Annual Report 2024

Task 47

Photo: *GE turbine on which aerodynamic measurements are carried out in the Dutch TIADE project.* *(Photo credit: Carel van Diggelen, TNO)*

TURBulent INflow Innovative Aerodynamics (TURBINIA)

Authors: Gerard Schepers, TNO, the Netherlands; Koen Boorsma, TNO, the Netherlands; Helge Madsen, DTU, Denmark; Georg Pirrung, DTU, Denmark

Task 47 commenced in 2021 aims to foster collaboration in the field of high-quality, detailed aerodynamic measurements for megawatt-scale turbines in atmospheric flow. Given the complexity of such measurements, sharing experiences proved to be a valuable way to accelerate learning curves.

Additionally, a variety of aerodynamic models, ranging from low-fidelity BEM to high-fidelity CFD, have been employed by numerous research institutes and industrial partners players. These models have been used to simulate measurements obtained from the DanAero experiment, where also simulations of the 15 MW Reference Wind Turbine (RWT) designed in IEA Tasks 37/55 were carried out.

In 2024, the first phase was completed and reported. Several aerodynamic measurement programs were conducted also with new measurement techniques. The lessons learned were documented to benefit future aerodynamic experimentalists. However, a significant bottleneck was the confidentiality of machine data, which hindered the use of these measurements in a common validation round. It was also noted that modeling challenges become more pronounced with larger wind turbines.

A proposal for a second phase has been approved, spanning four years from January 2025 until December 2028.

Introduction

To enhance aerodynamic understanding and so improve wind turbine design methods, conventional wind turbine measurements, such as power and blade root bending moment measurements, lack sufficient detail, necessitating detailed aerodynamic experiments. These experiments measure pressure distributions along rotor blades and potentially other properties like local blade inflow and boundary layer characteristics.

Such measurements are complex and specialized. Until now, the Danish DanAero experiment on a 2 MW rotor with an 80 m diameter has been the only public example at a megawatt scale. However, recently, several institutes in other countries have launched new experiments for turbines up to 8 MW, undergoing similar learning processes for aerodynamic measurements. To support this, Task 47 was established to share experiences and accelerate learning curves.

Additionally, valuable knowledge is gained by comparing results from the DanAero experiment with various aerodynamic models, ranging from low-fidelity Blade Element Momentum (BEM) to high-fidelity Computational Fluid Dynamics (CFD), with Free Vortex wake and panel models in between. Simultaneously, simulations on a 15-MW Reference Wind Turbine (RWT) generated in IEA Tasks 37/55 helped identify aerodynamic knowledge gaps for designing 15-MW scale turbines.

These activities ultimately improve aerodynamic models for turbines up to 15 MW, leading to more competitive turbine designs. The consortium of the TURBINIA is listed in table 1.

COUNTRY/SPONSOR	INSTITUTIONS
Denmark	Technical University of Denmark (DTU), Siemens-Gamesa Renewable Energy
France	ECN, ONERA, IFP Energies Nouvelles
Germany	Forwind/Fraunhofer IWES, University of Stuttgart (IAG), Kiel University of Applied Sciences, WINDnovation, German Aerospace Center DLR, Enercon, UAS Emden/Leer
Italy	CNR-INM, PoliMi, University of Rome “La Sapienza” University of Rome “Roma Tre” - University of Florence, Politecnico di Bari
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
Sweden	Uppsala University Campus Gotland
Switzerland	Eastern Switzerland University of Applied Sciences (OST)
United States	National Renewable Energy Laboratory (NREL), Sandia National Laboratory (SNL)

Table 1. *Countries Participating in Task 47*

Progress & Achievements

In TURBINIA phase I, valuable aerodynamic data was collected through several measurement programs. However, the associated turbine model information is generally restricted, limiting collaborative validation and comparison. The DanAero experiment is an exception, but this experiment was conducted around 2010 already, after which it took 5 to 10 years to release the machine data.

Similar advocacy efforts are needed to release the machine data of the experiments from TURBINIA phase I to ensure that the entire research community can also benefit from these other measurements.

An important highlight is the application of new aerodynamic measurement techniques including various techniques for pressure distribution measurements along the blade and wake rake measurements on a wind turbine. An example of flow visualization with tufts is shown in figure 1.

In terms of modelling the comparisons for the DanAero turbine revealed discrepancies, particularly with Blade Element Momentum (BEM) theory, which tends to overestimate fatigue loads due to its limitations in accounting for sheer and non-uniform flow conditions. This is an important finding as BEM-based

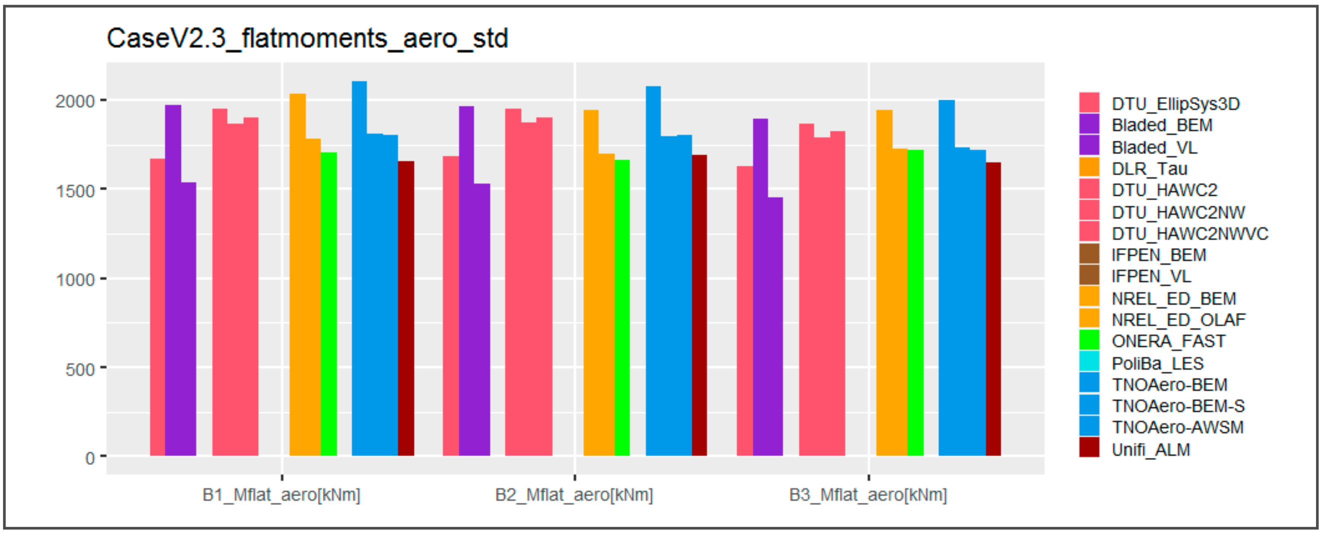

Figure 1. *Standard deviation of blade root flatwise moment on 15 MW RWT at shear, calculated by a variety of models.* (Source: K. Boorsma et al [6].)

models are the industry standard for wind turbine design, where discrepancies are expected to increase with rotor size.

Therefore, the performance of calculational models was also assessed for a larger turbine, i.e. the 15 MW Reference Wind Turbine, as designed in IEA TCP Wind Task 37/55. These calculations confirmed that BEM-based models overpredict fatigue loads (example in figure 2). A high sensitivity of the calculated loads to specific BEM implementations was found, suggesting there is no single, universally applicable BEM model even though literature often refers to THE BEM model.

Another observation on the 15 MW RWT is the large torsion angles at the tip (around 2 degrees even at a low wind speed of 7.5 m/s), with significant differences between partners. These large torsion angles impact performance, control, and loads, making accurate modeling crucial.

Highlights

- Showing the standard deviation of the blade root flatwise moment on the 15 MW RWT at sheared conditions (figure 1). The results are calculated by various participants with efficient engineering models is much higher than the standard deviation from corresponding higher fidelity models which implies

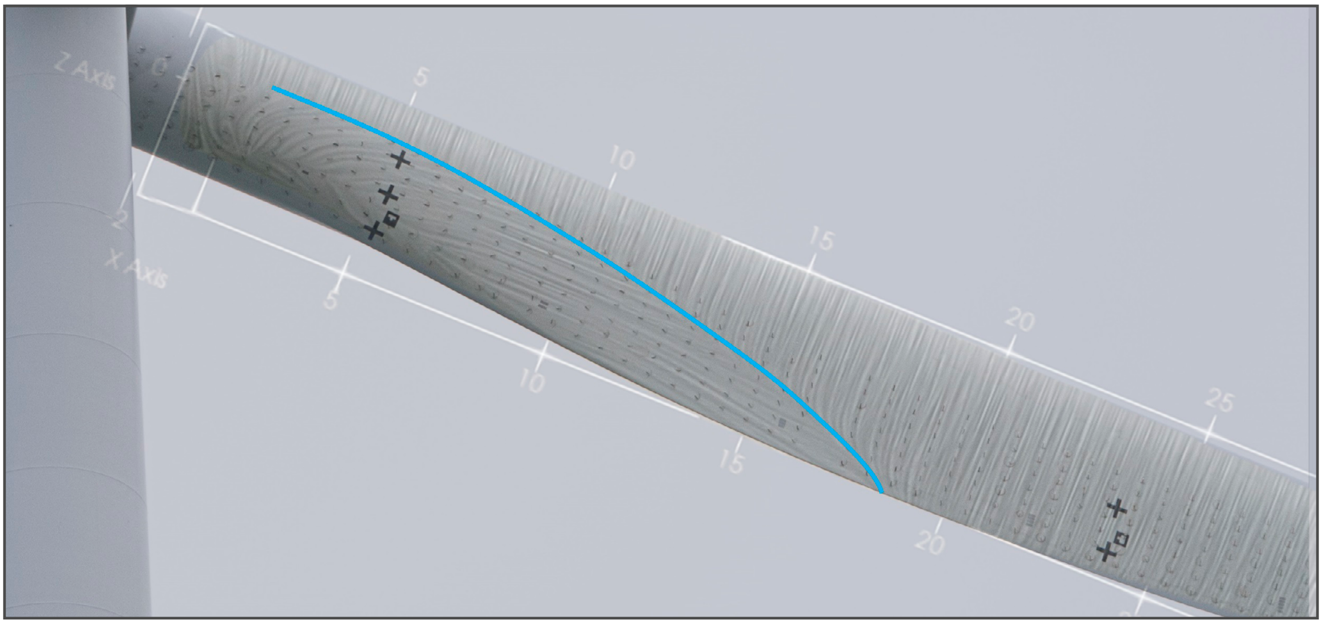

Figure 2. *Comparison between streamlines from tufts and calculations.* (Source: M. Caboni et al [7].)

an overprediction of fatigue loads from the industrial BEM models. Moreover, a strong sensitivity is found in the way the induced velocities are modelled in BEM.

- A joined article from the TURBINIA consortium about the challenging modelling of shear was accepted for oral presentation at the Science of Making Torque Conference [3].

- Making use of detailed aerodynamic measurement techniques as shown in figure 2 where the streamlines are visualized with tufts and compared with CFD calculations.

Outcomes & Significance

The most important outcomes include:

A **final report** with the most important results [6]

Innovative aerodynamic measurement technologies applied to large scale wind turbines

A document with **best practices** on how to do detailed aerodynamic measurements

Documented databases of detailed aerodynamic measurements on various wind turbines

Validated aerodynamic (and related aeroelastic) models to design large scale wind turbines (up to 15 MW) with guidelines for model improvements

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 find positions in the wind industry after graduation. In this way, they spread the TURBINIA knowledge in industry.

Next Steps

The first phase of TURBINIA ended in December 2024. The second four years phase began on January 1, 2025, focusing on the IEA 22 MW RWT turbine. The task will start with simulations at simple, uniform flow conditions where complexity will be increased gradually in a systematic way to identify model deficiencies. This approach helps target relevant complexities. Collaboration on detailed aerodynamic measurements from TURBINIA-1 will continue. Also, strategies will be explored to make use of detailed aerodynamic measurements despite data confidentiality limitations to benefit the broader aerodynamic community.

References

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Task Contact

Gerard Schepers
TNO, the Netherlands
gerard.schepers@tno.nl

Koen Boorsma
TNO, the Netherlands
koen.boorsma@tno.nl

Websites:
iea-wind.org/task47/