Developments of the offshore wind turbine wake model Fuga

This is the final report of the project entitled Risø DTU Modelling Services carried out by DTU Wind Energy (formerly known as Risø National Laboratory) as part of the Carbon Trust's Offshore Wind Accelerator Stage 2 under a contract with Carbon Trust. The project is a follow-up to a Carbon Trust's Offshore Wind Accelerator Stage 1 project called Linearized CFD Wake models. The earlier project resulted in the development, implementation and validation of the Fuga model. Fuga is a linearized CFD model that can predict wake effects for offshore wind farms. The main purpose of Stage 2 is to add more features to Fuga and turn it into a useful tool for offshore wind farm developers. The new features consist in:

- **Flexibility.** Including the ability to cope with several types of turbines in the same project, thus making it possible to predict inter farm interactions. The graphical user interface has been greatly improved and a number of input/output facilities have been added.

- **Stability effects.** The effect of stability has been added through a modification of the eddy viscosity based on Monin-Obukhov theory. The numerical solver developed in Stage 1 has been generalized in order to make it deal with the modified equations.

- **Meandering.** Meandering has been included in the form of a post processing of the model results that bend and twist the wake centreline. The meandering centrelines are calculated using a Gaussian process developed on the basis of measured spectra. An analysis of meteorological data from Horns Rev has been made in order to quantify the impact of non-stationarity of the wind direction. The results are generalized so as to account for the uncertainties imposed by a ten minute mean value trend as well as by the distance between turbines and the met mast. The old model has been validated against a number of data sets. Some of these tests have been repeated in order to demonstrate and validate the new model features. Production data from Horns Rev 1 have been re-analysed using well defined selection criteria for which the developed uncertainty models apply, and a comparison with data is made. Even if the model predictions fall within estimated error bars, the model seems to over predict the measured efficiencies by a few percent. The model works best for unstable, neutral and light stable conditions whereas the results for stable and very stable conditions are questionable. We suspect this is caused by a failure of the numerical solver that becomes progressively more severe as the stability increases.