Stereoscopic PIV Measurement of the Flow in the Tip Region of an Axial Waterjet Pump

Long Abstract

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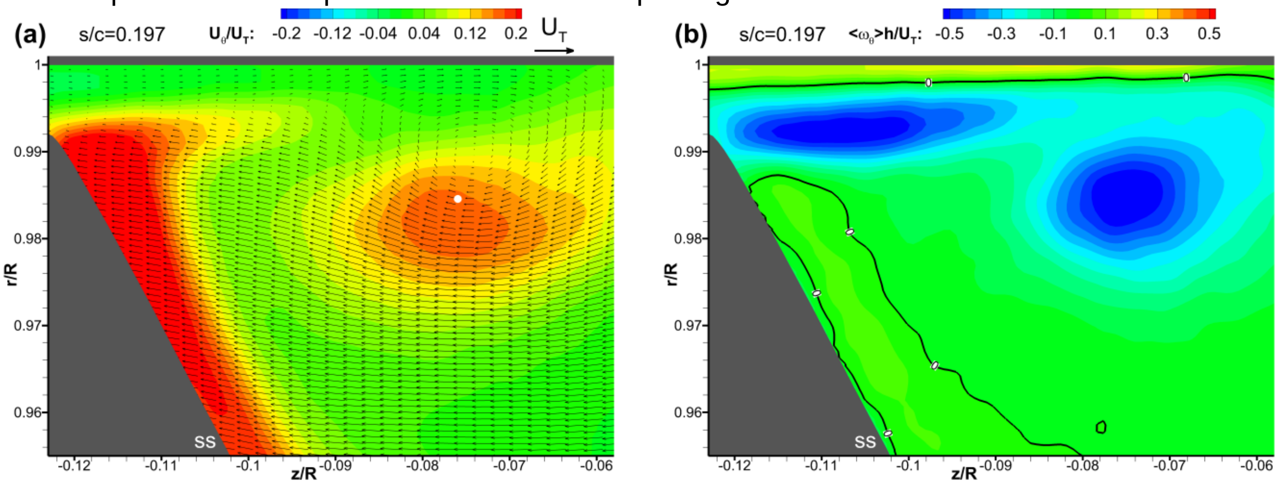
Introduction

Many phenomena involved in axial turbomachines are related to the clearance between blade tip and casing endwall, where the pressure difference across the blade tip leads to the roll-up of tip leakage vortex (TLV). Numerous studies have been done by researchers to reduce the adverse effects induced by TLV but the detailed flow structure in the tip region is still not fully revealed. Turbomachinery applications usually have limited visual access to the rotating parts and make optical measurements difficult. However, the unique optical refractive index-matched facility in Johns Hopkins University (JHU) enables unobstructed measurements and has been used on several turbomachine models, including a waterjet pump [1]. The present waterjet pump, AxWJ-2 is the second prototype of an axial waterjet pump designed by Michael et al [2], which can serve as a benchmark and a foundation for new design and analysis. Cavitation breakdown tests on AxWJ-2 have been discussed in pervious publications [3], and the results of stereoscopic particle image velocimetry (SPIV) will be shown in this paper.

Methods

A series of SPIV measurements have been performed on AxWJ-2 pump following the trajectory of the TLV across the blade passage. The experiments are conducted in the JHU index-matched facility that houses a transparent acrylic rotor within a casing made of the same material, providing unobstructed access to the entire pump. High magnification data (0.1 mm vector spacing) resolves the tip gap flow, the backflow emanating upstream from the tip, and provides detailed description of the formation, growth, migration and eventual bursting of the TLV. By using a less-magnified, but larger field of view, another set of measurements are taken to provide a comprehensive database covering the whole blade passage. We present both instantaneous and phase-averaged results (based on 1000 instantaneous realizations) to elucidate the complex and three-dimensional flow around the tip region. Figure 1a is a sample of phase-averaged circumferential velocity (u_θ), with in-plane (axial-radial) velocity vectors overlaid at s/c = 0.197, where s is the chordwise coordinate and c is the chordlength, and Figure 1b is the circumferential vorticity (ω_θ). Distributions of turbulent kinetic energy (TKE) and in-plane turbulence production rate are provided. Figure 1c is the TKE distribution at s/c=0.197. The TKE is elevated near the blade suction side (SS) tip corner, in the shear layer connecting the SS tip corner and the TLV, in the endwall separation region, as well as around the TLV core. As the TLV migrates across the blade passage, the region of elevated TKE grows and occupies an increasing fraction of the tip region. The normal and shear Reynolds stress demonstrate high inhomogeneity and anisotropy. A breakdown of the components of in-plane turbulence production suggests that the axial extension and compression of flow are dominant. Also the sum of in-plane turbulence production rates and the mean turbulence transport terms correspond to the regions of the elevated TKE. The full paper will display results for a series of planes, following the development and transport of TLV in the blade passage.



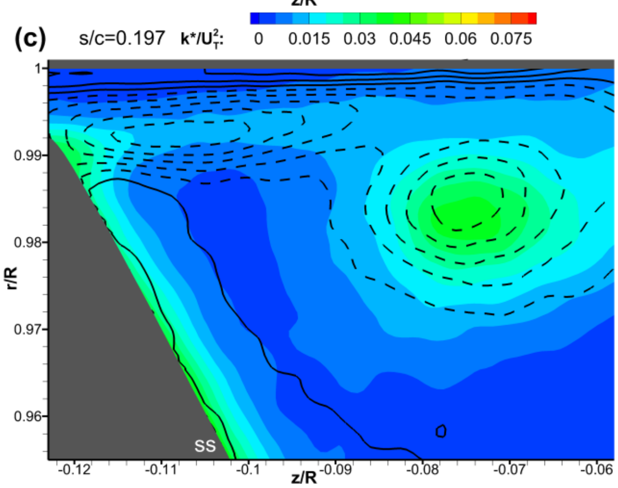


Figure 1. (a) The distribution of phase-averaged circumferential velocity (u_θ) with in-plane (axial-radial) velocity vectors overlaid, (b) the distribution of circumferential vorticity (ω_θ) and (c) the distribution of TKE at s/c = 0.197. In (a), in-plane velocity components are diluted by 3 in the horizontal direction. In (b), the black contour line corresponds to ω_θ = 0. In (c), the black contour lines represent ω_θ and dashed ones for ω_θ < 0. The grey area represents the blade cross section or the casing endwall. Symbols: U_T – tip velocity, h – tip gap height, z-axial coordinate, r- radial coordinate, R – pump radius.

References

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