Simulation of the Hydrodynamic Energy Cascade in Erosive Cavitation

CaFE Innovative Training Networks

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Motivation

❖In many engineering applications it's not possible to simulate the final compressible vapour collapse with current computational resources. Instead, only a macro-scale simulation can be performed where micro-scale phenomena, leading to erosion, are extrapolated from the larger resolved scales.

❖This PhD project aims to identify the most important macro-scale properties governing the micro-scale erosiveness, based on the concept of hydrodynamic energy cascade introduced in the EroCav Handbook [1].

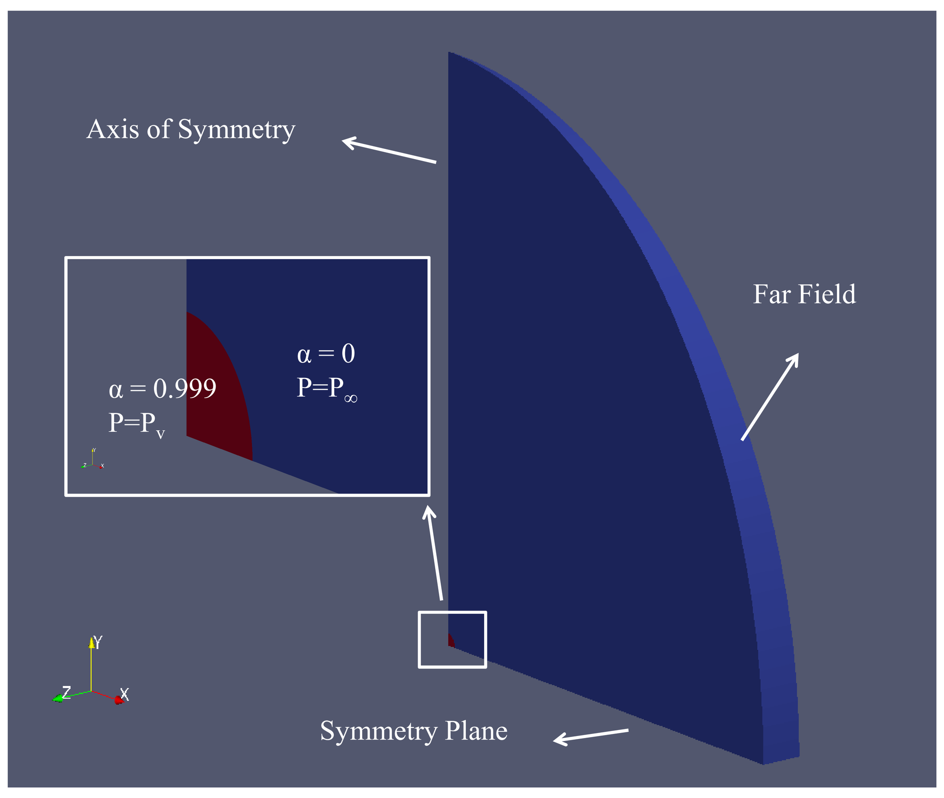


Figure 1. Simulation of a Collapsing Bubble

Bubble Shape	Environmental Pressure P_∞	Collapse time(s)	Produced Pressure Pulse (Pa)
Case 1	101325	3.7e-5	1.767e+7
Case 2	202650	2.57e-5	2.555e+7

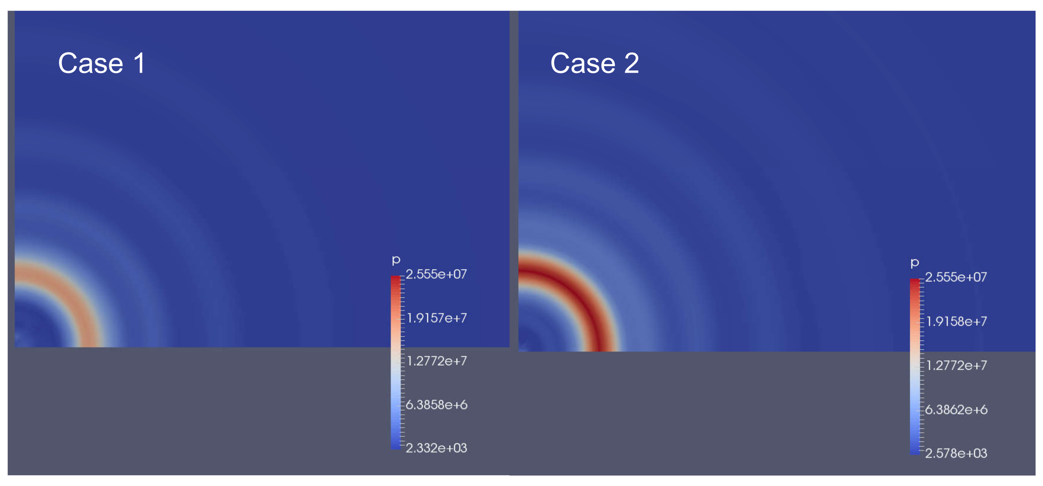
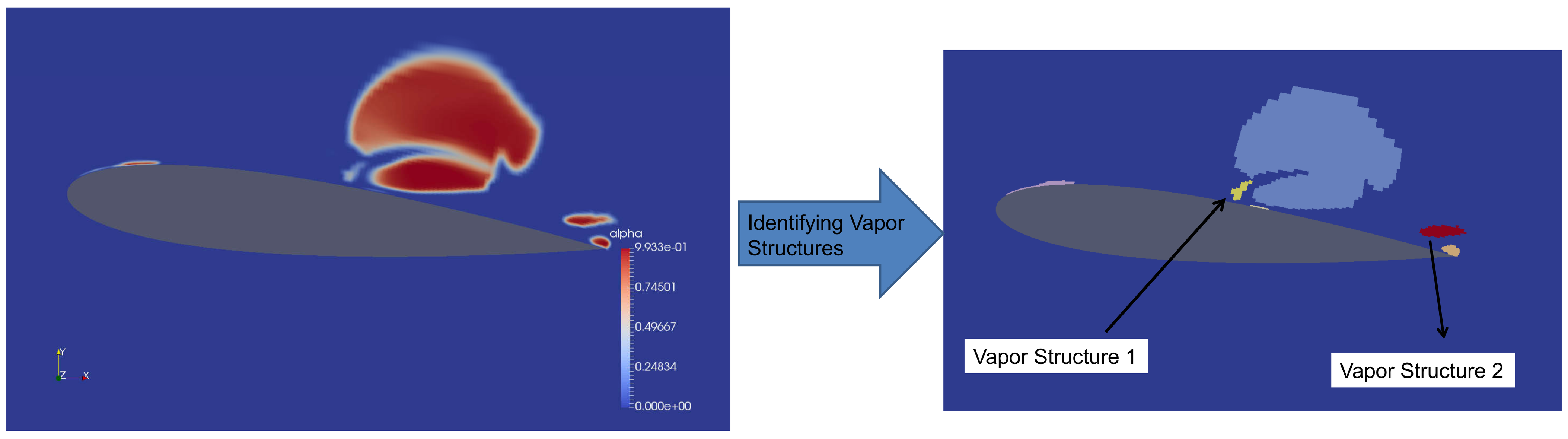


Figure 2. Pressure pulses produced by two bubbles with different collapse rates

Hydrodynamic Energy Cascade

❖This concept describes the energy transfer from macro-scale cavities to collapsing micro-scale cavities close to the surface. It was introduced in the EroCav Handbook [1] and further elaborated in [2]. The idea is that the erosiveness of a cavity can be estimated by analyzing the macro-scale kinematic collapse of that cavity. The detail of this energy cascade needs to be considered in a reliable erosion assessment[1].

❖One example, presented on this poster, of these kinematic features is the collapse rate.



Vapor structure	Collapse time(s)	Produced Pressure Pulse (Pa)
Vapor Structure 1	4e-5	~1e+7
Vapor Structure 2	6.4e-4	~1e+5

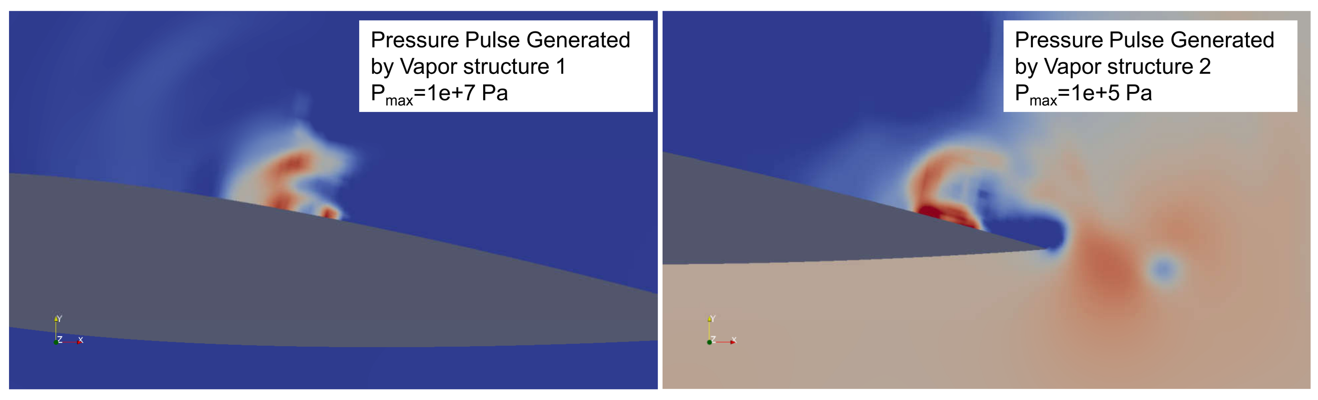


Figure 3. Pressure pulses produced by two cavities with different collapse rates

Numerical Tools

➢Compressible Euler density based solver has been implemented in OpenFOAM framework.

- oThe numerical flux is computed by HLLC-AUSM low-Mach Riemann solver[3].
- oSecond-order reconstruction is done by applying the limiter of Venkatakrishnan[4] to the computed gradients and then do a standard linear reconstruction
- oExplicit low storage Runge-Kutta schemes are used for advancing the solution in time
- oPhase change modeling is done by a compressible equilibrium cavitation model[3]

➢Incompressible solver for two immiscible fluids with phase change

- oUses a VOF(Volume of Fluid) interface capturing approach
- oA set of phase-change models are provided, e.g. Schnerr-Sauer model

➢A utility to identify vapor structures in each time step

Results

➢In order to validate the implementation of compressible solver, numerical solution of several single phase water flow cases are considered. These cases are 1D Water Hammer, 1D Riemann problem for water flow , and water flow over a 2D NACA0015 foil

➢For validation of compressible equilibrium cavitation model , simulation of a collapsing bubble is performed and the results are compared with the solution of Rayleigh-Plesset equation(figure 1) .

➢The simulation of another collapsing bubble with different environmental pressure(case 2 in figure 2) is conducted to study the effect of collapse rate on the produced pressure pulse. The result shows that higher collapse rate would lead to higher pressure pulse and possibly higher erosion risk.

➢Figure 3 shows the collapse behavior of two vapor structures in a cavitating flow over NACA0015 foil. In this case, two vapor structures collapse with different collapse time. The vapor structures with higher collapse rate produces a stronger pressure pulse.

Future Work

➢The compressible Euler solver will be extended to include viscous fluxes vector.

➢The utility for vapor structure identification will be further developed to be able to track the vapor structures during the simulation. Using this utility, it will be possible to track energy cascade from large cavities to smaller ones.

➢To evaluate the compressible and incompressible solvers for studying a cavitating flow, a simulation of a cavitating flows with experimental data will be performed using both solvers. A numerical analysis will be conducted on cavitating structures and their collapse behavior.

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