Stereoscopic PIV Measurements of the Flow along the Blade Pressure Side of an Axial Waterjet Pump during Cavitation Breakdown

Long Abstract

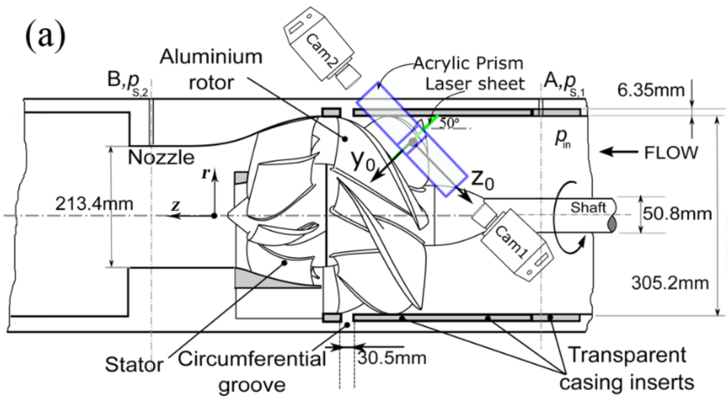
Huang Chen, Department of Mechanical Engineering, Johns Hopkins University, Baltimore, MD, USA
Nick Doeller, Department of Mechanical Engineering, Johns Hopkins University, Baltimore, MD, USA
Yuanchao Li, Department of Mechanical Engineering, Johns Hopkins University, Baltimore, MD, USA
Joseph Katz, Department of Mechanical Engineering, Johns Hopkins University, Baltimore, MD, USA

Introduction

The flow mechanisms causing cavitation breakdown in axial turbomachines have been a long-standing puzzle. Prior conceptual models have attributed this phenomenon to e.g. choking, blockage, complete coverage of the suction side (SS) of the blade with vapor, and formation of perpendicular cavitating vortices (PCVs) along the tip region of the blade [1–4]. The latter postulate has originated in our laboratory. However, recent experimental studies have demonstrated that using circumferential grooves to manipulate the tip leakage flow and suppress the PCVs does not alleviate the rapid performance deterioration during breakdown [5]. Furthermore, the clear liquid flow passage along the pressure side (PS) of the blade indicates that breakdown does not involve flow choking. It also occurs when the trailing edge region on the SS of the blade is still wetted. However, consistent with prior observations, the rapid reduction in pump performance begins when a slight decrease in pressure extends the attached/sheet cavitation on the blade SS into the blade overlap region. At this phase, the area covered by cavitation initially fluctuates, and then expands rapidly in the axial and radial directions to cover a substantial fraction of the blade. These phenomena have led us to postulate that partial blockage to the liquid through-flow, occurring when the cavitation reaches the overlap region, accelerates the flow along the pressure side, reducing the pressure there, and consequently, the blade loading. Recent stereo-PIV (SPIV) measurements in the non-cavitating fractions of the passage have indeed confirmed that when the mean pressure is decreased below the breakdown threshold, the liquid velocity increases and the pressure decreases significantly along the blade PS. These trends support the postulate that the decrease in performance and the rapid expansion of the cavitation are initiated by cavitation-induced blockage.

Methods

A series of SPIV measurements have been performed on the AXWJ-2 pump (Fig.1a) at different inlet pressures, covering conditions from little attached cavitation on the SS to the onset of cavitation breakdown. To avoid the detrimental reflections by cavitation bubbles, the measurements mainly focus on the flow along the blade PS, where there is no cavitation. The measurements are being performed in a refractive index matched facility using the setup illustrated in Fig.1a. The laser sheet is perpendicular to the flat exterior casing wall and oriented at 50° to the axial direction. For each inlet pressure, image pairs are acquired in several planes around the blade leading edge using a 81×121 mm^2 field of view that extends deep into the passage. Figs.1b and c compare the ensemble-averaged axial velocity in the leading edge plane when the inlet pressure is slightly above and below the cavitation breakdown pressure, respectively. Focusing on the PS of the blade (left side), the results indicate that the axial velocity along the PS increases by 10% from U_Z/U_T=0.38 to 0.42, despite the slight drop in the overall flow rate from φ=0.75 to 0.73. Using all the velocity components in the rotor frame of reference, the corresponding decrease in PS pressure based on Bernoulli's Equation is 20 kPa, indicating a striking decrease in rotor blade loading. This increase in velocity and decrease in pressure are accompanied with rapid expansion of the area covered by attached cavitation [5], which presumably decreases the through-flow area, creating a positive feedback system. The full paper will provide pressure distributions in several planes and for varying cavitation numbers showing the deterioration of blade loading as the through-flow area decreases.



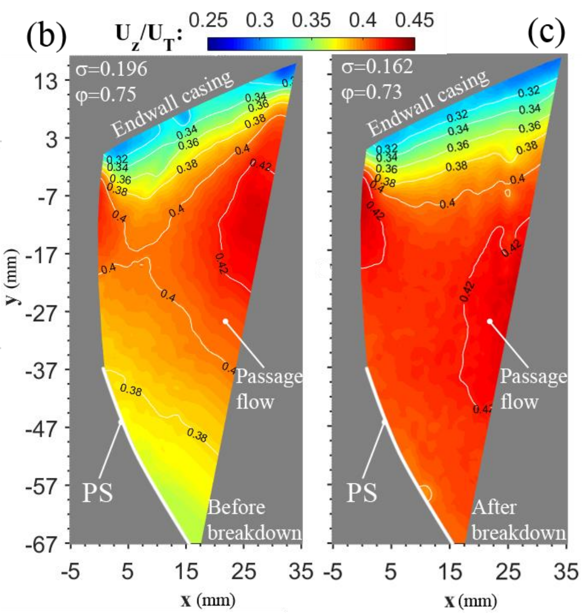


Figure 1: (a) The AXWJ-2 pump and the SPIV setup. Distributions of axial velocity when the inlet pressure is (b) slightly above and (c) below the cavitation breakdown condition.

References

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