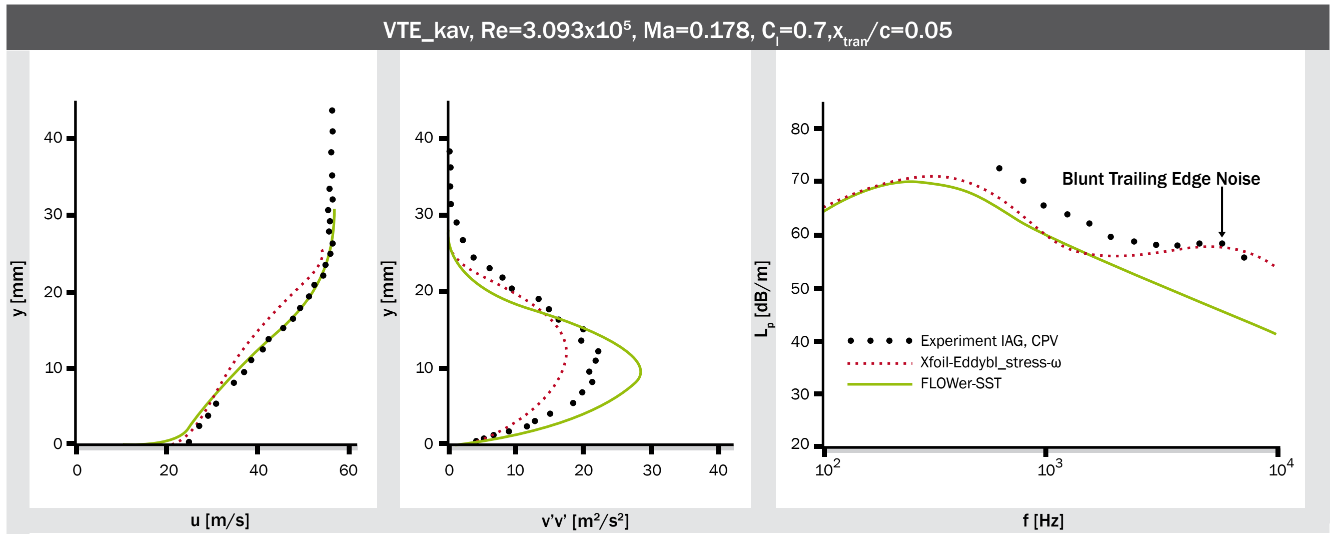

Figure 5: Boundary layer measurements and trailing edge noise on an airfoil compared to predictions.

Results achieved so far:
A RANS based CFD flow solver together with an appropriate turbulence model is coupled with the noise prediction scheme and first validation results are depicted in Figure 5. The detailed boundary-layer experiments have been conducted in the LWT at IAG, and comparison studies are carried out on the calculated noise source parameters and total noise spectra. The CFD computations are performed with isotropic Shear-Stress Transport (SST) two equation turbulence models. Encouraging results are obtained. New detailed BL measurements are ongoing.

RESULTS AND EXPECTATIONS

The final outcome is a design-basis consisting of tools and methods for aerodynamic and aeroelastic design of future large multi-MW turbines covering possible new and innovative concepts.

A summary of the results achieved so far includes:

- Bending-torsion coupling is important;
- Inflow shear is non-trivial and creates phase shifts;
- Dynamic stall models for the variable trailing edge concept has been developed and applied for aeroelastic predictions;
- Stability analysis including nonlinear effects (and structural modal damping prediction) has been performed;
- Noise prediction: Boundary layer predictions and measurements.

UpWind

SIXTH FRAMEWORK PROGRAMME

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- University of Patras
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Aerodynamics and aeroelastics

THE CHALLENGE

The overall objective of this work package is to develop an aerodynamic and aeroelastic design basis for large multi-MW turbines to facilitate the further development of multi-MW turbines, including new concepts.

The specific objectives of this work package (WP) are:

- The development of structural dynamic models for the complete wind turbine or components that can handle highly nonlinear effects e.g. from flexible blades with complex laminated composite and composite sandwich skins and webs;
- The development of advanced models on rotor and blade aerodynamics, covering full 3D CFD rotor models, free wake models and improved BEM type models;
- The aerodynamic and aeroelastic modelling of aerodynamic control devices;
- The development of models for analysis of aeroelastic stability and total damping;
- The development of models for computation of aerodynamic noise in order to design new airfoils and rotors with reduced noise emission.

The continuous upscaling of wind turbines towards multi-MW turbines has several fundamental implications on the aeroelastic modelling of the wind turbines. In general, the flexibility of the wind turbine structure increases so that more eigen frequencies coincide with peaks in the aerodynamic load input. Also, self induced loads from the eigen motion and flexibility of the wind turbine structure increases. The influence from elastic torsion of the blades of present MW turbines already amounts to 2-3 deg.

An increasing contribution of self-induced loads is one of the results of the upscaling of flexible constructions. Also an increasing part of the natural turbulence structures are comparable with the rotor diameter so that considerable difference in inflow velocity over the rotor disc is observed. This again leads to bigger variations in dynamic induction over the rotor disc.

Active control of aerodynamic loads becomes more important in order to reduce loads and increase stability. This is due to the increasing variations in loads over the rotor disc and the increased dynamic loading from eigen motion of the turbine. It is possible to apply “smart material devices” that can change the local shape or the structural characteristics of a blade segment.

The prediction of total damping for a wind turbine under varying operational- and external conditions, is crucial for the development and optimization of large stable wind turbines. The total damping consists of the aerodynamic- and structural damping in combination with the control actions and for an offshore turbine, the hydro-elastic damping of the foundation. The challenge is to further develop damping predictions in order to reflect on the needs arising from the upscaling of wind turbines.

WP1A1
WP1A2
WP1A3
WP1B1
WP1B2
WP1B3
WP1B4
WP2
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WP4
WP5
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WP8
WP9

UpWind

Aerodynamic noise is an important design parameter in the development of new wind turbine rotors and the constraints on maximum allowable noise often increase the cost of the rotor due to limitations of the tip speed.

THE RESEARCH ACTIVITIES

The work has been divided into five tasks. The research of the first part of the project is focused on:

- Quantifying the importance of nonlinear structural effects on loads and stability;
- Improving modeling and including effects of shear-coupling and large deformation into beam models and finite elements;
- Verifying and developing engineering aerodynamic models by application of full 3D unsteady CFD models in complex inflow such as strong wind shear;
- Overviewing requirements to aerodynamic and aeroelastic design tools in order to analyse the potential of different advanced control features and aerodynamic devices;
- Developing concepts to improve the link between CFD and aeroacoustics predictions.

WP 2.1 STRUCTURAL DYNAMICS-LARGE DEFLECTIONS AND NONLINEAR EFFECTS

Status:

- The flexibility increases by upscaling to multi-MW;
- Eigen frequencies coincide with peaks in the aerodynamic load input;
- Self induced loads increases (influence from elastic torsion can be 2-3 deg).

Results achieved so far:

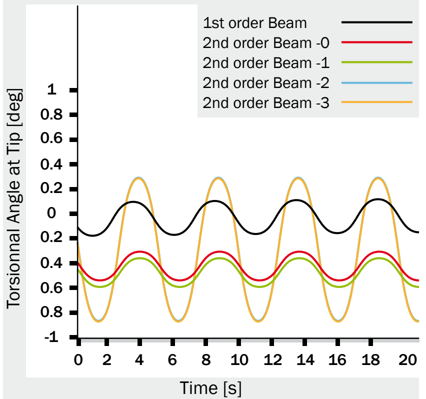


Figure 1: Predicted torsional deformation of blade (5 MW) by beam model taking different nonlinear effects into account.

Assessment of the important nonlinear couplings is performed by means of nonlinear aeroelastic simulations on the 5 MW reference wind turbine (a reference machine defined within IEA WE programme) which are compared to those of a conventional 1st order beam model. Through these comparisons, the effect of various nonlinear higher order structural couplings is quantified. Certain nonlinearities - especially those related to the coupling of the blade torsion with the blade bending - are of great importance and should be taken into account in the modeling of large flexible blades. This is illustrated in Figure 1, which shows, that the tip pitch is up to about one degree different due to nonlinear effects.

WP 2.2 ADVANCED AERODYNAMIC MODELS

Status (upscaling):

- Unsteady loading now depends on the actual modal forms of vibration;
- Unsteady aerodynamics is essential for load prediction as well as stability;
- Considerable difference in inflow velocity and variations in dynamic induction over the rotor disc;
- Shear effects become important.

Results achieved so far:

Computations with different models have been performed for the case of a strong wind shear in the rotor inflow for a MW wind turbine. The results from advanced CFD models are illustrated in Figure 2a. These computations show that there is an unexpected phase shift which causes the blade loads to be different in the horizontal position depending upon whether the blade is on its way up or down. This means that the wake is skew in the horizontal plane – a phenomenon that is not taken into account in the usual BEM codes. This is further illustrated in Figure 2b, where the blade's normal forces for the two positions (90 and 270 degrees azimuth) are given for different calculation methods.

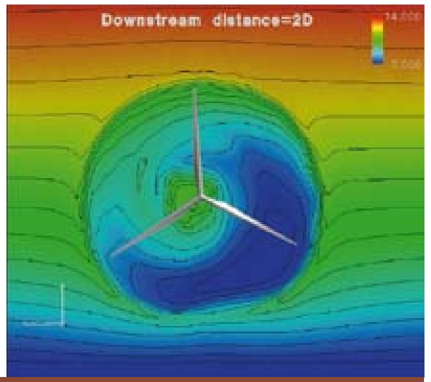
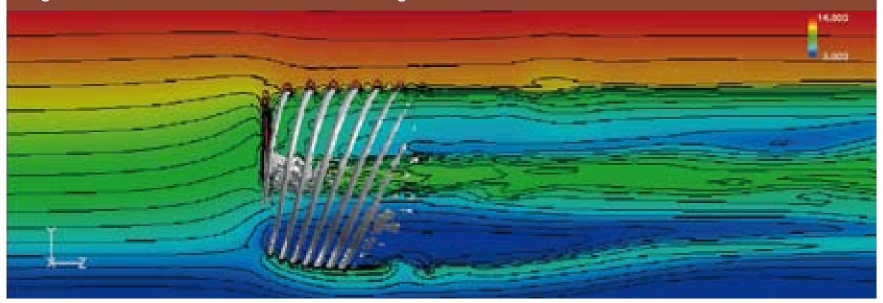


Figure 2a: CFD-calculation on a MW turbine with strong shear inflow.



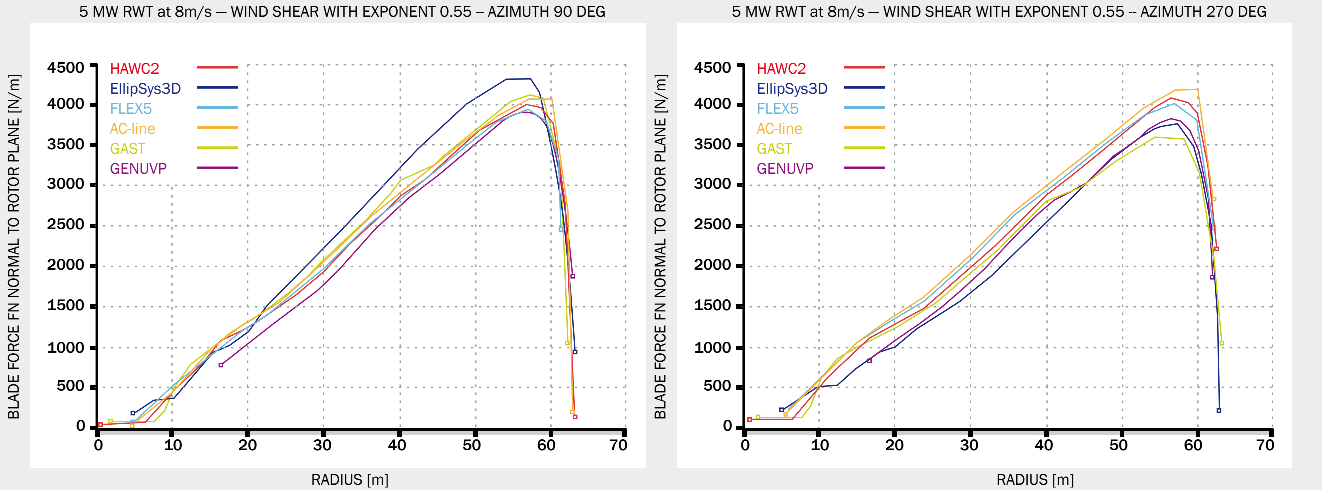


Figure 2b: Predicted blade axial force at 90 and 270 degrees azimuth by different models

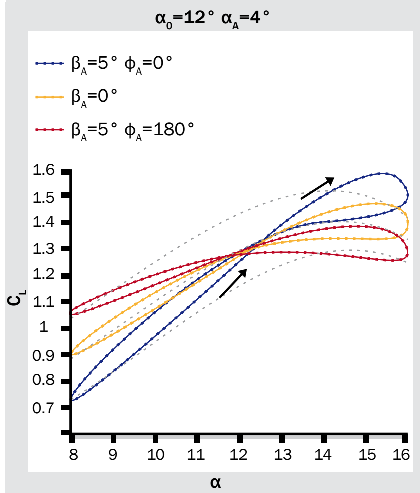
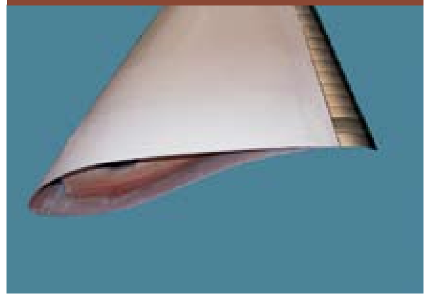


Figure 3: Dynamic stall loops for a pitching airfoil with a cyclic trailing edge deflection.



WP 2.3 AERODYNAMIC AND AEROELASTIC MODELING OF ADVANCED CONTROL FEATURES AND AERODYNAMIC DEVICES

Status:

- Potentials in active control of local aerodynamic loads;
- Potentials in active control of local structural characteristics.

Results achieved so far:

Focus has been on the development of unsteady aerodynamic models for the simulation of a variable trailing edge flap that can be incorporated in aeroelastic simulation tools to identify the potentials with respect to load reduction or power enhancement by application of this concept for large MW turbines. How one model works is illustrated in Figure 3, which reflects the effect of a combined pitching motion of an airfoil with a trailing edge flapping movement at different phases corresponding to a changing camber line. The trailing edge flap movement can either increase or decrease the lift curve slope depending on the phase, and is thus an efficient way to control the loading on a blade.

WP 2.4: AEROELASTIC STABILITY AND TOTAL DAMPING PREDICTION INCLUDING HYDROELASTIC INTERACTION

Status:

- Development of aero-servo-elastic stability tools was performed in STABCON project;
- Need for aero-servo-hydro-elastic stability tools and design guidelines.

Results achieved so far:

Stability tools have been further developed e.g. to account for large deflections. Deflection of the long slender blades results in coupling between the different deflections and thus changing stability characteristics. An example of this is illustrated in Fig. 4, where the frequency and damping of the lowest damped mode (the edgewise/torsional mode) is shown as function of tip speed for a non-deflected and a deflected blade (red), respectively. The mode corresponds to a kind of "flutter mode" which is stable for all tip-speeds considering the blade is non-deflected, however, for the deflected blade, which is closer to reality; this mode gets unstable beyond 100 m/s tip speed.

WP 2.5 COMPUTATION OF AERODYNAMIC NOISE – RANS BASED ACOUSTICS MODELS

Status:

- Aerodynamic noise is a design parameter influencing cost;
- Design codes for prediction of broad band noise give reasonable overall results;
- Improvements needed for detailed airfoil and blade design;
- Considerable improvements of 2D and 3D RANS CFD computations;
- Challenge is to compute the generation of noise with local turbulence parameters up through the boundary layer height at the airfoil trailing edge.

Figure 4: Frequency and damping for a non-deflected and a deflected blade (red), respectively (5 MW turbine).