Analytical verification of flutter prediction for large wind turbine rotor blades

This paper was presented at The Science of making Torque 2012, 9-11 October 2012, Oldenburg, Germany

C. Lindenburg

December 2012
ECN-M--12-077

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www.ecn.nl
P.O. Box 1
1755 ZG Petten
The Netherlands

Authors

C. Lindenburg[1]

Corresponding author: lindenburg@ecn.nl

Trend in aeroelasticity of large blades

Large blades become relatively light and more slender to remain cost efficient. This results in lower frequencies of vibration.

Torsional frequency reduces and torsion deformation increases.

•More elastic twist, which affects the aerodynamic performance

•Static instability 'divergence' if the aerodynamic centre is closer to the Leading edge than the shear centre.

•Dynamic instability 'flutter'; mainly involves flat bending & torsion.

Large blade design should involve aeroelastic stability.

Deformed shape and 'divergence' can be analysed with *Blademode*

Flutter can be found from an 'overspeed analysis' with *Focus+Phatas*

The phenomena of 'flutter'

•"Flutter": 'A vibration that is fed by unsteady aerodynamic loads'.

•Modern large wind turbines may have 'flap-torsion' flutter.

•Flap-torsion flutter was already observed at fast flying airplanes.

•The 'classical' flap-torsion flutter vibrates with the torsion frequency; the interaction with flap forces and deformations play a dominant role.

•The detailed aeroelastic blade model allows Phatas to analyse flutter.

Validation of flutter analysis with *Focus+Phatas*

•Phatas has a detailed structural model for blade aeroelasticity.

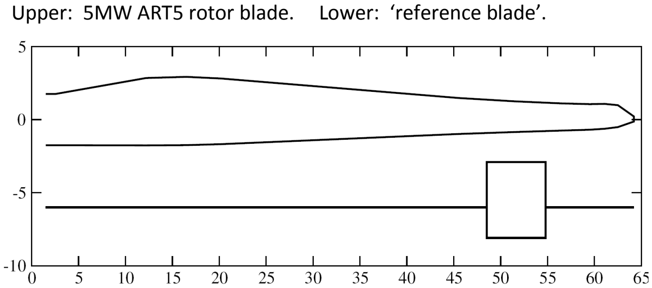
•The complexity of Phatas makes it hard to validate the flutter speed.

•Analytical solutions are only possible for a 2 d.o.f. reference blade.

•A Phatas model is made with similar properties as 2 d.o.f. model.

•'flutter analyses' with Phatas are compared with analytical solutions.

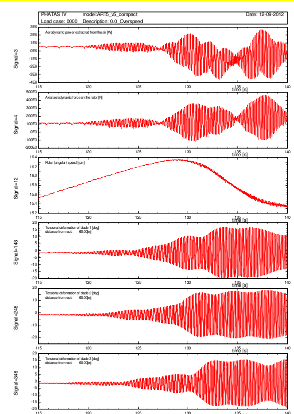
Upper: 5MW ART5 rotor blade. Lower: 'reference blade'.



Example of flutter analysis for the 5MW ART5 rotor

- Flutter is analysed by overspeeding of an idling rotor with pitch = 7deg.
- Advantage is that it includes many aspects (pre-bend, aft-swept) .
- Difficult: define when flutter starts.
- Choice has to be made for time increment, structural damping.
- Fortunately; overspeed analysis shows flutter for many turbines.

Graphs show: power, thrust, rotor speed, and 3 times tip torsion.



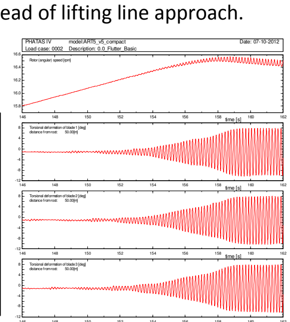
Analytical flutter speed versus flutter speed of Phatas

•Analytical solutions only show the effect of apparent mass and the use of the 75% chord a.o.a. instead of lifting line approach.

Graph is for condition 3

Table lists flutter speeds [rpm]

Condition	Phatas	Analytic
0. Lifting line, No App.mass	18.55	18.23
1: a.o.a.75%, No App.mass	19.4	
2: Lift. line, Apparent mass		17.82
3: a.o.a.75%, Apparent mass	16.2	18.73
4: As 3, with Dynamic stall	17.5	
5: As 3, with edge bending	16.0	



Conclusions

The calculations with Phatas for the reference blade with its finite spanwise dimension and which include higher order bending modes, still show reasonable agreement with analytical solutions.

Surprisingly the use of the angle-of-attack at 75% chord for the unsteady aerodynamic loads does not make a strong difference.

•Edgewise bending does not play a remarkable role in flutter.

•*Focus+Phatas* is suitable for flutter analysis of large rotor blades.

Acknowledgements

The presentation of this poster was made possible by ECN.

For more details of this investigation contact the author:

lindenburg@ecn.nl (+31) 224564341

[1] ECN Wind Energy, P.O. box 1, 1755 ZG Petten, The Netherlands.