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NUMERICAL MODELLING OF CAVITATING FLOW WITH SPECIAL EMPHASIS ON SHOCK INDUCED DYNAMIC LOADS

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ABSTRACT

Due to the operating conditions of pumps, turbines and fuel injection systems, local evaporation - cavitation - of the working fluid cannot be avoided. Thereby, the characteristics of the flow as well as the thermodynamic properties of the fluid change significantly due to the occurrence of highly compressible two-phase mixtures of liquid and vapour. The vortical nature of cavitating flows leads to the fragmentation of large-scale two-phase structures. Any sufficient pressure raise in the surrounding liquid enforces the collapse-like condensation of the vapour content within these fragments. These collapses result in multidimensional shock structures that propagate through the fluid and initiate the onset of condensation of adjacent fragments. Furthermore, the impingement and subsequent reflection of shocks at the surfaces of pump or turbine blades leads to instantaneous pressures of several hundred bar which is supposed to be a driving mechanism of cavitation erosion.

The aim of the present investigation is the modelling and simulation of the dynamic phase transition of complex 3-D unsteady liquid flows including the formation and propagation of collapse-induced shocks. We therefore developed the CFD-Tool **CATUM - Ca**vitation **T**echnische **U**niversität **M**ünchen, which is a conservative finite volume method based on the weak form of the balance laws for mass, momentum and energy [1]. For this investigation, the employed thermodynamic model is based on an equation of state for liquid water (modified Tait equation), on one for water vapour (ideal gas law), and on one for saturated water/vapour states (Oldenbourg polynomials). Meta-stable or supercritical thermodynamic conditions are not modelled and the effects of viscosity are neglected.

The calculation of the numerical fluxes is based on the theory of characteristics, including a necessary modification of the pressure flux to enable the simulation of steady and unsteady low Mach number flow without the use of preconditioning. Nonlinear reconstruction procedures (WENO, TVD) in space and an explicit 4-stage Runge-Kutta procedure in time lead to an efficient high resolution discretization that is necessary to resolve wave dynamics.

To validate the CFD-Tool **CATUM** we present a series of numerical simulations and compare the obtained numerical results with experimental visualisations and analytical solutions. Figure 1 depicts the comparison of the simulated time history of the radius of

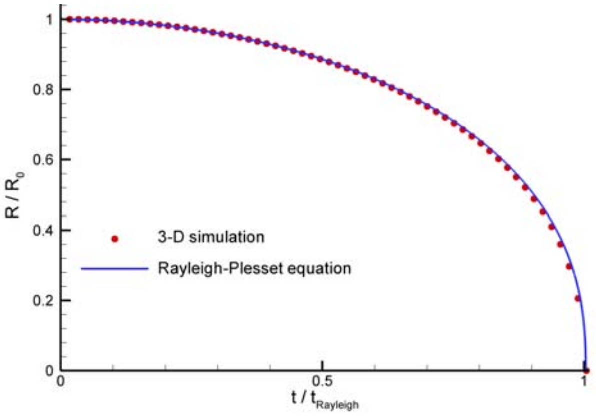

Fig .1: Comparison of theory/numerics of the evolution of the radius of a collapsing vapour bubble.

a collapsing vapour bubble (dots) with the analytical solution of the Rayleigh-Plesset equation (line). The agreement of the 3-D numerical simulation with the theoretical model demonstrates the capability of **CATUM** to accurately reproduce even severe gradients that especially occur during the last stages of the collapse of a liquid embedded vapour bubble. Figure 2 shows the comparison of the experimentally [2] and numerically observed unsteady cavitation clouds on top and in the wake of a 3-D prismatic body in a rectangular test-section. Besides the agreement of the macroscopic structures we observe a significant correlation of the numerically predicted domains of shock induced dynamic loads on the bottom wall of the test-section with the experimentally determined areas of intense cavitation erosion.

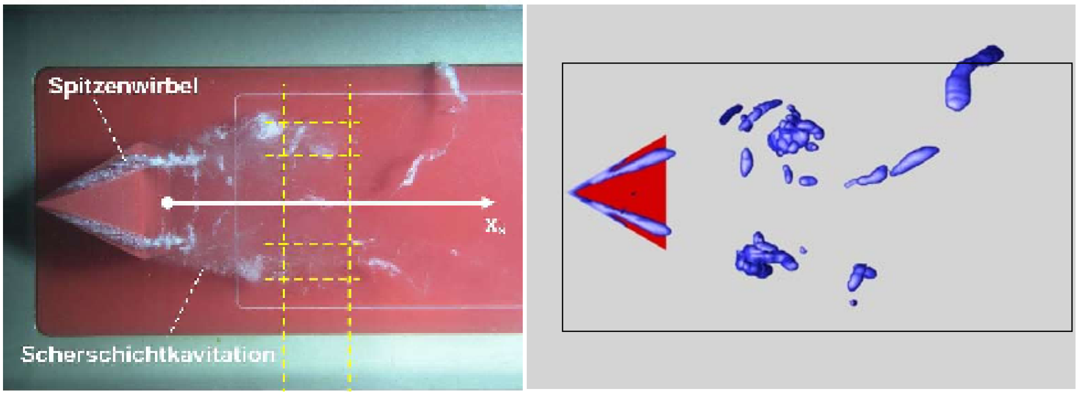

Fig .2: Comparison of experimentally/numerically observed instantaneous cavitation structures behind a prismatic body. Blue surfaces indicate regions of vapour volume fraction $\alpha \geq 5$ %.

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