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Measurement uncertainty of fatigue properties and its effect on the wind turbine blade reliability level

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Abstract

Wind turbine rotor blades are large composite structures performing most of their design life under random cycle loading patterns. Material properties of the building ply exhibit also variability. In order to assure a safe and cost effective design, uncertainty related to the basic variables should be quantified and taken into account in design calculations. Here in, for the first time, measurement uncertainty for the fatigue properties of the composite material is quantified following principles of metrology [1] and based upon appropriate experimental data [2]. The effect of considering this type of uncertainty directly on the blade failure probability is investigated by enhancing probabilistic analysis tools developed for application on wind turbine blades [3]. The application is performed on the INNWIND.EU reference 10MW wind turbine blade with 90m length [4]. Sensitivity analysis is further performed on the fatigue analysis details with respect to the final reliability estimation, such as the selection of Constant Life Diagram (CLD) and the discretization strategy followed in the rainflow counting method.

Objectives

A methodology was developed:

- to quantify measurement uncertainty for fatigue properties
- to facilitate comparisons among different material candidates
- To give a clearer picture of those uncertainties (epistemic ones) that should be reduced by additional effort, so that the target reliability level is maintained and the use of materials optimized on the structure

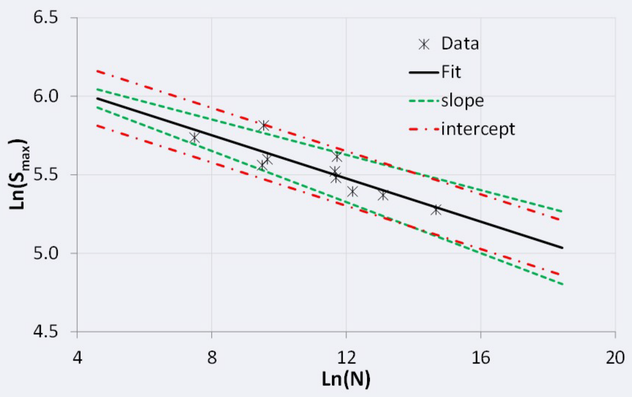
Methods

- Power Law model ($S_{max}=AN^B$) to fit the data
- Maximum Likelihood Estimators (MLE) to estimate parameters
- Uncertainty propagation law combined with the finite difference method to quantify measurement uncertainty
- Crude Monte Carlo (of sample size 1,000,000 values) to estimate β index values. $P_f=\Phi(-\beta)$

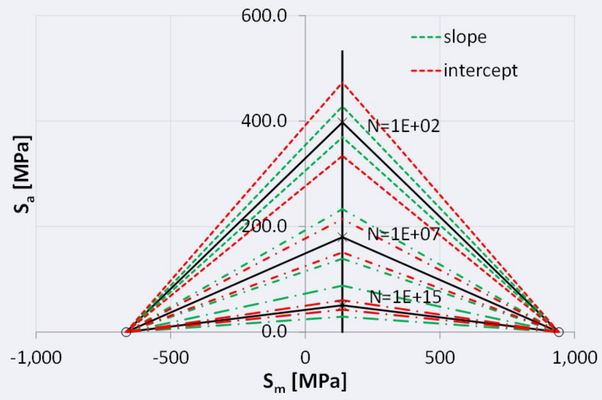
Results

- Effect of measurement uncertainty on the S-N curve and the CLD graph when varying successively the slope and intercept parameter of the power law model plus/minus one standard deviation
- Sources of uncertainties: test instruments, test specimen and testing procedure

S-N curve (R=-1)

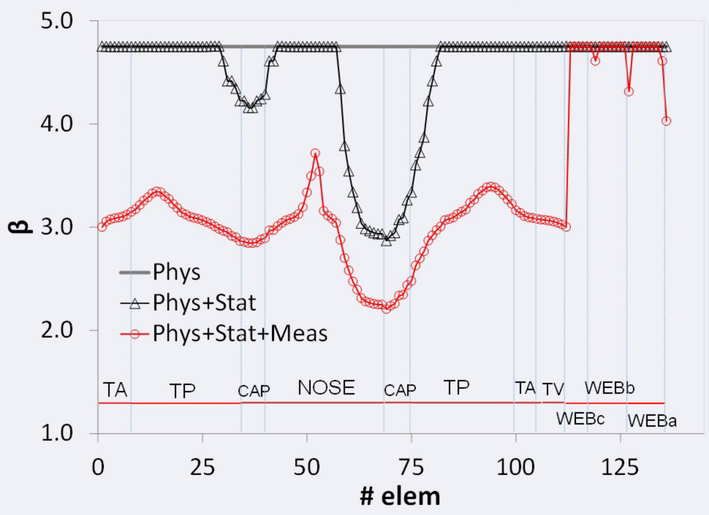


Shifted Goodman Diagram

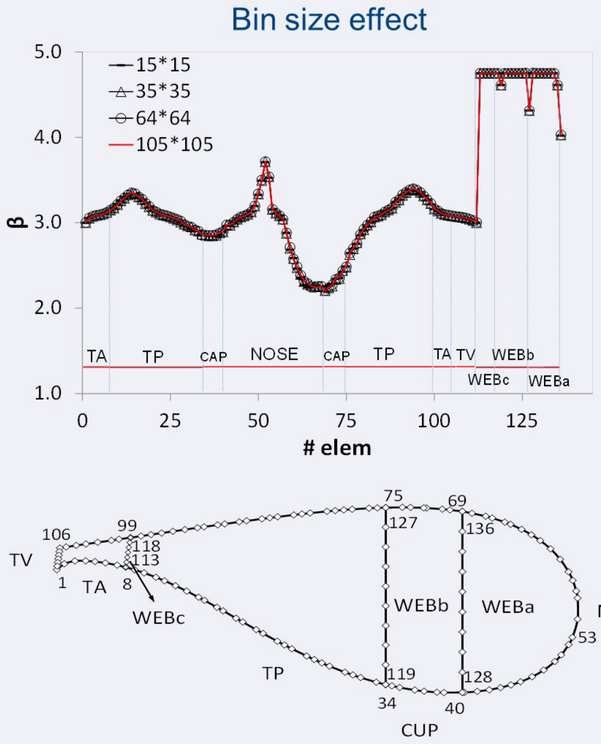


- Reliability estimations at several points along the blade section

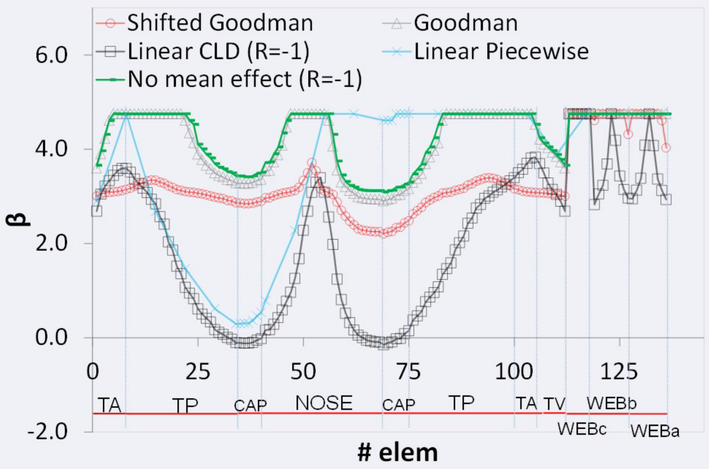
Measurement uncertainty effect



Bin size effect



CLD selection effect



Conclusions

1. Measurement uncertainty greatly affects :
   - the S-N curve position
   - the location of the constant life lines in the CLD graphs
   - the blade reliability level
2. CLD selection can result in either optimistic or conservative reliability estimations
3. Bin size options for the rainflow counting method has a limited effect on blade reliability level

References

[1] Joint Committee for Guides in Metrology (JCGM) 100:2008. Evaluation of measurement data-Guide to the expression of Uncertainty in Measurement, 2008
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[3] DJ Lekou, TP Philippidis. PRE-and POST_THIN: A Tool for the Probabilistic Design and Analysis of Composite Rotor Blade Strength. Wind Energy, 12, 2009, 676-691
[4] C Bak, F Zahle, R Bitsche, T Kim, A Yde, LC Henriksen, MH Hansen, JPAA Blasques, M Gaunaa, A Natarajan. The DTU 10-MW reference Wind Turbine. Danish Wind Power Research 2013, Fredericia, Denmark, May 27 2013.

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