Development of numerical model in the RANS solver for 3D cavitation simulation on marine propeller

Keun Woo Shin, PhD student
**Cavitating flows**

- Cavitation: Phase change from liquid to vapor by pressure drop
- Negative effects: performance degradation, vibration, noise and erosion
- Cavitation types: bubble, sheet, cloud and vortex cavitation
Cavitation model

- Homogeneous equilibrium model: \( \rho_m = \alpha_v \rho_v + (1 - \alpha_v) \rho_i \)
- Momentum equation with \( \rho_m \) and \( \mu_m \)
- Pressure correction with volume flux and \( \dot{m} \):
  \[
  \frac{\partial u_j}{\partial x_j} = -\frac{\dot{m}}{\rho_v}
  \]

- Vapor transport equation based on Rayleigh-Plesset equation:
  \[
  \frac{\partial}{\partial t}(\rho_v \alpha_v) + \frac{\partial}{\partial x_j}(\rho_v u_j \alpha_v) = -\dot{m}, \quad \dot{m} = \begin{cases} 
  -C_e \sqrt{\frac{2}{3} \frac{p_v - p}{\rho_i}} (1 - \alpha_v) & \text{for } p < p_v \\
  C_c \sqrt{\frac{2}{3} \frac{p - p_v}{\rho_i} \alpha_v} & \text{for } p > p_v 
  \end{cases}
  \]

- In-house RANS solver, EllipSys3D
- \( k-\omega \) SST turbulence model
Cavitation on a 2D hydrofoil

- NACA66 (mod) section for $\text{Re} = 2 \cdot 10^6$

- Steady leading-edge cavitation for $\alpha = 4^\circ$, $\sigma = 0.91$

- Unsteady mid-chord cavitation for $\alpha = 1^\circ$, $\sigma = 0.38$

Pressure coefficient on the suction side from experiment (Shen, Y.J. and Dimotakis, J.S, “The influence of surface cavitation on hydrodynamics forces”, 22nd ATTC, 1989) and computation
Cavitation on a 3D wing

- Swept and non-swept wings of NACA16-206 section


Meshed grid of computational domain

Meshed grid of wing surface
Cavitation on a 3D wing

- Non-swept wing for $Re=1.2 \cdot 10^6$, $\alpha=6^\circ$, $\sigma=0.628$

- Swept wing for $Re=1.2 \cdot 10^6$, $\alpha=6^\circ$, $\sigma=0.585$

Snapshot from experiment (Ukon, 1986) and iso-contour of $\alpha_v=0.1$ from computation

Vapor fraction distribution at 0.4-span from the root
Cavitation on a conventional propeller

Meshed grid of computational domain for a blade with rotating polar coordinates and cyclic boundary condition

- $J=0.446$, $\sigma_n=1.6$ in uniform inflow

Snapshot from experiment
(Experimental result refers to Li, D.Q, Lundström, P., Leading edge: open water characteristics and cavitation inception tests of a conventional propeller and a highly skewed propeller, SSPA report, 2002)

Iso-contour of $\alpha_v=0.1$ from computation
Cavitation on a highly skewed propeller

Meshed grid of computational domain

- $J=0.603$, $\sigma_n=2.271$
  in uniform inflow

Snapshot from experiment
(Kuiper, G., Leading edge: Data of selected propellers, Report No.16206-2-RD, Marin)

Iso-contour of $\alpha_v=0.1$
from computation
**Conclusion & Future work**

- Reasonable agreements in the distributions of pressure and vapor for sheet cavitation
- Physical characteristics of cavitation
- To be improved for cloud cavitation and vortex cavitation
- To be tested with other turbulence models, LES, DES and transition model.
- To be tested for strong cavitation
- To be tested for a ship propeller in behind-hull wake field
The end