TASK 29 REPORT 2020

Analysis of aerodynamic measurements

DANAERO EXPERIMENT (PHOTO CREDIT: H.A MADSEN)

Technology Collaboration Programme
by iea

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The best strategy to improve aerodynamic knowledge is to perform experiments specifically devoted to the measurement of aerodynamic blade properties.

Moreover, it should be realized that conventional wind turbine measurements of, e.g., power and blade root bending moment lack sufficient detail, requiring very special rotor aerodynamic experiments (often called detailed aerodynamic experiments). In these detailed aerodynamic experiments, pressure distributions at different locations along the rotor blades should be measured wherever measurements of, e.g., inflow velocities and boundary layer transition are useful.

The first three phases of IEA Wind TCP Task 29 primarily relied on wind tunnel measurements taken on a rigid 4.5 m rotor with steady wind inflow. The fourth phase of Task 29 began in January 2018 and ended in December 2020. In this phase, data were made available from the DanAero experiment, in which detailed aerodynamic measurements were taken on a 2 MW turbine which was subject to aero-elastic effects and turbulent inflow.

Progress and achievements

The overall objective of Task 29, phase IV, was to cooperate on the analysis of the measurements taken within the DanAero project. The analysis has resulted in an improved aerodynamic understanding and models. In order to meet this objective, more than 20 leading institutes on the field of wind turbine aerodynamics cooperated closely. At the end of the Task (December 2020) the conclusions and results were described in a final report [1]. The most important result is a documented database of high-quality detailed aerodynamic measurements on a 2 MW turbine by which a long-standing wish from the aerodynamic wind community has been fulfilled, i.e. to have detailed aerodynamic measurements taken on a large-scale turbine under atmospheric conditions. Until now, detailed aerodynamic field measurements were available from the IEA Wind Tasks 14 and 18 only, but these measurements were performed in the 1990s on outdated turbines with less advanced measurement techniques. The database is made available to the Task 29 participants after signing a 'light NDA'.

After the release of the database, the cooperation within Task 29 made it possible to perform a thorough analysis of the DanAero data by a large consortium with ample manpower. This enabled a critical scrutiny of the measurements and important learning was gained on how to do these dedicated aerodynamic experiments.

The level of detail from the DanAero experiment enabled a high-level validation of design codes, which went far beyond a conventional validation. In addition, several validation rounds have been carried out where calculations are compared with DanAero measurements. The first calculational round considered a simple, steady, and axi-symmetric case defined at conditions close to a measurement case with little shear and little yaw. This was followed by a comparison case with a large shear and with a large yaw and shear.

TABLE 1. COUNTRIES PARTICIPATING IN TASK

Table 1. Task 29 Participants in 2020

	Country/Sponsor	Institution(s)
1	CWEA	Chinese Wind Energy Association (CWEA)
2	Denmark	Technical University of Denmark (DTU), Siemens- Gamesa Renewable Energy
3	France	ECN, EDF, ONERA, IFP Energies Nouvelles
4	Germany	Forwind/Fraunhofer IWES, University of Stuttgart (IAG), Kiel University of Applied Sciences, WINDnovation, German Aerospace Laboratory DLR, Enercon, UAS Emden/Leer
5	Italy	CNR-INM PoliMi, RSE
6	Netherlands	Netherlands Organisation for Applied Scientific Research (TNO), CWI, Delft University of Technology, Suzlon Blade Technology (SBT), Det Norske Veritas- Germanischer Loyd (DNV-GL), LM, University of Twente,
7	Sweden	Uppsala University Campus Gotland
8	Switzerland	UAS Rapperswil
9	United States	National Renewable Energy Laboratory (NREL)

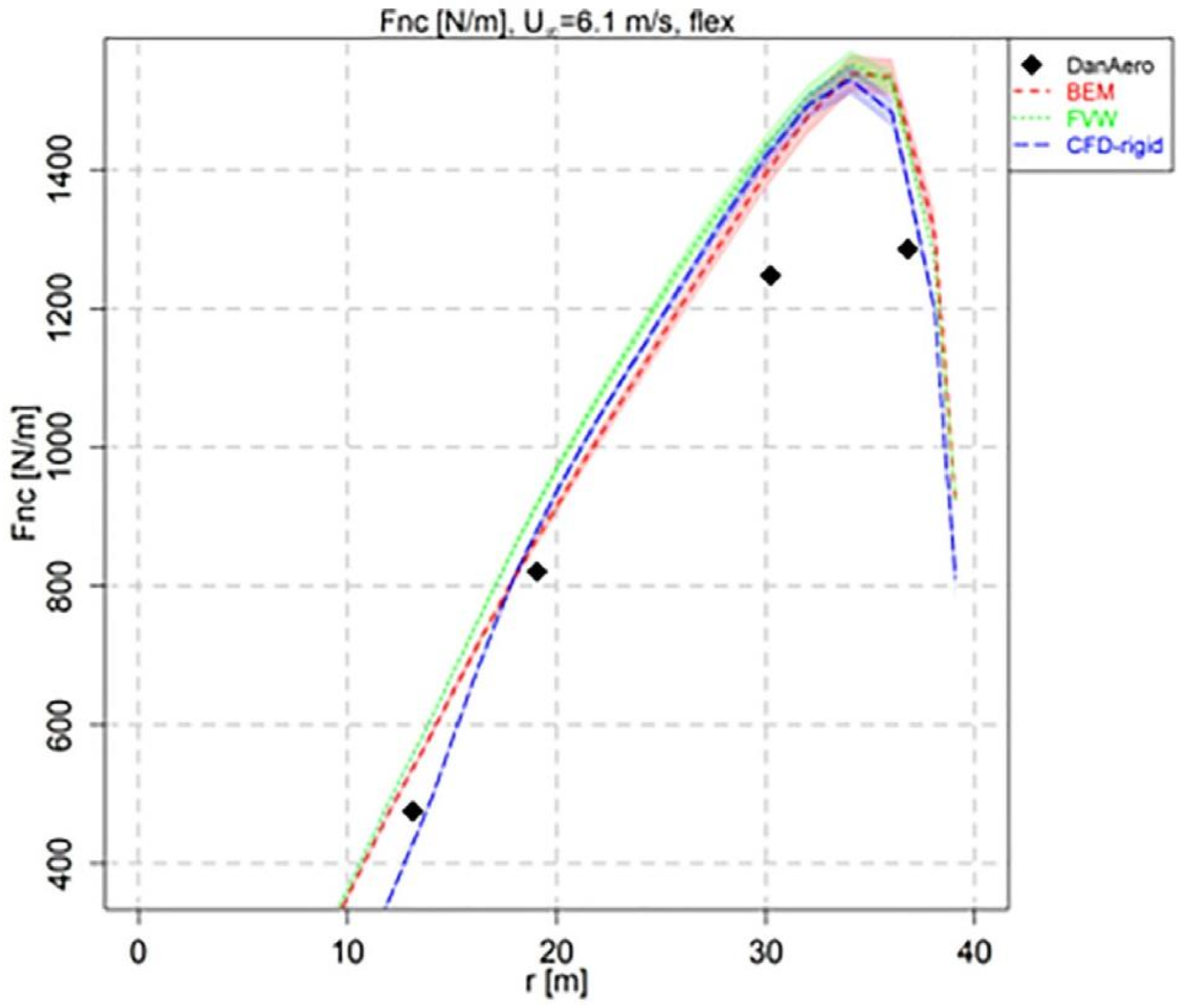

FIGURE 1 AERODYNAMIC NORMAL FORCE AS A FUNCTION OF RADIAL POSITION: DANAERO MEASUREMENTS ARE COMPARED WITH RESULTS FROM VARIOUS TYPES OF CODES: BEM, FVW, AND CFD.

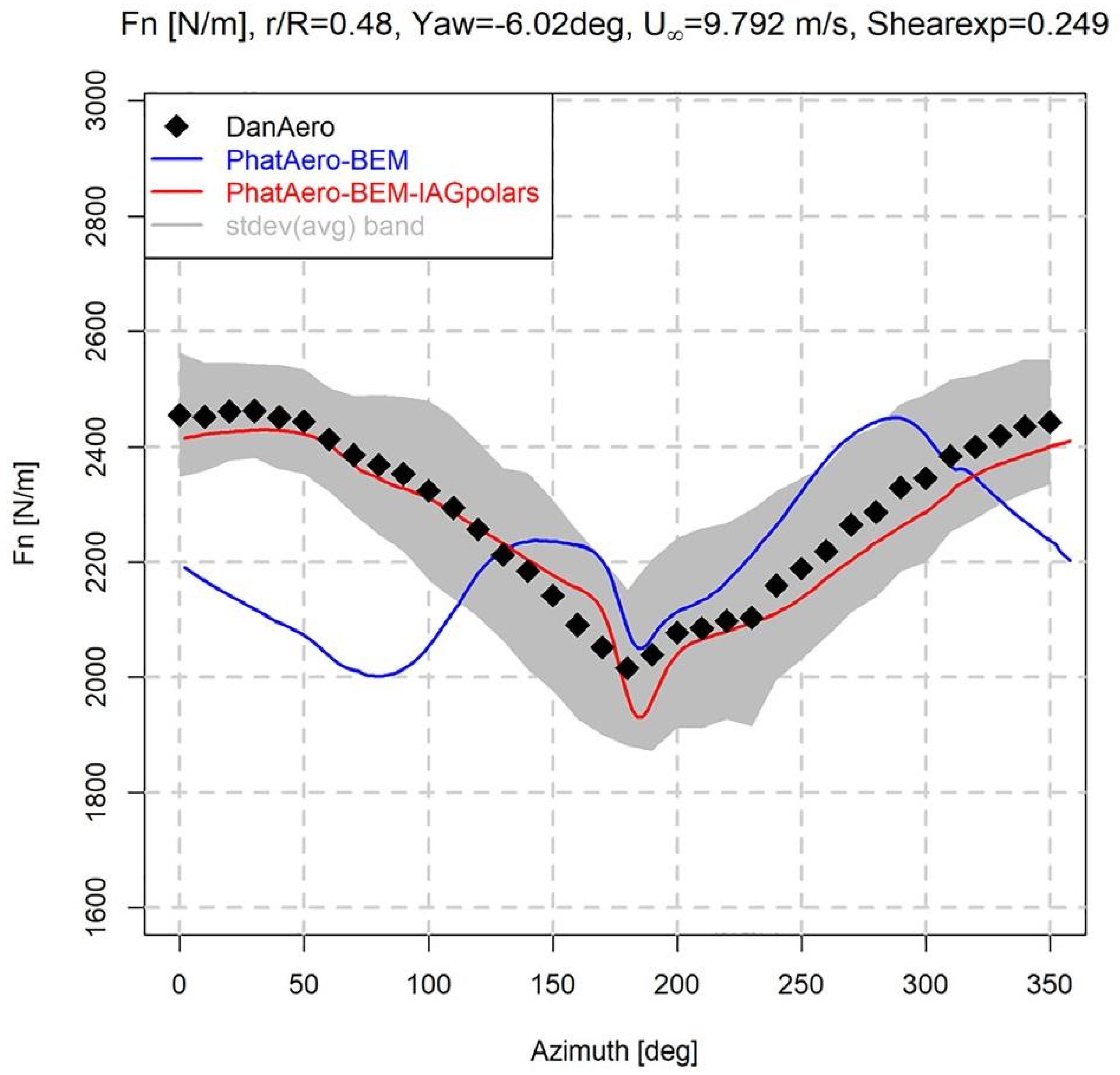

FIGURE 2 AERODYNAMIC NORMAL FORCE AT 48% SPAN AS FUNCTION OF AZIMUTH ANGLE IN HIGH SHEAR: DANAERO MEASUREMENTS ARE COMPARED WITH RESULTS FROM AN INDUSTRIAL BEM CODE USING PRESCRIBED AIRFOIL DATA (INDICATED WITH PHATAERO-BEM) AND USING AIRFOIL DATA EXTRACTED FROM A HIGH FIDELITY CFD CODE (INDICATED WITH IAG-POLARS).

Calculations have been performed with high fidelity, but time consuming, Computational Fluid Dynamic (CFD) codes and with efficient but lower fidelity engineering Blade Element Momentum (BEM) methods as used by industry. Calculations with intermediate methods like free vortex wake (FVW) models and panel methods have been added too. Intermediate models are higher fidelity than BEM but less time consuming than CFD. Both BEM and FVW methods are lifting line methods, i.e. the modelling of the airfoil aerodynamics relies on tables with airfoil characteristics where CFD and panel methods model the airfoil aerodynamics directly. An example of a comparison is shown in Figure 1, where the average results from different model categories are presented.

Generally, the mutual agreement between simulation results from the same model type in phase IV is better than in the previous phases of Task 29. The agreement between calculations and measurements however is sometimes poorer than the agreement found in the previous phases of Task 29. This was partly caused by measurement issues, but also by the much more challenging conditions in the present phase where a large turbine with aero-elastic deformations is modelled in atmospheric conditions with turbulent and inhomogeneous inflow, in contrast to the relatively easy, steady wind tunnel environment and small wind turbine with negligible aero-elastic effects as considered in the previous phases.

The differences with measurements mainly appeared in the results from the engineering BEM methods. It was encouraging to see that the results from higher fidelity codes like CFD and FVW often agree much better (though not perfect) with the measurements. This is illustrated in Figure 2 where a result with high shear is modelled with a standard BEM model and with a BEM model using CFD synthesized airfoil data.

The available data have also been used for fundamental physical understanding. Thereto different types of inflow have been studied including wake inflow, where moreover 3D effects, boundary layer transition, aero-elastic effects and acoustics were studied. Attention was also paid to consistent comparisons between aerodynamic calculations and measurements under turbulent inflow. The lessons from Task 29 led to several recommendations. An important lesson from Task 29 was that conventional measurement lack detail so that specific aerodynamic measurements are needed for validation of aerodynamic models. An additional lesson was that many data points are needed for a valid statistical calibration, and measurements are needed on a representative scale. This then led to the recommendation that much more detailed aerodynamic measurements are needed on an even larger scale. Another lesson learned is that such measurements are difficult to do, which led to the recommendation that practical experiences from the few aerodynamic experiments that have been or are to be performed should be shared.

Outcomes and significance

The most important outcomes include:

- A documented database of high-quality detailed aerodynamic measurements that were used for validation of aerodynamic and aero-elastic codes for research and industrial purpose.
- Improved and validated aerodynamic and aero-elastic models for wind turbine design codes and improved insights on the aerodynamic behavior in turbulent inflow.
- Best practices on how to do detailed aerodynamic measurements that are currently being carried out at several places around the globe.
- Dissemination of the generated wind turbine aerodynamic knowledge through a large number of publications, presentations and other activities.
- Support to the Wind Energy Human Capital Agenda. Approximately 100 students (MSc and PhD) worked largely or completely in the 4 phases of IEA Wind Task 29 where at least 25 of these students found positions in the wind industry after graduation. In this way, they spread the Task 29 knowledge in industry.

Next steps

IEA Task 29 is finished but the above-mentioned recommendations and lessons formed input to a new IEA Task 47 Innovative aerodynamic experiment technologies and simulations on wind turbines in turbulent inflow.

In IEA Task 47 several countries will cooperate on the field of new detailed aerodynamic measurements. Task 47 started on 1 January 2021 and it will last until 31 December 2024.

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