KompZert: a step ahead on the road towards subcomponent testing for rotor blades

Arno van Wingerde[1], Margarita Glöckner[2]
[1]Section of Composites and Materials Mechanics, Division Structural Components, Fraunhofer IWES, Am Seedeich 45; 27572 Bremerhaven; Germany
[2] Section Rotor Blades, DNV GL RC, Brooktorkai 18, 20457 Hamburg

e-mail: arno.van.wingerde@iwes.fraunhofer.de, margarita.gloeckner@dnvgl.com

Arno van Wingerde
Chief Scientist Fraunhofer IWES.
Leader Subprogram "Structures and Materials" in EERA JP Wind, member ETIP MB; IEC 61400-5, CASMaT International Advisory Board

Margarita Glöckner
Senior engineer rotor blades, Renewables Certification, DNV GL

Abstract

In this paper, the theoretical and practical applications of subcomponent tests of rotor blade for wind turbines are investigated based upon the German research project "KompZert" carried out by Fraunhofer IWES and DNVGL. Certification aspects and business cases are highlighted to show how subcomponent tests could be integrated into the rotor blade certification process.

Background
In contrast to many other industries, such as automotive and aeronautical industries, the wind energy industry uses relatively few subcomponent tests for rotor blades. Instead, the current approach is to emphasize material tests for the material properties, design a new rotor blade and then carry out a full scale blade test to verify the design assumptions.

Beyond inherent technical reasons, for instance the monolithic nature of a rotor blade, there are limitations within the certification procedure and standards, which all but preclude subcomponent tests. In order to allow innovation, an established path for verifying the performance of a technical detail and "A-B" comparisons of various structural solutions is needed.

In principle, the current procedure requires a full scale blade test when even a single material or structural detail is exchanged. Moreover, the available worldwide test capacity, especially for larger blades, could be insufficient to carry out all required tests. Another problem with the current approach is the lack of statistical data for the blades, since typically only one blade is tested. Furthermore, it can safely be assumed that the lack of standards for certification based on subcomponent test is a serious impediment to the development of new rotor blades: full scale blade tests are hardly suitable for "what-if" scenarios, where various solutions for a structural problem are compared on an experimental basis

A number of applications of the subcomponent test for certification purposes are conceivable:

- During the full-scale test of a rotor blade, a detail failed, e.g. due to manufacturing deficiencies. After quick repairs, reinforcing the affected area, the rest of the blade was found to able to withstand the test loads. A dedicated subcomponent test could be used to supply evidence that the detail design is adequate.
- After certification of a blade, a detail is altered, for instance due to another production method. A subcomponent test may be used in lieu of a full scale blade test to show that the altered detail is adequate for the blade certification requirements.
- In case of serial damages, component tests may be used to show that the damage does not grow and/or does not endanger the structural integrity of the blade, possible omitting the need for repairs.
- Component tests may be used to establish design values. A common example is the use of pull-out test of metal inserts. The determined design strengths may be applied to different blade designs as long as the comparability in the root area is ensured.

The last option can also be used outside of the certification, to make internal comparisons between various solutions for blade details, in order to optimise the design and manufacturing methods prior to the design and certification test of a rotor blade.

In order for subcomponent testing to become a viable option for certification, a number of issues need to be addressed:

- Technical quality: can a subcomponent test successfully mimic a full scale blade test, or at least capture the relevant boundary conditions accurately?
- Certification aspects: can a subcomponent test have similar partial test factors as a full scale blade test? If not, the subcomponent test will not be economically viable, since the designer is “punished” for not carrying out a full scale blade test.
- Economical aspects: can the test be carried out at a price level that is attractive for the customer? In principle, a subcomponent test is cheaper than a full scale blade test, but tests only a small part of the blade. Also, a subcomponent test typically requires more effort than a full scale blade test to get the boundary conditions right.

Certification background

Also the certification bodies acknowledge the current limitations and therefore DNVGL approached Fraunhofer IWES to setup a research project on subcomponent testing for certification: KompZert, where a catalogue of subcomponent tests is established, to show which subcomponent tests could be used in a certain scenario.

The certification of a rotor blade design is based on full-scale blade tests and coupon material tests. The coupon material tests are carried out to determine the design properties for the design analysis whereas the full-scale blade test is mainly aiming at verifying the design assumptions. In a validation and testing concept often referred to as the “building block approach”, these two types of tests can be considered as the lowest and the highest level of a test pyramid as shown in Figure 1.

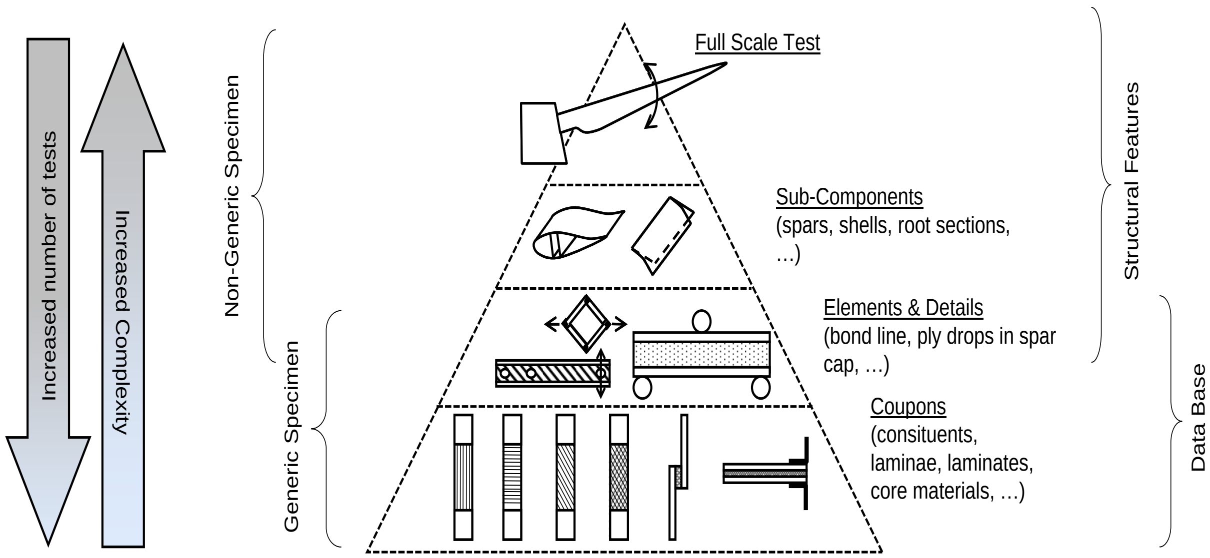

Figure 1 **The test pyramid**

Figure 2 visualizes a few components which might be subject to a component test. Apart from those details, ply-drops and sandwich chamfering lend themselves to subcomponent testing.

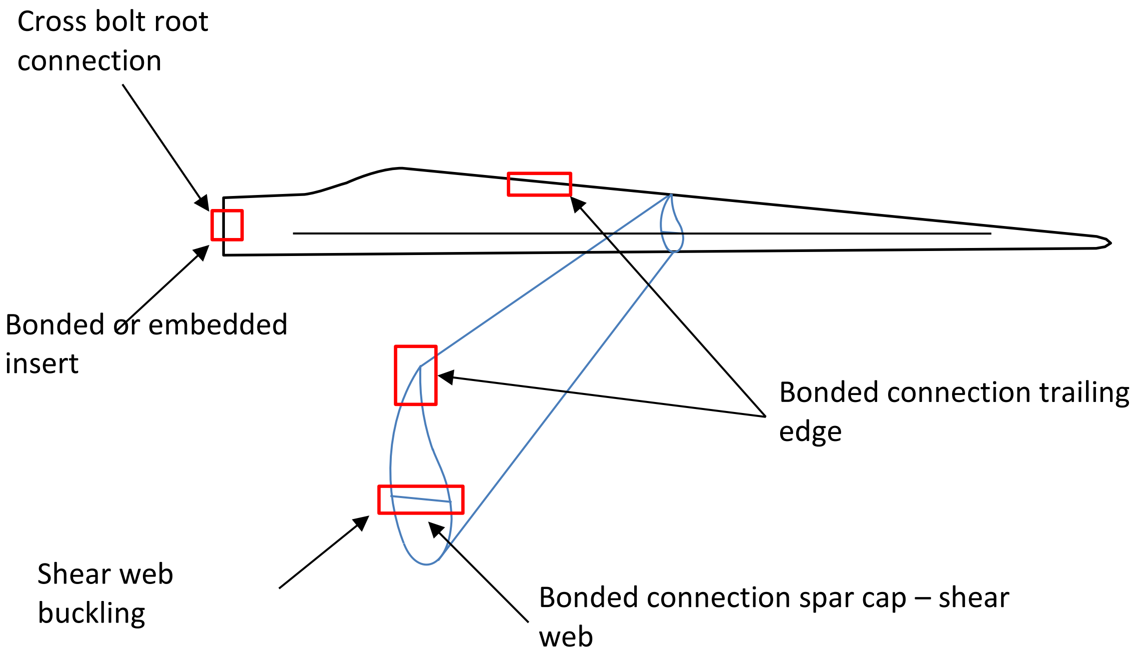

Figure 2 Components considered in the draft test catalogue of KompZert

Component tests shall be developed based on theoretical analyses. Depending on the complexity of the topic, analytical or finite element analyses are required to determine the boundary conditions for the test and to predict the test results such as deflections and strains. Another very important objective of the theoretical analysis is the definition of valid and invalid failure modes. The general approach for the theoretical analyses connected to all component tests is shown in Figure 3.

Problem
↓
Global blade FE analysis (I)
↓
Select component dimensions
+
Determine boundary conditions for component from (I)
↓
Detailed FEA for component (II)
+
Comparison of (I) + (II)
↓
Detailed FEA with test boundary conditios and test load (III)
+
Comparison of (II) + (III)
↓
Specification of valid/invalid failure modes
+
Specify limits of transferability on different applications
↓
Component test
↓
Comparison of FEA results (II) with test results
↓
For strength evaluations:
Determination of characteristic design strengths
+
Design Evaluation

Figure 3 General approach for theoretical analyses connected to component tests

Component testing can be divided into the strength evaluation and the model validation, which are discussed below.

Component tests for strength evaluations

These tests may, for example, be used to determine the strength of a spar cap to shear web bonded connection. Since the design strengths shall be applicable to different situations, the specimen may be designed in a conservative generic manner. To determine design properties, a statistical analysis of the test results shall be performed which requires a minimum amount of 6 test specimens for static and 12 specimens for fatigue properties. The component tests do usually not replace the design analysis. They are comparable to material tests. However, depending on the test set-up, partial test factors have to be applied.

Component tests for model validations

This application may, for example, be performed if a local design modification renders the full-scale blade test of a blade certification invalid. In this case, a repetition of the full-scale blade test would lead to high costs. For model validations the emphasis is placed on the theoretical analysis. Thus, the validation of the theoretical model may be performed based on one specific test specimen. The disadvantage of a component test for model validation is that the result is not applicable to any other situation and it shall not be used as an input for a strength analysis. For a model validation the partial test factors component tests are based on the full-scale blade test of IEC 61400-23 and DNVGL-ST-0376.

In general, the range of the partial test factors is relatively wide. This is necessary since the amount of uncertainties rise when boundary conditions are specified or when specimens are built under laboratory conditions instead of a standard blade production. Thus, component tests open the door to very accurate testing but at the same time contain many risks of influencing the result in an unrealistic manner. Furthermore, the partial test factors have to account for inaccuracies of the load application.

Example for a model validation component test

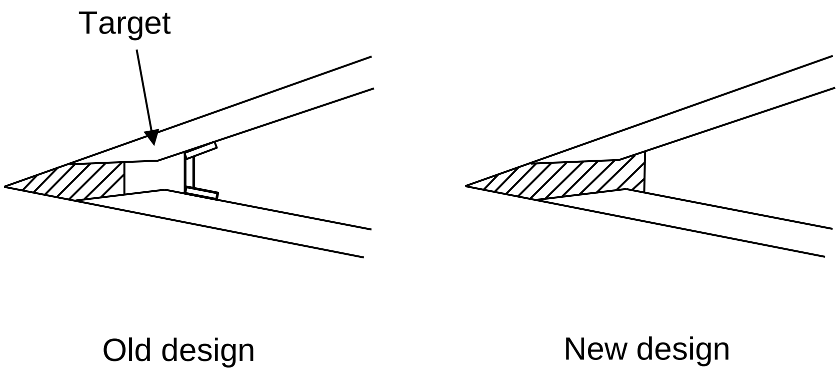

Figure 4 Example for a local design modification

Figure 4 shows a design modification which in principle has rendered the full-scale blade test of the blade certification invalid. A repetition of the blade test is costly and might be avoided using a subcomponent test. The aim of full-scale blade tests is to validate the theoretical analysis. Thus, the same objective is relevant for this component test and the validation may be based on one test specimen and on the same test loads as for the original full-scale blade test.

For this example, a number of assumptions were made:

- It is assumed that the design modification is local and thus has no influence on the global mass and stiffness distribution.
- All analyses are deemed to have been repeated based on the new design and panel buckling could be excluded as a critical failure mode.
- Additional analyses were performed to determine the boundary conditions of the test specimen and the critical load components.

Although pumping of the cross-section due to the Brazier effect is not a specific test load for the full-scale blade test, this loading might be relevant for the trailing edge connection and thus, the analysis either has to show that the pumping is not relevant for this specific design, or the component test has to cover the peeling load on the trailing edge, perhaps by executing separate peeling tests, with specimens as shown in the right hand side of Figure 5.

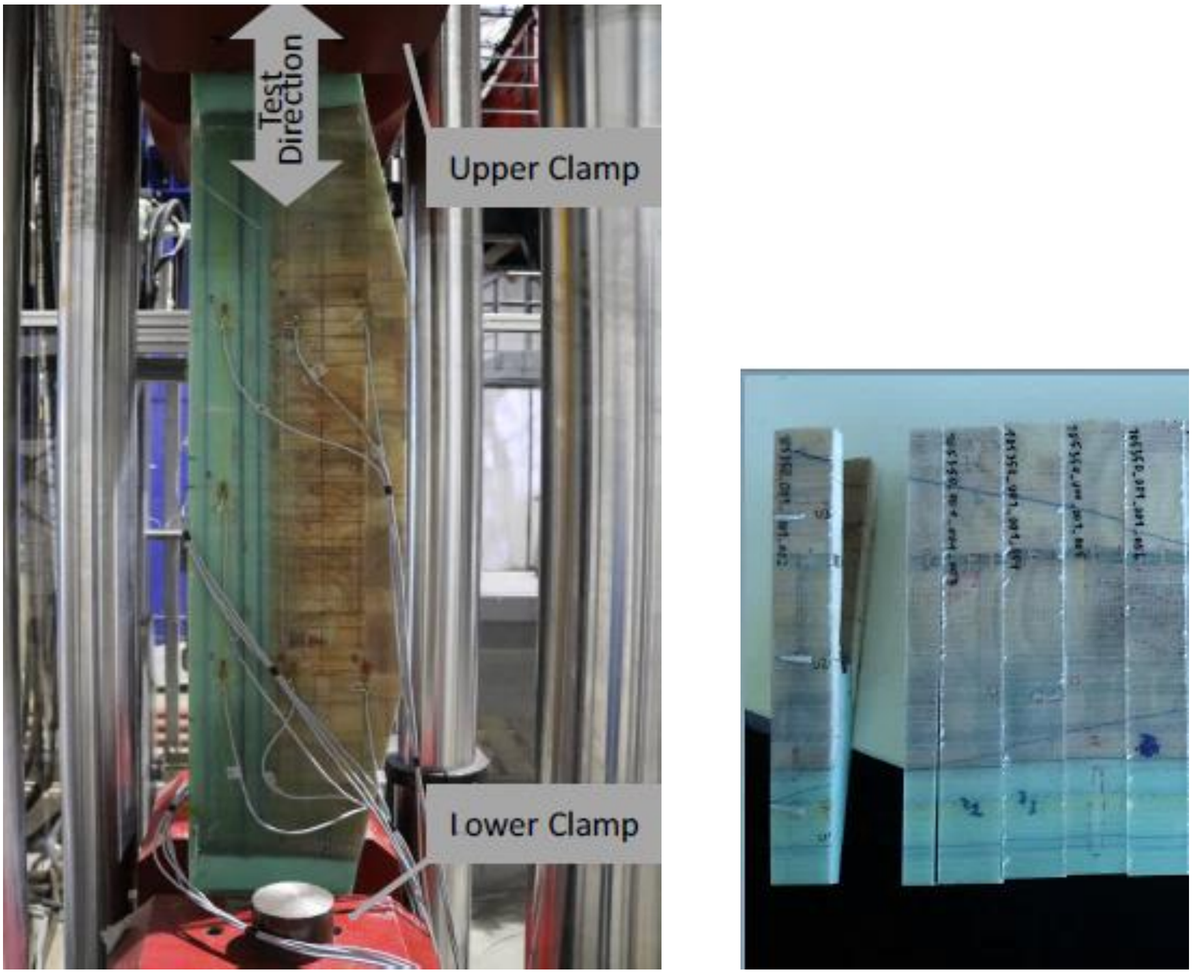

Figure 5 Example of a trailing edge test with eccentric axial load and peeling test specimens

The specimen size is defined by a number of factors:

- The size of the design modification.
- The transition area between old and new design.
- Perhaps including a small part of old design for comparison reasons.
- Sufficient length to allow for relevant buckling modes, if applicable.
- Enough distance to the supports and load introduction points so as not to influence the stress field in the critical part of the specimen unduly.

Before the test is started, the valid and invalid failure modes shall be defined.

The applicable ranges of the partial test factors for this case are listed below.

For the static test:

$$\gamma_{ts} = \gamma_{ts0} \cdot \gamma_{ts2}$$

Static test	Partial test factors
γ_{ts0} specimen to blade variation (production process, scaling, etc.) + blade to blade variation	1.1
γ_{ts2} accuracy of load application and boundary conditions	1.0 – 1.2
γ_{ts} partial test load factor	1.1 – 1.32

Table 1 Partial test factors for the static test

For the fatigue test:

$$\gamma_{tf} = \gamma_{tf0} \cdot \gamma_{tf2}$$

Fatigue test	Partial test factors
γ_{tf0} specimen to blade variation (production process, scaling, etc.) + blade to blade variation	1.25
γ_{tf2} accuracy of load application and boundary conditions	1.05 – 1.2
γ_{tf} partial test load factor	1.33– 1.52

Table 2 Partial test factors for the fatigue tests

It is important to note that these partial load factors can be the same as for full scale blade tests, so there is no inherent "punishment" for using subcomponent tests instead of full scale blade test. However, this is dependent on the quality of the subcomponent tests.

Experiments within the project

The experimental work in the project serves to show how such subcomponent tests could be carried out in practise. An example of such subcomponent test, although not part of KompZert, is described by M. Rosemeier and M. Bädge in another paper at ISMEM 2017 [1].

The experiments serve to highlight which restrictions apply and what partial safety factors would apply as well as to provide a "reality check" on the catalogue.

In the examples carried out within the KompZert project itself, the "effects of defects" in the chord-web bond lines are investigated by a number of beam tests.
The trailing edge tests carried out there was carried out for two different load cases. Firstly, a test of a few m long trailing edge, under an eccentric axial load, such as the tests outlined in [1], followed by cutting the damaged trailing edge into short slices and submitting them to peel tests.

Together, a number of realistic scenarios have been established which could serve as the basis for future design guidelines and negotiations between manufacturers and certification bodies, thereby allowing practical application of subcomponent tests by the industry for certification purposes.

Outlook

The overall effort needed to establish a strong theoretical, numerical, experimental and practical background, needed for the industry to unlock the potential of subcomponent tests is massive. An even further ranging target is to fully understand the relation between design, manufacturing, operation and the development of material and structural properties during manufacture as well as in operation may take as much as 10-20 years and well over 100 million €. It is clear that such an effort can only succeed if many organisations in many countries work together, which is exactly why, in the framework of EERA JP Wind, Subprogram "Structures and Materials" DTU and Fraunhofer IWES are setting up a first multinational project where these institutes set up the framework of the project and other institutes within Europe can join in, based on a "bring your own money principle", so each research organisation will be funded by its own government. In contrast to a traditional EU project, it is hoped that the overall overhead and "marketing" efforts will be much smaller – leaving more budget for the actual research. Together with a more flexible approach and at least two really large partners, it is expected that the first project will contribute significantly to a better understanding of the structural behaviour of the rotor blade.

References

[1] Malo Rosemeier, Moritz Bätge, "A novel single actuator test setup for combined loading of wind turbine rotor blade segments", ISMEM 2017