Wind Farm Modelling with OpenFOAM

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Project Supervisor: Gavin Tabor

Introduction and Project Aims

OpenFOAM has a been widely used throughout the Wind Farm Modelling MEng Group Project supervised by Professor Gavin Tabor. This project has been carried out in partnership with the Centre for Modelling & Simulation (CFMS), and seeks to investigate improved turbine wake modelling techniques for wind turbines and arrays of turbines, through the use of CFD and Linear programming approaches.

This poster seeks to present a selection of the work carried out using OpenFOAM in this project. This includes a summary of the various computational models used, studies into the effects of the Atmospheric Boundary Layer (ABL) on turbine power and wake structure, an investigation into the behaviour of large arrays of turbines using LES and DES, and a methods based investigation into comparing CFD simulations with large experimental datasets.

For further information on this work please contact George Hyde-Linaker: gh309@exeter.ac.uk

Actuator Modelling in OpenFOAM

OpenFOAM was used to implement an actuator line method (ALM) approach to the modelling of wind turbines where the equivalent blade forces are distributed along lines through the domain. These can then be rotated about a central point to simulate rotor rotation. This method boasts the ability to simulate more complex rotor effects than simpler disk methods such as the presence of root and tip vortices.

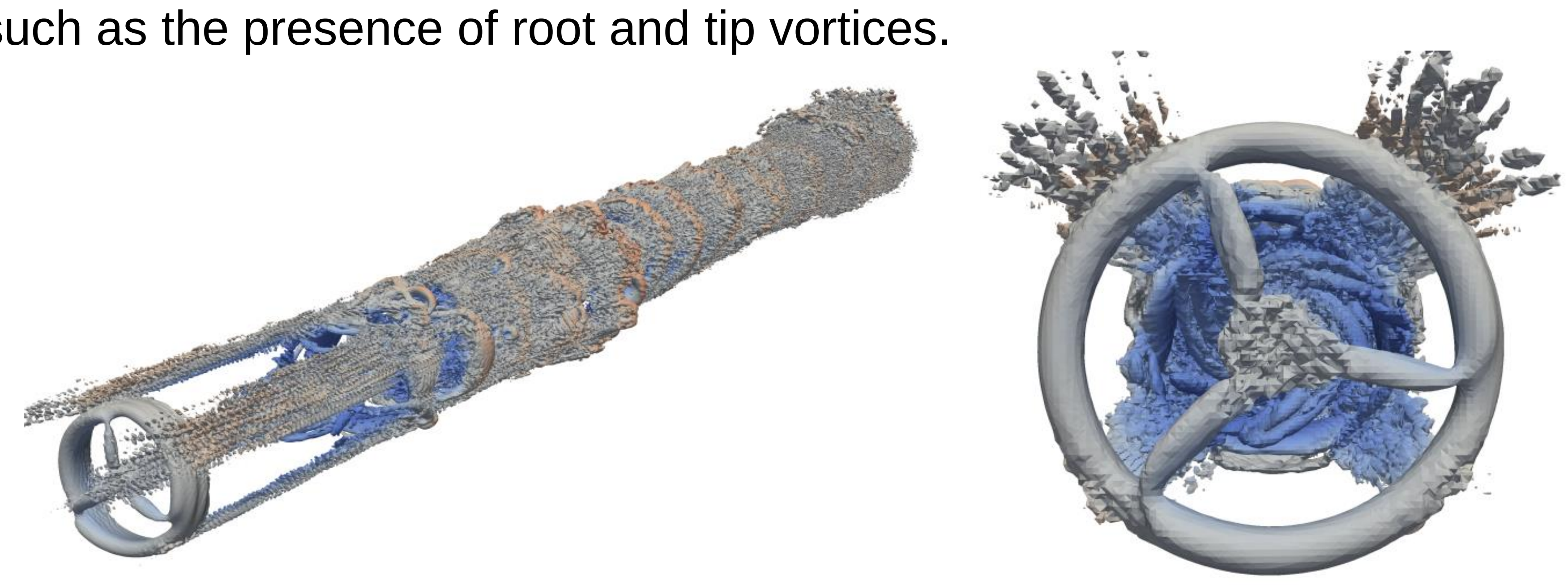


Figure 1: Contour of the second invariant of the velocity gradient tensor 'Q', used as a visualisation tool for turbulence. This represents the local balance between shear strain rate and vorticity magnitude, showing that vortex effects are represented in the simulation.

This model was compared to a range of actuator models in OpenFOAM. These included actuator disk models with a range of volume force distribution methods. A uniform force distribution, a Goldstein Optimum distribution associated with an ideal turbine operating at the Betz limit and a blade element method BEM coupled model using look-up tables.

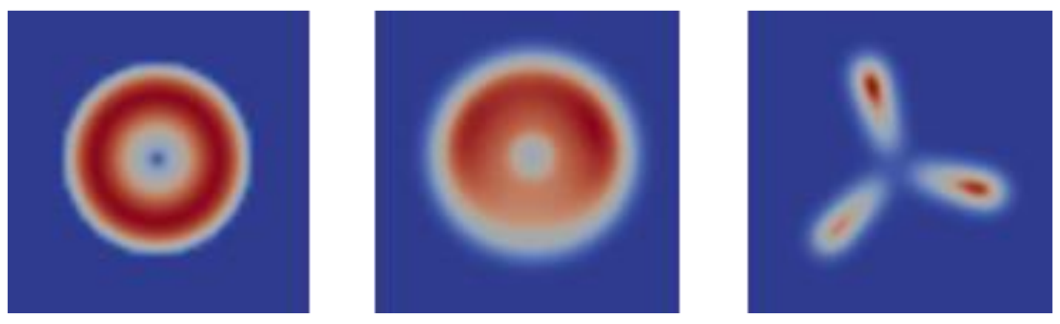


Figure 2: actuator model force distributions for the Goldstein Optimum, BEM, and ALM (left to right)

Atmospheric Boundary Layer

One major aspect of wind farm modelling is the accurate representation of the turbulent atmospheric boundary layer (ABL) at a reasonable computational cost.

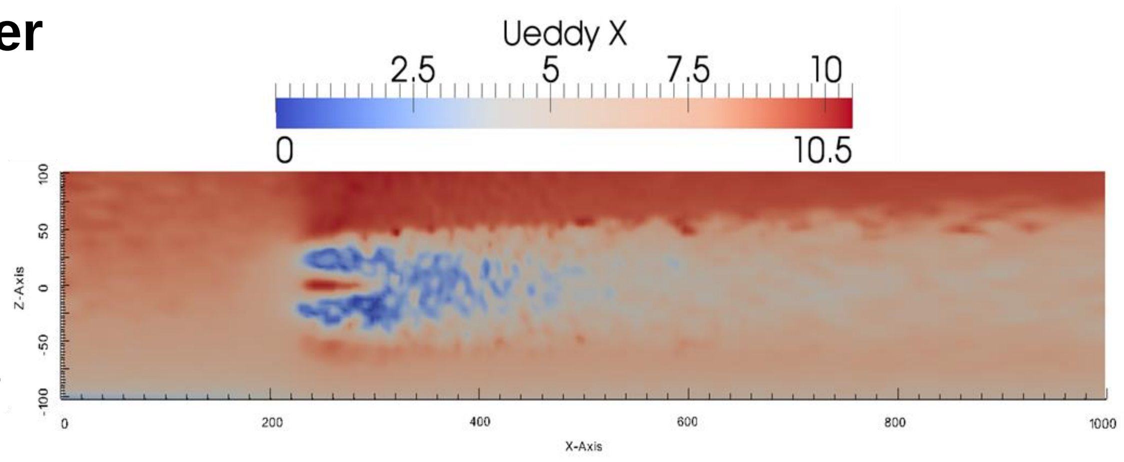


Figure 3: turbine wake including ABL interaction

This project has developed a solver that incorporates an actuator disk model with a synthetic eddy method (SEM) and an ABL velocity profile inlet condition. This implementation is shown in **Figure 3**. The implementation described produces a uniform ABL velocity profile with eddies imposed onto the mean flow via the SEM. This approach aims to mimic the turbulence within the ABL.

Figure 4 shows the relative velocity against relative height of the ABL predicted at offshore wind farm locations with the fluctuation of turbulent eddies incorporated.

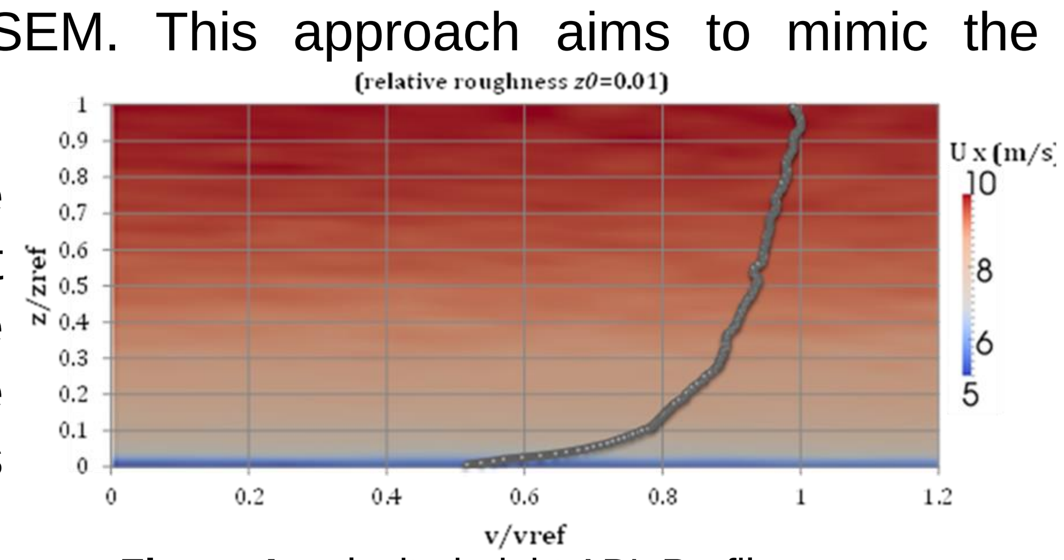
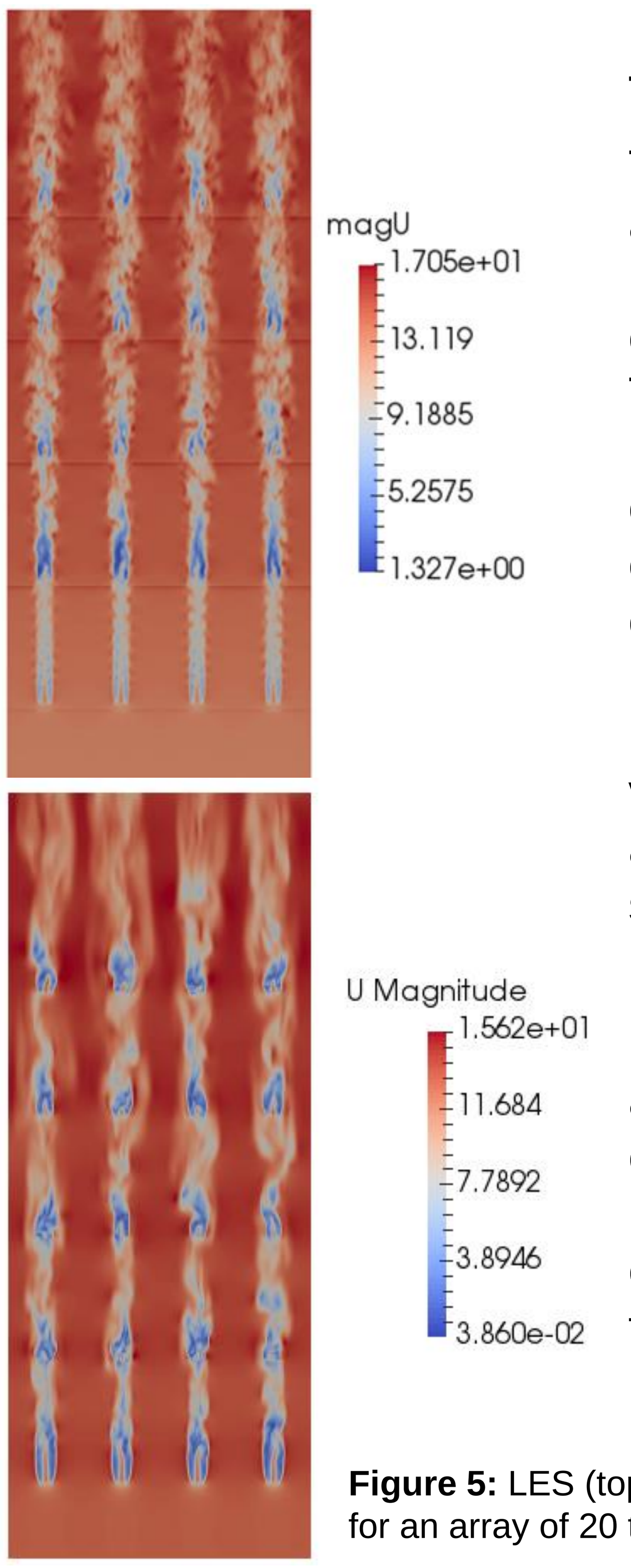


Figure 4: velocity-height ABL Profile

LES and DES Flow Simulations for an Array of Turbines



The wake interaction within an array of turbines was investigated using an actuator disk model to create an array of 20 turbines. This case was used to investigate model behaviour and array power output under various wind conditions, looking into the effects of yaw and wind magnitude on predicted power yield. An investigation into the use of various turbulence models was also undertaken, including simulations using LES and DES.

Figure 5 shows a comparison between the results for the LES and DES simulations As would be expected, the LES simulations proved far more computationally expensive, taking roughly ten times as long to solve for an identical case.

Figure 5: LES (top) and DES (bottom) simulations for an array of 20 turbines

CFD Validation against large Experimental Datasets

The development of methods for the comparison of large experimental datasets with the results of CFD simulations is an important area of research into wind energy. Increased use of remote sensing technologies such as SODAR and LiDAR to measure flow characteristics around wind farms has led to a need to investigate new approaches to aid validation of CFD models against this data.

As a part of this project, data comparison techniques were investigated using the results of a Particle Image Velocimetry (PIV) experiment investigating flow downstream of a submerged hull. OpenFOAM was used to investigate the case, using a full resolved boundary layer mesh and both RANS and LES turbulence modelling to simulate the turbulent wake.

Initial work on the comparison between PIV and CFD velocity component datasets has given a correlation of 0.977, and further work aims to identify a range of statistical and graphical approaches for the comparison of the datasets as a whole.

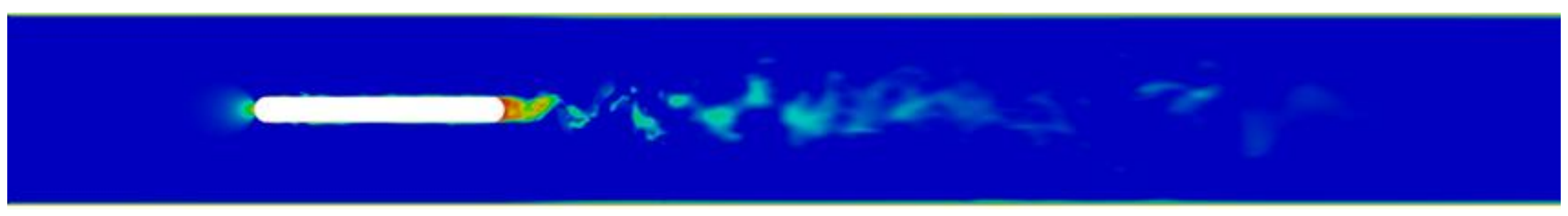


Figure 6: LES simulation of wake formed behind submerged hull

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