BGCE Honours Project 2011

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Stochastic Modeling of Atmospheric Wind in Application to Aeroelastic Simulation of Rotating Blades

In this project a method of generating turbulent velocity inlet condition is implemented. The generated velocity fluctuations have the same statistics as of the atmospheric wind and match the reference spectra very well. However, for a CFD simulation with this inlet data, numerical schemes should be selected such that the inlet wind properties are preserved throughout the domain. The goal of generating fluctuating boundary conditions is to study dynamic wind loading on structures. In the second part of this work, generated inlet data is used for Fluid-Structure Interaction simulation of a rotating blade. First, aero-elastic behavior of the blade without rotation is analyzed. Then, using an ALE frame, FSI simulation of a rotating blade is performed. The considerable effect of blade deformation in power generation is showed. Furthermore, the importance of having a realistic inlet condition in calculation of wind load on the blade is studied. It was observed that even though the mean power generation is not sensitive to the wind dynamics, structural load on the blade can be highly underestimated by using a uniform velocity at the inlet.

Inlet Generator:

Goal: Generate turbulent velocity fluctuations with the same second order statistics as in atmosphere.

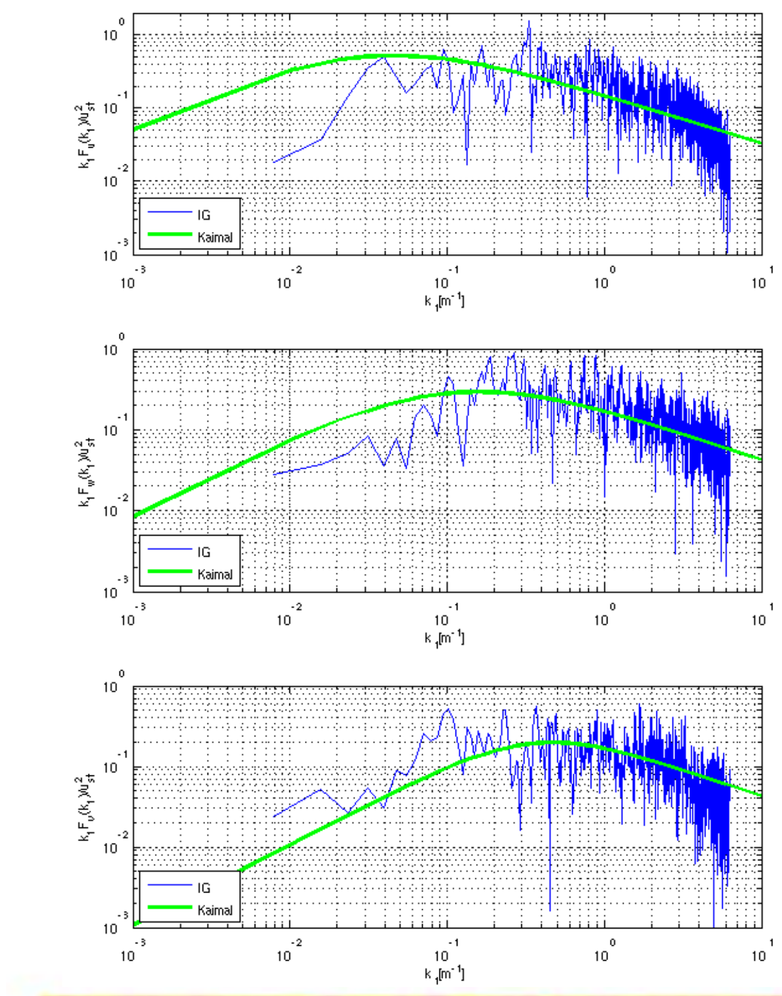
Application: Analysis of dynamic wind loading on structures.

Algorithm:

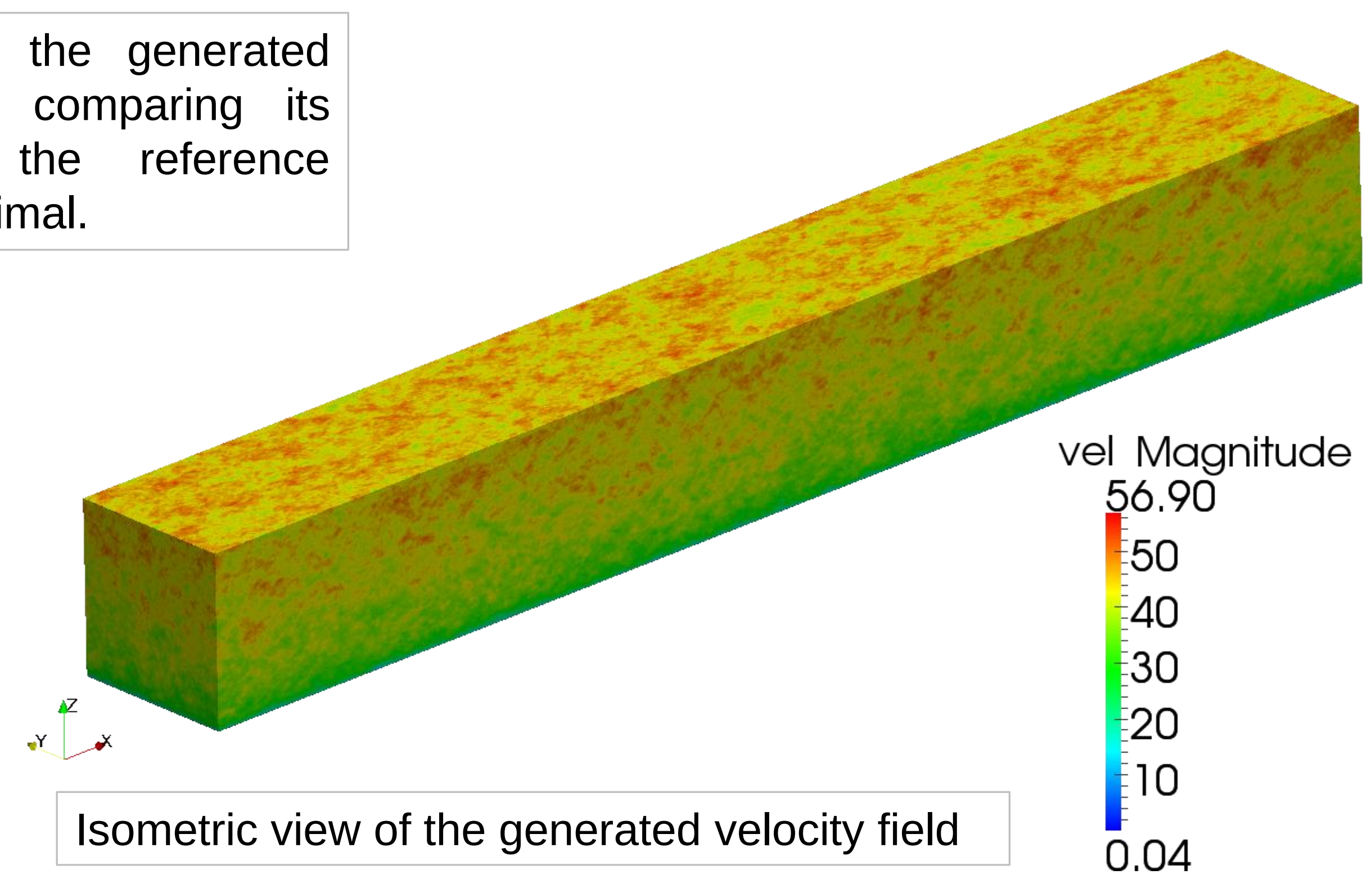
1) Calculate the matrix $C_{ij}(\mathbf{k})$.
2) Generate the Gaussian variable $n_j(\mathbf{k})$ and multiply it by $C_{ij}(\mathbf{k})$.
3) Take the inverse Fourier transform of the product to get velocity fluctuations.

Algorithm description:

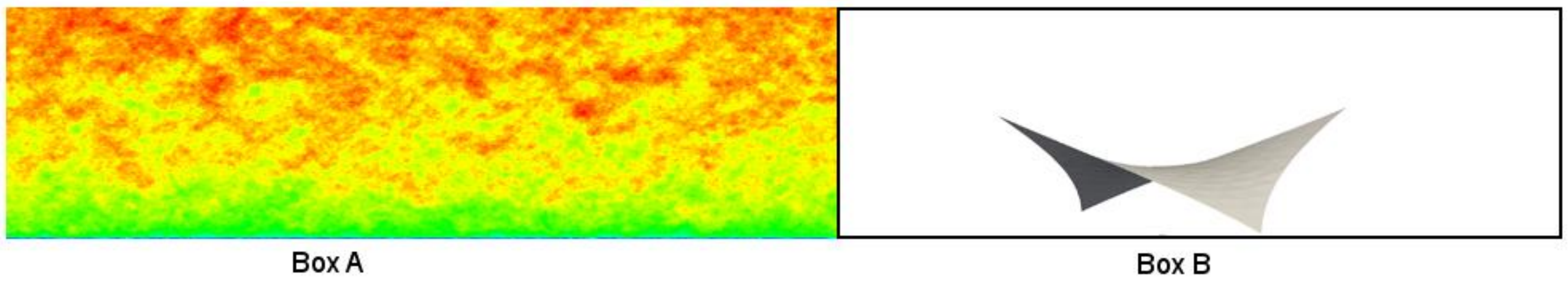
Gaussian distribution of velocity fluctuations is assumed. The method is based on wave superposition. Contribution of eddies of different size to velocity at each point of the domain is calculated in matrix C. It is multiplied by the vector, n, to enforce Gaussian distribution. Velocity in physical domain is then calculated by taking the inverse Fourier transform.



Evaluation of the generated fluctuations by comparing its spectra with the reference spectra from Kaimal.



Isometric view of the generated velocity field



The generated velocity field (Box A) is attached to the inlet of the computational domain (Box B), where CFD simulation is performed. Inlet data is fed into box B with a predefined streaming velocity and at each time step the corresponding data from box A is used as the inflow boundary condition for CFD simulation in box B.

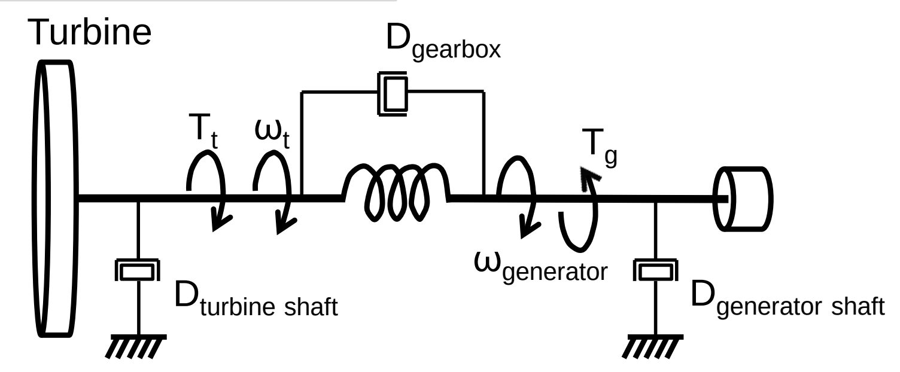
FSI Simulation of rotating blade:

The generated inflow data is used for FSI simulation of a representative blade. The simulated blade is a rectangular plate with 60 degree twist along its length. Angular velocity of the blade is calculated from the torque applied on it by the wind flow. A linear model is used for the resisting torque from the generator. Bending deformation of the blade is calculated using linear Euler-Bernoulli beam formulation.

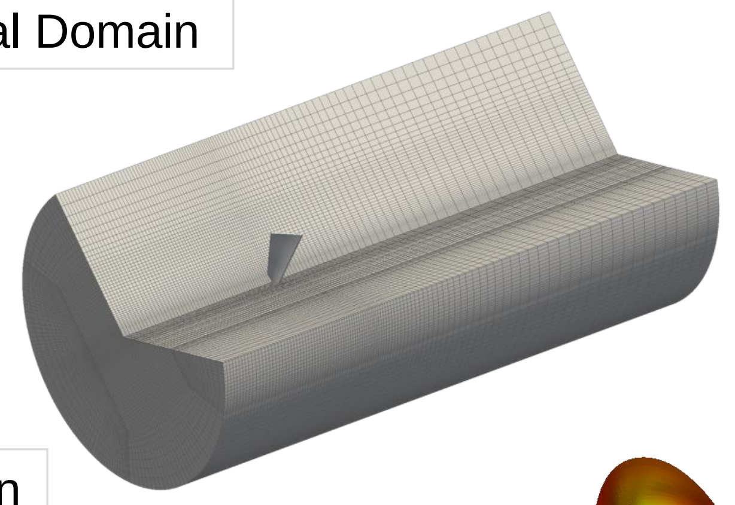
Using fluctuating inflow condition is of foremost importance in analysing dynamic effects like fatigue. This importance is observed by performing simulations for uniform inflow condition (blue curves) and also for fluctuating inflow (green curves). Higher peak loads where observed for the case of fluctuating inflow.

The role of flexibility of the blade is also studied by comparing the results of rigid rotating blade with the results of aero-elastic rotating blade. Lower power generation was observed for the case of aero-elastic blade.

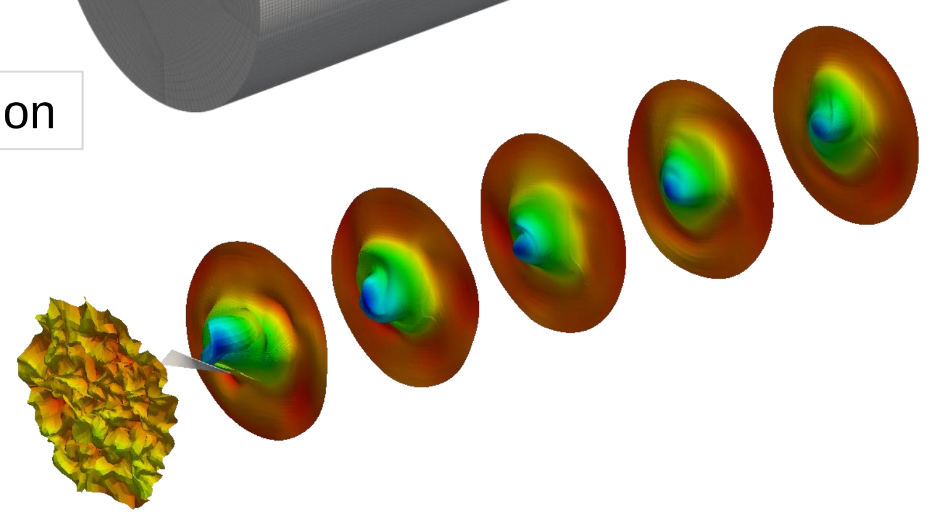
General derive train model



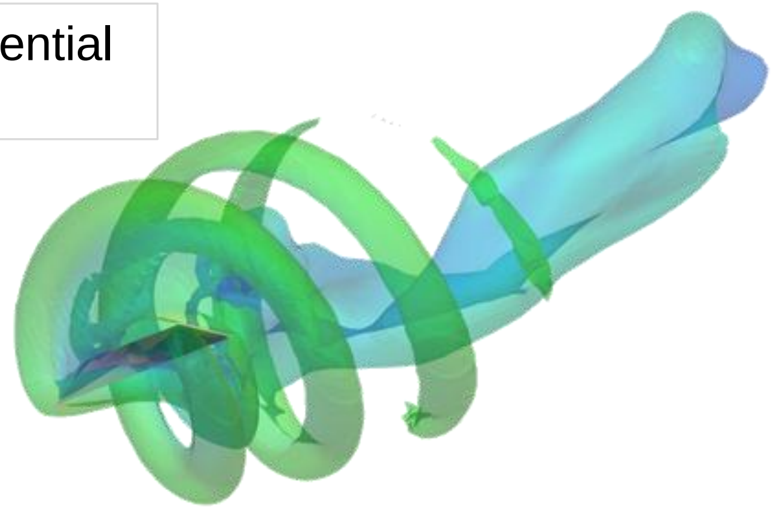
Computational Domain

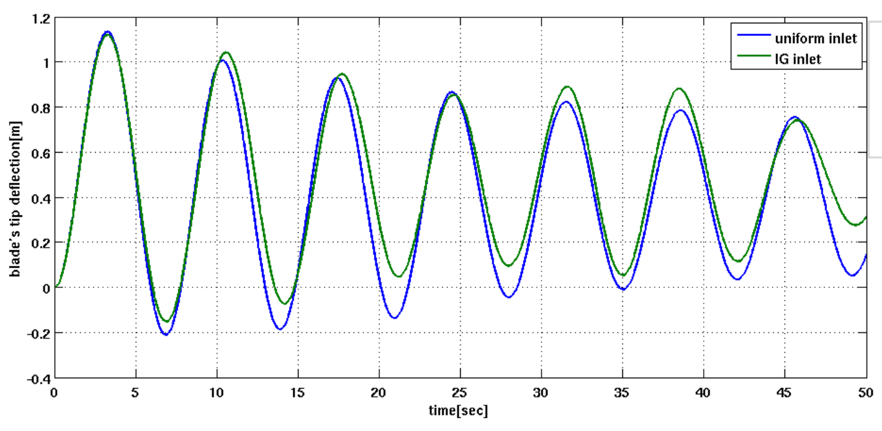


Wake Rotation

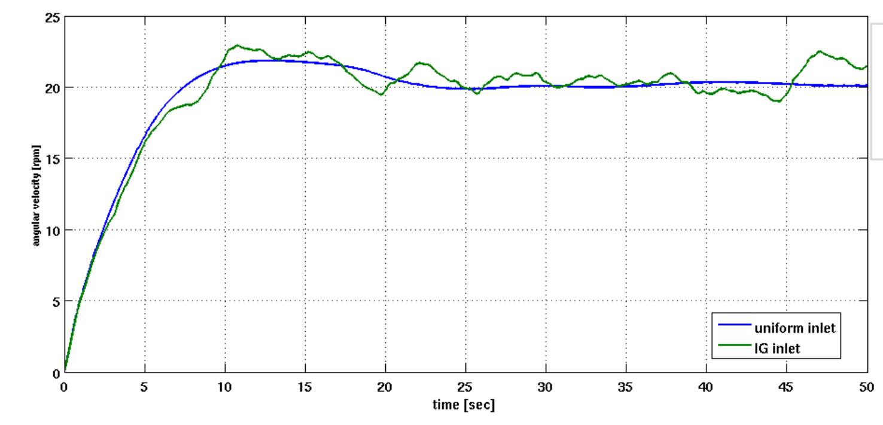


Isosurface of tangential velocity of 2.1 m/s

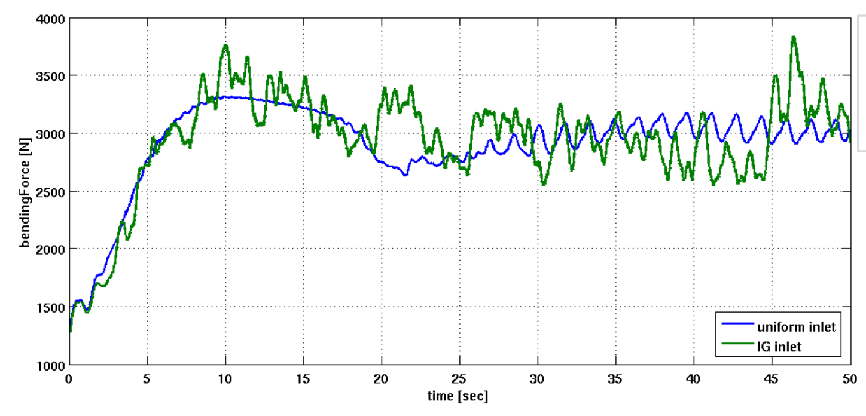




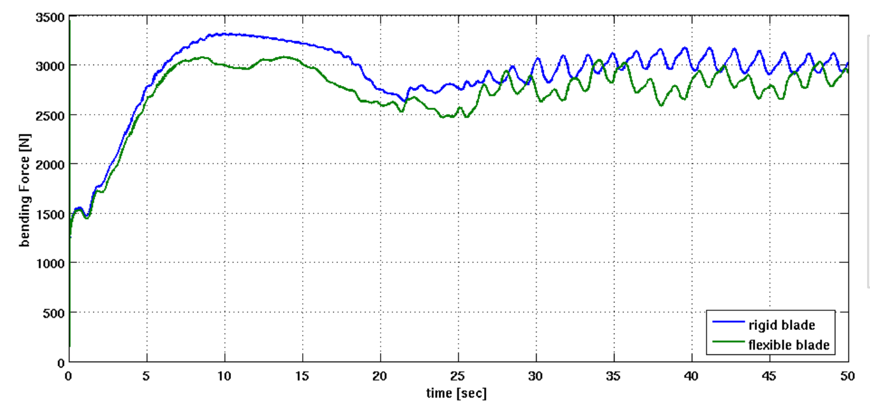
Tip deflection for non-rotating blade simulation



Angular velocity in rotating blade simulation



Bending force in rotating blade simulation



Comparison of bending force in aero-elastic rotating blade with rigid rotating blade

Conclusion:

A method for generating fluctuating velocity inlet conditions for simulation of atmospheric boundary layer is implemented. The generated inflow data is used for aero-elastic simulation of rotating blade. It was observed that fluctuations of the applied force using turbulent inlet conditions is much higher compared to uniform inflow condition, maximum bending load on the blade was also higher for the case of fluctuating inlet conditions. It highlights the importance of using turbulent fluctuating boundary condition for performing fatigue analysis of wind turbine blades.

References:

- J. Mann. Models in micrometeorology. Technical report, 1994.
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