Extension of the Full Cavitation Model for Cryogenic Fluids

H. Q. Yang and Ashok K. Singhal
CFD Research Corporation
Huntsville, AL35805, USA
Email: hqy@cfdrc.com; aks@cfdrc.com; Web: www.cfdrc.com

Abstract

The full cavitation model, originally reported in 2000, has been quite successful in a variety of industrial applications simulated with several CFD codes including CFD-ACE+ and Fluent. The objective of this study is to extend the model for cryogenic fluids and to demonstrate its capability for propellant fed turbo pumps of liquid rocket engines.

Turbo pumps are crucial components of all primary propulsion systems powered by liquid propellant rocket engines. As the pump blades move through a fluid, cavitation is a major concern. Most of the cavitation models assume an equilibrium system based on the constant saturation vapor pressure and physical properties. However, liquid rocket systems are very different in that the operating temperature is elevated relative to the critical temperature of the fluid, at which the ratio of liquid to vapor density is lower and consequently more liquid mass has to vaporize to sustain a cavity. In modeling thermo-sensitive cryogenic fluids, the thermal effects must be taken into account. This also requires a strong coupling of the energy equation with fluid dynamics in a cavitation model.

First, the energy equation was modified to include the phase change effect due to cavitation. The variable physical properties, such as vapor pressure, liquid density, vapor density, thermal conductivity, specific heat, fluid viscosity, surface tension, and evaporation heat for the cryogenic fluids from NIST tables were implemented into the computer code (CFD-ACE+). In addition, a special treatment was designed to ensure numerical convergence since large variation of the vapor pressure with respect to temperature is typically involved for the cryogenic fluids.

The Hord's experiment was chosen for the validation as it is so far the most complete and comprehensive measurement set available in the literature. The calculated pressure and temperature profiles along a hydro foil at different flow conditions for both nitrogen and hydrogen fluids were compared with experimental measurements. Without any modification to the empirical constants (that were originally calibrated with water), the predicted results matched remarkably well with the experimental data, and showed much improvement than the previous predictions for liquid nitrogen. Furthermore for the liquid hydrogen, there is significant improvement in the temperature recovery region compared to previous predictions.