DNS of Vortex Cavitations in Turbulent Separated Layer

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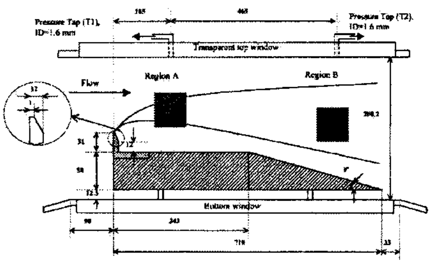
Abstract: We conducted a direct numerical simulation (DNS) to establish database for the purpose of improvement of practical method which is applicable to cavitating turbulent flows. Cavitations caused by spanwise and streamwise vortices, which are typical features in high shear layer, is represented by a simple model and interaction between vortices and cavities is reproduced. The qualitative agreement between computation and experiment are reasonable. Cavities due to streamwise vortices in a shear layer seem to attenuate turbulent eddies.

Introduction

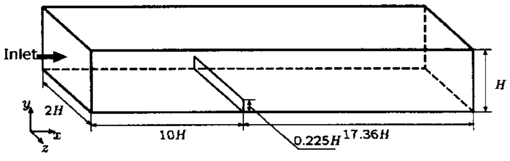
Flows in hydro-machineries are affected by various types of cavitations. Since 1990's, several methods have been proposed for the numerical simulation of flow fields including unsteady cavitation. Attached (sheet) cavitations and cloud (bubble) cavitations are reasonably reproduced. However, the influence of turbulence has not taken into account completely in previous simulations although most of cavitating flows are turbulent. This causes inaccuracy in predicting the cavitation inception because the local minimum of pressure is thought to be corresponding core of turbulence vortices. On the other hand, the effect of cavitation on turbulence has usually been omitted. Therefore, to establish the computational method for turbulent cavitating flows, the interaction between cavitation and turbulence vortices should be correctly modeled.

The aim of our study is to address the modeling strategies considering two questions. (1) How are fine-scale vortices in turbulence related to cavitation inception? (2) How does the cavitation modify turbulent vortices and turbulence statistics? Since both are interactive phenomena, they must be analyzed by two-way methodology. Typical and appropriate example for our objective is the separated flow behind a thin fence in a two-dimensional channel. Iyer and Cessio [1] visualized various types of vortex cavitations and they reported the turbulence statistics in the wake region.

In this report, we show the results of the direct numerical simulation [2] with cavitation model, which was developed by us [3]. The influence of cavitation on Reynolds stress profile is compared 'qualitatively' with experimental observation [1], because the flow configuration was simplified in our simulation. Then, to consider the mechanism of turbulence modification, the relationship between cavitation and primary (spanwise) vortices and the secondary (streamwise) vortices are observed. Also the effect of cavitation on each elementary vortex is discussed.



(a) Experimental setup by Iyer and Cessio [1]



(b) Computational domain for our DNS [2]

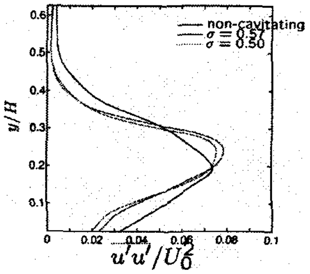
Figure 1: Flow configuration for cavitating separated flow

Results and Discussions

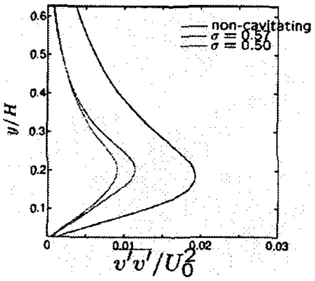
Figure 1 illustrates the flow field to be considered. The sharp edge is placed in almost the two-dimensional channel. Our computational setup [2] is simplified one of the referred experiment [1]. Reynolds number based on the bulk velocity and channel width is 10000, which is much lower than that in the experiment.

Figure 2 shows Reynolds shear stress components for non-cavitating flow and for the cases of the cavitation numbers 0.50 and 0.57. The cavitation number is defined by $\sigma = (p_\infty - p_v)/(0.5\rho U_\infty^2)$, where p_∞ and U_∞ are reference pressure and velocity, p_v

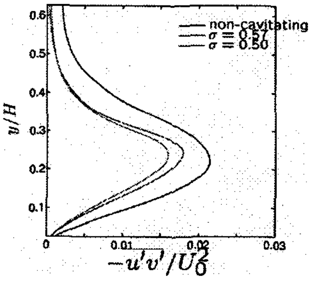
the vapor pressure, ρ the density of fluid. The streamwise component (Fig.2(a)) is not so affected by cavitation but the lateral component (Fig.2(b)) remarkably decreases when the cavitation number decreases. As a result, the shear component (Fig.2(c)) is reduced. The tendency of the turbulence modification, including mean velocity profile, is consistent with experimental measurement in Fig.1(a).



(a) Streamwise (normal)



(b) Lateral (normal)



(c) Shear

Figure 2: Comparison of Reynolds stress between cavitating and non-cavitating flows

Figure 3 shows an example of instantaneous flow field at the cavitation number 0.57. Streamwise vortices develop in the region between two neighboring spanwise vortices, as commonly known in mixing layer. At the instance shown here, cavitation is observed mainly in the spanwise vortices. In addition, cavitations occur in the upstream side of each streamwise vortex, where the local minimum of pressure is detected. Then it can be observed that the development of streamwise vortices is attenuated in the case of cavitation.

Conclusion

The major findings by our numerical simulation are as follows.

1. Due to the significant reduction in lateral component of velocity fluctuation, Reynolds shear stress is attenuated in the wake of cavitating separated flow, in comparison to that in the non-cavitating flow.
2. Cavity inception is corresponding to the primary and the secondary vortices in the separated shear layer.
3. The secondary vortices have a profile of Burgers type. The cavity that developed from the upstream end of the vortices attenuates this vortical structure.

It should be noted that the fine scale structures are not resolved in the practical simulations such as RANS and LES. Thus the above-mentioned interactive phenomena, namely the cavitation inception at the core of turbulence vortices and the Reynolds stress modification due to cavitation, should be modeled. Probably, the former may be based on the recent knowledge of statistics of fine-scale turbulence and the latter must be based on this kind of direct numerical simulations.

In the presentation, our recent result about the influence of cavity to the development of a Burgers vortex will be shown.

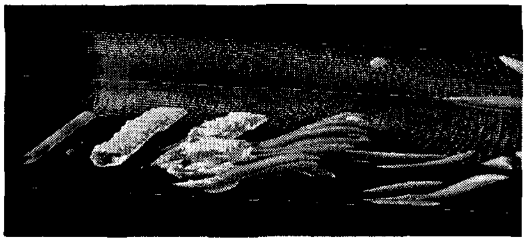


Figure 3: Visualization of vortices and cavitation regions of instantaneous flow field at the cavitation number 0.57: Vortices are shown by Laplacian of pressure and color on them indicates pressure value; Cavitations are shown by gray clouds for iso-surface of 0.01 void fraction; Vectors in the back section are velocity colored by the value of streamwise component.

References

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