Steady-state cavitation modeling in an open source framework
Theory and applied cases

Long Abstract

Lucian Hanimann
Competence Centre Fluidmechanics and Hydromachines
Lucerne University of Applied Science and Arts

Luca Mangani
Competence Centre Fluidmechanics and Hydromachines
Lucerne University of Applied Science and Arts

Ernesto Casartelli
Competence Centre Fluidmechanics and Hydromachines
Lucerne University of Applied Science and Arts

Matthias Widmer
Competence Centre Fluidmechanics and Hydromachines
Lucerne University of Applied Science and Arts

Introduction

Besides the fact that cavitation is most often an unsteady phenomenon [1, 2] it is necessary to have a robust and reliable software able to represent the steady state flow patterns. Especially in the early design state it is mandatory to be able to predict the occurrence of cavitation without time consuming transient computations.

The authors will therefore give a short summary of the theory behind different cavitation models and their implementation into an in-house modified version of OpenFOAM®.

The main focus of the paper will then point out the integration of mixture type cavitation models into a pressure correction based steady-state solver. Different strategies have been tested and a stable formulation was found.

1. Methods

The used solver is an in-house, 3D, unstructured, object-oriented finite volume code. It is implemented into the framework of OpenFOAM® [3, 4] and designed to solve steady-state compressible and incompressible RANS-Equations [5]. The pressure-based solver uses a SIMPLE-C like algorithm with special treatment of the pressure correction [6] and is capable of handling multiple references of frame (MRF). Full second order upwind scheme for convection discretization has been used for all computations. An overview of the code capabilities and developments is given in [7].

The following four mixture type cavitation models have been integrated:

- Kunz et al. [8]
- Park, Ha, Merkle [9, 10]
- Yuan, Weixing, Sauer, Schnerr [11, 12]
- Zwart, Gerber and Belamri [13]

Turbulence model modifications as suggested by Schnerr [14] have been tested and compared. Results will be presented

The major challenge was the stability issues of numerical implementations found in literature. While transient solutions can be achieved, prediction of steady-state phenomenas is impossible.
A stable formulation of the phase change contribution to the pressure correction equation was then found by a linearization and implicit integration.

Validation against measurement data and commercial code was carried out based on the following testcases. Profound validation results will be presented.

- Dupont, Naca0009 [15, 16]
- Nurick [17]
- Rouse and McKnown [18, 16]

After the validation campaign, the code was then used in industrial applications.

References

[1] Benoit Pouffary. Numerical modelling of cavitation. Technical report, DTIC Document, 2006.

[2] Rickard E Bensow and Göran Bark. Simulating cavitating flows with les in openfoam. 2010.

[3] OpenCFD. *OpenFOAM User Guide*. OpenCFD Limited, 2012.

[4] OpenCFD. *OpenFOAM Programmers Guide*. OpenCFD Limited, 2012.

[5] L. Mangani, C. Bianchini, A. Andreini, and B. Facchini. Development and validation of a c++ object oriented cfd code for heat transfer analysis. *ASME Summer Heat Transfer*, (AJ-1266), 2007.

[6] L. Mangani. *Development and Validation of an Object Oriented CFD Solver for Heat Transfer and Combustion Modeling in Turbomachinery Application*. PhD thesis, Università degli Studi di Firenze, Dipartimento di Energetica, 2008.

[7] Ernesto Casartelli and Luca Mangani. Object-oriented open-source cfd for turbomachinery applications: A review and recent advances. *ASME Turbo Expo*, (GT2013-95285), 2013.

[8] Robert F Kunz, David A Boger, David R Stinebring, Thomas S Chyczewski, Jules W Lindau, Howard J Gibeling, Sankaran Venkateswaran, and TR Govindan. A preconditioned navier–stokes method for two-phase flows with application to cavitation prediction. *Computers & Fluids*, 29(8):849–875, 2000.

[9] Charles L Merkle, Ding Li, and Venkateswaran Sankaran. Multi-disciplinary computational analysis in propulsion. *AIAA Journal*, 4575, 2006.

[10] W Park, C Ha, and C Merkle. Multiphase flow analysis of cylinder using a new cavitation model. 2009.

[11] Weixing Yuan, Jürgen Sauer, and Günter H Schnerr. Modeling and computation of unsteady cavitation flows in injection nozzles. *Mécanique & industries*, 2(5):383–394, 2001.

[12] Weixing Yuan and Günter H Schnerr. Numerical simulation of two-phase flow in injection nozzles: Interaction of cavitation and external jet formation. *Journal of Fluids Engineering*, 125(6):963–969, 2003.

[13] Philip J Zwart, Andrew G Gerber, and Thabet Belamri. A two-phase flow model for predicting cavitation dynamics. In *Proceedings of the Fifth International Conference on Multiphase Flow, Yokohama, Japan*, 2004.

[14] GH Schnerr. Modeling of unsteady cavitating flows: Status and future development. In *Proceedings of the 6th International Symposium on Experimental and Computational Aerothermodynamics of Internal Flows*, pages K1–K21, 2003.

[15] Philippe Dupont. Etude de la dynamique d'une poche de cavitation partielle en vue de la prédiction de l'érosion dans les turbomachines hydrauliques. *Diss. EPF Lausanne*, 1993.

[16] Sandor Bernad, Romeo Susan-Resiga, Sebastian Muntean, and Ioan Anton. Numerical analysis of the cavitating flows. *Proceedings of the Romanian Academy, Series A*, (12006), 2006.

[17] WH Nurick. Orifice cavitation and its effect on spray mixing. *Journal of fluids engineering*, 98(4):681–687, 1976.

[18] Hunter Rouse and John S McNown. Cavitation and pressure distribution: head forms at zero angle of yaw. 1948.