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Towards a More Realistic Fatigue Loading for Laboratory Testing of Wind Turbine Blades

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Summary & Objectives

Full scale blade fatigue testing is complex & time consuming

NaREC have developed a new method: dual-axis compact resonant mass (CRM):

- ➢Flap & edge loads are applied **simultaneously**
- ➢Test **time** & **cost** are reduced significantly
- ➢Stress patterns observed by the blade are more complex

The **ERU's finite element (FE) wind turbine rotor model** is used to understand the dual-axis CRM method better

This work carries 2 main **objectives**.

Validation of the FE blade model:

- ➢Using the experimental data provided by NaREC, check that the FE model reproduces the main features adequately

Establish the main characteristics of the dual-axis CRM fatigue test method:

- ➢Compare the strain patterns obtained during a dual-axis CRM test with those obtained in the FE simulation of operational blade loading, consisting of gravity, centrifugal and aerodynamic loads

Methods

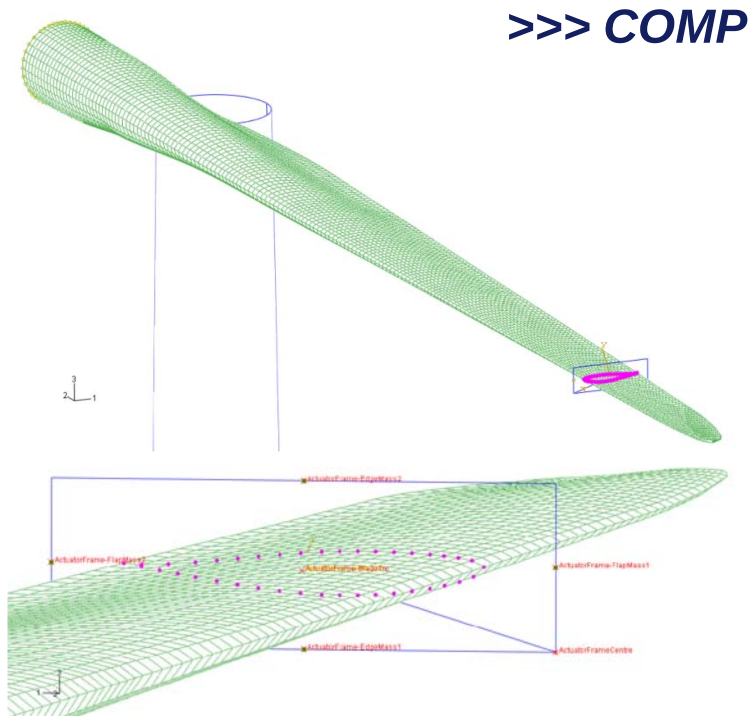
>>> EXPERIMENTAL

In the dual-axis CRM test, the blade is mounted to a vertical reaction wall with its pressure side facing upwards. The self-weight of the blade participates to a preferential loading that is consistent with in-service aerodynamic loads.

A frame consisting of hydraulic actuators and ballasts is then mounted on the blade. The ballasts are oscillated at the **natural frequencies** of the system in both the flap and edge directions.

The blade is instrumented with **strain gauges around a section in the root transition area**, measuring deformations in the blade longitudinal direction. The gauges were calibrated with the blade installed on the test fixture. This reference point was also used for the computational analyses.

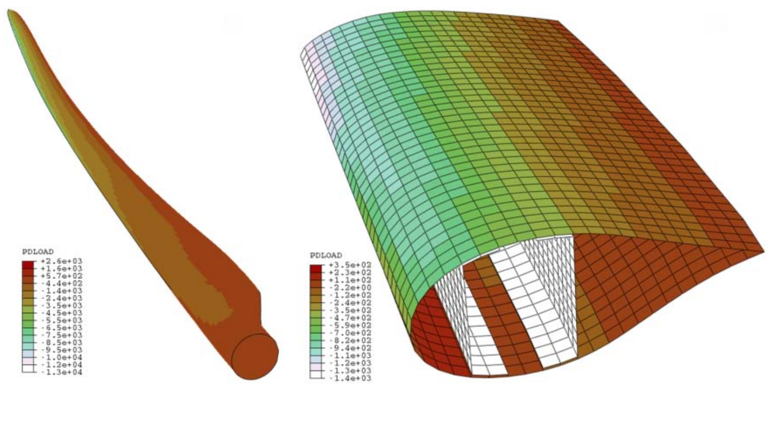
>>> COMPUTATIONAL



The simulation of the dual-axis fatigue test is conducted by taking into account the full system dynamics. The blade loading configuration is reproduced and the inertial loads, as well as damping, are included in the analysis.

A 1-minute time-based simulation is conducted, encapsulating around 50 flap and 100 edge cycles. The time-histories of longitudinal strain in the equivalent root transition section are extracted.

Other computational runs were conducted to simulate typical operational loads of the blade. The main loads due to **gravity, centrifugal effects & aerodynamics** are introduced and **non-linear static solutions** are produced.

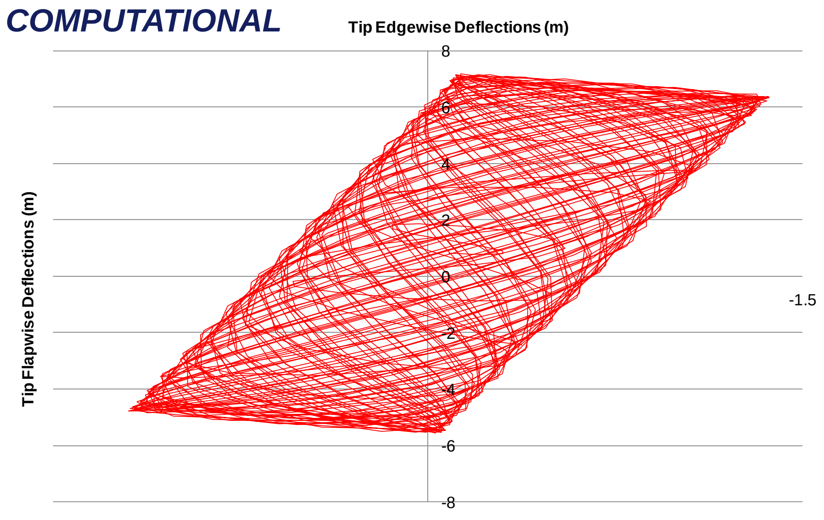


The aerodynamic loading routine is embedded in the Abaqus Python script that builds the FE model. It is based on the BEM theory but applies the loads through a representative fully distributed pressure field. Load concentration constraints are therefore avoided.

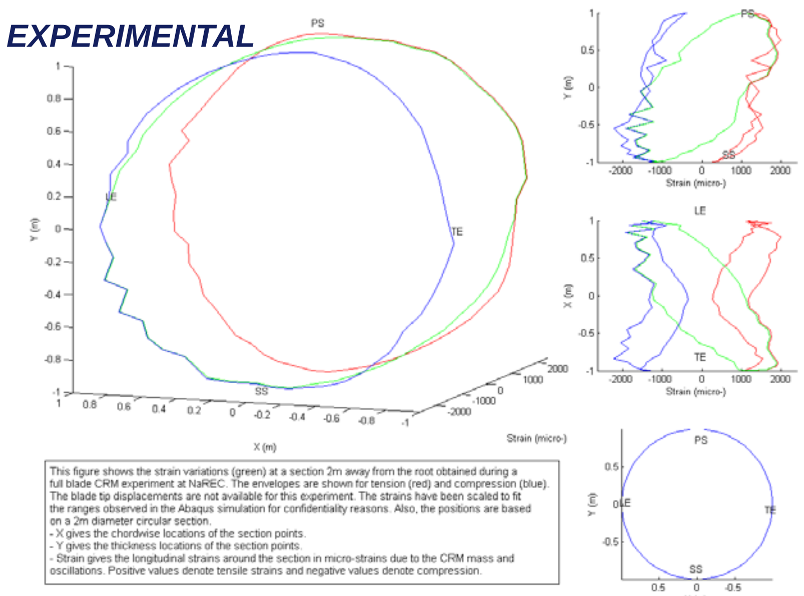
The FE computations are conducted with a 36m-long exemplar 2MW blade used as a baseline in the Supergen Wind consortium. This model does not match the blade used in the experiments but is broadly representative.

Results

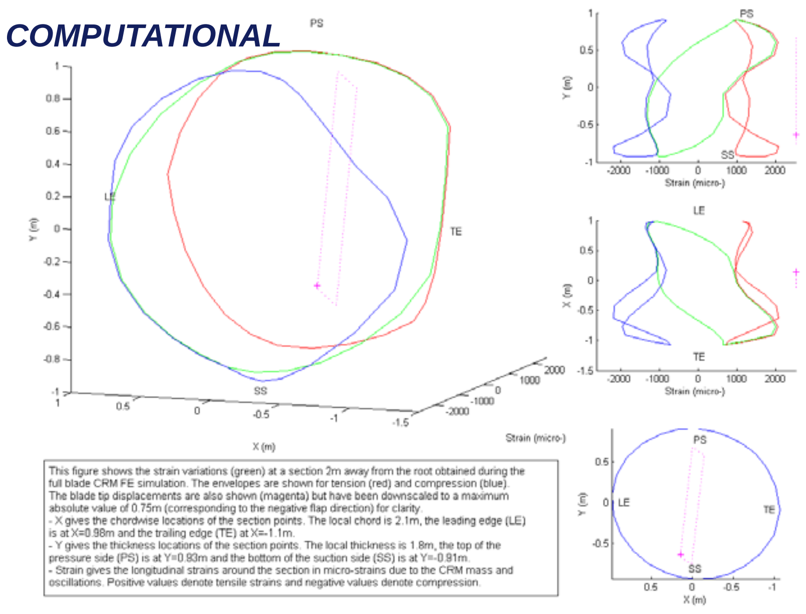
The 1st interesting result from this work regards the **Flap/Edge coupling** of wind turbine blades. The figure below shows the Flap vs Edge blade tip displacement for the FE computation. A flap load on the blade will also result in a small edgewise deflection and conversely an edge load would impose small flap component. It can be seen in this figure that the coupling between flap and edge is reproduced in the model. The CRM method leads to situations where the blade is **loaded simultaneously in flap & edge**, unlike what occurs during single-axis tests.



The **strain data from the 2m blade section** can then be looked at. A 3D plot snapshot is shown in the figures on the right, for both the experimental data (top) and the computation run (bottom).



This figure shows the strain variations (green) at a section 2m away from the root obtained during a full blade CRM experiment at NaREC. The envelopes are shown for tension (red) and compression (blue). The blade tip displacements are not available for this experiment. The strains have been scaled to fit the ranges observed in the Abaqus simulation for confidentiality reasons. Also, the positions are based on a 2m diameter circular section.
- X gives the chordwise locations of the section points.
- Y gives the thickness locations of the section points.
- Strain gives the longitudinal strains around the section in micro-strains due to the CRM mass and oscillations. Positive values denote tensile strains and negative values denote compression.



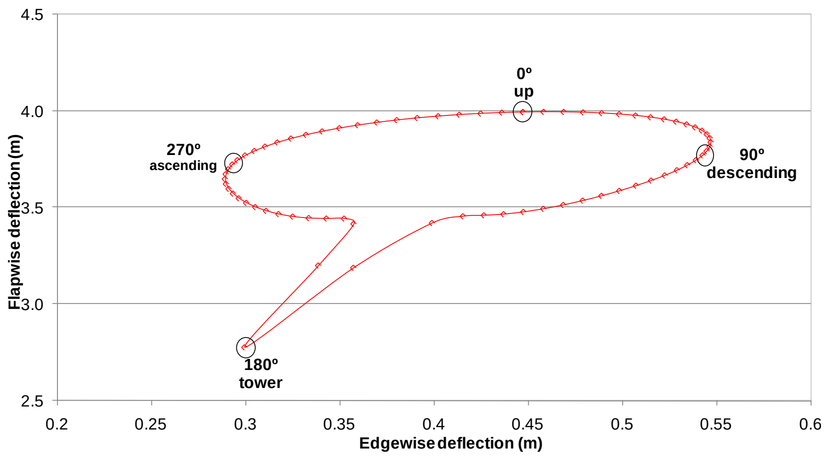
This figure shows the strain variations (green) at a section 2m away from the root obtained during the full blade CRM FE simulation. The envelopes are shown for tension (red) and compression (blue). The blade tip displacements are also shown (magenta) but have been downscaled to a maximum absolute value of 0.75m (corresponding to the negative flap direction) for clarity.
- X gives the chordwise locations of the section points. The local chord is 2.1m, the leading edge (LE) is at X=0.98m and the trailing edge (TE) at X=-1.1m.
- Y gives the thickness locations of the section points. The local thickness is 1.8m, the top of the pressure side (PS) is at Y=0.93m and the bottom of the suction side (SS) is at Y=-0.91m.
- Strain gives the longitudinal strains around the section in micro-strains due to the CRM mass and oscillations. Positive values denote tensile strains and negative values denote compression.

The CRM oscillations applied in the computations were scaled so that the strains observed around the 2m section ranged by approximately 4000μ-strains peak-to-peak. An arbitrary scaling is applied to the experimental data to obtain similar amplitudes, and the geometry of the section is based on a simple 2m circular profile.

The maximum strains are observed in areas where **combination loads** take place, which would not be highlighted through single-axis tests. The exact computational strain profile is very sensitive to the local composite layup modelled. Since no layup information was available for the experimental blade, results comparisons are limited.

Finally, blade operational loads are considered through the FE model. The graph on the right shows the blade tip displacements during a rotation of the blade. Please note that these are results of quasi-static calculations. It can be seen that, due to the blade's complex shape and structural details, as well as the tilt and cone angles used in modern wind turbine rotors, the trace is not symmetrical but skewed. This results in combination loads where **flapwise & edgewise loads** are **applied simultaneously**.

Blade tip deflections during 1 rotation under the effects of **gravity**, **centrifugal effects** (18rpm) and **aerodynamic loading** (12m/s wind with tower shadow and wind shear)



Conclusions

- The Flap/Edge coupling of wind turbine blades implies that the 2 loading directions are associated. This dependence means that simultaneous loading puts the structure under strain patterns unexplored during single-axis testing. Moreover, there is indication that standard operation also places the blade under such combination loads and that dual-axis CRM testing could be more representative.
- More comparisons of CRM test output should be made with operational data provided by field testing and by dynamic FE model. The ERU will develop the structural analysis model towards studying wind turbine dynamics in more detail.
- This study provided an opportunity to use the structural analysis model in the context of experimental fatigue testing. Dynamic analyses were conducted and the Flap/Edge coupling was well observed in both the experimental and computational results. Further validation with more operational or test data would be beneficial, notably with local layup & construction information to enable better strain output validation.

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