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Power Generation Quantity and Foundation Design Load of NREL 5MW Model considering Aerostatic Coefficient Uncertainty

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ABSTRACT

Geometrical shape of a blade is important factor that influence to the power generation quantity and the foundation design load. A blade, which looks like airplane wing, should be streamline shaped and have the property of lift force generation. Although the blade is frequently on near the state of 'stall' that can maximize the lift forces, most of analysis programs are using only mean values of aerostatic coefficients of the blade section. The variation of the lift force in the region of high attack angle is dramatically high. The power generation quantity and foundation design load should be analyzed considering the effect of the lift force variation. In this study, the relation between the power generation quantity and the foundation design load of NREL 5MW model are analyzed considering aerostatic coefficient uncertainty of the blade sections. Aerostatic coefficients were calculated 2D CFD analysis.(Kim 2013)

1. INTRODUCTION

The FSI effect of wind turbine structure should be analyzed to estimate exact responses of the structure because the loads transmitted to the support are varied by wind fluctuation and structural deformation. But 3D FSI analysis needs huge amount of computational resources so that makes it hard to perform. Recent development of high performance computing technology makes the full scale CFD analysis possible. This study develops fluid structure interaction code that contains open source library, Elmer, and simulates an ultimate wind state offshore turbine considering wind speed fluctuation.

2. THEORY

2.1 Computational fluid dynamics

The CFD library used in this study [1] stabilize the solution while using equal degree

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of shape function orders to the pressure and velocity, by introducing streamline upwind/Patrov-Galerkin (SU/PG) method which adds a square term of governing equation's residual to Galerkin weighted function. The moving mesh was emulated by arbitrary Lagrangian-Eulerian (ALE) method. The governing equation discretized by Glaerkin Least Square method by using the open source library. FSI software developed in this study [2] is consists of three parts which are fluidic, structural and interaction part as shown at Figure 1. If n is the number of parallel analysis node. The n number of fluidic modules give same number of parted pressure results.

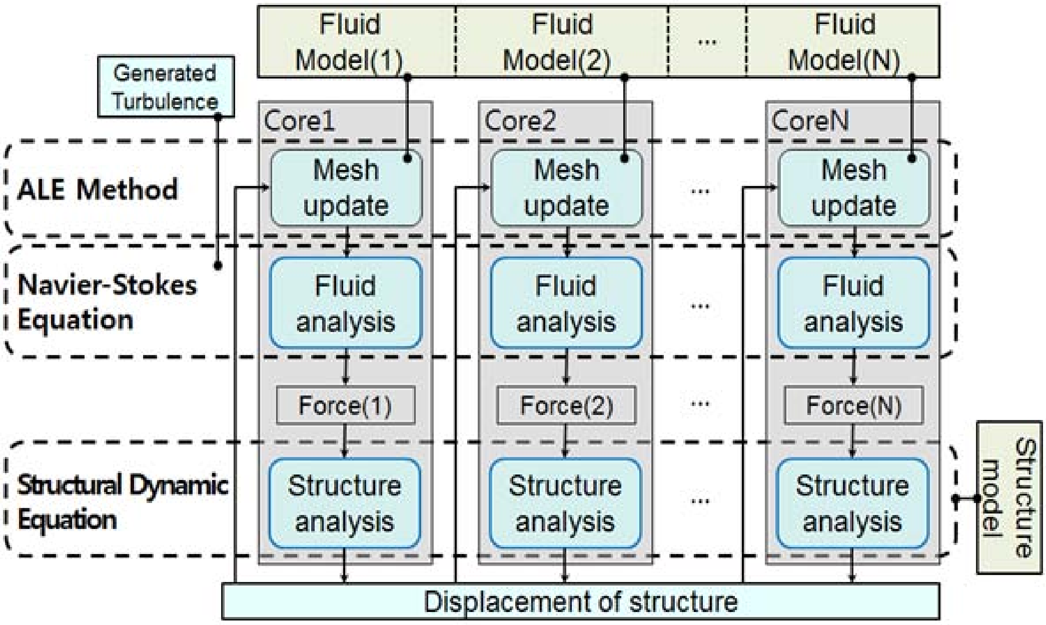

Figure 1: Flowchart of developed fluid structure interaction program

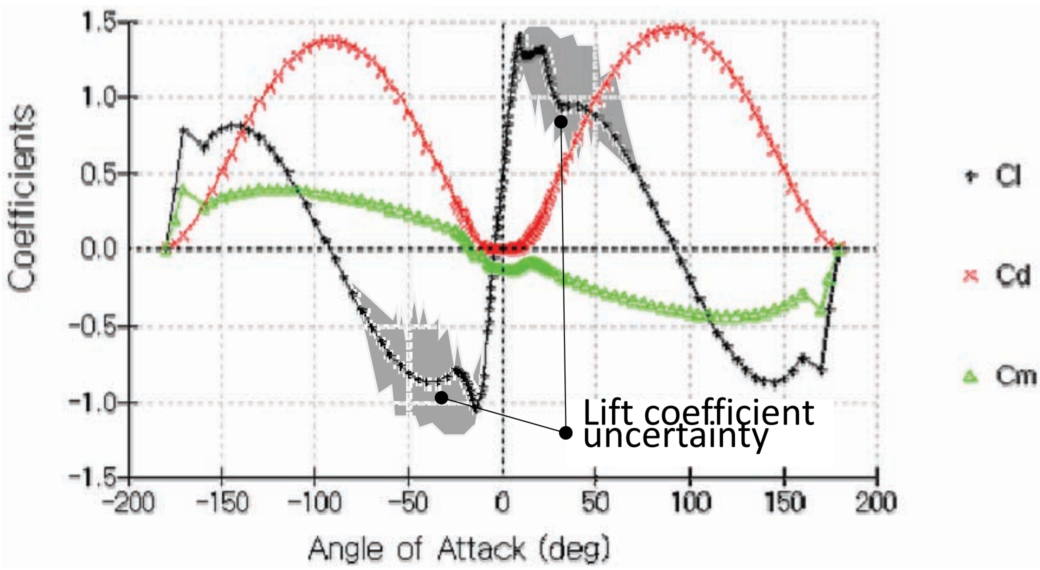

Figure 2: Lift coefficient uncertainty

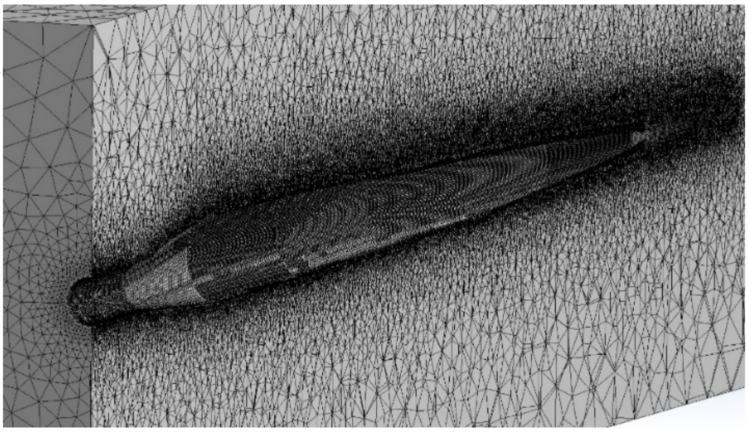

Figure 3: Generated Mesh of a Blade of the Analysis Model

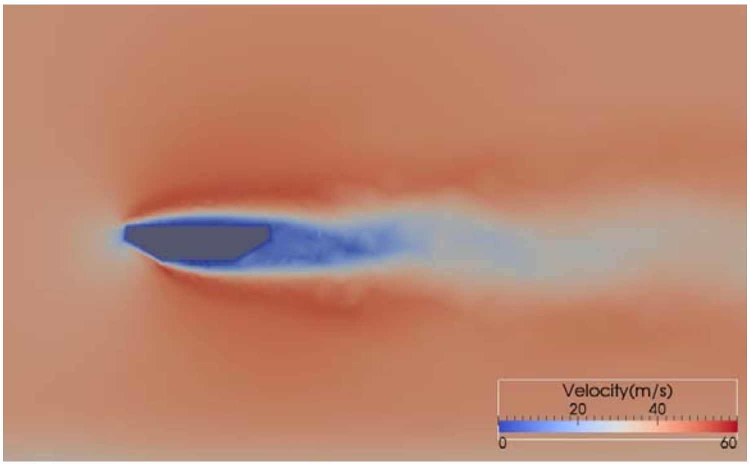

Figure 4: 2D CFD analysis

Interaction part transfers these results to the structural part in a concept of modal analysis. Structural part calculates modal displacement at each time step and the interaction part turns it back to the fluidic parts. In case of analysing 3.4 million tetrahedron elements using 64 nodes at once, it takes about 5~20sec at each time step.

2.2 Structure model

The object of this study was to analyze response differences between the case of considering FSI effect and the other case of not considering the effect for a support structure of a wind turbine under the 50-year return period ultimate wind speed. The geometries of the structure should be exactly defined to perform the CFD analysis. NREL 5MW reference turbine [3, 4] is selected by target upper structure.

The mass and stiffness of the turbine and the blade was referenced from the NREL 5MW turbine and the blade shape is generated using the airfoil geometries of DOWEC 6MW turbine [5]. The length of the blade is 63.333m and the chord is 4.557m. The model of ambient fluid region of one blade shown as Figure 2 is constituted using 358,652 nodes and 1,985,609 tetrahedron elements.

3. NUMERICAL SIMULATION

In case of using blade momentum theory to calculating the wind turbines responses, the process of calculating aerostatic coefficients of the airfoil section is needed. Furthermore, many of commercial codes could not consider the FSI effect. However, 3D CFD analysis of this study calculated the responses directly without any aero-static and dynamic coefficients. The two results shows relatively similar tendency but the differences are getting larger in process of time. From the results, in case of considering FSI effect, the ultimate loads transferred to the support structure have a tendency of decrease 3~7%.

4. CONCLUSION

This study calculates the load of a support structure of a static state wind turbine under the ultimate wind condition, and compares the results of considering FSI or not. The results of this study are listed below.

1. Supercomputer executable 3D CFD code which can consider FSI effect has been developed. The program developed in this study is constituted by CFD, structure and interaction modules, can use 30~1000 computing nodes at a time. It reduces analysis time from 3 more month to less than 2 days.
2. Even in that case of using wind tunnel test, the detailed flow of the wind cannot be verified. This study calculates wind turbine ambient wind velocity and pressure, and analyzes the detailed wind flow and surface loads on the structure to estimate the structural responses.
3. The blade momentum theory which is used to calculate wind load on the blade cannot consider the FSI effect. In the case of using flutter derivatives to consider FSI effect, the accuracy of the response will be limited. But 3D CFD can directly calculate the FSI responses.

Three-dimensional CFD analysis has lesser error factor than wind tunnel test and can analyze the aerodynamic responses and detailed wind pressure distribution on a structure. To investigate the wind induced responses more exactly, 3D CFD considering FSI effect should be executed. If the numerical results are verified by the measurement and the computation equipment are developed continuously, the proposed CFD method can be one of the good alternative for the wind tunnel tests or field measurements.

ACKNOWLEDGEMENTS

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