19th Australasian Fluid Mechanics Conference
Melbourne, Australia
8-11 December 2014

Turbulent Cavitating Vortical Structures and their Impact on the Performance of Turbomachines

D. Tan[1], R.L. Miorini[2] and J. Katz[1]

[1]Department of Mechanical Engineering
Johns Hopkins University, Baltimore, MD 21218, USA

[2]General Electric Global Research Center
1 Research Circle, Nishkayuna, NY 12309, USA

Abstract

Due to the low pressure in their cores, vortices are often the first site of cavitation inception in a variety of turbulent flows. Examples include shear layer eddies and tip vortices. In other cases, instabilities associated with cavitation causes formation large scale structures, such as the destructive, periodically shed cloud cavitation forming downstream of attached cavitation, e.g. in regions of adverse pressure gradients on the suction side of lifting surfaces. In highly loaded turbomachines, such as rocket fuel pump inducers, axial cavitating vortical structures protrude upstream of the rotor, a phenomenon associated with large scale instabilities, and adverse effects on the machine performance.

Degradation in performance by cavitation in confined turbopumps, in which there is a narrow gap between the rotor blade tip and the endwall casing, has been a longstanding puzzle. As the mean pressure at the entrance to the machine (or the non-dimensional cavitation index) is gradually reduced, for a while, even extensive levels of cavitation have little impact on the global machine performance. However, at a certain stage, the flow rate and head rise across the pump deteriorate rapidly, a phenomenon commonly referred to as cavitation breakdown. To elucidate the processes causing this phenomenon, we have performed a series of observations on the evolution of cavitating structures within a waterjet pump, and correlated the observed phenomena with the performance of the machine. The experiments have been conducted in the optically index matched facility at Johns Hopkins University using both a transparent (index matched) impeller, which facilitates unobstructed observations, and a metal impeller that could better withstand the unsteady loading under heavy cavitation. These experiments include high speed imaging, as well as performance and pressure fluctuation measurements on the enwall casing. The latter are used for determining the pressure difference across the blade at several locations.

The high speed images reveal that performance breakdown is associated with the formation of cavitating vortices in the tip region that are aligned perpendicularly to the suction side (SS) surface of the blade, and extend to the pressure side (PS) of the neighboring blade. With decreasing cavitation number, the number, radial extent, and strength of these perpendicular cavitating vortices (PCVs) increase, and they appear to 'block' the flow in the tip region (see Figure 1). In the waterjet pump, the PCVs develop due to interactions between the tip leakage vortex (TLV) and the cloud cavitation shed from the trailing edge of the sheet cavitation on the SS surface of the blade. The TLV entrains the vortical cloud cavitation, and realigns it in the blade-normal direction. This interaction appears to be local and does not cause significant performance breakdown when it occurs in regions where neighboring rotor blades do not overlap. However, as the pressure is reduced, and the trailing edge of the attached cavitation along with cloud cavitation extend to the entrance of the region where blades do overlap, the PCV connects to the pressure side of the neighboring blade, close to its leading edge. At this point, the measured pressure difference across the tip of the blade decreases rapidly, i.e. the blade loading near the leading edge diminishes. Accordingly, the pump performance deteriorates. With further decrease in cavitation index, as the PCVs grow in size and number, they migrate radially inward, and pull the TLV under them. As prior studies have shown, somewhat different phenomena occur in inducers, where the strong leakage flow extends well upstream of the blade leading edge. In this case, the formation and alignment of cavitating 'backflow vortices' has been attributed to interactions of the leakage with the bulk passage flow.

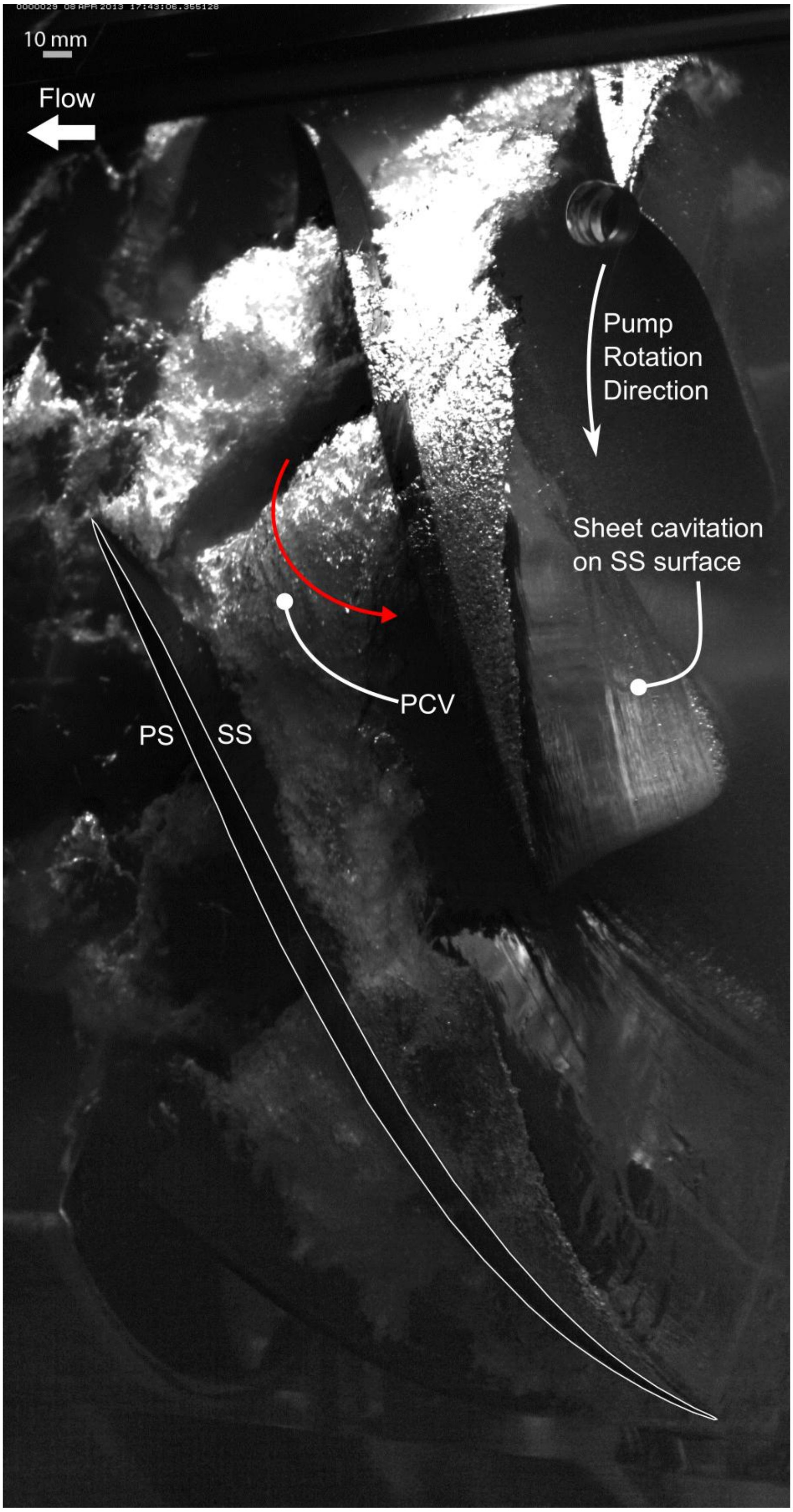

Figure 1. A side view showing a pair of massive perpendicular cavitating vortices blocking the flow in the tip region of the rotor passage in a water jet pump during cavitation breakdown. The bulk flow is from right to left, and in the shown perspective, the blades are moving downward.