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Direct Numerical Simulation of Interaction between Cavitation and Turbulence Vortices

*** Kie OKABAYASHI[1], Takashi OHTA[2] and Takeo KAJISHIMA[2]**

[1] Graduate School of Enginnering,
Osaka University
2-1 Yamadaoka, Suita city, Osaka,
565-0871 Japan
Email:oka-kie@fluid.mech.eng.osaka-u.ac.jp

[2] Department of Mechanical Engineering,
Osaka University
2-1 Yamadaoka, Suita city, Osaka,
565-0871 Japan
Email:ota@mech.eng.osaka-u.ac.jp
kajisima@mech.eng.osaka-u.ac.jp

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ABSTRACT

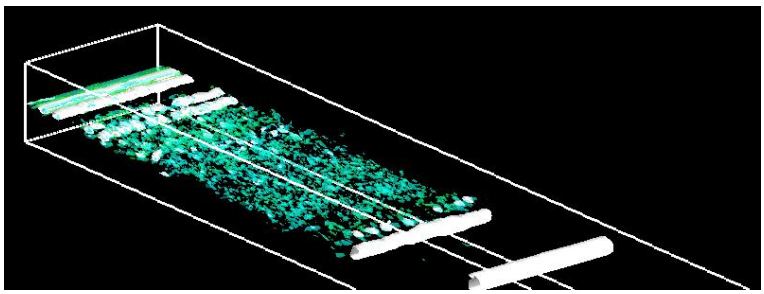
Flows in hydro-machineries are affected by various types of cavitation, and most of them are in turbulence. To simulate such cavitating turbulent flows, Large Eddy Simulation (LES) or Detatched Eddy Simulation (DES) have been applied with cavitation model[1][2]. In LES or DES, the effects of subgrid scale (SGS) fine vortices are modeled, while low pressure area in the core of the elementary fine voritices can become source of cavity. Previous practical methods (including LES and DES) have not taken account of the effects of cavitation which occurs in fine-scale elementary vortices. This could reduce the accuracy in predicting turbulent modulation by cavitation[3] as well as cavitation inception. In this situation, adequate method for cavitation in turbulence is eagerly needed.

To obtain a better understandings for model development, two Direct Numerical Simulation (DNS) were applied in our group. First, a DNS of a shear flow caused by a fence was conducted and the interaction between cavitation and vortical structure was investigated[4]. We could observe cavitation in the core region of turbulence eddies, which had a profile of Burgers vortex. Then, a DNS of cavitation in a single vortex which was assumed as elementary vortex in turbulence was conducted[5]. This DNS result suggests that streamwise vorticity of the vortex are decreased by cavity expansion. The interaction phenomena are qualitatively represented by a simple model, which is based on the assumption of constant circulation along a closed circle due to sudden cavity expansion. This model can become a basic concept of cavitation turbulent model.

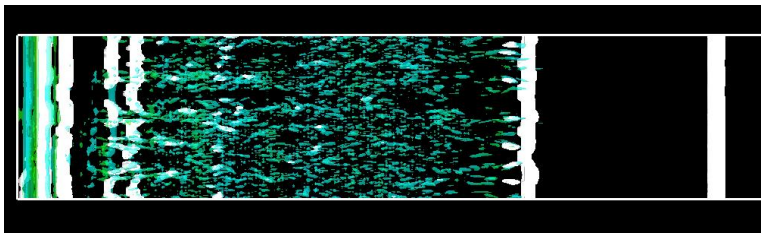
In this study, we aim at development of the turbulence model which takes into account cavitation in elementary vortices. On the basis of our prior works[4][5], we are planning to construct a LES model which represents the modulation in kinetic energy and dissipation rate of SGS elementary voritces corresponding to cavitation inception or contraction. We select three-dimentional spatially-developing mixing layer as the flow field for modeling. Mixing layer is a typical example of free turbulence and there are a lot of theoretical, experimental and numerical investigations for it.

Figure 1 shows the overview and top view of the instantaneous flow field. Vortical structure is indicated by colored isosurface of second invariant of velocity gradient tensor Q. Here, color represents pressure. Cavity is indicated by white isosurface of liquid volumetric fraction f_L (void fraction is 0.1%). In this figure, we can observe primary roll-cell vortices (Kelvin-Helmholtz roller) followed by secondary streamwise vortices. Secondary vortices are stretched in the streamwise direction. Cavity is formed in low pressure areas of roll-cell vortices and streamwise vortices.

In this calculation, characteristic vortical structure of mixing layer is reproduced. In particular, elementary fine vortices in tubulent flow can be resolved. This DNS database is expected to become the basis of development of cavitation LES model.



(a) Overview



(b) Top view

Figure 1: Instantaneous contours of vortex and cavitation indicated by pressure-colored isosurface of $Q = 230$ and white isosurface of $f_L = 0.999$

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