Numerical Assessment of Cavitation Erosion for a Nozzle Flow Configuration

Citation for the original published paper (version of record):

Özgünoglu, M., Arabnejad Khanouki, M., Bensow, R. et al (2021). Numerical Assessment of Cavitation Erosion for a Nozzle Flow Configuration. 11th International Symposium on Cavitation (CAV2021)

CAV2021
11th International Symposium on Cavitation
May 10-13, 2021, Daejon, Korea

Numerical assessment of cavitation erosion for a nozzle flow configuration

Mehmet Ozgunoglu [1]*, Mohammad Hossein Arabnejad [1], Michael Oevermann [1,2], Rickard Bensow [1]

[1]Chalmers University of Technology, Sweden
[2]Brandenburgische Technische Universität Cottbus – Senftenberg, Germany

Abstract: The main purpose of this study is to numerically investigate and predict the cavitation erosion mechanisms in a nozzle flow configuration. To do this, an injector type geometry is numerically investigated with the open-source CFD package OpenFOAM. A compressible Euler approached is applied for two operating conditions, where results are compared with other studies from the literature. Spectral statistics and maximum surface pressure results are compared with experiments. Results show that the proposed modelling approach is capable to explain main cavitation structures that promotes erosion.

Keywords: Cavitation Erosion; Compressible flow modelling; Bubble Collapse; Nozzle Flow; Shedding

1. Introduction

The ability to perform cavitation erosion assessment at the initial stage of the design process is highly advantageous. This allows for an early and cost-efficient detection of problematic design features. Considering that experiments may be expensive and long-lasting, we're here evaluating the use of CFD, computational fluid dynamics, methods. Besides the potential cost benefit, the additional flow details accessible through CFD improves the possibility of making good design changes.

This study is an initial step of a long-lasting objective to provide detailed cavitation erosion assessment for industrial dual-fuel injectors. So, as an injector type geometry, the experimentally investigated canonical nozzle flow configuration [1] is numerically investigated with the customized open-source software [5].

In order to capture collapse induced shock-wave [8], a well-known mechanism of cavitation erosion, fluid physics are represented via a compressible set of equations. The flow is expected to be inertia driven thus an Euler/Inviscid formulation is used.

In order to assess the predictive capability of the modelling technique and the numerical settings, numerical results are presented in both with temporal and spatial perspective. Moreover, they are compared with existing experimental results [1,2] and other reported computations [2–4].

2. Methodology

Thermodynamic properties of the fluid are modelled with a barotropic formulation. Hence, it is assumed that the thermodynamic equilibrium is spatially preserved for both liquid and vapor phases. The liquid phase is represented with the Tait equation of state [6], while the mixture phase is formulated with isentropic vaporization process assumption, proposed a formulation by Egerer et al. [7].

Collapse-induced shock-waves possess the spatial information i.e., where the collapse occurs. Mihatsch et al. [4] developed a "collapse detector algorithm" using this physical insight. Basically, this method is recording the pressure and location of the computational cell if the divergence of the velocity field changes sign. We here use this algorithm as implemented in OpenFOAM by Arabnejad et al. [5]., 1/8 portion of the original geometry is deemed sufficient as the computational domain. This choice was confirmed to be fine by simulating also a 1/4 domain with no significant differences noted. Below, Figure 1 shows the computational domain, which has $2x10^5$ hexahedral elements, together with the applied

---

* Corresponding Author: Mehmet Ozgunoglu, omehmet@chalmers.se

boundary conditions. Simulations are carried out on one computational grid, in order to be consistent between cases with respect to low frequency statistics [3,4].

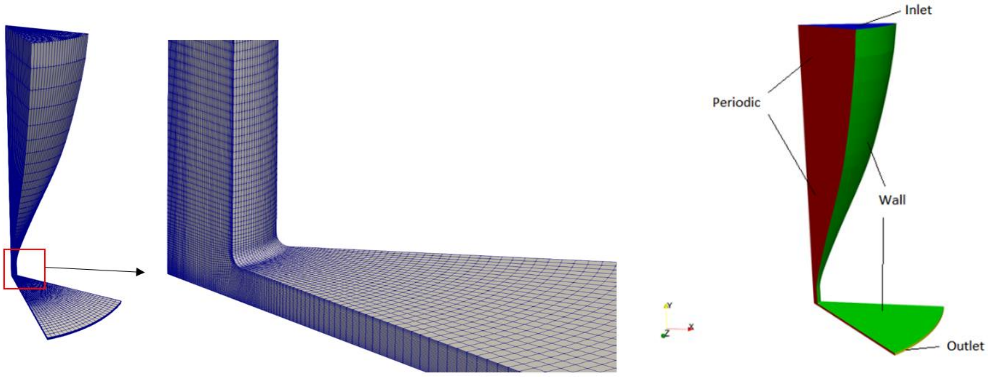

Figure 1. Computational domain and the boundary conditions

Table 1. Operating conditions.

Upstream pressure (bar)	Downstream pressure (bar)	Flow rate (l/s)	Cavitation number
20	9.5	5.60	0.9
40	18.9	8.25	0.9

Two operating conditions, which are listed in Table 1, are studied. Operating pressure condition on upstream is set as 40 and 20 bar respectively by determining 9.5 and 8.9 bar static pressure at the outlet, corresponding to reported experimental conditions by Franc et al [1]. Constant velocity in the normal direction is applied to the inlet in order to match the corresponding experimental mass flow rate. Periodicity is provided at the rotationally symmetric boundaries.

Periodic behavior of the cavitation structures is examined with spectral analysis of the statistics. Fast Fourier Transform is applied with the welch method, including the default overlap and window length of 0.01 s. Experimental flush-mounted pressure sensor is represented numerically via surface probe having the same sensitive sensor diameter/position [1] on the lower surface. Vapor volume fraction is the another tracked parameter to understand the periodic behavior of the cavitation structures.

3. Results

Figure 2-a shows the maximum wall pressure values recorded on the surfaces for both operating conditions. Maximum pressure values are recorded until 100ms. Naturally, the higher maximum pressure values are seen for the higher operating pressure. Experimental erosion pattern [1] is also presented in Figure 2-b together with the three erosion-expected positions in order to provide a comparison with computations. These positions on each wall are radially sketched with the continuous white line on each surfaces in Figure 2-a. On the lower wall, the radial extent of the "position 1" is given in interval between 19-32 mm, whereas, "Position 2" and "Position 3" on the upper wall are located with 17-27 mm and 8-11 mm extensions respectively. So, the erosion locations are well matched, if the maximum pressure locations can be considered as pitting locations.

* Corresponding Author: Mehmet Ozgunoglu, omehmet@chalmers.se

Figure 3 shows the frequency spectra of the vapor volume fraction with four characteristic frequencies detected. As confirmed by the previous computational study [4], “f1”, “f2” and “f3” increase with increasing pressure. However, “f4” is not dependent to the operating pressure, it is due to the reflection of the collapse-induced pressure waves. The lowest characteristic frequency “f1” is related to the change of the total vapour volume in the radial extent [4], “f2” represents the shedding behaviour and “f3” is the first harmonic couple of this. The shedding frequency of both conditions are captured very similar (1100 Hz and 1500 Hz) to those obtained in [3,4]. We note that previous studies [3,4] state that the grid has effect on low frequency resolution.

Lastly, Figure 4 shows the comparison of the frequency spectra of the numerical sensors for both conditions. It can be said the aforementioned grid resolution effect is still consistent for the low frequency statistics. However, dominant frequencies and harmonic couples of the both operations are in good agreement with the experiments.

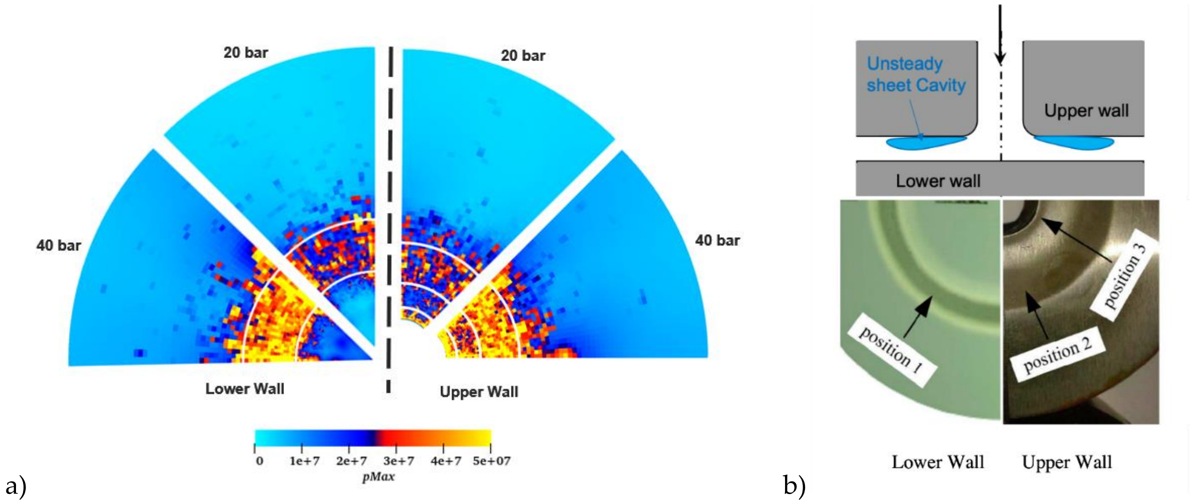

Figure 2. **a)** Maximum pressure values recorded on lower and upper surfaces for both operations b) Experimental erosion pattern on both surfaces [1]

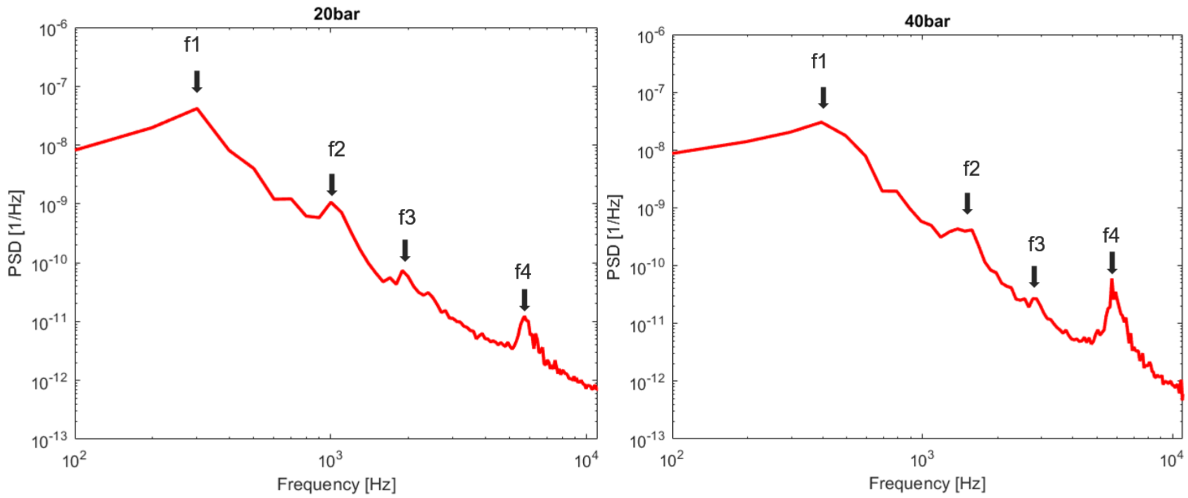

Figure 3. Frequency spectra of the vapor volume fraction with respective characteristic frequencies **a)** 20 bar, **b)** 40 bar

* Corresponding Author: Mehmet Ozgunoglu, omehmet@chalmers.se

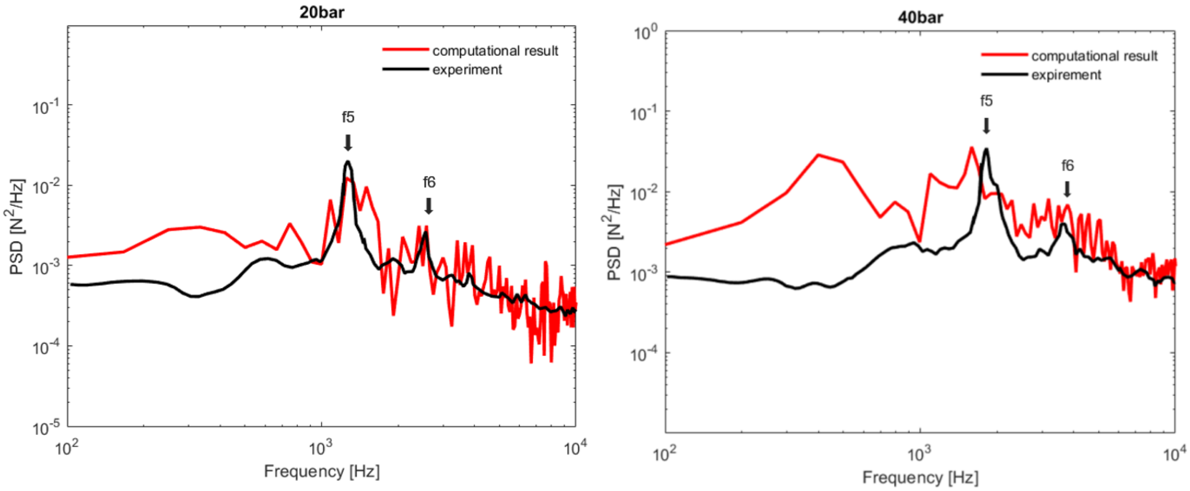

Figure 4. Frequency spectra of the computational and experimental numerical sensor with respective characteristic frequencies
a) 20 bar, **b)** 40 bar

4. Conclusions

Although the current modelling approach does not include any viscous effects, the current predictive capability of the modelling and analysis strategy provides promising results for evaluating the risk of cavitation erosion. Therefore, this strategy will be considered as an initial approach to examine injector systems with much more complex geometries and / or operating conditions.

Further studies will focus on the industrial-type geometries and fluids. It will also include the viscous/turbulence effect together with different type of equation of state closures.

Acknowledgments: This study is funded by the European Union Horizon 2020, EDEM project, a Marie Skłodowska-Curie Action Innovative Training Network project, grant number 861002.

References

1. J. Franc, M. Riondet, A. Karimi, and G.L. Chahine. Impact load measurements in an erosive cavitating flow. Journal of Fluids Engineering, 133(12):121301, 2011.
2. M. Gavaises, F. Villa, P. Koukouvinis, M. Marengo, and J. Franc. Visualisation and LES simulation of cavitation cloud formation and collapse in an axisymmetric geometry. International Journal of Multiphase Flow, 68:14–26, 2015.
3. M.H. Arabnejad, Assessment of cavitation erosion risk based on single-fluid simulation of cavitating flows, Department of Mechanics and Maritime Sciences, Chalmers University of Technology, 2020, Ph.D., Thesis
4. M. Mihatsch, S. Schmidt, and N. Adams. Cavitation erosion prediction based on analysis of flow dynamics and impact load spectra. Physics of Fluids, 27(10):103302, 2015.
5. M.H. Arabnejad, R. Bensow, dbnsCavitatingFoam: A density-based solver with equilibrium cavitation models in the OpenFOAM framework, 2020
6. L. Yuan-Hui. Equation of state of water and sea water. Journal of Geophysical Research, 2(10):2665–2678.
7. C. Egerer, S. Hickel, S. Schmidt, and N. Adams. Large-eddy simulation of turbulent cavitating flow in a micro channel. Physics of Fluids, 6(8):085102,2014.
8. I.H. Sezal, S.J. Schmidt, G.H. Schnerr, M. Thalhamer and M. Förster, Shock and wave dynamics in cavitating compressible liquid flows in injection nozzles, Shock Waves, 19 (1) (2009), pp. 49-58

* Corresponding Author: Mehmet Ozgunoglu, omehmet@chalmers.se