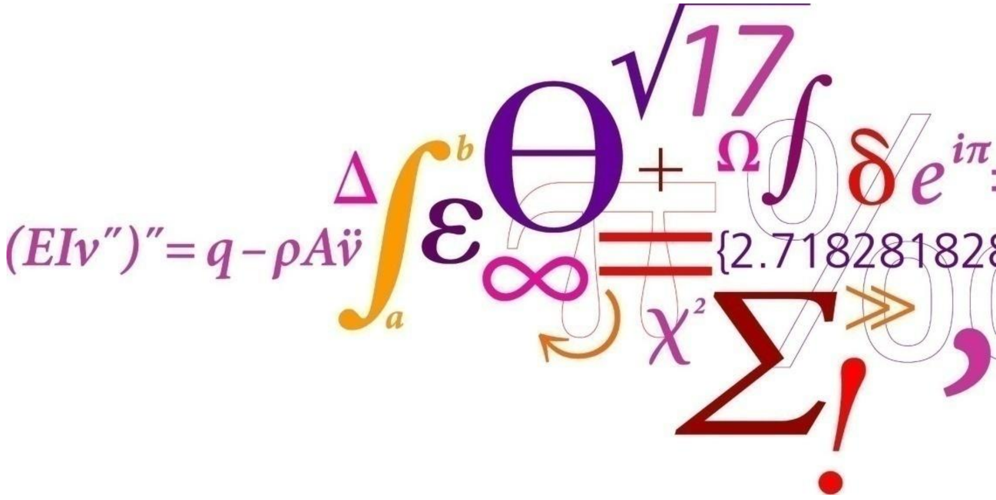
Development of numerical model in the RANS solver for 3D cavitation simulation on marine propeller

Keun Woo Shin, PhD student



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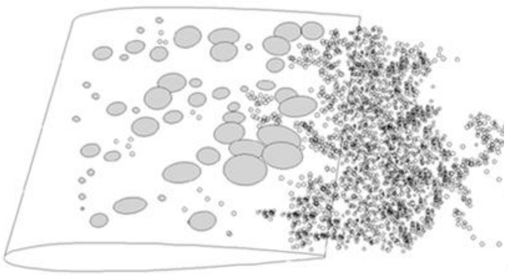
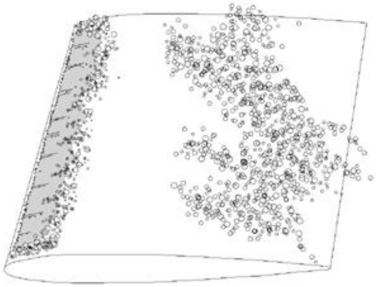
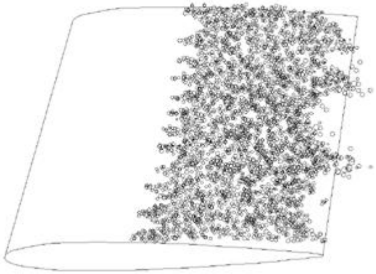
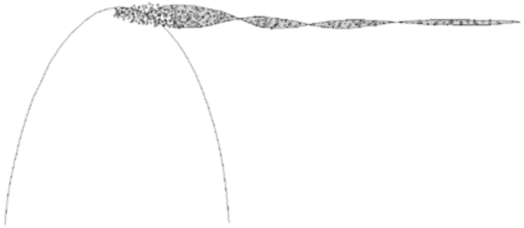
Cavitating flows

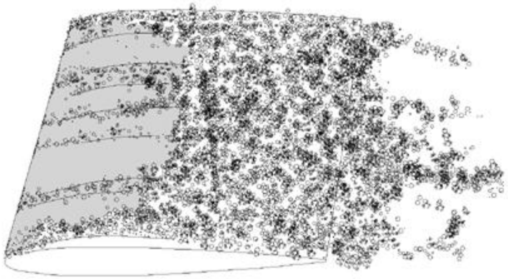
- Cavitation: Phase change from liquid to vapor by pressure drop
- Negative effects: performance degradation, vibration, noise and erosion
- Cavitation types: bubble, sheet, cloud and vortex cavitation

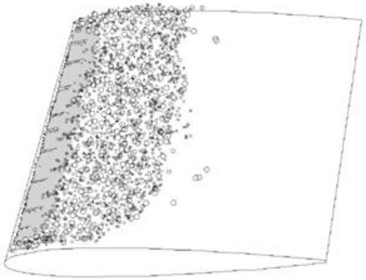

Bubble cavitation

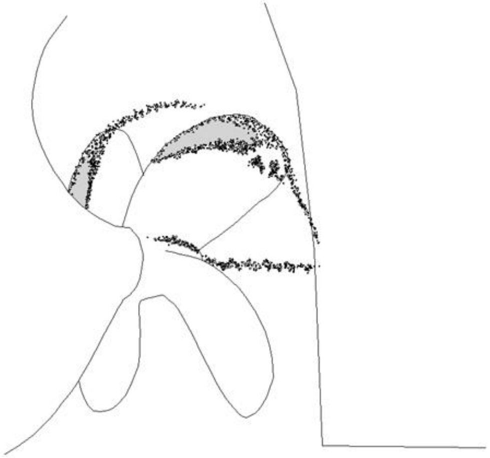

Sheet cavitation and cloud cavitation


Sheet cavitation


Vortex cavitation


Super cavitation


Sheet cavitation


Cavitation around a ship propeller

Cavitation model

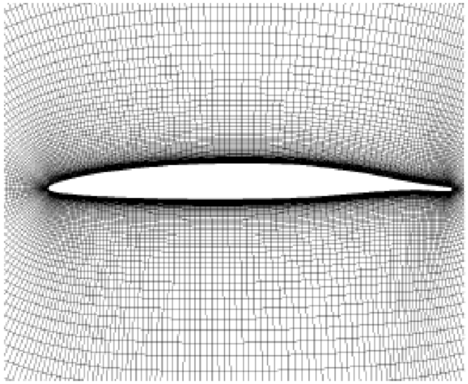
- Homogeneous equilibrium model: $\rho_m = \alpha_v \rho_v + (1 - \alpha_v)\rho_l$
- Momentum equation with ρ_m and μ_m
- Pressure correction with volume flux and $\dot{m}$: $\dfrac{\partial u_j}{\partial x_j} = -\dfrac{\dot{m}}{\rho_v}$
- Vapor transport equation based on Rayleigh-Plesset equation:

$$\frac{\partial}{\partial t}(\rho_v \alpha_v) + \frac{\partial}{\partial x_j}(\rho_v u_j \alpha_v) = -\dot{m}, \qquad \dot{m} = \begin{cases} -C_e \sqrt{\frac{2}{3}\frac{p_v - p}{\rho_l}}(1 - \alpha_v) & \text{for} \quad p < p_v \\ C_c \sqrt{\frac{2}{3}\frac{p - p_v}{\rho_l}}\alpha_v & \text{for} \quad p > p_v \end{cases}$$

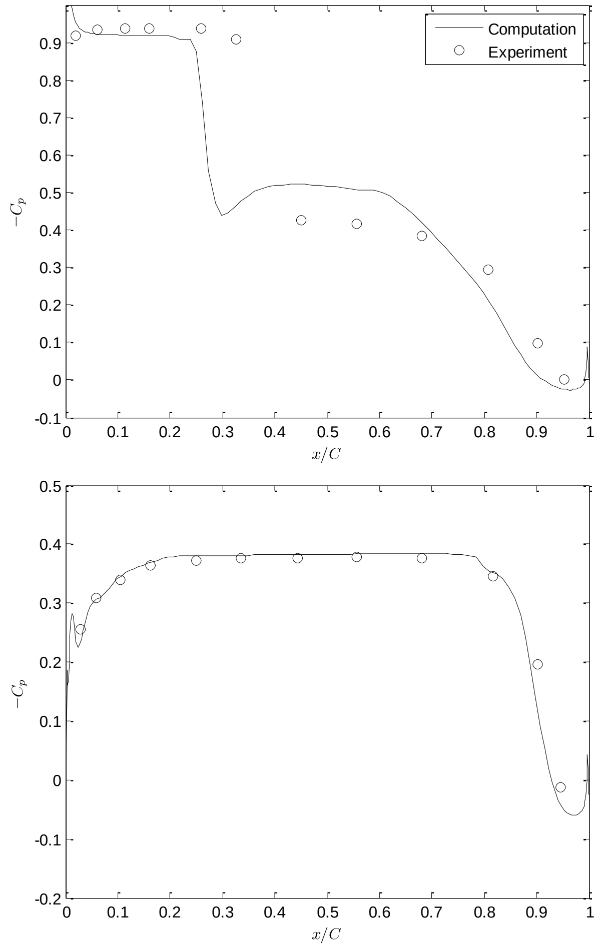
- In-house RANS solver, EllipSys3D
- k-ω SST turbulence model

Cavitation on a 2D hydrofoil

- NACA66 (mod) section for $Re=2\cdot10^6$

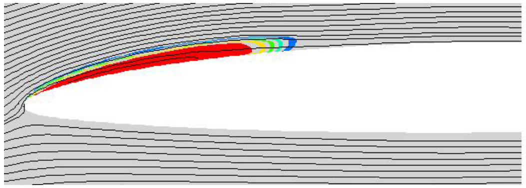


Meshed grid

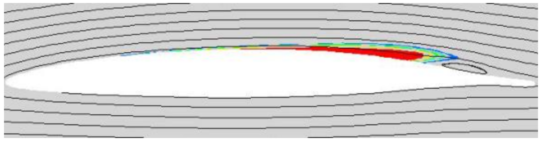


Pressure coefficient on the suction side from experiment (Shen, Y.J. and Dimotakis, J.S, "The influence of surface cavitation on hydrodynamics forces",22nd ATTC, 1989) and computation

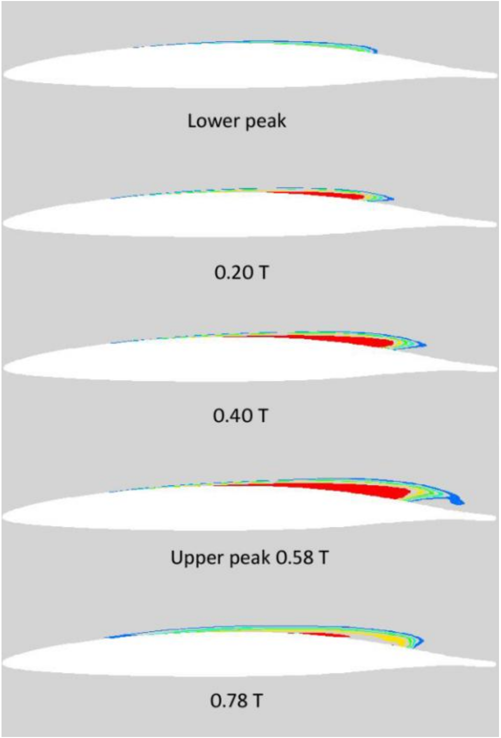
- Steady leading-edge cavitation for α=4°, σ=0.91



Vapor fraction distribution and streamline



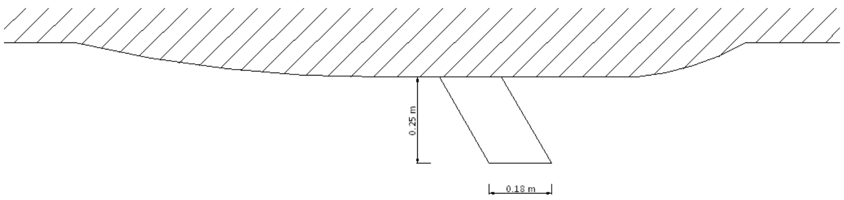
- Unsteady mid-chord cavitation for α=1°, σ=0.38

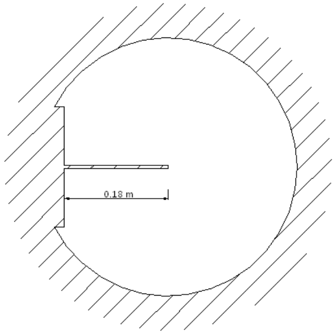


Periodic fluctuation of cavity

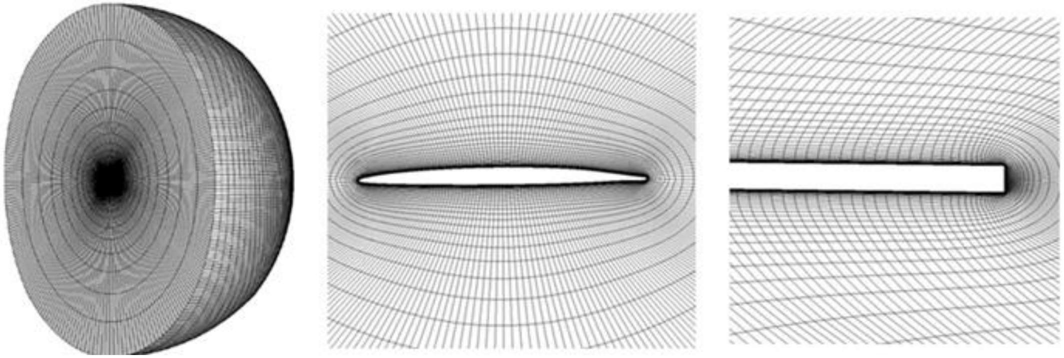
Cavitation on a 3D wing

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

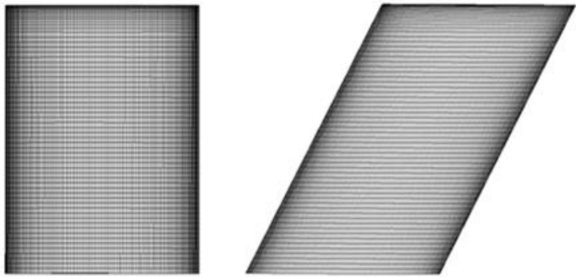




Setup in experiment (Ukon, Y., “Cavitation characteristics of a finite swept wing and cavitation noise reduction due to air injection”, Int. Symp. Propeller and Cavitation, 1986)

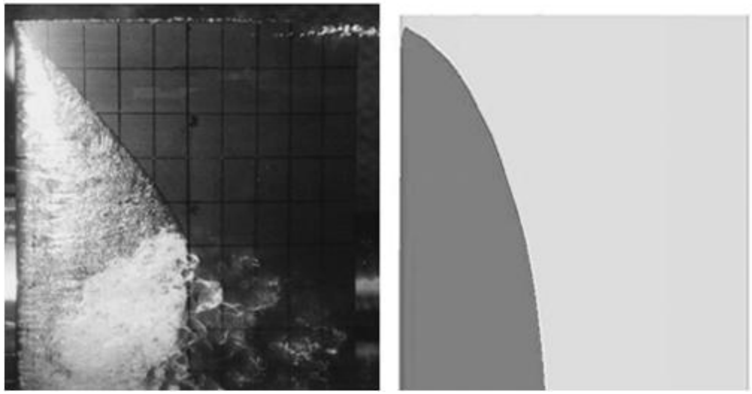


Meshed grid of computational domain

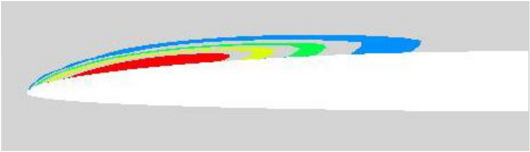


Meshed grid of wing surface

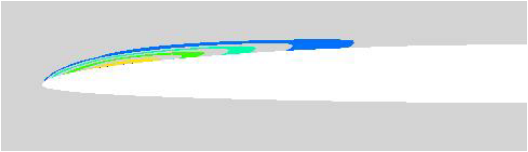
Cavitation on a 3D wing



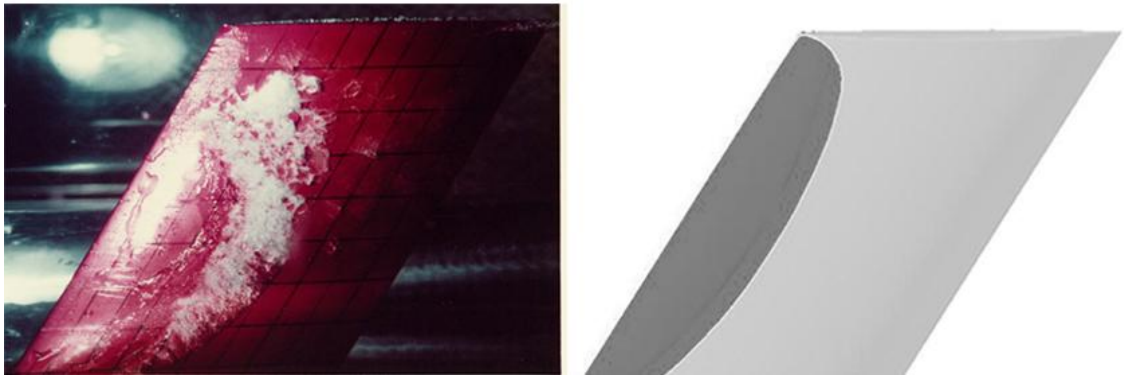
- Non-swept wing for $Re=1.2\cdot10^6$, $\alpha=6^o$, $\sigma=0.628$



Vapor fraction distribution at 0.4·span from the root

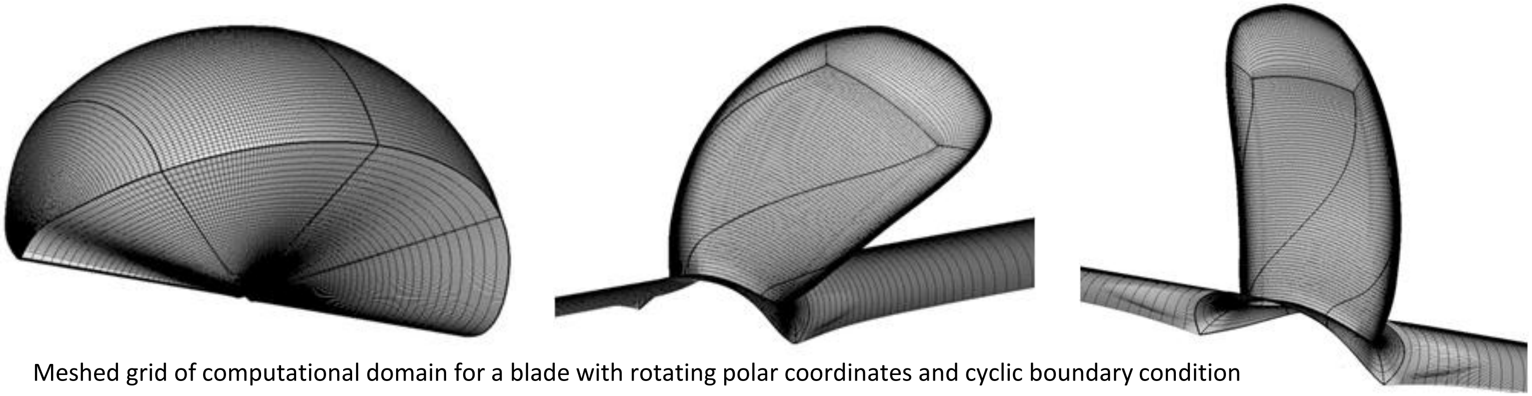


- Swept wing for $Re=1.2\cdot10^6$, $\alpha=6^o$, $\sigma=0.585$

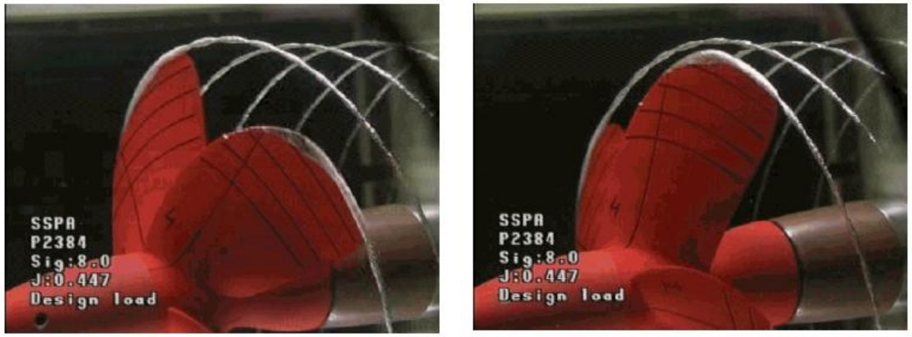


Snapshot from experiment (Ukon, 1986) and iso-contour of $\alpha_v=0.1$ from computation

Cavitation on a conventional propeller

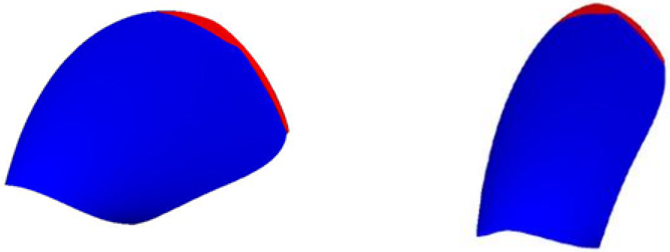


Meshed grid of computational domain for a blade with rotating polar coordinates and cyclic boundary condition



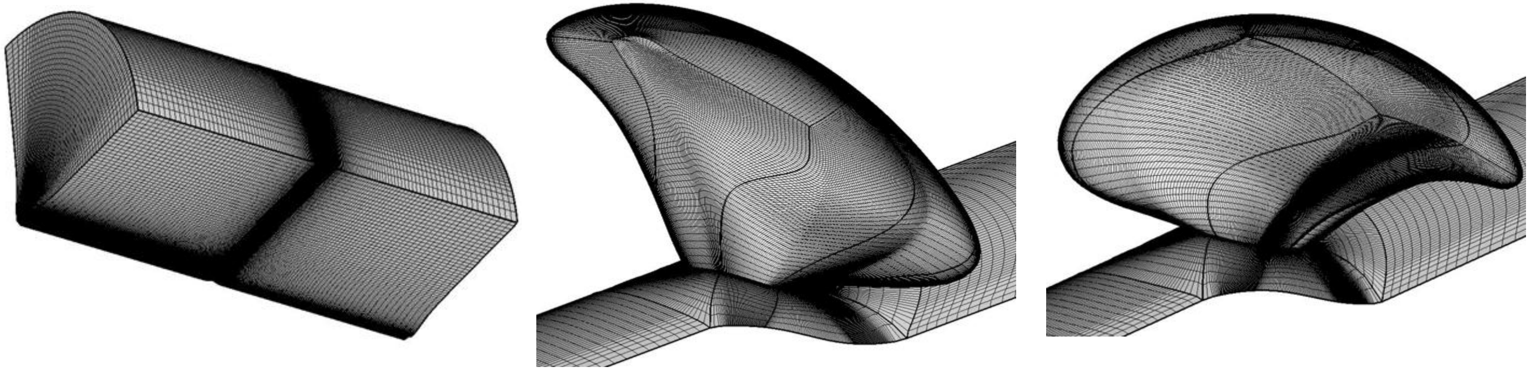
- J=0.446, σ_n=1.6 in uniform inflow

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)



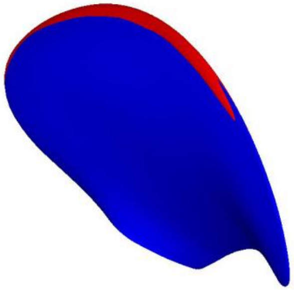
Iso-contour of α_v=0.1 from computation

Cavitation on a highly skewed propeller



Meshed grid of computational domain

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



Iso-contour of α_v=0.1 from computation

- J=0.603, σ_n=2.271 in uniform inflow

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