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"VISVE – A VIScous Vorticity Equation model applied to cylinders, hydrofoils and propellers"

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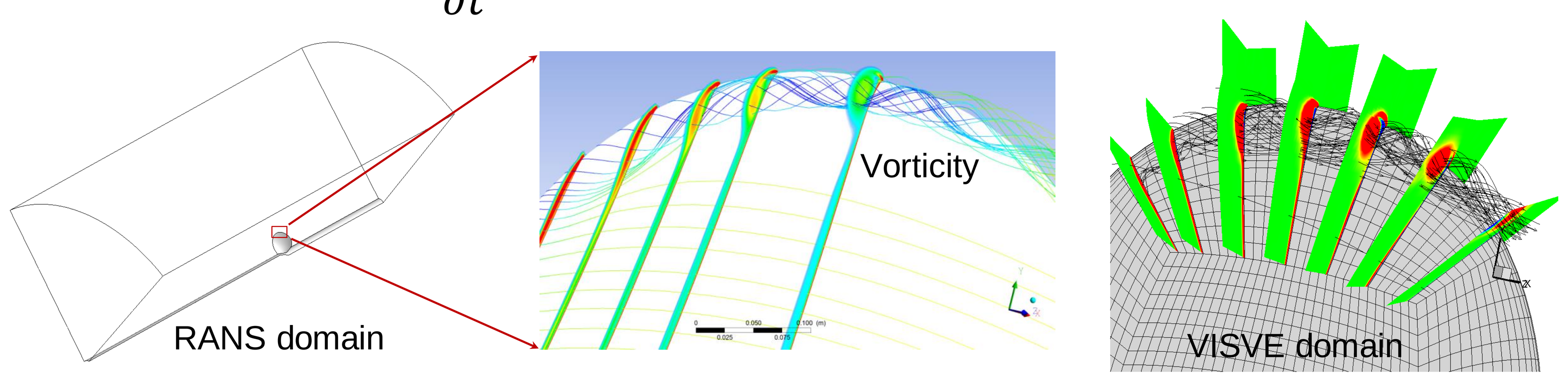
Introduction

Unlike velocity, vorticity is a locally concentrated quantity. So, if we solve the vorticity equation, the computational domain can be significantly reduced.

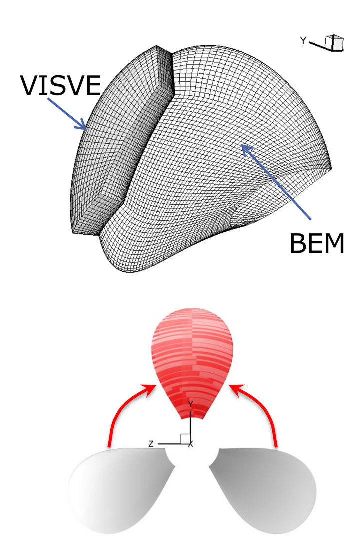
$$\frac{\partial \boldsymbol{\omega}}{\partial t} + \nabla \times (\boldsymbol{\omega} \times \mathbf{q}) = -\nu \nabla \times (\nabla \times \boldsymbol{\omega})$$



Objectives

This study is aimed at developing an accurate and computationally efficient numerical tool, VISVE, which can locally correct the results from the panel method, to model the effects of the LEV on the propeller performance and extend its application to the backing condition for hydrofoil and unidirectional and alternating flow around cylinders.

- Only the flow on key blade is needed to be modeled. For axisymmetric case: duplicate the variables of the key blade. For non-axisymmetric case: use the variables of the key blade at different blade angles.
- Since only the vicinity of the propeller is needed to be modeled without using periodic boundary conditions, the grid generation can be significantly simplified. Actually, this process can be made automated.
- In 2D, the vorticity equation can be simplified. Thus it is worthwhile to first develop and validate the prototype of VISVE solver in 2D.

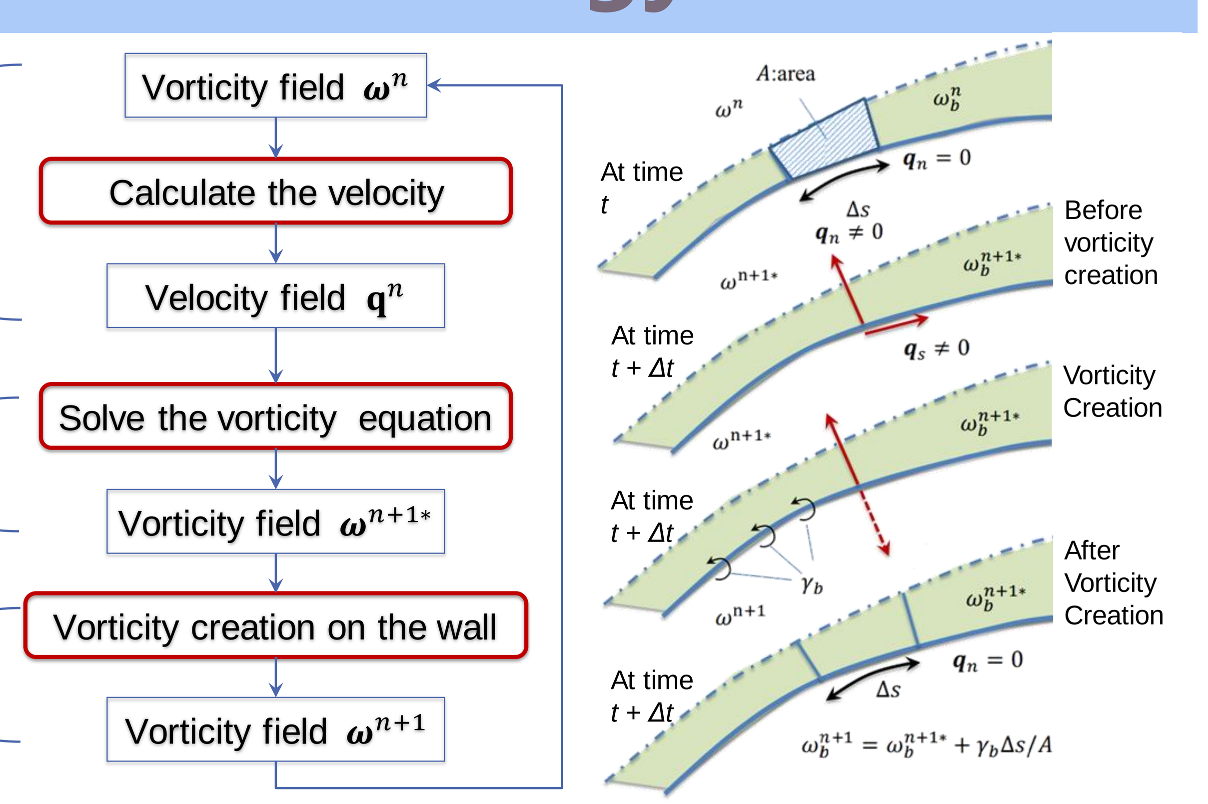


Methodology

Vorticity-velocity Solver: Given a vorticity field $\boldsymbol{\omega}^n$, compute the corresponding velocity field $\mathbf{q}^n$.

Vorticity equation solver: Marching the vorticity equation to the next time level.

Vorticity creation: Enforce the no-slip and non-penetrating boundary conditions on the wall.



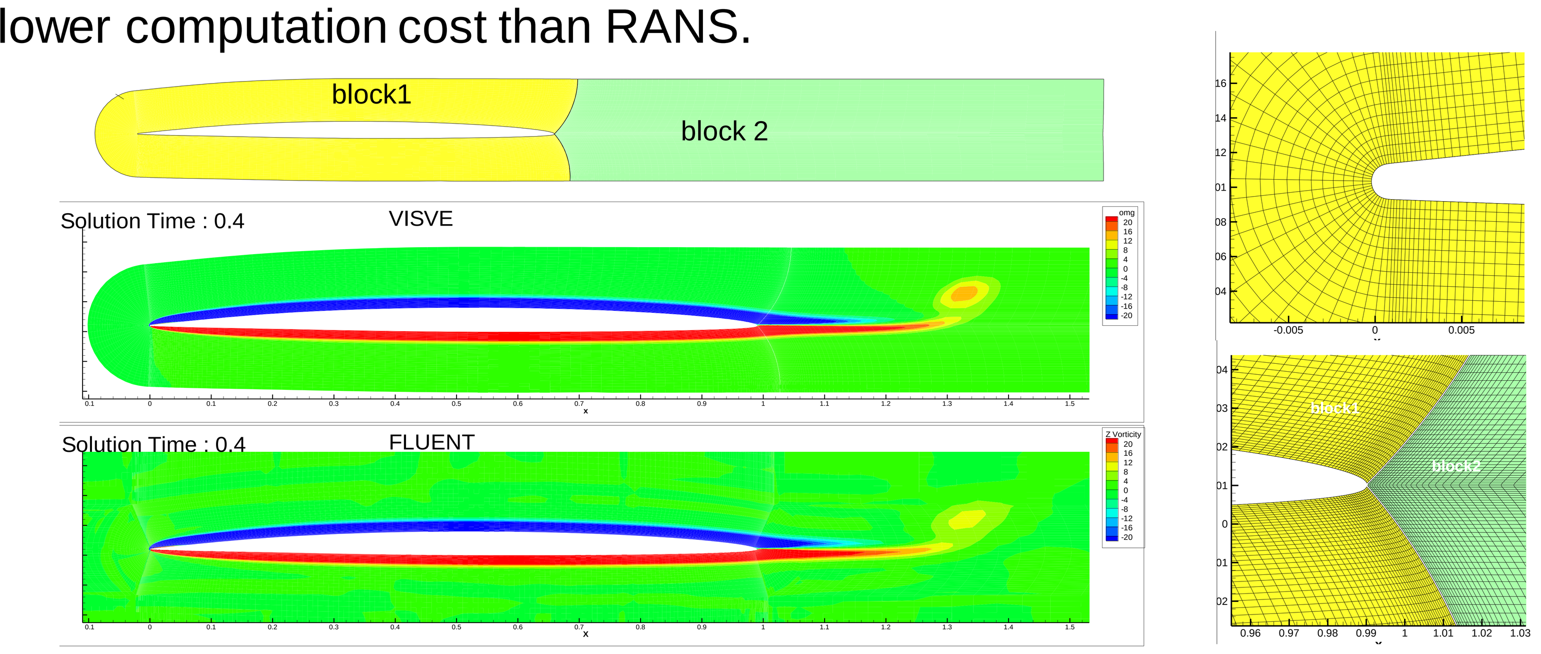
Applications

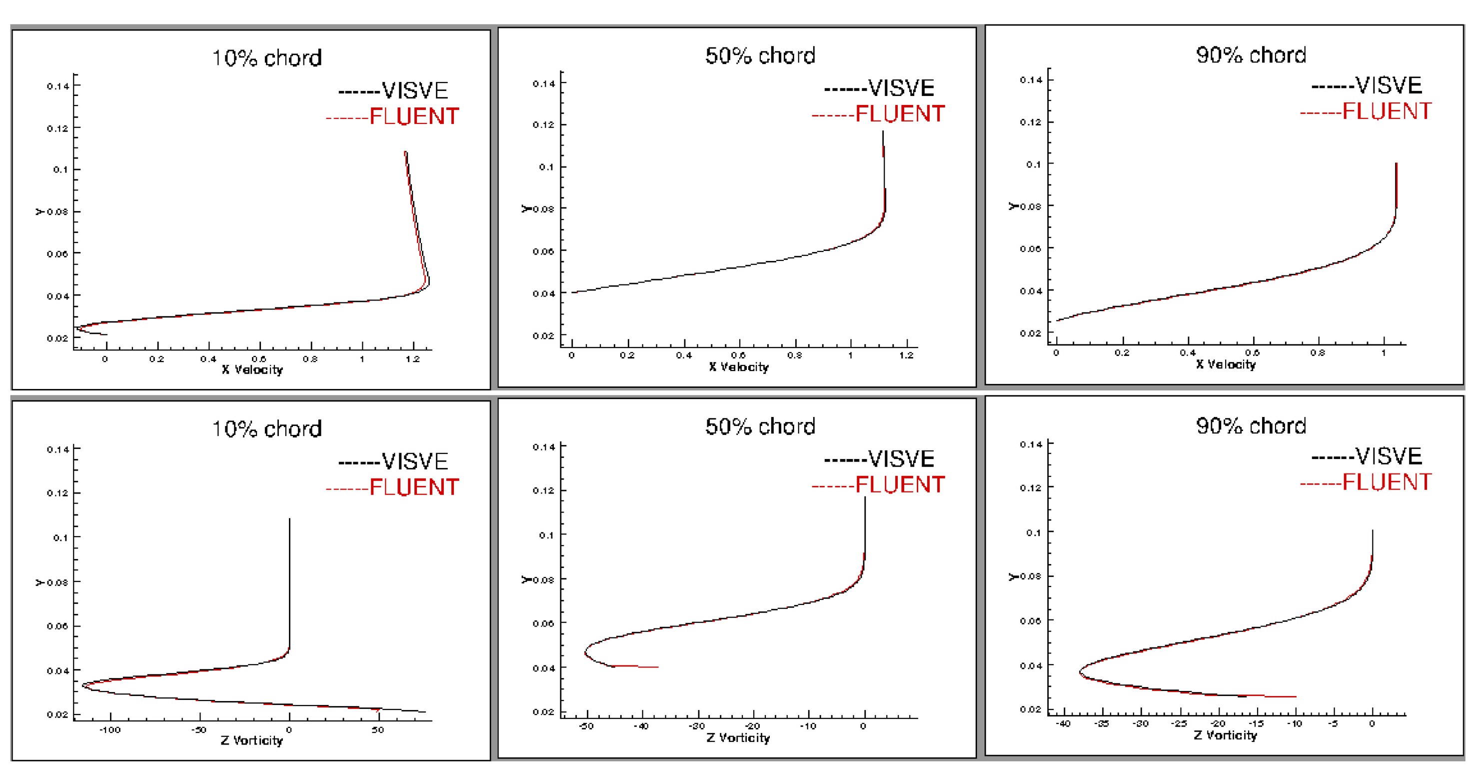
Hydrofoils in backing conditions

The treatment of backing condition involves two major difficulties :

- The boundary layer theory fails at the sharp leading edge and it is hard to find the stagnation point even for the inviscid theory.
- Flow separates at the rounded trailing edge and the position of the detachment point of the boundary layer is unknown.

VISVE is capable of dealing with backing condition hydrofoil with much lower computation cost than RANS.





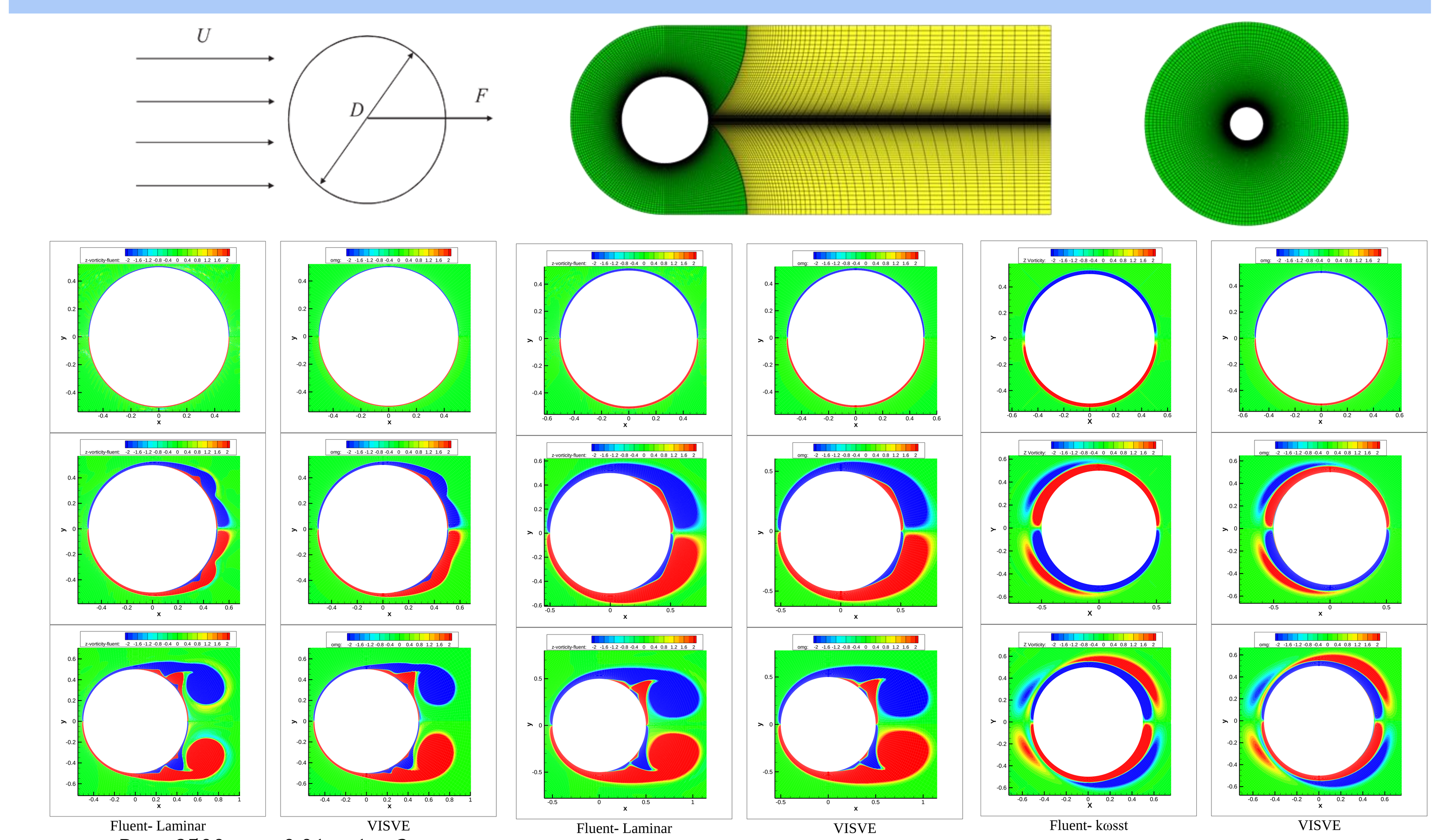
The agreement with fluent results confirms the reliability of VISVE codes for hydrofoil in backing conditions. The comparison of computation time and domain shows the efficiency of VISVE.

Method	VISVE	RANS (FLUENT)
Cell No.	**23,150**	66,198
Total Running Time (for 1e5 time steps)	**6h** (1 node,**16** cores)	10h (2 nodes, **32** cores)

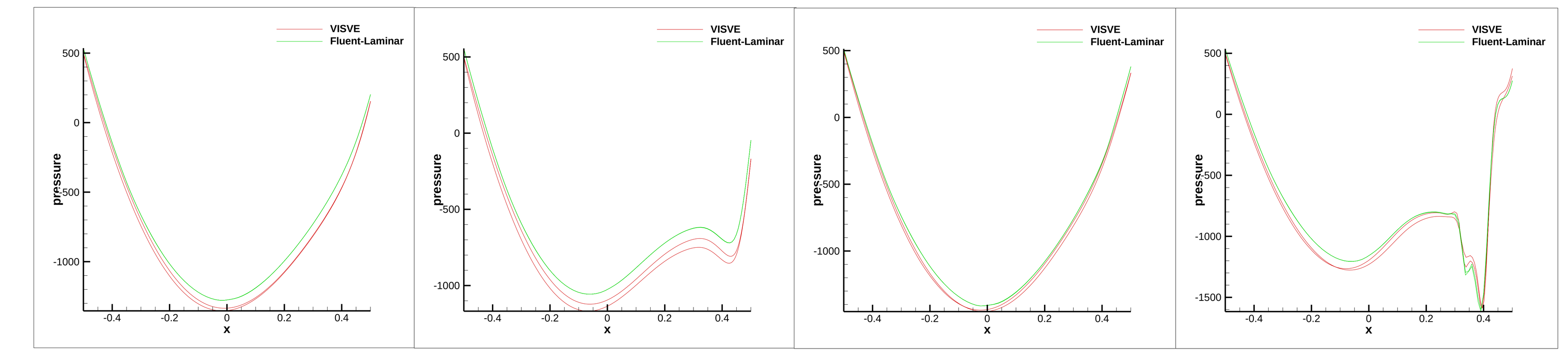
Flow around cylinders

In the case of unidirectional flow around cylinder, the vortices travel downstream. When it comes to alternating flow, vortices will travel on both sides of the cylinder. In this study, we use orthogonal grid with only one O block, which will be appropriate for both cases.

Applications

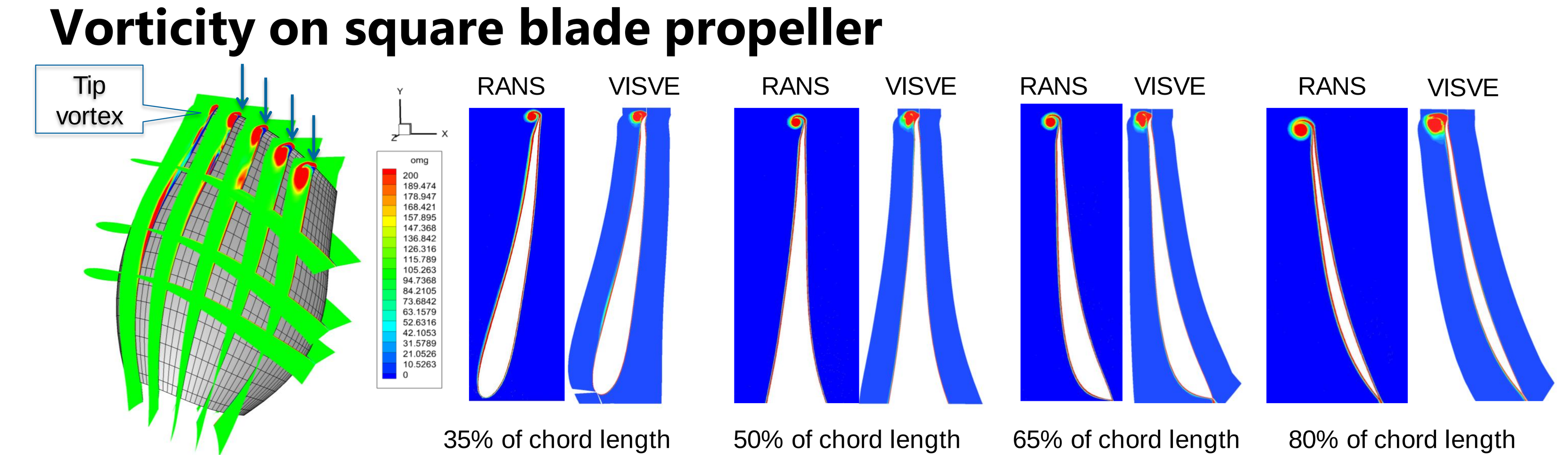


$Re = 9500,\ t = 0.01s,\ 1s,\ 2s$ $Re = 1000,\ t = 0.01s,\ 1s,\ 2s$ $KC = 2, Re = 994,\ t = 0.01s,\ 1s,\ 2s$



Pressure (unidirectional flow): $Re = 1000,\ t = 0.5s,\ 1s$ Pressure (unidirectional flow): $Re = 9500,\ t = 0.5s,\ 1s$

Vorticity on square blade propeller



35% of chord length 50% of chord length 65% of chord length 80% of chord length

Conclusions and Future Work

- The results of velocity and vorticity from VISVE and RANS agree well with each other in all cases.
- VISVE is more efficient than RANS. With higher level of parallelization, VISVE can get more efficiency.
- The domain size of VISVE is much more smaller than that of RANS. The grid generation in VISVE can be made automated.
- In the future, VISVE needs to be improved to handle more 3D applications. Our next goal is to model the tip gap flow, flow in ducted propeller, propeller in backing condition and flow around riser.