Mechanical Engineering Doctoral Defense

Fundamentals and Applications of N-pulse Particle Image Velocimetry-accelerometry: Towards Advanced Measurements of Complex Flows and Turbulence

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abstract

Over the past three decades, particle image velocimetry (PIV) has been continuously growing to become an informative and robust experimental tool for fluid mechanics research. To date, PIV is widely applied to studying turbulence coherent structures, complex multi-phase flows, etc., and the ability to offer 4-D flow information, i.e. in space and time dimensions, makes PIV unprecedentedly attractive. Compared to the time when PIV was invented, its performance, given by the dynamic range, has been improved by about an order of magnitude (Adrian, 2005; Westerweel et al., 2013). Further improvement requires a breakthrough innovation, which constitutes the main motivation of this dissertation. N-pulse particle image velocimetry-accelerometry (N-pulse PIVA, where N>=3) is a promising technique to that regard. It employs bursts of N pulses to gain advantages in both spatial and temporal resolution. The performance improvement by N-pulse PIVA is studied using particle tracking (i.e. N-pulse PTVA) as a logical starting point, and it is shown that an enhancement of at least another order of magnitude can be achieved for the dynamic range. Furthermore, the addition of pulses enables direct estimation of acceleration, and thus opens the way to evaluating fluid force. This is demonstrated in the context of an oscillating cylinder interacting with the surrounding fluid. We successfully measured the cylinder motion, the fluid velocity and acceleration, and the fluid force exerted on the cylinder. On the other hand, the implementation of N-pulse PIVA, especially for high-speed flows, relies on the use of multiple cameras due to the insufficient framing rate of a single camera. Camera registration then becomes critical for N-pulse PIVA to yield reliable acceleration results. Such issue is addressed with the residual misalignment reduced down to 0.001 pixel. Finally, by virtue of the superior performance of N-pulse PIVA, applications to measuring particle-shock dynamics and turbulence statistics are presented. Both of them are implemented in form of particle tracking to fully utilize its inherent advantage of high spatial resolution.

January 30, 2018; 12:00 PM; ERC 490