MEASUREMENT OF TURBULENCE IN FLOWS WITH SYSTEM ROTATION

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1. Introduction : Multi-stage Turbomachinery Flows

Among all fluids engineering applications that involve a system rotation, turbomachines constitute the largest, the most diverse and the most widely used class of devices in engineering. The three-dimensional, turbulent and unsteady nature of the flow field within a turbomachine, which can be compressible in gas turbines and two-phase in marine applications, strongly affects the overall performance, efficiency, vibration and noise characteristics of these devices.

Understanding of the complex flow physics, cause-and-effect relations, and their effects on performance requires detailed experimental data on the evolution of the mean and fluctuating components of the flow in a rotating environment, which is characterized by unsteady and spatially non-uniform strain fields generated by blades and wakes, flow curvature, Coriolis and centrifugal forces. In multi-stage machines, upstream wakes modulate the performance and modify the boundary layers on the blades, and in-turn are chopped, strained, and the turbulence within them is modified as they pass through a rotor passage.

Experiments investigating unsteady interactions in turbomachines have mostly been performed using single point measurements by traversing between the blade rows and within the blade passages, both in stationary and rotating frames of references. These measurements have been performed using a variety of probes including hot-wire, hot-film, LDV, split hot-film, fivehole pitot, high response pressure transducer, etc. (e.g. Chesnakas and Dancey [1990], Stauter et al. [1990], Zaccaria and Lakshminarayana [1995], Prato et al. [1998], Suryavamshi et al. [1998a,b], Sentker and Reiss [2000]). Although the amount of experimental data is substantial, inherently, these measurements cannot cover the entire stage, and as a result, miss some of the details essential for understanding the complex physical mechanisms involved. Only experimental data that covers the entire flow field in a multi-stage turbomachine can resolve all the ‘‘causes and effects.’’ Thus, in recent years Particle Image Velocimetry (PIV) applications in turbomachinery measurements have been continuously increasing (Dong et al. [1992a, b], Day et al. [1996], Tisserant and Bruegelmans [1997], Gogineni et al. [1997], Sanders et al. [1999], Sinha et al. [2000a, b], Balzani et al. [2000], Wernet [2000, 2004], Wernet et al. [2001, 2002], Woisetschlager et al. [2002, 2003], Estevadeordal et al. [2002, 2005], Liu et al. [2004], Ibaraki et al. [2006], Porreca et al. [2009]). More detailed information on the application of the PIV technique in turbomachinery measurements can be found in Uzol and Katz [2007], Voges et al. [2011].

PIV requires optical access for the laser sheet and the camera to the region of interest, whereas the flow field in a multi-stage turbomachine is usually optically obstructed by the