THE FULL CAVITATION MODEL

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Abstract

The full cavitation model [1,2] accounts for all major first-order effects, i.e. vapour formation, turbulent fluctuations of pressure and velocity, non-condensible gases, surface tension and bubble dynamics. The model has been quite successful in a wide variety of industrial applications. Recently we have been working on extending this model to three important areas:

- Flows with variable non-condensible gas concentrations, due to injection and mixing of gas, absorption of gas into liquid, and desorption of gas (deaeration); and
- Nonisothermal flows due to mixing of different temperature fluids and heat transfer through walls or other means.
- Liquid compressibility for high pressure variations and transient cavitation

This paper summarizes the mathematical formulation and initial model assessments. All computations have been performed with the CFD-ACE+ code, and exhibit physically correct trends, as well as numerically stable behaviour.

1. Introduction

When a liquid flows into a region where its pressure is reduced to vapour pressure, it boils and vapour pockets develop in it. The vapour bubbles are carried by the flow field until they reach a region of higher pressure, where they suddenly collapse. This process is called cavitation. If the vapour bubbles are near to a solid boundary when they collapse, the forces exerted by the fluid rushing into the cavities create very high-localized pressures that cause pitting of the solid surface. The phenomenon is accompanied by noise and vibrations that have been described as similar to gravel going through a centrifugal pump [3].

The purity of the liquid in question and the amount of dissolved gases were found to influence the cavitation process. For instance bubbles in aerated water might withstand several pressure oscillations. This was not observed for pure water.

Tests made on chemically pure liquids show that they would sustain high tensile stresses of the order of mega Pascals. This is in contradiction to the concept of cavities forming when pressure is reduced to the vapour pressure. It is hence generally accepted that cavitation is related to nuclei that enhance bubble growth in low-pressure regions. The nature of nuclei is not thoroughly understood yet.

There are two categories of cavitation:

- Acoustic cavitation: Pressure waves travelling through a liquid at the speed of sound might cause large pressure fluctuations, which might cause the liquid to boil and evaporate as indicated above. The compressibility of the liquid, the change of liquid and gas properties with pressure and gas volume fraction as well as the speed of sound all influence the cavitation process [4]; and
- Hydrodynamic cavitation: Mainly occurring due to high speed turbulent flow detaching from the surface and the related pressure reductions [5].

Cavitation generally causes several problems, such as

- Reduction of useful channel space for liquid flow,
- Load asymmetry,
- Damage of flow passage,
- Vibration and noise; and
- Reduction of machine life.

There are also some desirable applications, such as

- Washing machines,
- Surgical procedures,
- Liquid-solid separators,
- Removal of organic contaminants from water; and
- Ultrasonic cleaning.

Protection against cavitation or enhancing it when required should start with the system design. Simulation techniques resolving the flow conditions in detail could provide a reliable means to predict the susceptibility of the system to cavitate and support optimization efforts.

Simulation models are confronted by two types of challenges:

- Realistic modelling of several interdependent physical phenomena; and
- Robust numerical procedure for handling inherently steep variations in fluid density, due to very large ratios of liquid, vapour, and gas densities, in conjunction with complex geometries, often with moving parts.

To meet such stiff requirements, the present authors have developed and reported the full cavitation model [1,2], with implementation in the commercial code, CFD-ACE+ [6]. This model has been found to be quite general and successful; i.e. capable of realistic predictions, without having to adjust empirical coefficients, for a wide range of problems including automotive oil and water pumps, fuel injection systems, high performance rocket turbo-machinery, and biomedical devices with high-frequency piezoelectric motion.

The full cavitation model accounts for all of the first-order physical effects, including liquid-vapour phase changes, turbulence, surface tension, presence of non-condensible gases, thermal effects and liquid compressibility.