Development and Validation of Structural Models for Wind Turbine Composite Blades

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Abstract

Wind turbine blades are generally made of composite materials due to their high strength-to-weight ratio and good fatigue performance. The inherent complexity of composite materials and the complicated blade structural layout makes accurate and efficient structural modelling of wind turbine composite blades quite challenging. In order to facilitate the structural design optimization of wind turbine composite blades, it is crucial to develop validated structural models for the blades. In this paper, both 3D parametric FEA (finite element analysis) model and 1D beam model for wind turbine composite blades are developed. A Matlab code called ParaFemBlades is developed to read input data and then to output a series of APDL (ANSYS Parametric Design Language) commands, which can be used to automatically generate the 3D FEA model of wind turbine composite blades in ANSYS. The 1D beam model for wind turbine composite blades is developed based on Euler-Bernoulli beam theory. A series of benchmark computational tests are then performed, validating the developed 3D FEA model and 1D beam model.

Background and Motivation

Wind turbine blades are generally made of composite materials due to their good fatigue performance and high strength-to-weight ratio. Due to the inherent complexity of composite materials and the complicated blade structural layout, accurate and efficient structural modelling of wind turbine composite blades is quite challenging.

Structural models used for wind turbine composite blades can be roughly classified into two groups, i.e. 3D FEA (finite element analysis) model and 1D beam model. Input data of 3D FEA model are the blade geometry information and the blade structural layout information. Constructing 1D beam model requires cross-sectional properties of the composite blades, such as mass per unit length and sectional stiffness, which can be obtained by using specialized cross-sectional analysis models, e.g. CBCSA [1]. The schematic of structural models for wind turbine composite blades is presented in Fig. 1.

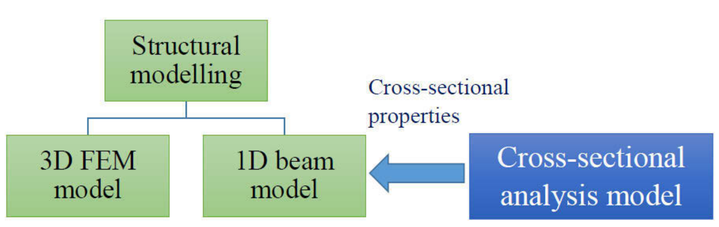

Figure 1. Schematic of structural models for wind turbine composite blades

In order to facilitate the structural design optimization of wind turbine composite blades, it is crucial to develop validated structural models for the blades.

Aims and Objectives

This study aims to develop and validate structural models for wind turbine composite blades. This is achieved through the realization of the following objectives:

- To develop a parametric FEA model of wind turbine composite blades
- To develop a beam model of wind turbine composite blades
- To validate the parametric FEA model and beam model against each other and against available experimental data

Methods

- **Development of 3D Parametric FEA Model**

Due to the complicated aerodynamic shape and structural layout of a wind turbine composite blade, generating a 3D FEA model of the blade using general-purpose commercial finite element packages, such as ANSYS and Abaqus, is tedious and time-consuming.

In order to facilitate the generation of 3D FEA models of wind turbine composite blades, a Matlab code called ParaFemBlades (**Para**metric **F**inite **e**lement **m**odelling of wind turbine composite **Blades**) has been developed. The blade geometry information (such as chord and twist angle distributions) and the blade structural layout information (such as shear web locations and composite layups) are stored in text files. The Matlab code ParaFemBlades reads the input files and then outputs a series of APDL (ANSYS Parametric Design Language) commands, which can be recognized by ANSYS to perform parametric finite element modelling of wind turbine composite blades. The schematic of the parametric FEA model is presented in Fig. 2, and the flowchart of ParaFemBlades is depicted in Fig. 3.

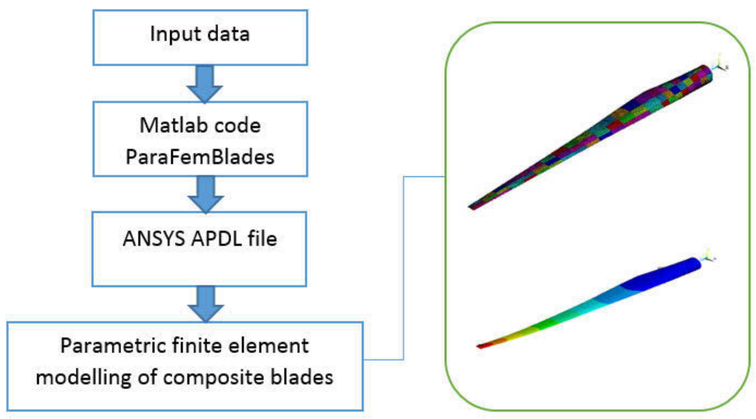

Figure 2. Schematic of parametric FEA model

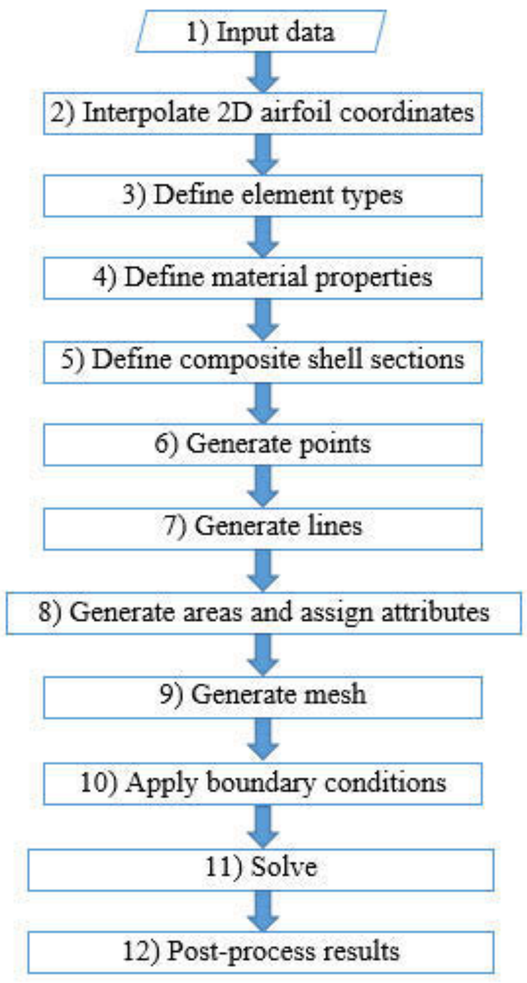

Figure 3. Flowchart of ParaFemBlades

- **Development of 1D Beam Model**

In this work, a beam model for wind turbine blades is developed based on Euler-Bernoulli beam theory.

Results

In order to validate the structural models developed in this work, three case studies are performed. In the first case study, the beam model is validated against modal testing results of a horizontal axis wind turbine (HAWT) blade. In the second case study, the beam model is further validated against modal testing results of a vertical-axis wind turbine (VAWT). In the final case study, the results of 3D FEA model are compared with the results of 1D beam model.

- **Case A: Truncated RB70 wind turbine blade**

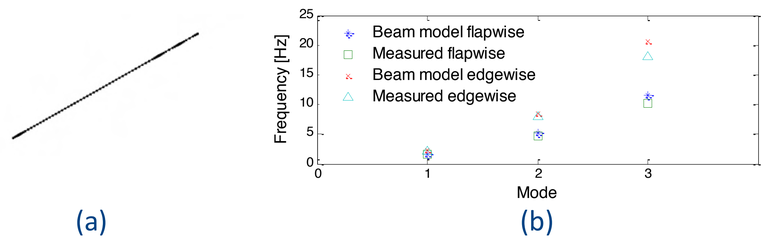

Figure 4. Truncated RB70 wind turbine blade: **a** beam model, **b** modal frequency

- **Case B: Sandia 34m VAWT**

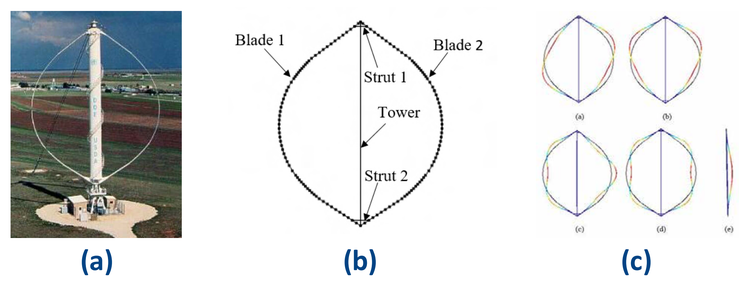

Figure 5. Sandia 34m VAWT: **a** photograph, **b** beam model, **c** modal shapes

Table 1. Modal frequencies of Sandia 34m VAWT

Mode	Measurements [2]	Beam Model	Diff. (%)
1st FA (Hz)	1.060	1.007	5.00
1st FS (Hz)	1.060	1.009	4.81
2nd FA (Hz)	2.060	1.997	3.06
2nd FS (Hz)	2.160	2.018	6.57
1st BE (Hz)	1.810	1.819	0.50

- **Case C: WindPACT 1.5MW wind turbine blade**

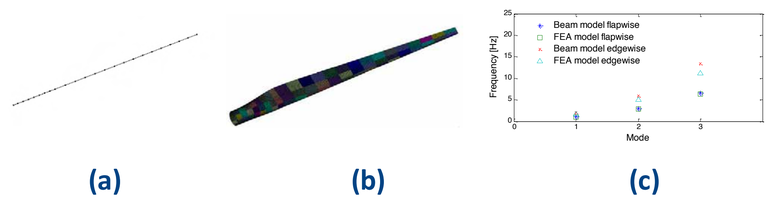

Figure 6. WindPACT 1.5MW wind turbine blade: **a** beam model, **b** FEA model, **c** modal frequencies

Conclusions

In this work, both 3D parametric FEA (finite element analysis) model and 1D beam model for wind turbine composite blades are developed. The following conclusions can be drawn from the present study:

- Modal frequencies calculated from the beam model match well with the modal testing data of both RB70 blade and Sandia 34m wind turbine, which confirms the validity of the beam model.
- Modal frequencies calculated from the beam model show reasonable agreement with the results of 3D FEA model for the WindPACT 1.5MW wind turbine, which confirms the validity of both models.
- Compared to 3D FEA model, 1D beam model saves much computational time and is able to provide reasonable results. Therefore, the 1D beam model is recommended to be used at the preliminary design stage. 3D FEA model is valuable at a later design stage to verify the preliminary design and to examine detailed stress distributions within the blade structure.

References

[1] L. Wang, X. Liu, L. Guo, N. Renevier, and M. Stables, "A mathematical model for calculating cross-sectional properties of modern wind turbine composite blades," Renewable Energy, vol. 64, pp. 52-60, 2014.
[2] T. D. Ashwill, Measured data for the Sandia 34-meter vertical axis wind turbine: Sandia National Laboratories, 1992.