

Testing of Rotor Blades

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Summary

Current approval of rotor blades comprises characterization of materials, full-blade tests with static up- and down-bending, and a modal analysis. In addition to these tests, cyclic testing of full-size rotor blades is increasingly discussed to become subject of official certification procedures. Open questions regarding their operational relevance, large investment costs and long duration of up to 4 months for forthcoming large blades now deepen the demand for a new testing methodology. Component testing and scaling methods, highly developed calculation methods, and the definition of blade families of closely related structures are proposed to increase the relevance as well as to decrease costs and duration of the approval procedure.

1. Introduction

The still growing size of wind turbines and their impending offshore use imply increasing loads on all components. Rotor blades of a length of up to 90 m with a maximal cyclic bending moment of about 100 MNm are expected in the future /1/. An important object of research regarding this development is a new test methodology to prove the technical maturity of the new blades, especially for their use under maritime load configurations. The current cyclic testing procedures of full blades imply giant test rigs and difficult configurations to generate local strains and stresses of high operational relevance in the entire blade. Even though reservations against this type of testing exist from a scientific and economic perspective, there are international efforts that cyclic full-scale blade testing as described in /2/ should become a regular requirement for certification of rotor blades.

However, before a possible realisation of such significant regulations, a view to light aircraft certification procedures might be useful. Wings of, e.g., sailplanes are very similar to rotor blades concerning materials, structural details and manufacturing technologies. The respective 40 years' experience in the certification process of composite aircraft shows that the knowledge of the fatigue behaviour of primary components like spar beams and representative wing structures are an informative and economic way for fulfilling all respective safety issues of the aeronautical certification requirements /3-6/.

2. Standard Verification of the Technical Reliability of Rotor Blades

The design of rotor blades implies consideration of an overall frame structure and aerodynamic profiling, construction of components like blade to hub connections, spars and caps, as well as the use of materials like fibre-reinforced plastics (FRPs), core materials, adhesives and wood. Standard approval of rotor blades comprises characterization of the materials mainly regarding strengths and stiffness, and full-blade tests /7/. Normally, these full-blade tests include static up- and down-bending in flapwise and edgewise direction (Fig.1), and a modal analysis of at least the first natural oscillation, again in flapwise and edgewise orientation. If relevant, torsional oscillations and damping are also characterized. These tests are performed partly within the certification of rotor blades and within the quality assurance of rotor blade manufacturers.

The life-time of perfect FRP-structures is in general regarded as being not determined by fatigue. Correspondingly, fatigue tests are not applied to characterize undamaged FRP-structures. However, during recent years, full-size cyclic testing of rotor blades has been discussed regarding its significance to identify weak points in the design and failures in the blade structure, e. g., caused by the use of new materials and manufac-

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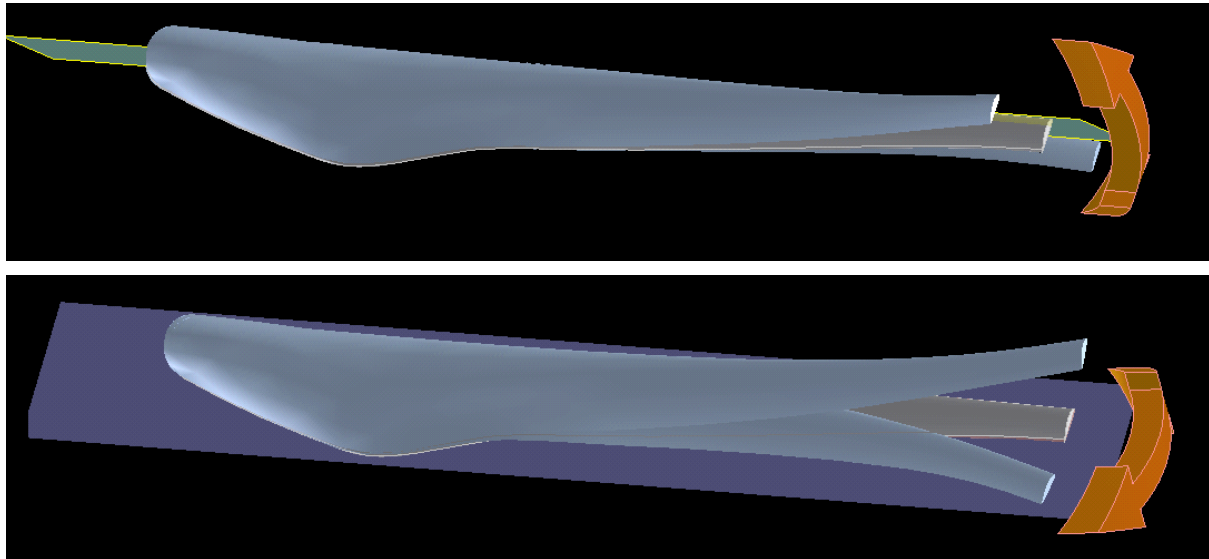


Fig. 1: Schematic drawing of flapwise (upper panel) and edgewise (lower panel) bending of a rotor blade.

turing faults. Especially important for such tests is a lifelike simulation of the external loading configurations to obtain realistic local strains and stresses in the rotor blade structure.

One argument contrary to cyclic testing is a lack of in-service relevance, i.e., the correlation between tested and in-service fatigue and failure behaviour is unidentified. Also, blades of a length of up to 70 m and 90 m are expected in future, corresponding roughly to 10 MW and 20 MW wind turbines, respectively. For these blades, one can extrapolate blade masses of 35 t and 65 t, necessary dynamic bending moments of 50 MNm and 100 MNm, and lowest natural frequencies of 0.5 Hz and 0,4 Hz, respectively. Corresponding test rigs and test procedures are technically difficult as well as economically not compliant with current product development times: The duration to perform a typical test sequence of cyclic tests in edgewise and flapwise direction for a 90m blade would take about 4 months. In addition to the technical objections against full-size cyclic testing, this further deepens the demand for alternative cyclic testing methods.

3. New Testing Methodology for Rotor Blades

Approaches to a new testing methodology for rotor blades of increased operational relevance and economics consider scale-up/scale-down methods, component testing of critical parts in combination with small specimen material testing, and advanced calculation methods. Fig. 2 shows schematically a sequence of testing methods which may serve to deduce a new testing methodology for rotor blades. The sequence comprises materials and small specimen tests, followed by small/simple component tests, larger/complex component tests and full blade tests. The shaded area represents very diagrammatically the amount of numerical simulation or calculations in relation to experimental simulation or testing. Comparatively little calculations are needed to perform materials and small specimen testing as well as full-size blade testing, as compared to component testing as discussed below.

On the lowest level, e. g., characteristic data of materials or adhesive bonds are determined. Here, a lot of experimental work faces comparatively little calculation efforts. On the next stage, stresses and strains are analysed in components of increased operational relevance. This includes already comprehensive calculations to design the components and deduce the testing load configurations from the full-blade loads. The third stage is generally of the same nature as the second stage, except for an increased size and complexity of the components and load configurations, respectively. Possible examples for such tests are full-size components for the blade to hub connection, sections to simulate buckling and large beams with embedded structural details of the main spar. Component testing requires intensive numerical simulation. The highest level

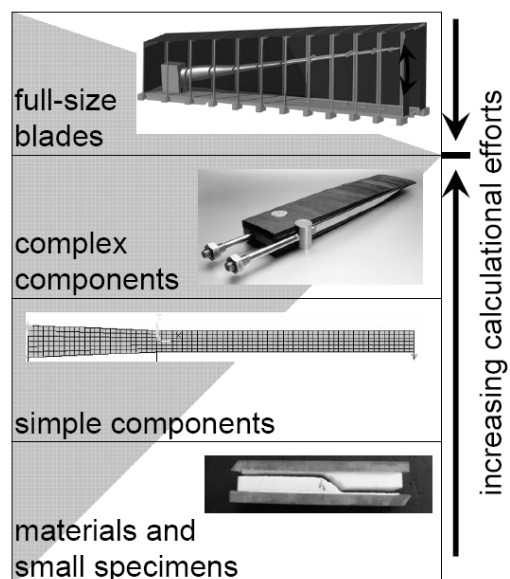


Fig. 2: Sequence of testing methods of increasing size of test structures.

is cyclic testing of full blades, which may be used to validate component tests or to verify the quality of a blade production.

Component Testing

The relevance of component testing within the entire process of the qualification of complex technical systems is generally accepted /8/. By numerical tools, the design of the components including the expected loads and stresses must interactively be optimised to reproduce the operational strains and stresses of the full blade as close as possible. Such tests allow an improved experimental simulation of real operational load configurations and a more knowledge-based approach for design enhancements or materials selection.

Beside component tests for, e.g., connections or buckling, beam tests /5,6,9/ appear to be a very good compromise regarding on one hand the simplification of complex load configurations and on the other hand their closeness to reality. For example, Fig. 3 shows a computer model of a CRF-beam designed to reproduce a critical stress configuration in a spar cap.

Tests with beams of typically some meter length are performed to determine component and material properties more realistically as with smaller specimen tests. To obtain realistic stress distributions in the so-called failure section of such test beams, it is necessary to develop their geometry and structure with the aid of highly developed simulation tools like finite element analysis. In this way, beam tests to simulate the size of defects in adhesive bonds or three dimensional stress states in thick-walled components can well represent the original structural parts.

Beams are also designed to reflect design details of caps, adhesive bonds, shafted and spliced junctions, thickening / thinning sections and repair processes. In addition to the design of the beams and corresponding test procedures, the mechanical characteristics of the applied materials under different ambient conditions like temperature and moisture are also needed. Thus, comprehensive material and small specimen testing is an integral part of realistic beam testing. Beam testing performed in this way is assumed to play a crucial role within future certification procedures for rotor blades.

Up- and Down-Scaling

Both, for component and full blade testing, verified scaling procedures to downscale current and future large structures to smaller test structures for experimental testing would further reduce the experimental testing demand. Similarly, up-scaling of existing smaller blades or components to larger structures could simplify the development of new blades with reduced testing times and costs. E.g., the expected weight gain of a down-scaled 45m test-blade as compared to a 60m

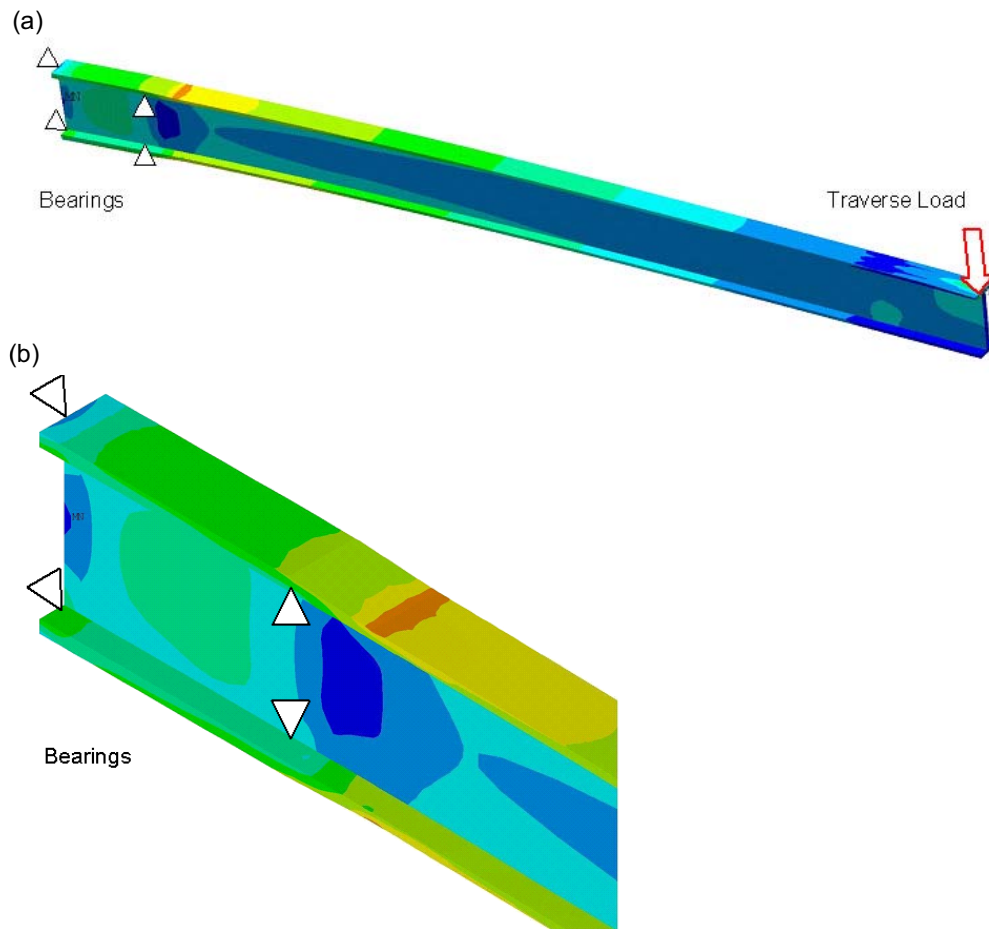


Fig. 3: Stress intensity distribution at a full beam (a) and a full beam root section (b).

full-size test blade is $(45/60)^3 = 0,75^3 = 0,42$, roughly corresponding to an equal cost saving. The test durations themselves are given by the natural frequencies of the blades. We adopt frequencies of 1.0 Hz and 0.6 Hz for the 60m blade for the first mode edgewise and flapwise oscillations, respectively, and a down-scaling of these frequencies by a factor of $1/(45/60)=1.33$. This reduces the total test duration for 2×10^6 cycles edgewise and 10^6 cycles flapwise from 43 to 32 days. Our assumption for the scaling of the natural frequencies is based on a statistical evaluation of available blade data. Even important will be the cost reduction. The energy which is needed for a 45m blade test compared to a 60m blade test is reduced by the order of about two to three. So, about $(45/60)^{2.5} = 0.49$ or 50% energy saving seems to be possible.

However, dislike established procedures for up- and down-scaling of components out of isotropic materials /10/, scaling of the mechanical behaviour of anisotropic materials like fibre reinforced plastics (FRP), foams and wood is still a challenge. Basic questions will have to be solved, for example how the thickness of a FRP panel can be down scaled and what is the corresponding scaling law. Also, in a quite practical sense, already in the easy case of a single one-layer unidirectional FRP-sheet, simply reducing the strength or the diameter of the fibres proportional to the overall thickness reduction is currently not possible.

Conclusion

Testing of rotor blades by currently accepted procedures appear to be very costly and time consuming as the blades grow in size. It is doubtful whether they can be expected for the future. Alternative procedures have been discussed, based on component testing and scaling of blade structures. Both request an extensive development of calculation methods, even though in different forms, and of experimental work to obtain characteristic data for materials and scaling laws. In a situation of a continuous evolution of an already existing blade, derivatives of such a "blade representative" to form a corresponding "blade family" may be tested and verified with much reduced efforts with established component tests and scaling procedures.

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References

- [1] Beurskens, J., *Is long term R&D necessary for the continuation of Large Scale Development of Wind Energy?*, DEWEK 2004, Wilhelmshaven, October 20-21, 2004
- [2] IEC/TS 61400-23 Wind turbine generator systems – Part 23: Full-scale testing of rotor blades
- [3] W. Thielemann, F. Franzmeyer, Wissenschaftliche Untersuchungen über die Anwendung von glasfaserverstärkten Kunststoffen (GFK) in hochbeanspruchten Leichtbauteilen, Teil VIII, IFL TU Braunschweig, Bericht 69-02
- [4] Ch. Kensche, Service Life of a Sailplane Made of CFRP, IV. National and I. International Meeting on Composite Materials, 19-21 November 1980, Milano/Italy
- [5] H. Kossira, P. Wetjen, Belastungsversuche an GFK-Holmen von Segelflugzeugen zum Nachweis einer sicheren Lebensdauer von 6.000 Flugstunden, IFL-IB 81-04
- [6] H. Kossira, G. Glatzel, Lebensdaueruntersuchungen an Holmen, IFL-IB 90-02
- [7] Guideline for the Certification of Offshore Wind Turbines, Chapter 6.2. Germanischer Lloyd, Nov. 2003
- [8] Joosse, P. A., van Delft, D.R.V., van Wingerde, A. M., Kensche, Ch.W., Korsgaard, J., et al., Using carbon fibres for a cost effective large blade. Global Windpower Conference & Exhibition, Paris, France, 2-5 April 2002, EWEA, AWEA, IWTMA, (2002)
- [9] Kensche, Ch.W., Krause, O., Lifetime prediction of highly loaded composite structures. 18th Annual Technical Conference, Gainesville, Florida, 20-22 Oktober 2003, American Society of Composites, (2003)
- [10] Müller, R.K., Handbuch der Modellstatik, Springer-Verlag Berlin, Heidelberg, New York 1971