

Wind Energ. Sci. Discuss., author comment AC3
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Reply on RC1

Pablo Noever-Castelos et al.

Author comment on "Validation of a modeling methodology for wind turbine rotor blades based on a full-scale blade test" by Pablo Noever-Castelos et al., Wind Energ. Sci. Discuss., <https://doi.org/10.5194/wes-2021-24-AC3>, 2021

Dear Sarah Barber,

The authors gratefully thank you for taking the time and providing your very thorough and constructive review. We believe that the paper has been improved significantly by your suggestions. Please find our answers to all your comments, by either corrected or added text sections or comments on your suggestions. We hope to have adequately accommodated all your concerns and thank you again for your contribution.

ABSTRACT

- Line 4: "However, there is a lack of test results for which the blade data are completely available": it's not entirely clear what this means. Please be more specific about which data you are talking about.

"... lack of test results for which also the finite element model with blade geometry and layup as well as the test documentation and results are completely available."

- Line 5: Please explain why this "one particular methodology" is validated. Is it the most common / important one?

"... this paper is to validate the presented fully parameterized blade modeling methodology that is implemented in an in-house model generator, and to provide respective test results for validation purpose to the public. This methodology includes parameter definition based on splines for all design and material parameters, which enables fast and easy parameter analysis."

- Line 6: Please explain why providing test results to the public for an in-house methodology is important / interesting.

The test results are not limited to our methodology or tool validation, but shall be provided for the complete community. The thorough documentation of the test procedure and results should be interesting for anyone trying to validate a model generator. The necessary blade information can be made available upon request and will be published in a repository in near future.

- Line 7: Why not mention the name of the code here?

Thank you for your opinion. We prefer to keep the abstract as neutral as possible. Moreover, as the software does not play any significant role for this work, the name is omitted. However, it is named later in the work.

- Line 8: Again, it's not clear to me exactly what "all relevant data" are. Same for the next sentence: "some data have been measured" doesn't really make sense to me.

"A static full scale blade test is performed, which is used as the validation reference. All information, e.g., on sensor location, displacement and strains, are available to reproduce the tests."

- Line 9: Why not mention "according to IEC 61400-23" here?

The reference is included now.

- Line 13: Please quantify "good".

Concerning another later comment, we have defined validation tolerances. In the abstract we replace the good agreement by:

"Overall, the global results meet the defined validation thresholds during bending, though some improvements are required for very local analysis and especially the response in torsion."

- Line 14: Why and how do you conclude that "good" comparisons are equal to "validated"?

With respect to the previous statement, we rate the modelling strategy as validated, excluding the torsional behaviour, which is not traced back to the modelling strategy, but the shell-element capability of predicting torsion.

INTRODUCTION

- Generally: The "story" in this section is unclear. I suggest splitting this section into "Motivation", "State-of-the-art" and "Objectives of this paper", and move the paragraph starting at line 50 to the "Objectives of this paper" section, together with the paragraph starting at line 64.

The introduction was split into:

- *State-of-the-art 3D Finite-Element Modeling of WindTurbine Blades*
- *Objectives of this paper*
- *Outline*

And the paragraphs were sorted according to your suggestion.

- Line 17: "designated": do you mean "expected"?

The wording was corrected.

- Line 20: I suggest writing "...one time only per blade design"

The wording was corrected.

- Lines 26-27: Does "have to be performed" mean that this has to be done because of the standard or in order to reach the required accuracy, in which case what is the required accuracy and why?

It is not necessarily about accuracy, rather about not modelling or predicting certain phenomena in 2D.

"Nevertheless, at a final stage 3D FE analyses have to be performed in order to obtain a reliable blade design and account for structural details, e.g., adhesive joints, longitudinal geometric discontinuities, ply drops, or local buckling analysis, which are not considered in a 2D-FE-analysis."

- Line 29: I don't really understand how automated model creation avoids model errors. Please elaborate on this.

"... avoiding modeling errors caused by the user during a manual model creation."

- Line 30: "neglecting details on structural information": such as?

Expression replaced by:

"... QBlade for example focuses on the aerodynamic blade design, applying only an Euler-Bernoulli beam approach for the structure."

- Line 32: what do you mean by a "proper composite definition"? Please explain this better

Expression extended to:

"... taking into account a composite layup definition ..."

- Line 36: specify what you mean by a "high discretization of stations" (how many?)

Expression extended to:

"... high discretization of stations along the blade span (e.g., 45 stations for a 20~m blade) ..."

- Line 41: I guess you mean here "the best compromise between accuracy and costs" rather than "a solution at minimum costs"??

The wording was corrected.

- Line 55: here you need to say why the method presented here is better, i.e. is it just more accurate or is it also more computationally efficient, thus offering a better compromise between costs and accuracy?

This bullet list is added to the objective section of the Introduction:

"The presented method combines and extends several aspects of the different aforementioned software packages. The benefits are:

- *it generates airfoils independent from any neighbouring geometry and uses the relative thickness distribution to position these along the span. This assures the geometry*

distribution, as this avoids any overshoot due to spanwise geometry interpolation.

- *any parameter which may vary over the radius can be defined as spline, e.g., relative blade thickness, layer thickness, material density or stiffness.*
- *it enables flexible and easy parameter studies due to the simple parameter variation based on splines.*
- *it is designed for research, as different modules can be easily replaced by an alternative code, e.g., airfoil interpolation, adhesive modeling.*
- *it generates an FE-Model in MATLAB and provides already an interface to ANSYS APDL and BECAS, however interfaces to other FE-software can easily be implemented. "*

- Line 56: This is important because..? Please elaborate.

Included in the previously mentioned bullet list.

- Lines 77-78: "Generally good agreement..." Please remove this sentence. It doesn't belong in the introduction, just the conclusions and the abstract!

Sentence removed from introduction.

MODEL CREATION FRAMEWORK

- Line 87: please specify what you mean by "efficient" (quick? easy?).

"... enables ... design parameter variations in an easy way .."

- Lines 100-110: it is not that clear which sentences correspond to which blocks in the figure. Please help readers by putting the relevant block name in brackets when it's not obvious, i.e. "First, the blade segmentation, i. e. the discretization in span-wise direction, is defined ("eval. CS geometry") (note -I don't even know if that's correct). Actually, it would be even better if you could number the blocks and refer to them in the text.

- Lines 111-117: same comment as above.

- Lines 123-131: same as above.

Thank you for that suggestion. The blocks in the flow charts were extended by indices, which are used to refer them in the description.

- Line 147: "there are no relative displacements between the master and the slave nodes". I'm not an expert on this: are there any consequences of this? Is it OK to do this? Maybe elaborate here.

"The rigid connection implies that the deformation of the blade at the load frames is restricted. Similar to the real blade test according to IEC-64100, the load frames neighbouring blade sections cannot be evaluated, as the structural response is influenced by the quasi-rigid constraints."

MODELLING OF THE TEST BLADE

- Line 165: please quantify "negligibly small" (and how you decide what "negligible" is in this context)

"deviations in the outer geometry are negligibly small (Chord length < 10 mm and thickness < 8 mm)"

- Line 173: put 5.2m in terms of relative position (xR) in brackets too. Also, indicate if the pressure side is the top or bottom (it's not obvious from that

picture and we don't know which direction the blade is moving in :-)).

The additions are added in parenthesis at the respective position and all other locations in the rest of the text.

- Lines 173-175: be more specific about these deviations. Is this picture just an example of one deviation? Were all sections like this or just this one?

"This was actually found throughout the whole blade, where the thickness varied between 20 and 30 mm. The design defined a thickness of 9 ± 3 mm."

- Line 175: "is much thicker than specified in the design"...please explain how the picture shows this (is it the green part that is sticking out? and mark it on the picture!

The bonding is marked in the picture and referred to in the text.

TEST DESCRIPTION AND VIRTUAL MODELING

- Line 198: The sentence " the weight of the blade bolts was subtracted from the total mass." doesn't really make sense: you don't subtract a weight from a mass. Be careful to be consistent with weight and mass (weight = mass x g).

Thank you for highlighting this error, which was corrected!

- Line 219: It's a bit strange that you mention "fatigue test" here as if it was obvious that you were carrying out "the fatigue test", whereas it is actually the first time you mention the word. "The fatigue test" therefore needs to be first introduced and described.

The expression about the fatigue test was removed, as it is not a necessary information for this paper and raises confusion as you have stated.

- Line 225: Explain why "almost horizontally" and what the consequences of this "almost" are.

The "almost" was erased as it is described in the upcoming sections.

- Line 238: Error in what? Displacement? Strain? And 0.5% of what?

"Preliminary verifications showed that the corresponding error in the displacement is less than 0.5 % with respect to a simulation that accounts for gravitation throughout the whole simulation."

- Line 264: again, please write what these radii are in terms of % along the span.

Done.

- Line 297: I'm not entirely sure what you mean by "the torsional moment is not parallel to the pitch axis" - that the moment is not applied around the pitch axis? Surely what you mean is that the applied forces are not perpendicular to the blade chord? Why does this influence the axis around which the moment is applied? Also, please be more specific about the descriptions here. Why did you assume that the location is 30 m above the ground (why not 10, or 100?) What is the consequence of this assumption?

"Because the blade is still mounted at a block angle of 7.5° the torsional moment is not fully aligned with the pitch axis, as the forces do not act exactly in the cross sectional plane."

The correct location is at 18 m above ground. However, the results did not change, as the angle deviation of the rope suspending the blade is relatively small <1 deg, compared to the 30 m location.

"... location is 18m above ground (y-direction, approximately crane height). By this, deflections parallel to the floor, due to load application, would only result in small angle deviation of the perpendicular force."

- Line 303: "....as discussed in section 3"

- Section 4.4: This belongs in Section 3. I don't get why you have described some of the segment measurements in Section 3 and some here.

This was added in Section 3 to clarify why the cross-sectional discussion is split into different sections.

"During the manufacturing procedure and the latter testing, several different properties of the blade are captured. From these, the FE model only covers the geometrical deviations such as the chord, thickness and adhesive geometry deviations. However, mass and stiffness adaption, to meet the measured natural frequencies and masses, or displacements will not be covered, as this would demand a thorough model updating procedure, which would go beyond the scope of this work. Therefore, this Section will refer to the geometrical measurements and the rest will be covered in Section 4."

COMPARISON OF RESULTS

- Line 325: Please explain why you didn't first obtain the mass in the numerical model and then add mass until these values matched, before continuing with the simulations.

See previous comment.

- Line 325: Explain how you estimated the measurement uncertainties.

"All measurement uncertainties are based on given sensor uncertainties and taking the worst case combination of those."

- Line 328: Quantify "perfectly" (i.e. to the nearest two decimal places).

"The location of the CoG matches perfectly in the chord direction, i.e., with a precision to the nearest two decimal places."

- Line 332: How do you decide what "acceptable" is?

Thank you for highlighting this significant weakness of the paper. However, it is difficult to find a reference for validation tolerances, as these are somehow subjective/arbitrary. We have tried to define some reasonable thresholds based on a presentation and respecting manufacturing tolerances.

"In order to rate the validity of the model, it is necessary to identify specific thresholds. However, these are hardly found in literature, especially as different applications and fidelity levels may demand other thresholds. Exemplary, Safarian.2015reports validation

requirements for finite element analysis according to the Federal Aviation Regulation of the U.S. government, where a displacement deviation of <5% between the simulation and experiment is typically acceptable for global effects and local effects measured in form of strains allow for a maximum of 10% deviation. Whereas strains exceeding these values require a re-evaluation of the model. These regulations refer to aviation applications, which also apply finite element shell models for the analysis comparable to our use case. Therefore, we will apply a 5% threshold for global displacements, whereas a 10% threshold will be applied on the cross-sectional strain results. These margins should also cover measurement uncertainties, as the DWS and the strain gauges offer a quite narrow uncertainty band, 0.6% and 2%, respectively. Thresholds for masses are harder to define as these depend on the measurement setup, in our case with up to 2.5% uncertainty. Plus, not all additional masses were correctly documented and thus not modeled. Same problem holds for natural frequencies ω , following and respecting unknown mass variation and typically a maximum of 5% material tolerances (including density and stiffness according to private communication with manufacturers), it is also hard to define thresholds for the frequencies. Therefore, both mass and frequencies will be discussed individually."

- Lines 332-345: Can you give the reader some idea of how good these comparisons are? Do other comparisons of experiments and simulations show similar results? Or are yours much better or worse than others?

I have found some comparable modal simulation of the same blade:

"Similar deviation ranges can be found in Knebusch.2020 for the same blade but with a different model, with errors between 1.8% to 9.7% for flapwise and edgewise modes and up to 22% for the torsion mode."

- Line 378: Clarify exactly what you mean with "due to the wrong twist". Wrongly measured? Wrongly simulated? Wrongly assumed?

The wording twist is somehow confusable with the structural designed twist of the blade. Therefore it is replaced by "rotation" or "rotation around the z-axis". Additionally the expression "due to the wrong twist" is corrected to:

"... due to the wrong predicted rotation along the z-axis."

- Line 410: "Such high errors during torsional loading may base on the shell element with a node offset to the exterior surface used for this model": Do you have any suggestions to improve / solves this?

This is included in the conclusion:

"However, modern flexible blade design, which is driven to its material and structural integrity limits and includes intentional torsion for load alleviation, requires accurate predictions for all load cases in order to be reliable. Looking a step further, especially fatigue damage calculation, therefore, needs correct strain or stress predictions of the models. The authors currently work on evaluating blade modeling by means of solid elements and/or solid shell elements. Although, we lose computational efficiency of the shell element models, this way, the accuracy in torsional response should be improved significantly, as well as the correct representation of geometrical shape and 3D tapering can be realized. This should shed light on the discrepancy in torsion"

- Line 425: "because the sandwich core material vanishes towards the trailing edge": Can you explain what this means please? Does this happen in the simulations but not in reality?

"... the sandwich core material vanishes suddenly towards the trailing edge, due to the shell elements and their missing capability of tapering single materials in their sections as done in the real layup."

- Line 441: Explain what you mean by "a wrong calibration or malfunction of the strain gauge"

"Unlike the edge-wise case a failure of the strain gauge at $S = 0.3$ was recorded in the experiment, which can be seen in the discontinuity of the experimental results."

- Section 5.5: Again, it's not clear to me why these couldn't be "calibrated" before running/repeating the simulations

Commented before

Technical corrections

Thank you for your technical corrections, which were all considered in the revision. Additionally, the paper has gone through a proof-reading process.