters.

The measurement volume covered the mid-longitudinal plane of the propeller and was sufficiently thick to achieve the calculation of the out of plane gradients as well as to resolve the topology of turbulent flow structures in the propeller wake. Tomographic measurements were phase locked with the propeller position to resolve the flow field evolution during a complete revolution.

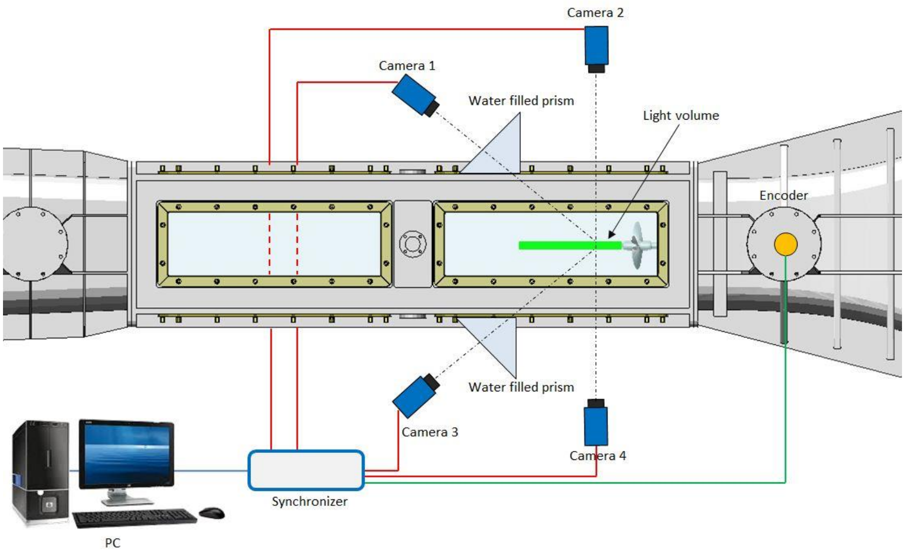

Figure 1: TOMOPIV experimental set up

References

Okulov VL, Sørensen JN. (2007). Stability of helical tip vortices in rotor far wake. J. Fluid Mech, 576. 1–25.

Felli M, Camussi R, Di Felice F. (2011a). Mechanisms of evolution of the propeller wake in the transition and far fields, J. of Fluid Mechanics, 1-17.

Felli M, Falchi M. (2011b). Propeller tip and hub vortex dynamics in the interaction with a rudder. Experiments in Fluids, Vol. 51, Issue 5, pp 1385-1402.

Ianniello S, Muscari R, Di Mascio A. (2013) Ship underwater noise assessment by the acoustic analogy part II: hydroacoustic analysis of a ship scaled model. J Mar Sci Technol.

Felli M, Falchi M, Dubbioso G. (2015a). Experimental approaches for the diagnostics of hydroacoustic problems in naval propulsion. Journal of Ocean Engineering, 106:1–19.

Violato D, Scarano F. (2013). Three-dimensional vortex analysis and aeroacoustic source characterization of jet core breakdown. Physics of Fluids, 25, 015112.

Elsinga GE, Scarano F, Wieneke B, Van Oudheusden BW. (2006). Tomographic particle image velocimetry, Experiments in Fluids, 41:933–947

Felli M, Falchi M, Dubbioso G. (2015b). Tomographic-PIV survey of the near-field hydrodynamic and hydroacoustic characteristics of a marine propeller. Journal of Ship Research, 59 (4), 201-208.