Report 2022
Task 47

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TURBulent INflow Innovative Aerodynamics (TURBINIA)

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To enhance aerodynamic understanding, specialised blade experiments are essential. Traditional wind turbine measurements often fall short of providing detailed insights.

The IEA Task 47 TURBINIA, TURBulent INflow Innovative Aerodynamics initiated in 2021, their Task spanning the next four years. The Task aims to facilitate collaboration in the field of high-quality, detailed aerodynamic measurements for MW scale turbines in the atmospheric flow. Such measurements are notoriously difficult to execute. Currently, the only public example is the Danish DanAero experiment which was executed in the final phase of IEA Task 29.

Recently, several countries initiated new experiments which study turbines up to a scale of 8 MW and have experienced similar learning processes using new measurement techniques. Therefore, the ability to share experiences is seen as a fruitful way to ameliorate learning curves.

Table 1. Task 47 Participants in 2022

	MEMBER/SPONSOR	PARTICIPATING ORGANISATIONS
1	**Denmark**	Technical University of Denmark (DTU), Siemens- Gamesa Renewable Energy
2	**France**	ECN, ONERA, IFP Energies Nouvelles
3	**Germany**	Forwind/Fraunhofer IWES, University of Stuttgart (IAG), Kiel University of Applied Sciences, WINDnovation, German Aerospace Center DLR, Enercon, UAS Emden/Leer
4	**Italy**	CNR-INM, PoliMi, University of Rome "La Sapienza", University of Rome "Roma Tre" - University of Florence, Politecnico di Bari
5	**Netherlands**	Netherlands Organisation for Applied Scientific Research (TNO), CWI, Delft University of Technology, Suzlon Blade Technology (SBT), Det Norske Veritas (DNV), LM, University of Twente
6	**Sweden**	Uppsala University Campus Gotland
7	**Switzerland**	Eastern Switzerland University of Applied Sciences (OST)
8	**United States**	National Renewable Energy Laboratory (NREL)

Moreover, a sound scientific approach requires mutual exchange between measurements and theory, where experiments provide insights to develop theory and vice versa. Therefore, aerodynamic measurements are analysed and simulated by a large group of research institutions and industries using a variety of codes, ranging from low-fidelity BEM to high-fidelity CFD. Similarly, simulations are carried out on a 15 MW Reference Wind Turbine as designed in IEA Task 37.

In 2022, several aerodynamic measurement programs were instigated, and a variety of interesting data has been collected. The findings of these are documented for the benefit of future experiences of aerodynamic experimentalists. Additionally, calculational cases have been defined by the DanAero experiment and the 15 MW Reference Wind Turbine, leading to important insights into aerodynamic modelling aspects.

Introduction

The best strategy to improve aerodynamic knowledge is to perform experiments that are specifically dedicated to the measurement of aerodynamic blade properties. Therefore, it is important to highlight that conventional wind turbine measurements, such as power and blade root bending moment, lack a sufficient level of detail. As a result, specialised rotor aerodynamic experiments (often denoted as detailed aerodynamic experiments) are needed. In these detailed aerodynamic experiments, pressure distributions at different positions along the rotor blades were measured. Measurements, such as local blade inflow and boundary layer properties, are particularly valuable to further understanding the aerodynamics involved.

Specifically, these measurements are needed in the investigation of multi-MW scale turbines due to the fact that the aerodynamic modelling challenges increase with the size of the wind turbines. Additionally, such measurements are specialised and difficult to execute. The Danish DanAero experiment, created in the final phase of IEA Task 29, is the only public example to be executed at MW scale so far. Recently, additional countries have initiated new experiments for turbines up to a scale of 8 MW. However, they share a common struggle in navigating the learning curves associated with these aerodynamic measurements. Therefore, the new Task, TURBINIA: TURBulent INflow Innovative Aerodynamics, was created to enable stakeholders to share their experiences with these measurement techniques and overcome its learning curves more efficiently.

Nevertheless, it should be noted that aerodynamic knowledge is not solely advanced through measurements. A comprehensive scientific approach requires a symbiotic relationship between measurements and theory, where experiments inform the development of theory, and theory generates the need for further experimentation. Therefore, the DanAero experiment, possibly alongside other experiments, is used as validation material for many design codes that rely on a wide variety of aerodynamic models, ranging from low-fidelity BEM to high-fidelity CFD, with Free Vortex wake and panel model in between. Additionally, simulations are generated on a 15 MW Reference Wind Turbine, as designed in IEA Task 37. From these simulations, aerodynamic knowledge gaps for the design of 15 MW scale turbines have been identified. The synergy between experiments and theory will enhance the aerodynamic knowledge level, which eventually leads to more efficient aerodynamic design models and highly competitive designs for 15 MW wind turbines.

Progress and Achievements

Out of the several aerodynamic measurement programs that have begun, some have already provided initial results. The analysis of the results compared to their theoretical calculations is mentioned in the Highlights section. Furthermore, several new measurement techniques have been developed, such as a more efficient measurement of surface pressure and/or boundary layer information.

Moreover, a calculational case has been defined as a result of the DanAero experiment, which enables comparisons to be made based on time series data. Significant progress was achieved in improving the calibration between calculations and measurements. However, this project remains challenging due to the limited resolution of wind speed measurements that are used as input. These uncertainties are expected to decrease when using the new experiments from TURBINIA, as LIDAR measurements are expected to provide detailed mapping of the inflow. Regarding CFD modelling, an additional challenge emerged due to the fact that each CFD code convects turbulence in a different manner, which led to variations in wind fields observed in the rotor plane.

An additional noteworthy observation was the substantial difference in standard deviation of induced velocities between BEM and vortex codes. The discrepancy is surmised to be caused by the challenges of modelling non-uniform inflow in BEM, which is considerably important in regard to large turbines. In an effort to draw attention to these differences, a new case is defined at prescribed shear which is simulated by a variety of codes.

Furthermore, a standard input for the 15 MW Reference Wind Turbine has been defined with help from IEA TCP Wind Task 37. Using this input, many participants supplied results from a large variety of aerodynamic models on the 15-MW Reference Wind Turbine at uniform steady inflow (see Highlights section). Results from these tests have been compared, and improvements in the models are being implemented based on these findings.

Highlights

The figure below (Figure 1) displays the normal force at 25% blade span as a function of the azimuth angle measured during the TIADE 3.8 MW experiment (one of the experiments which was adopted by TURBINIA). The measurements are compared to calculations. Notably, the largest forces are found at 0-360 degrees, indicating the blade position pointing upward. Meanwhile, the lowest values occur when the blades point downward at 180 degrees. This variation over the azimuth angle is attributed to wind shear, where the dip at 180 degrees is caused by tower shadow. In general, these effects are well-modelled. As measurements from local aerodynamic forces on turbines of this particular scale are very rare, this serves as crucial validation material for future studies.

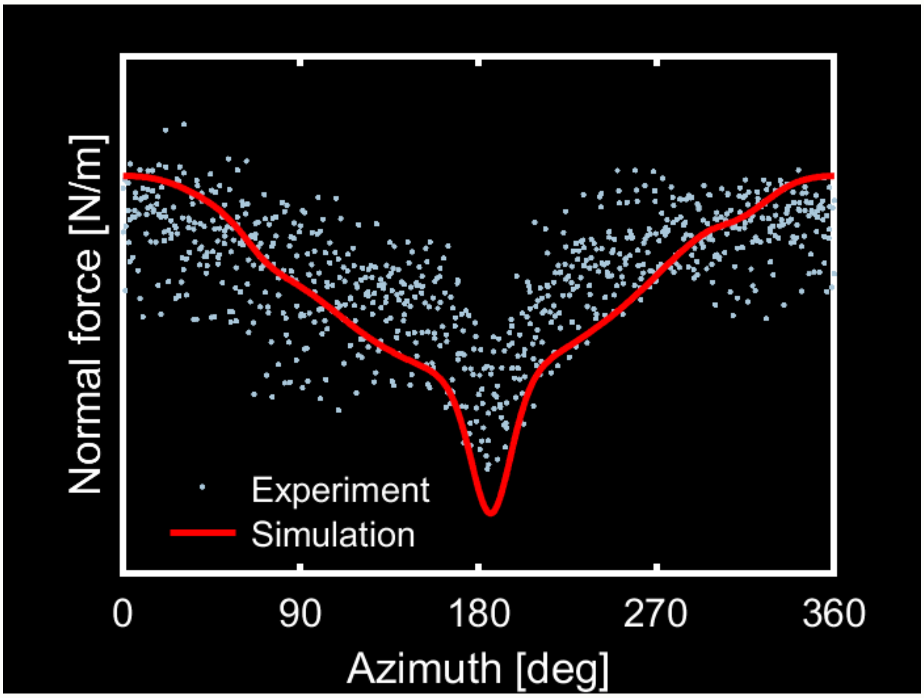

Figure 1.

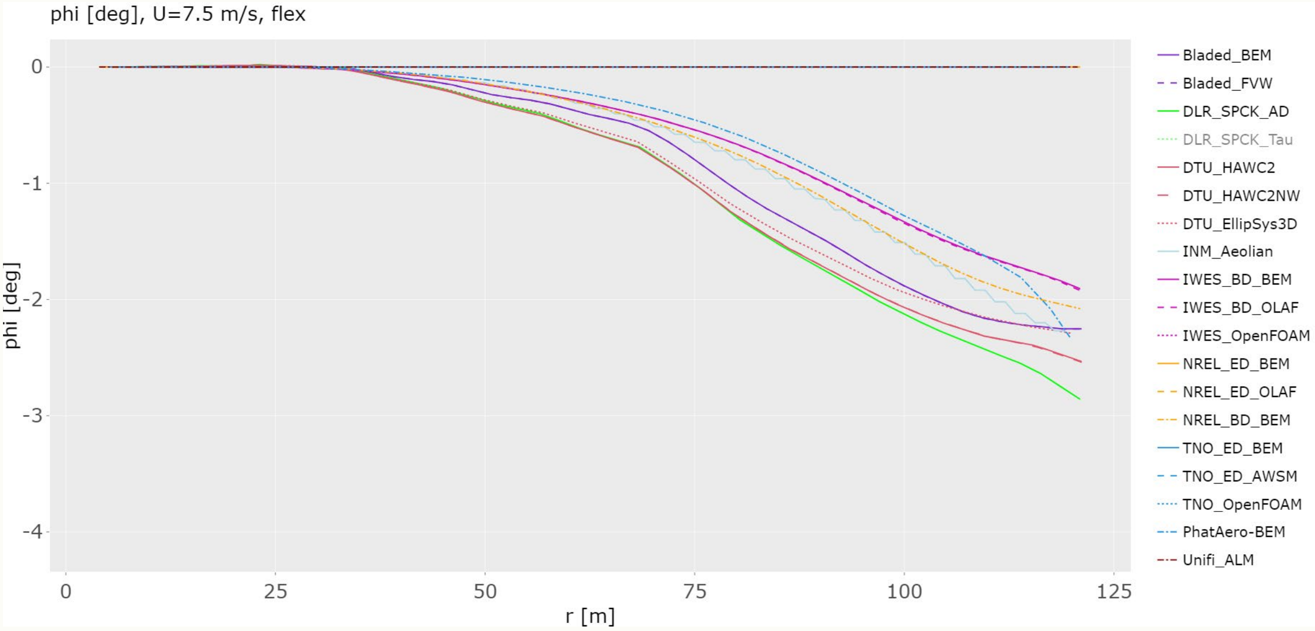

Figure 2.

Figure 2 shows the torsion angle (phi) as a function of the radial position of the 15 MW Reference Wind Turbine calculated by a large variety of codes. Notably, some codes, particularly CFD codes, do not model flexibilities. Therefore, they calculate a zero-torsion angle. Nevertheless, CFD codes provide valuable high-fidelity results concerning pressure distributions and other aerodynamic details, which help improve lower-fidelity codes. Furthermore, it has been discovered that torsion angles at the tip of larger turbines are in the order of 2 degrees, despite a relatively low wind speed of 7.5 m/s. These findings suggest that a large torsion angle has a significant impact on the performance, control, and loads. Therefore, the ability to accurately model torsion angles is crucial for aerodynamic research.

Outcomes and Significance

The most noteworthy outcomes of Task 47 include the following:

- Innovative aerodynamic measurement technologies applied to large-scale wind turbines.
- Documentation of best practices for conducting detailed aerodynamic measurements.
- Documented databases of detailed aerodynamic measurements on various wind turbines.
- Improved and validated aerodynamic and related aero-elastic models for designing large-scale wind turbines of capacities up to 15 MW.
- Dissemination of the generated wind turbine aerodynamic knowledge through publications, presentations, and other activities where the Wind Energy Human Capital Agenda is supported by employing many students and PhD's in TURBINIA. These students will secure positions in the wind industry after graduation, effectively disseminating Task 47 knowledge in the industry.

Next Steps

The next steps are aimed at performing more detailed aerodynamic measurements in several facilities. The key insights will be documented for the benefit of future experiments. Furthermore, the shortcomings of BEM in modelling non-uniform conditions will be further investigated by comparing results from BEM codes with results from more advanced models in sheared conditions. Additionally, a mutual comparison of calculations from a wide variety of codes on the 15-MW Reference Wind Turbine, in turbulent conditions, will provide insights into the modelling capabilities of large turbines.

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