Research Report（April, 2020- March, 2021）

Enrollment from April 2020 Department of Modern Mechanical Engineering LIU YANG

I. List of Papers

1. 山崎 智司, 劉 洋,張 雨菲, 倉石 孝, 滝沢 研二, Tayfun E. Tezduyar, "複数風車の後流解析のための効率的な計算手法の構築", 計算工学講演会論文集 Vol. 25 (2020 年 5 月)
2. 劉 洋, 山崎 智司, 張 雨菲, 倉石 孝, 張 福林, 滝沢 研二, Tayfun E. Tezduyar, "Multi-Domain Computation of Wind Turbine Wake Flows" [No.20-1] 日本機械学会 2020 年度年次大会 講演論文集〔2020.9.13-16, 名古屋〕

II. List of Talks

日本機械学会 2020 年度年次大会, (Zoom online talk).

III. Research Results in AY2020

1. **Parametric Design and Geometry Modeling for Rotating Machinery Isogeometric Analysis** (**IGA**).

We developed a visual programing block especially suit for rotating machinery geometry modeling based on Grasshopper 3D. The main advantage is that, with the block, people can easily change important parameters of rotating machinery model such as airfoil type and number of periodic features for computational analysis and design optimization purpose. The code block also facilitates non-uniform rational B-splines (**NURBS**) surface regeneration when necessary. Currently, we applied it to the NREL 5MW wind turbine modeling (see Figure 1).

Figure 1 NREL 5 MW Wind Turbine Geometry

2. **NURBS Mesh Generation and Mesh Relaxation for NREL 5 MW Wind Turbine and KVLCC2 Ship.**

Generating high quality NURBS mesh which has a smoother transition from the smallest elements (blade tip) to the largest ones (wind farm) for wind turbine analysis and keeping the total amount of elements as less as possible requires special technique. Because of this, there are seldom whole wind turbine simulations using structured grid. To overcome the difficulty, we use Space–Time Variational Multiscale (**ST-VMS**) method for flow computations with Slip Interfaces (**ST-SI**) (see Figure 2) to enable mesh moving and keep the number of elements as less as possible.

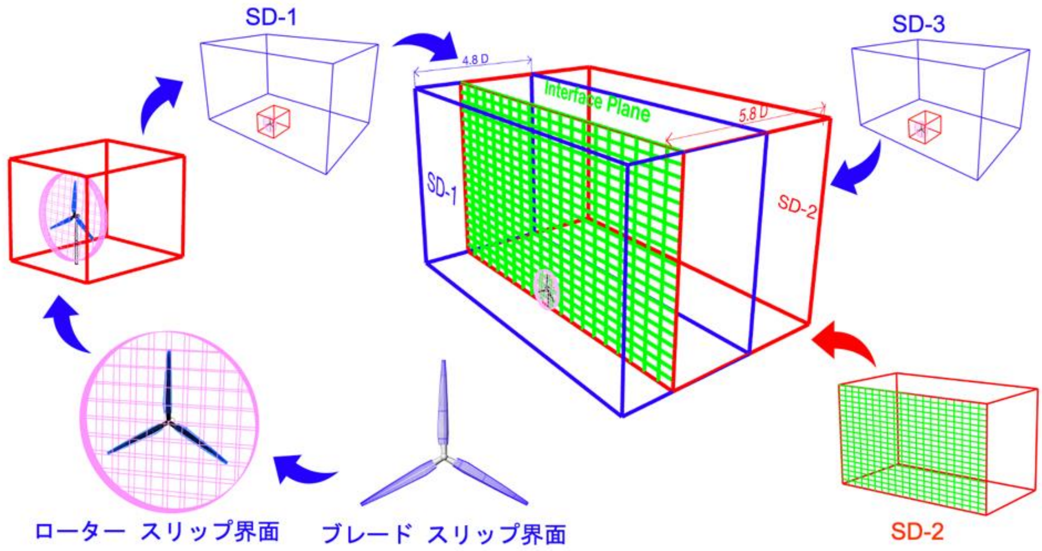

Figure 2 SIs in the computation domain

We also use in-housed developed mesh relaxation technique to relax the NURBS mesh. The relaxed mesh will have lower aspect ratio and higher orthogonality (see Figures 3 and 4).

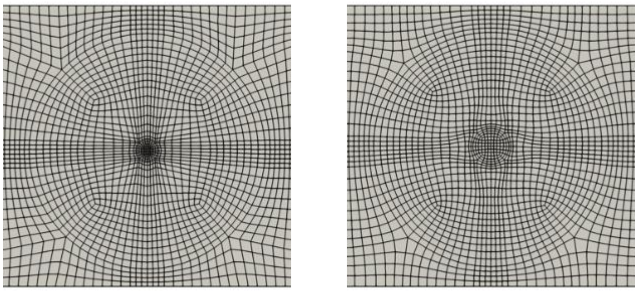

Figure 3 Mesh before (left) and after (right) relaxation

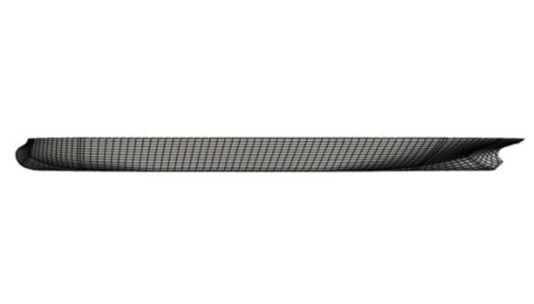

Figure 4 Mesh representing KVLCC2 ship

3. **Computation Results of NREL 5MW Wind Turbine**

The aerodynamic torque of single wind turbine from computation is shown in Figure 5, and vortex features are observed around the blade tip (see Figure 6).

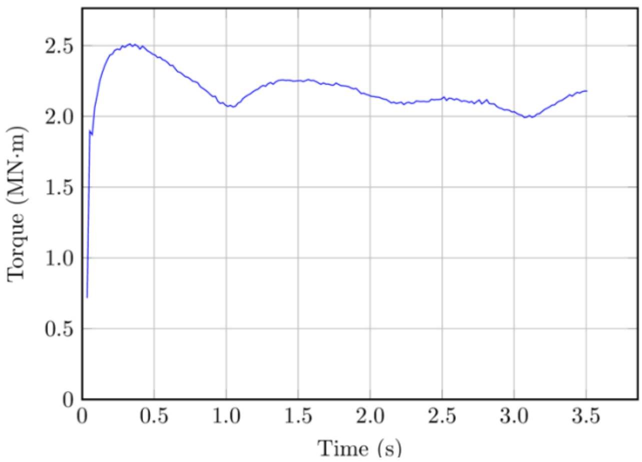

Figure 5 Time history of aerodynamic torque

Figure 6 Vorticity visualized with Q criterion

IV. Research Plan for AY2021

1. Validation of Weakly Enforced Boundary Conditions on Applications of Wind Turbine Wake Analysis

Good computation results will not come in the absence of boundary layer representation, but we also do not want to increase the total amount of elements for considerations of computation costs. The weakly enforced essential boundary conditions were first proposed for the advection–diffusion equation and for the Navier–Stokes equations of incompressible flows in Bazilevs and Hughes (2007) in an effort to improve the accuracy of the stabilized and multiscale formulations in the presence of unresolved boundary layers and it was further refined and studied on a set of challenging wall-bounded turbulent flows. In the future work, we will apply weakly enforced essential boundary condition formulation to the problem of aerodynamics of wind turbines at full and wind turbine wake analysis.

2. Verification of the multi-domain method (MDM) on Applications of Wind Turbine Wake Analysis

After successfully applied weakly enforced boundary conditions and get right aerodynamic torque from single wind turbine computations, we will move to two wind turbines case and do wake analysis. To overcome the difficulty of big problem size and large-scale range of wake analysis, we will implement and verify MDM. In MDM, the dimension of subdomains and position of interface, i.e., how the interface split the subdomain containing wind turbine should be determined carefully in order to maintain high accuracy. We will study these two factors by comparing the velocity and pressure data obtained through aerodynamics simulations using connected single mesh (see Figure 7) and partitioned multi domain meshes (see Figure 8). We will also compare vortex patterns visualized from simulations with results observed from experiments to make sure that the computation is good.

Figure 7 Single computation domain

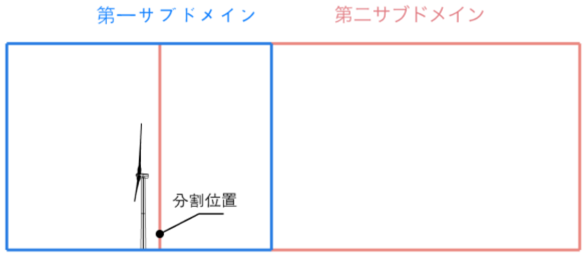

Figure 8 Multi computation domain

3. Fluid–Structure Interaction Simulation of Upstream and Downstream Wind Turbines

After verifying the role of weakly enforced boundary condition and MDM through pure aerodynamic simulations, we will add structure part and consider the deformation of slender wind turbine blade, especially the downstream one. Downstream wind turbine inevitably ingests the wakes produced by upstream one which have velocity deficit and higher turbulence comparing to the free stream. This will lead to performance degradation and short life expectancy of the wind turbine. We will study how much the downstream wind turbine is affected based on power generation and blade oscillations.