Predicting Dynamics of Cavitating Vortices and their Relation to Surface Erosion

CaFE Innovative Training Networks

HORIZON2020 Marie Skłodowska-Curie actions

Abstract

Maritime industry has a strong interest in the assessment of cavitation erosion risk in an early design stage, not only to avoid exhaustive maintenance costs, but also to incorporate cavitation risk as a design parameter in design optimization.

This project aims at further development of numerical cavitation erosion prediction models.

A hypothesis by Terwisga et al. [1] states that vorticity tends to focus the acoustic power release due to a cavity collapse and thus the erosive impact on the solid surface in both space and time. At the current stage, special focus is on the question to what extent mass transfer models can capture weak compressible effects in the cavitating regime, which is supposed to affect the vorticity within the cavity.

Introduction

Two different ways to model cavitation in pressure-linked equations, originally designed for fully incompressible flows, are compared.

1) Cavitation modelling via a barotropic equation of state and a corresponding compressibility law [2] (s. Figure 1)

$$\rho(p)=\frac{\rho_l}{2}\left[1+\frac{\rho_v}{\rho_l}+\left(1-\frac{\rho_v}{\rho_l}\right)\tanh\left(\frac{2(p-p_v)}{c^2_{s,min}(\rho_l-\rho_v)}\right)\right]$$

2) Cavitation modelling via a volume fraction transport equation including a source term (mass transfer model). The mass transfer model, similar to the model by Merkle et al. [3], is applied to an incrementally increasing/decreasing pressure at a point of zero gradient.

$$\nabla\cdot U=-\frac{1}{\rho}\frac{\partial\rho}{\partial t}=\left(\frac{1}{\rho_v}-\frac{1}{\rho_l}\right)\dot{m}$$

$$\dot{m}=\begin{cases}-\dfrac{C}{\rho}(1-\gamma)(p-p_v) & \text{if} \quad p>p_v\\ -\dfrac{C}{\rho}\gamma(p-p_v) & \text{if} \quad p\leq p_v\end{cases}$$

$$\rho=\gamma\rho_l+(1-\gamma)\rho_v$$

$$p(t)=p_v\pm\dot{p}\,\Delta t$$

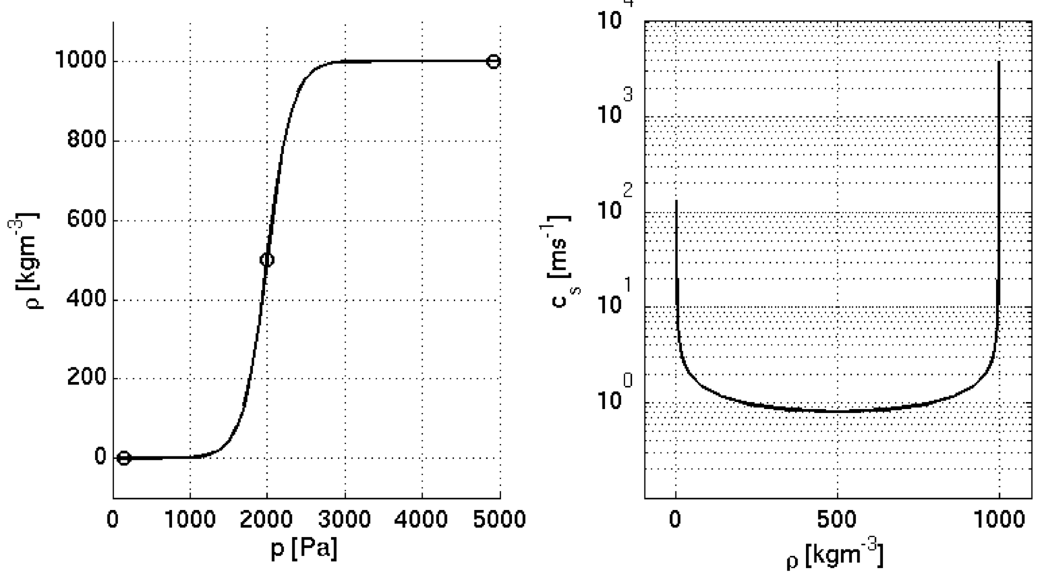

Figure 1. Barotropic state curve (left) and corresponding speed of sound curve (right) with a minimum speed of sound of 0.8 ms^{-1}

Methods and Materials

- Implementation in **OpenFOAM**, starting from the incompressible two-phase flow solver **interPhaseChangeFoam**
- Solving the Euler equations and neglecting surface tension
- Validation against results obtained from the fully compressible solver **CATUM** planned

Results

Starting from vapour pressure, the mass transfer model is applied to linearly increasing (condensation) and decreasing (vaporization) pressure. The density curve is compared to the one obtained by the barotropic model.

Case A: $-\frac{1}{\rho}\frac{\partial\rho}{\partial t}=\left(\frac{1}{\rho_v}-\frac{1}{\rho_l}\right)\dot{m}$

Case B: $-\frac{1}{\rho}\frac{\partial\rho}{\partial t}=\left(\frac{1}{\rho_v}-\frac{1}{\rho_l}\right)\dot{m}\,\dot{p}$

$\rho_v=1\,\mathrm{kgm^{-3}}$, $\rho_l=1000\,\mathrm{kgm^{-3}}$, $p_v=2000\,\mathrm{Pa}$

Case A

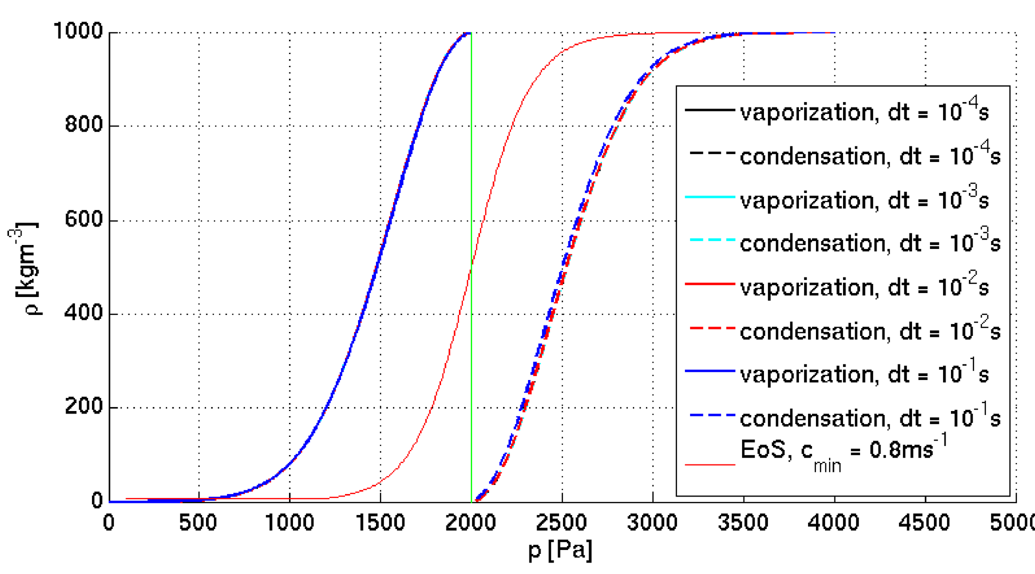

Figure 2. Variation of the time step size; the red line represents the barotropic model; $C=0.5$

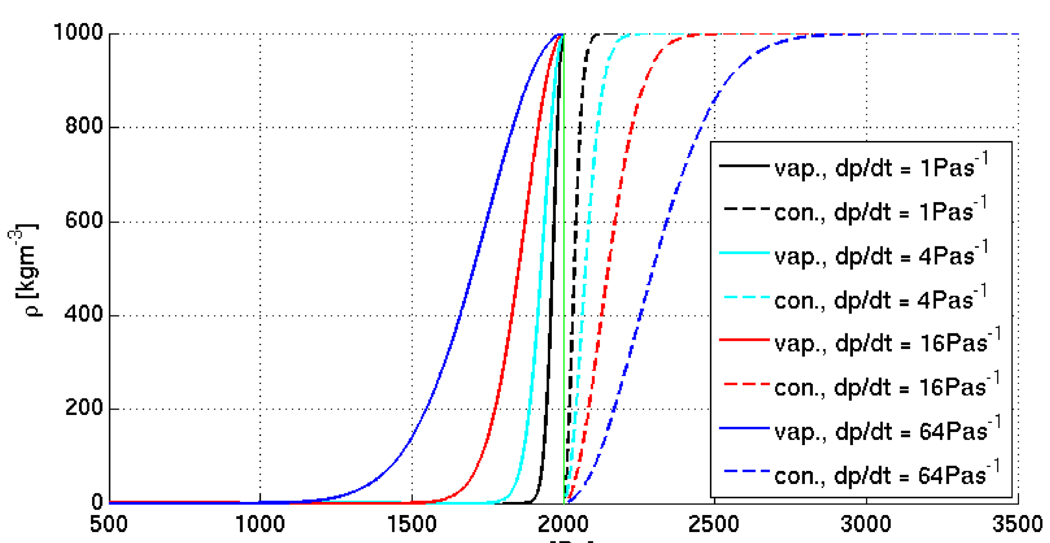

Figure 3. Variation of the pressure growth/decay rate; $C=1$

Case B

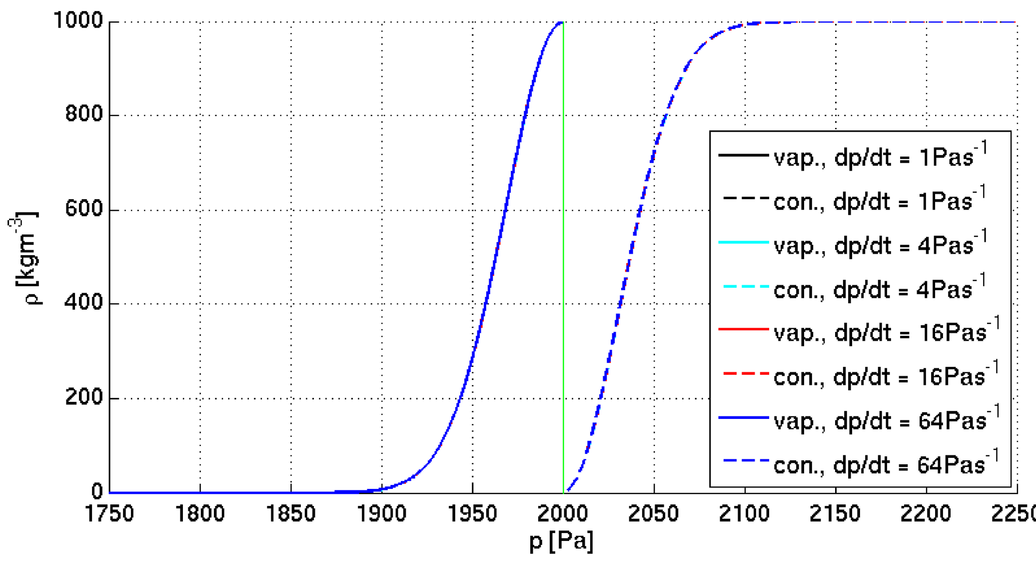

Figure 4. Scaling the mass transfer rate with the pressure growth/decay rate; $C=1$

Application of the Schnerr-Sauer model [4]

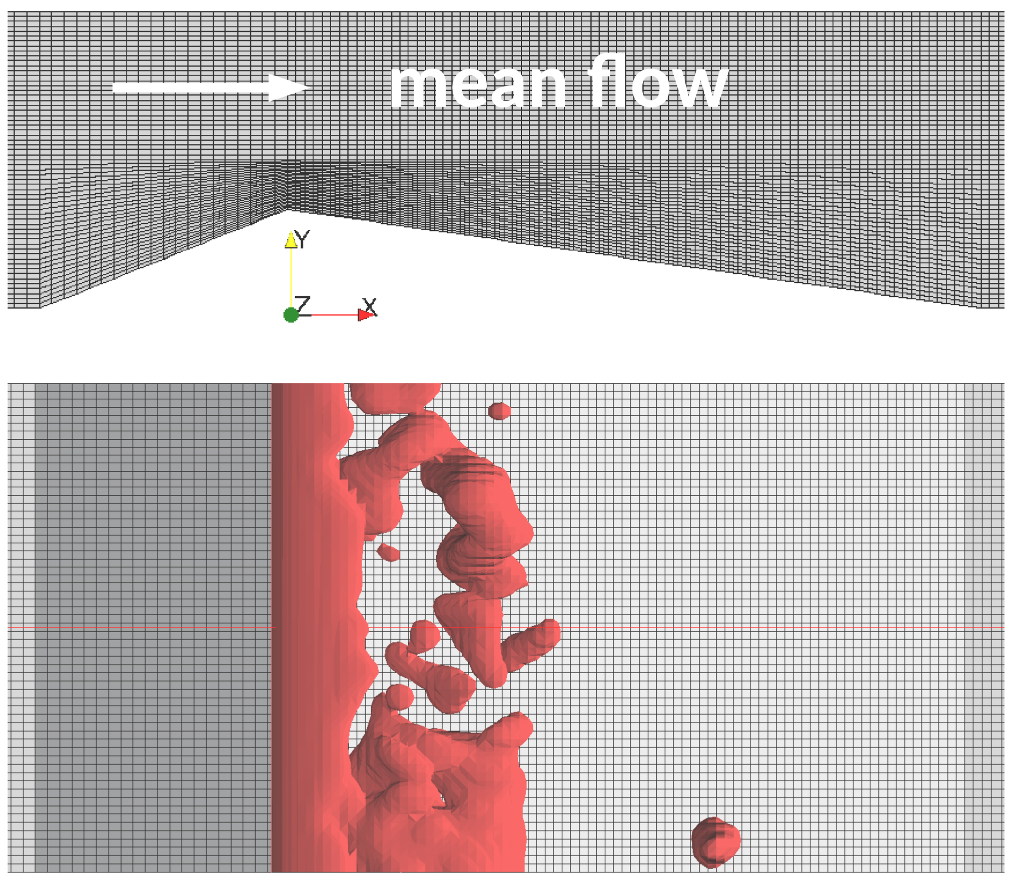

Figure 5. Vapour structures for the wedge test case for $C_a=2.1$

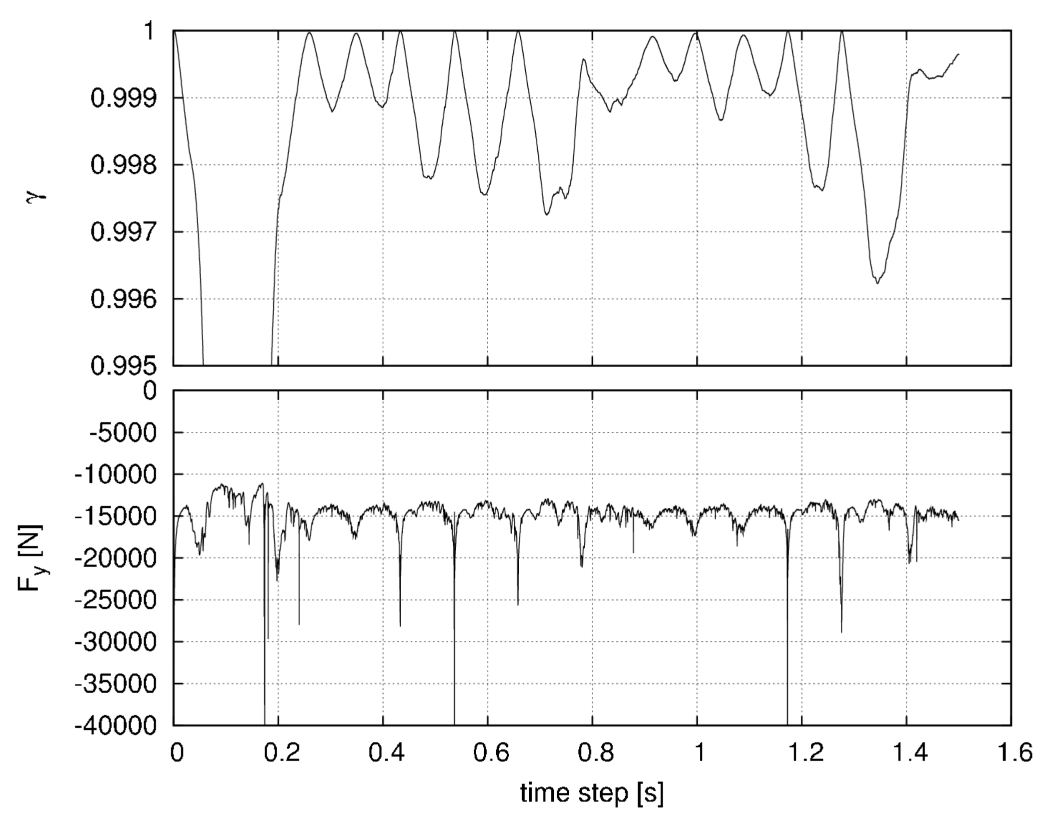

Figure 6. Cavity volume fraction (above) and integrated vertical force (below) over time

Conclusions

- **Compressible barotropic modelling:** Numerical treatment of the density time derivative in the pressure equation is challenging. The main difficulty arises from the highly nonlinear compressibility law within an otherwise linearized system [5].
- **Mass transfer model:** The source term can be associated with a compressibility term, similar to the fully compressible barotropic model, but it does not scale with the pressure time derivative. Thereby, more numerical robustness is achieved at the expense of physical accuracy. A careful study on the parameter sensitivity is required.
- **Erosion prediction:** Further research is recommended to clarify how the simplifying assumption in the mass transfer approach affects the feasibility of different erosion indicator models.

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References

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