11th World Congress on Computational Mechanics (WCCM XI)
5th European Conference on Computational Mechanics (ECCM V)
6th European Conference on Computational Fluid Dynamics (ECFD VI)
July 20 - 25, 2014, Barcelona, Spain

Numerical investigations of flows around turbopump inducer in cryogenic cavitating conditions

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Key Words: *All-speed two-phase flow, Cryogenic cavitation, Cavitation breakdown, Thermal effect, Parametric study*

For flow fields around rapidly rotating turbopump inducer to pressurize oxidizer and fuel in liquid rocket propulsion system, cavitation is known to be inevitable. Turbopump inducer is normally operated under low pressure conditions, and some degree of cavitation is known not to impede the suction performance in liquid propulsion system. But the suction performance of turbopump inducer is suddenly degraded by massive cavitation under some flow conditions, which is known as the cavitation breakdown. Therefore, identifying this critical operating condition and finding, if any, an improved configuration to delay the cavitation breakdown is one of the major concerns in developing turbopump system.

Recently, we have developed accurate and efficient baseline numerical fluxes (two-phase RoeM and AUSMPW+ schemes) for the computations of compressible/incompressible two-phase flows [1] and extended them into the cryogenic cavitation flows [2]. Numerical framework to describe rotational flow physics is based on the absolute velocity formulation. The homogeneous equilibrium model (HEM) with system precondition technique has been adopted, and Merkle's model [3], among others, is adopted to describe the cavitation process. Thus, the governing equations consist of mixture mass, momentum and energy conservation laws together with gas phase mass conservation law. Cryogenic fluid properties are generated from the standard thermodynamic database 12 from the National Institute of Standard and Technology (NIST) for pure fluids. Detailed numerical methods will be presented in the full paper.

As some of validation cases, Fig. 1 compares the computed results of Hord's experimental study [4] with experimental data and other reported results. Figure 2 shows overall performance comparison on KARI turbopump inducer under various flow conditions with cold water. Figure 3 is the comparison of computed local pressure data with experimental results, indicating that all of the numerical results match experimental data well. Furthermore, numerical simulations using liquid hydrogen and liquid oxygen as working fluids are carried out to examine the thermal effects of cryogenic fluids. Additional validations and computed comparisons will be given in the full paper.

The final objective of this work is to carry out shape design of turbopump inducer to delay the cavitation breakdown. As a preliminary study, we perform a parametric study on several major design variables, such as sweepback angle, blade incidence angle, tip clearance, casing diffusion angle and its starting location. Figure 4 shows the comparison of surface pressure distribution and cavitation region by changing the leading edge sweepback angle. Other parametric results and observations on flow physics will be presented in the full paper.

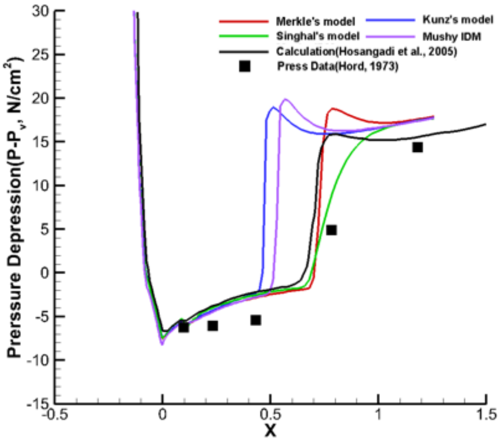

Figure 1. Comparison of pressure distribution on hydrofoil surface for cavitation models

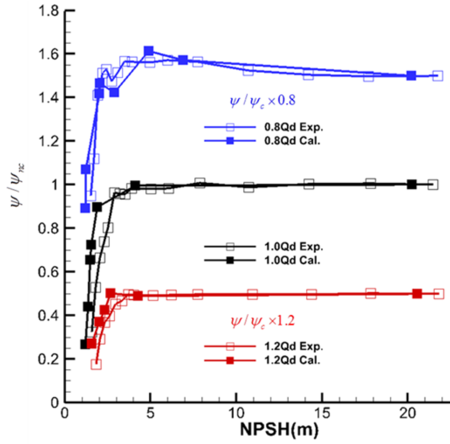

Figure 2. Comparison of normalized headrise coefficients between numerical results and experimental data

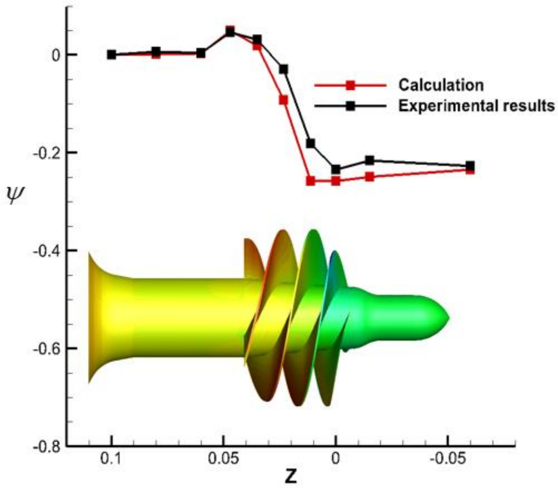

Figure 3. Local pressure comparison measured at inducer shroud

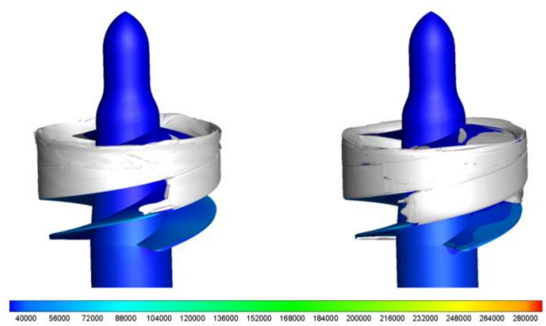

Figure 4. Parametric study on sweepback angle showing surface pressure distribution and cavitation region

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