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Cavitation Erosion Modelling Using a Poly-Disperse Fluid Formulation

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Extended Abstract

The collapse of cavitation bubbles and the resulting pressure wave and microjet are capable of damaging materials, resulting in surface deformations and material loss. Sustained cavitation results in reduced performance and longevity of engineering components and systems. Computational modelling of cavitation erosion presents a challenge due to the wide range of spatial scales (ranging from micron sized bubbles to meter sized industrial devices), as well as a temporal scale (ranging from bubble collapses in the order of milliseconds to erosion development in the order of hours). The proposed method of modelling cavitation erosion decouples the modelling into a bulk fluid flow model and a cavitation erosion model.

Bulk multiphase flow can be modelled using Euler-Euler and Euler-Lagrange frameworks, where the Eulerian framework is used to describe the continuous phase, while either the Lagrangian or Eulerian (mono or poly-dispersed) framework is used to describe the dispersed phase. A subset of the Euler-Euler framework, the poly-dispersed Multifluid model [1], is presented and its advantages and disadvantages compared to Population Balance Equation based models are discussed. The Multifluid model is validated using bubble column experimental data from Roig et al. [2]. As opposed to a commonly used mono-dispersed models, a poly-dispersed bubbly phase provides a more accurate description of bubble size, number and wall-distance.

Cavitation erosion models can be separated into macroscopic and mesoscopic models. While mesoscopic erosion models use pressures calculated for individual collapses to model surface erosion, macroscopic models consider bulk flow conditions to determine if, and to what extent, cavitation erosion occurs. Macroscopic microjet [3] and pressure wave [4] erosion models are validated using experimental data from an axisymmetric vertical nozzle case by Franc [5]. The models are extended to a poly-disperse formulation, where a single hemisphere sampling radius is replaced with n radii depending on the number of distinct bubble diameter classes.

Mesoscopic models use a bubble collapse pressure library which is calculated beforehand for a certain bulk liquid, making the approach applicable for a wider range of liquids, such as highly viscous lubricants. Unlike the Volume of Fluid interface capturing method used for the bulk fluid calculation, bubble collapses are based on sharp interface methods such as the Real Ghost Fluid method [6]. Multimaterial Euler simulations are calculated using the Montone Upstream-centred Scheme for Conservation Laws (MUSCL-Hancock) scheme [7], with a first-order Upwind method to update the level set and the Fast Sweeping method [8] to reinitialize the signed distance function. The model is validated quantitatively against one-dimensional analytical data and qualitatively for shock induced bubble collapses.

The proposed method couples the poly-dispersed formulation with the extended macroscopic cavitation erosion model to provide a more accurate and universal way of calculating the location of cavitation erosion. The method may be further extended by using mesoscopic models which determine the surface pressures due to individual bubble collapses.

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