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Data Article

CFD data of unsteady cavitation around a hydrofoil, based on an extended Schnerr-Sauer model coupled with a nucleation model

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ABSTRACT

The data presented in this article were the basis for the study reported in the research articles entitled “Characterization of unsteady cavitating flow regimes around a hydrofoil, based on an extended Schnerr-Sauer model coupled with a nucleation model” (De Giorgi et al., 2018)[1]. The reference study presented a spatio-temporal characterization of different cavitating flow regimes using Computational Fluid Dynamics (CFD). The authors evaluated the accuracy of an extended Schnerr-Sauer cavitation model. The accuracy of the numerical model has been improved by means of the introduction of a Density Correction Model of the turbulent viscosity, and a simplified Population Balance Modeling (PBM).

1. Data

CFD data concerning the dynamics of the vapor cavity over a temporal cycle of birth, growth, detachment and collapse are provided. Furthermore, the temporal signals and the FFT spectra of the spatially averaged liquid volume fraction α, the lift coefficient CL, the drag coefficient CD and the static pressure upstream derived from a virtual proble located 0.1 m upstream and placed along the

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Specifications Table

Subject area	*Aerospace Engineering, Mechanical Engineering*
More specific subject area	*Fluid dynamics, Cavitation, Computational modeling*
Type of data	*TIFF images (CFD contour plot), text file (Excels data)*
How data was acquired	*OpenFOAM CFD toolbox*
Data format	*Raw, analyzed*
Experimental factors	*A water flow around the NACA 0015 hydrofoil was investigated at 298K and in different cavitating conditions, as performed by Ref. [2]. The cavitation number was varied to reproduce different cavitating flow regimes, i.e. bubble cavitation, cloud cavitation and supercavitation.*
Experimental features	*Numerical simulations were performed by using the open source CFD toolbox OpenFOAM version 3.0.1, based on a Finite Volume formulation. The PBE model has been constructed on the code OpenQBMM v2.0.0. Even if thermal effects are negligible in the present test case, the numerical model has been developed also for non-isothermal flow and has been here applied in order to obtain an improved level of accuracy.* *The spatial and temporal characterization of the cavitating flow regimes based on the analysis of the flow field by means of statistical and frequency analysis.*
Data source location	*Lecce, Italy*
Data accessibility	*Data of current article*
Related research article	*"Characterization of unsteady cavitating flow regimes around a hydrofoil, based on an extended Schnerr-Sauer model coupled with a nucleation model" (De Giorgi* et al.*, 2018)* [1].

Value of the Data

- The data allow investigation of the effect of nucleation on the unsteady behavior of cavitating structures.
- The computational data can be used to verify modeling predictions of unsteady cavitating flows on hydrofoils.
- The data can be used for comparing with the results of other's simulation model by providing a benchmark.
- It can be used for CFD user training and improvement of the accuracy of numerical simulations of cavitating flows.

symmetry axis of the duct. In addition, the temporal signals of the cavity lengths estimated by thresholding at 0.9 are given. The average, minimum and the maximum cavity length are also documented. In particular the average cavity length has been derived by thresholding at 0.9 of the average field of α, while the minumum and the maximum correspond to the minimum and the maximum elongations of the vapor cavity. They are compared with the experimental data provided by Ref. [2], which have been derived by averaging of acquisition at a sampling rate of 30 fps.

In summary, the supplementary file includes the following data:

1. dataset of the snapshots of the contour field of the liquid volume fraction, the turbulent kinetic energy, the baroclinic vorticity and the dilatation vorticity, over a typical vapor cavity cycle during bubble cavitation at σ=2.1 (File1), cloud cavitation at σ=1.5 (File2), and supercavitation at σ=1.2 (File3);
2. temporal evolution (sampling rate of Fs=1000Hz) at σ=1.2 (column 2), σ=1.5 (column 3) and σ=2.1 (column 4), of the
   1. liquid volume fraction spatially averaged over the vapor cavity area developed into an investigation windows extended 0.01 m upstream and 0.125 m downstream with respect to the leading edge of the profile (File4);
   2. lift coefficient (File6);
   3. drag coefficient (File8);
   4. static pressure upstream derived from a virtual probe located 0.1 m upstream and placed along the symmetry axis of the duct (File10);
3. FFT spectra (sampling rate of Fs=1000Hz) at σ=1.2 (column 2), σ=1.5 (column 3) and σ=2.1 (column 4), of the
   1. liquid volume fraction spatially averaged over the vapor cavity area developed into an investigation windows extended 0.01 m upstream and 0.125 m downstream with respect to the leading edge of the profile (File5);

  2 lift coefficient (File7);
  3 drag coefficient (File9);
  4 static pressure upstream derived from a virtual probe located 0.1 m upstream and placed along the symmetry axis of the duct (File11);
4 temporal evolution (sampling rate of Fs=100Hz) at σ=1.2 (column 2), σ=1.5 (column 3) and σ=2.1 (column 4), of the cavity length Lcav obtained with thresholding at α=0.9 (File12);
5 average, minimum and maximum dimensionless cavity lengths Lcav/c (c is the hydrofoil chord, c=0.115 m), in comparison with the experimental maximum Lcav/c by Ref. [2](File13).

2. Experimental design, materials, and methods

A water flow around the NACA 0015 hydrofoil was investigated at 298K and in different cavitating conditions. Numerical simulations were performed by using the open source CFD toolbox OpenFOAM Version 3.0.1 [3], based on a Finite Volume formulation. The PBE model has been constructed on the code OpenQBMM v2.0.0 [4]. Based on a probabilistic number density function (NDF) uniquely determined by means of a moment inversion algorithm, which relates the local nuclei density to the nuclei diameter, the PBE is solved by means of the extended quadrature method of moments (EQMOM), which ensures a good accuracy with a reduced computational cost.

The k-ω Shear Stress Transport model (SST) was chosen owing to its good performance in dealing with confined flows.

The water flow was simulated by using a fixed time step of 1×10^{-4} s. In addition, a dual time stepping was introduced in order to solve the population balance equation. In particular, the original time step was decomposed into $N_{subcycle} = 30$ subcycles so as to determine a reduced time step.

The computational domain consisted of 93172 cells and extended 3c (c=chord length) upstream of the leading edge and 5c downstream of the trailing edge of the hydrofoil, and the chord of the hydrofoil is 0.115 m.

The flow was confined in a rectangular duct having a height of 0.12 m. The no-slip condition was imposed on the hydrofoil, as well as on the upper and bottom walls. The initial temperature field was set to 298 K. The inlet velocity of the flow was fixed at 4 m/s. The outlet pressure was derived from the cavitation number σ defined as:

$$\sigma = \frac{p_\infty - p_{v,\infty}}{0.5\,\rho\,U_\infty^2} \tag{1}$$

Concerning the boundary conditions, unsteady computations were initialized by means of the non-cavitating steady-state solutions, which in turn were constrained by setting the inlet velocity and the pressure outlet with values in accordance with [2]. In particular, the no-slip condition was imposed on the hydrofoil, as well as on the upper and bottom walls. Furthermore, the velocity of the flow was fixed at 4 m/s, which corresponds to a Reynolds number equal to 5.14×10^5. Using the Reynolds number and the fluid velocity at the inlet upstream, namely Re and U_∞, the turbulent kinetic energy k and the specific dissipation rate ω were initialized as follows:

$$I_t = 0.16\,Re^{-1/8} \tag{2}$$

$$L_t = 0.7\,c \tag{3}$$

$$k = \frac{3}{2}\,(U_\infty\,I_t)^2 \tag{4}$$

$$\omega = C_{\mu}^{1/4}\frac{k^{1/2}}{L_t} \tag{5}$$

where c is the hydrofoil chord, I_t is the turbulence intensity, L_t is the turbulent length and the coefficient C_{μ} was set to its default value equal to 0.09. The outlet pressure was derived from the cavitation number σ defined in Eq. (23). The initial temperature field was set to 298 K.

The characterization of the cavitating flow regimes concerned three different cavitation numbers corresponding to different cavitation regimes: σ=2.1 (bubble cavitation regime), σ=1.5 (cloud cavitation regime) and σ=1.2 (supercavitation regime).

The database of the National Institute of Standard and Technology (NIST) [5] was used for the determination of saturation and transport properties of water.

The data predicted by the numerical model were analyzed by statistical and frequency analysis.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.dib.2019.104226.

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