HAWC2 and BeamDyn: Comparison beetween Beam Structural Models for Aero-Servo-Elastic Frameworks

Presenting Author: Christian Pavese*
Co-authors: Qi Wang,† Taeseong Kim,‡ Jason Jonkman§ and Michael A. Sprague¶

I. Introduction

Wind turbine blades are highly complex composite structures, whose design presents advanced challenges. In recent years, the development of multi-megawatt wind turbine machines has brought blade designers to explore different cost-effective solutions, involving the manufacturing of larger, lighter and more flexible wind turbine blades. The increase in size and flexibility against the reduction in mass has augmented the importance of non-linear effects related to the structural behaviour of wind turbine blades. These effects include large deflections and rotations along with structural couplings such as bending-to-torsion. Hence, wind energy research started to focus on the necessity of developing models and tools able to accurately capture the response of these highly complex structures under aerodynamic loading.
In this paper, two beam models for aero-servo-elastic frameworks are presented, analyzed and compared:

- A new linear anisotropic beam element implemented into the non-linear aeroelastic multi-body code HAWC2 [1], developed by DTU Wind Energy
- A new nonlinear beam finite element model that uses the Geometrically Exact Beam Theory (GEBT) and where spatial discretization is accomplished with Legendre Spectral Finite Elements (LSFEs); the beam model is implemented as a module called BeamDyn [3], [4] for the new aeroelastic modularization framework FAST v8 [2], developed by the National Wind Technology Center at the National Renewable Energy Laboratory (NREL) in Boulder, Colorado

It is important to remark that even though the new HAWC2 beam element is based on a linear formulation, its implementation in a multibody system gives the possibility to capture non-linear effects such as large rotations and translations. Hence, even if the structure in HAWC2 is modeled using several linear bodies, a comparison with the beam finite element model implemented in BeamDyn can still be made despite the fact that the latter is based on a nonlinear formulation. Moreover, both these structural codes have been separately validated against results found in literature and experimental data. The purpose of this paper is not only to purely compare

*PhD Student, Technical University of Denmark, Department of Wind Energy - DTU Risø Campus, 4000 Roskilde, Denmark. Email: cpav@dtu.dk
†Research Engineer, AIAA Member - National Wind Technology Center, National Renewable Energy Laboratory, Golden, CO 80401
‡Associate Professor, Technical University of Denmark, Department of Wind Energy - DTU Risø Campus, 4000 Roskilde, Denmark.
§Senior Engineer, AIAA Professional Member - National Wind Technology Center, National Renewable Energy Laboratory, Golden, CO 80401
¶Senior Research Scientist, Computational Science Center - National Renewable Energy Laboratory, Golden, CO 80401

accuracy and performance of the two codes, but also to highlight the differences between the two approaches, setting up a specific series of benchmarking cases of increasing complexity. These cases involve only cantilevered beams and an isolated wind turbine blade, whereas a full aeroelastic comparison will be presented in future works by the authors.

II. Approach

A series of benchmarking cases are selected to provide a complete overview of the capabilities of the two structural codes. These benchmarking cases are listed below:

- Case 1: Static bending of a cantilever beam under five constant bending moments applied at its free end
- Case 2: Initially twisted and initially curved beam
- Case 3: Static analysis of a composite beam with a force applied at the free tip
- Case 4: Dynamic analysis of a composite beam with a sinusoidal force applied at the free tip
- Case 5: DTU 10MW Reference Wind Turbine (RWT) [5] blade natural frequencies

The analysis of the performances and responses of the two beam models starts from a simple and very common case (static bending of a cantilever beam) to move up to a complex tailored structure such as a wind turbine blade. Except for the DTU 10MW RWT blade natural frequencies, the other cases have been already used for the validation of BeamDyn and presented by Wang et al. [3], [4]. Nonetheless, these cases have been selected as base for this study, because they are suited to prove the capabilities of the two codes to model structures that show non-linear responses due to geometric and material couplings. The results obtained from the two codes have been compared to results found in literature or high-fidelity models generated using commercial Finite Element software such as ANSYS and Patran-Marc.

III. Results

As a sample of the results obtained through this code-to-code comparison, the case of the DTU 10MW RWT blade is presented. The complete results set, including the cantilevered beam cases, will be included in the final paper.

I. Case 5: DTU 10MW RWT blade natural frequencies

For the last case, the DTU 10MW RWT isolated blade [5] natural frequencies are identified in BeamDyn using impulsive force load cases. An impulsive force of 4 kN is applied first on the flapwise and then on the edgewise direction. Power Spectral Densities (PSDs) are computed from the tip displacement time series computed using BeamDyn and the results are compared to the natural frequencies computed with HAWC2 (eigenanalysis - blade mesh made of 26 bodies) and a Patran-Marc 3D FE model (20-noded layered continuum elements).
Figure 1 shows the PSDs of the two BeamDyn impulse test cases. In Table 1, natural frequencies are identified in HAWC2 and compared to the ones computed by BeamDyn.

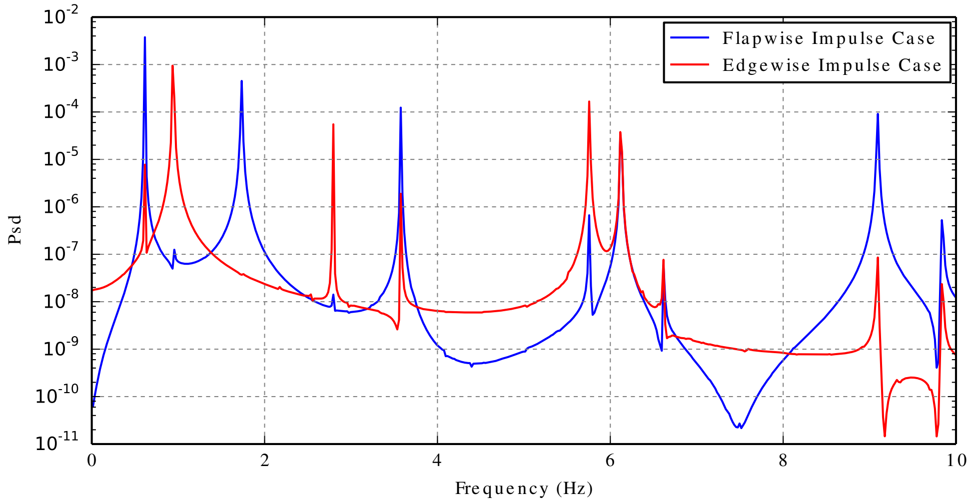

Figure 1: *BeamDyn - PSD of tip displacement in flapwise and edgewise directions for impulse load case. Blue curve: flapwise tip displacement for an impulse force applied on the tip in the flapwise direction. Red curve: edgewise tip displacement for an impulse force applied on the tip in the edgewise direction.*

Table 1: *DTU 10MW RWT natural frequencies comparison*

	PATRAN-Marc [Hz]	HAWC2 [%]	BeamDyn [%]
1st Flap Mode	0.615	-0.6%	0.0%
1st Edge Mode	0.971	-4.2%	-3.8%
2nd Flap Mode	1.764	-1.4%	-1.7%
2nd Edge Mode	2.857	-3.7%	-2.2%
3rd Flap Mode	3.592	-0.4%	-0.5%
1st Torsion Mode	5.753	-1.7%	-0.1%
4th Flap Mode	6.124	-1.1%	-0.1%
3rd Edge Mode	6.151	-0.3%	-0.2%

The results show good agreement between HAWC2 and Beamdyn. The difference between the natural frequencies of the beam models from the full 3D FE model are in the same range. The largest discrepancy is registered for the first edgewise mode with around 4% difference between the beam models and the FE model. The reason for this discrepancy is the strategy used to model the trailing edge in the FE model, where the 20-noded layered continuum elements allowed an higher degree of tailoring compared to the input data provided in the DTU 10MW RWT report [5]. The consequence of this FE-modeling strategy resulted in a stiffer blade in the edgewise direction.

IV. Conclusion

The comparison between two new structural codes for aero-servo-elastic frameworks, one developed by DTU Wind Energy and linked to the non-linear aeroelastic multibody code HAWC2, and the other, called BeamDyn, developed by the National Wind Technology Center at NREL as a module for the new modular framework FAST v8, has been presented. These new beam models have been implemented with the purpose of giving a better representation of the complex structural behaviour of modern wind turbine blades. To analyze the capabilities of the two codes, ad hoc benchmarking cases have been selected. A sample of the results obtained through the benchmarking has been provided for this abstract, while a complete and detailed overview and discussion of all the other cases will be provided in the final paper. The final outcome of the paper is not only to compare the performances and responses of the two codes, but also to highlight the advantages and drawbacks of the two different approaches.

V. Learning Objectives

The learning objectives for the current study are:

- Present two new beam models for aero-servo-elastic frameworks, able to provide an accurate representation of the complex behavior of modern wind turbine blades
- Compare the performances and responses of the two codes highlighting the advantages and drawbacks of the two different approaches
- Propose a series of benchmarking cases to investigate non-linear responses of cantilevered beams and isolated wind turbine blade analysis

References

[1] Taeseong Kim, Anders M. Hansen, Kim Branner, *Development of an anisotropic beam finite element for composite wind turbine blades in multibody system*, Journal of Renewable Energy, 2013, 59(2013) 172-183, Elsevier

[2] Jonkman, J.M., *The new modularization framework for the FAST wind turbine CAEtool*, Proceedings of the 51st AIAA Aerospace Sciences Meeting including the New Horizons Forum and Aerospace Exposition, Grapevine, Texas, January2013.

[3] Q. Wang, M. A. Sprague, J. Jonkman and N. Johnson *Nonlinear Legendre Spectral Finite Elements for Wind Turbine Blade Dynamics*, 32nd ASME Wind Energy Symposium, National Harbor, Maryland January 13-17, 2014

[4] Qi Wang, Nick Johnson, Michael A. Sprague and Jason Jonkman *BeamDyn: A High-Fidelity Wind Turbine Blade Solver in the FAST Modular Framework* 33rd Wind Energy Symposium, AIAA 2015, 5-9 January 2015, Kissimmee, Florida

[5] Christian Bak, Frederik Zahle, Robert Bitsche, Taeseong Kim, Anders Yde, Lars Christian Henriksen, Anand Natarajan, Morten Hartvig Hansen, *Description of the DTU 10 MW Reference Wind Turbine*, DTU Wind Energy Report-I-0092, July 2013