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Anisotropic Beam Element for Modeling of the Wind Turbine Blades

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Abstracts

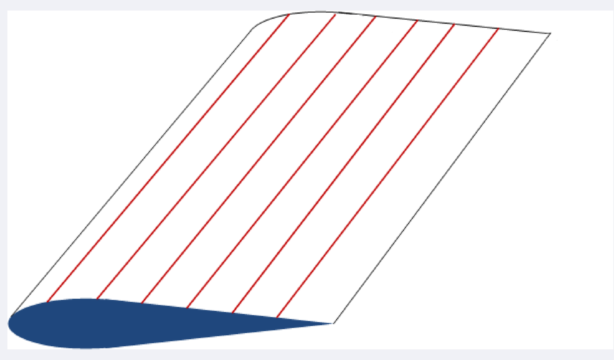
For modern MegaWatt (MW) wind turbines, composite materials are used for the blades. The composite blade introduce additional geometric couplings due to different layup angles of the composite materials. The tailoring capability of the composite blade could be used to passively control the wind turbine response and results in a decrease of fatigue loads and the risk of flutter. However the classical beam theories such as Timoshenko and engineering beam models used for the aeroelastic codes, HAWC2, FLEX, Bladed, FAST, cannot be used to investigate the additional geometric coupling effects of anisotropic materials.

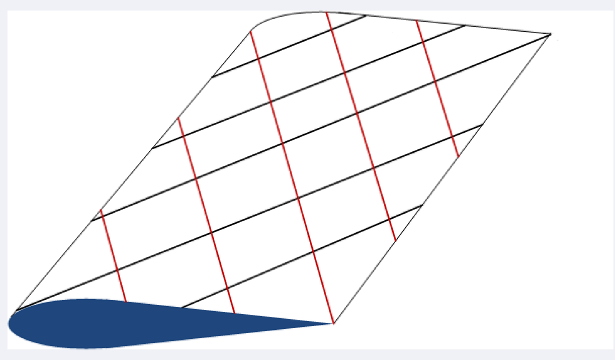
The main aim of this study is to develop beam element model for analyzing the anisotropic composite blades of wind turbines. Developed new beam element is validated with existing data. It has shown that anisotropic properties introduce not only additional deflections but also larger deflections due to coupling effects. Natural frequencies are also changed when the anisotropic characteristics are considered.

Objectives

- Typical layup conditions
  - Using 0° or symmetric layups (±θ°)
  - **No couplings are produced.**

0° layup case / Symmetric layup case



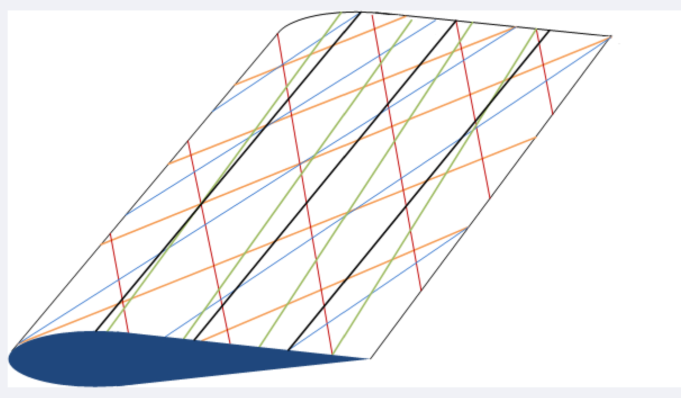


$$\begin{Bmatrix}F_x\\F_y\\F_z\\M_x\\M_y\\M_z\end{Bmatrix}=\begin{bmatrix}S_{11}&0&0&0&0&0\\&S_{22}&0&0&0&0\\&&S_{33}&0&0&0\\&&&S_{44}&0&0\\&\text{sym.}&&&S_{55}&0\\&&&&&S_{66}\end{bmatrix}\begin{Bmatrix}\varepsilon_x\\\varepsilon_y\\\varepsilon_z\\\kappa_x\\\kappa_y\\\kappa_z\end{Bmatrix}$$

$$\begin{Bmatrix}F_x\\F_y\\F_z\\M_x\\M_y\\M_z\end{Bmatrix}=\begin{bmatrix}S_{11}&S_{12}-S_{12}=0&0&0&0&0\\&S_{22}&0&0&0&0\\&&S_{33}&0&0&0\\&&&S_{44}&S_{45}-S_{45}=0&0\\&\text{sym.}&&&S_{55}&0\\&&&&&S_{66}\end{bmatrix}\begin{Bmatrix}\varepsilon_x\\\varepsilon_y\\\varepsilon_z\\\kappa_x\\\kappa_y\\\kappa_z\end{Bmatrix}$$

- Possible layup conditions
  - Using asymmetric layups
  - **Couplings are produced.**

Asymmetric layup case

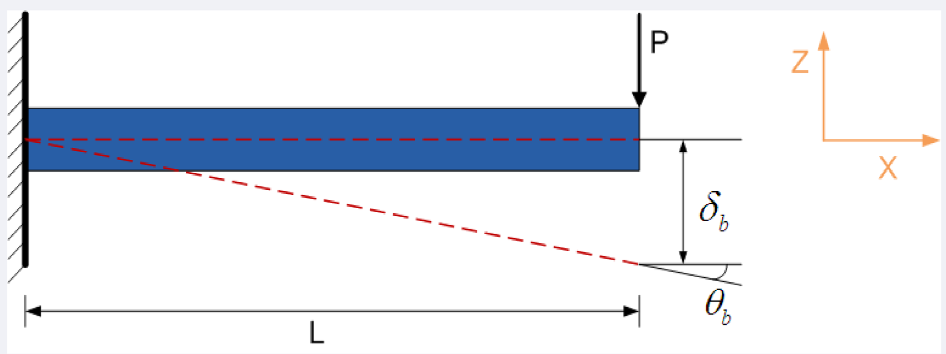


$$\begin{Bmatrix}F_x\\F_y\\F_z\\M_x\\M_y\\M_z\end{Bmatrix}=\begin{bmatrix}S_{11}&S_{12}&0&S_{14}&0&0\\&S_{22}&0&0&S_{25}&0\\&&S_{33}&0&0&S_{36}\\&&&S_{44}&S_{45}&0\\&\text{sym.}&&&S_{55}&0\\&&&&&S_{66}\end{bmatrix}\begin{Bmatrix}\varepsilon_x\\\varepsilon_y\\\varepsilon_z\\\kappa_x\\\kappa_y\\\kappa_z\end{Bmatrix}$$

Methods

General FEM approach is considered to develop new a Timoshenko beam model.

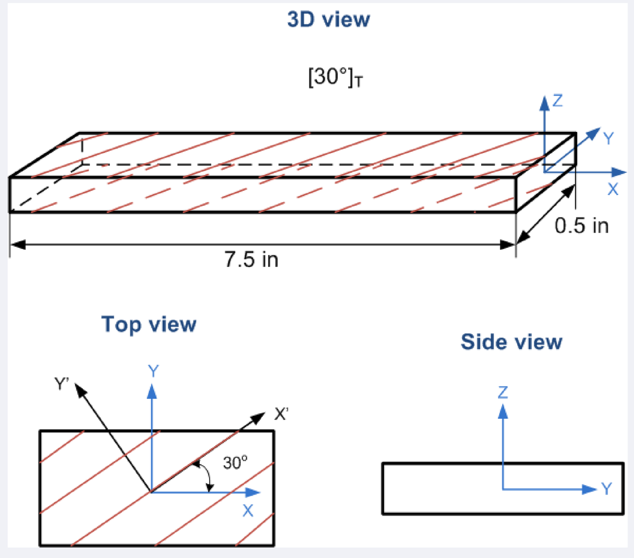
- 2 nodes element is fixed for structural elements in the new beam element.
  - 2 nodes element is used for aerodynamic elements.
  - Linear shape function is available.
  - Linear shape function needs to have more elements.
  - Time cost is increased.
- 2 nodes element with higher order of the polymonial shape function is developed.
  - Steady deflections of cantilevered beam are compared.



  - Natural frequencies (Hz) and mode shapes for box beams are compared.
  - Cross-section stiffness and mass matrix are given from the references.

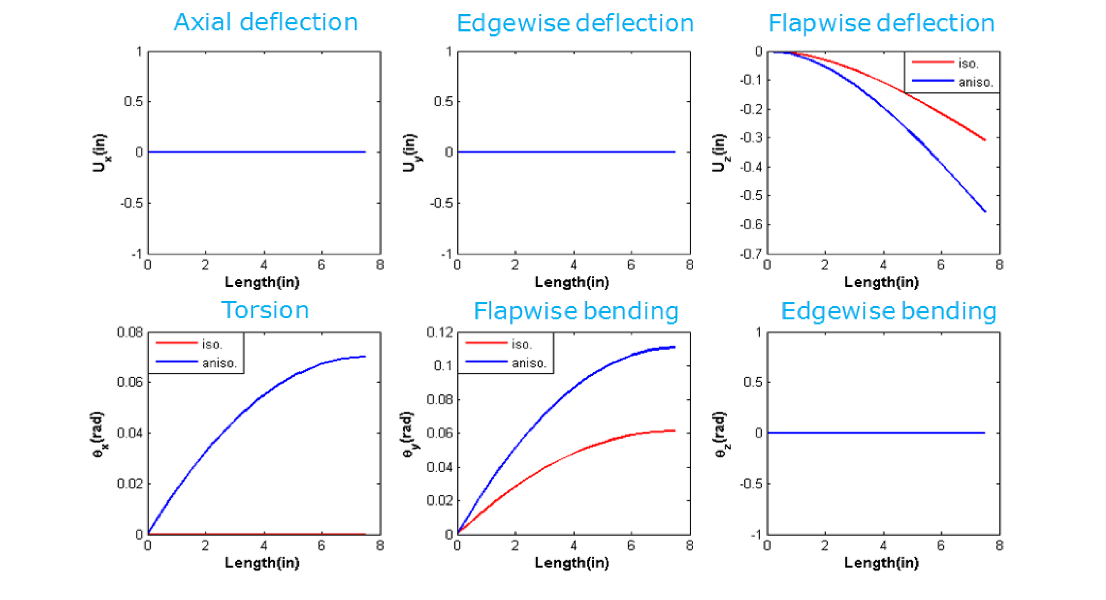
Results

- Case I: Wenbin Yu (2007)
  - Length of the beam: 7.5*in*
  - Graphite-Epoxy $[30°]_T$, rectangular box beam



$$[s]=\begin{bmatrix}S_{11}&S_{12}&0&0&0&0\\&S_{22}&0&0&0&0\\&&S_{33}&0&0&0\\&&&S_{44}&S_{45}&0\\&\text{sym.}&&&S_{55}&0\\&&&&&S_{66}\end{bmatrix}$$

  - Deflections and rotations

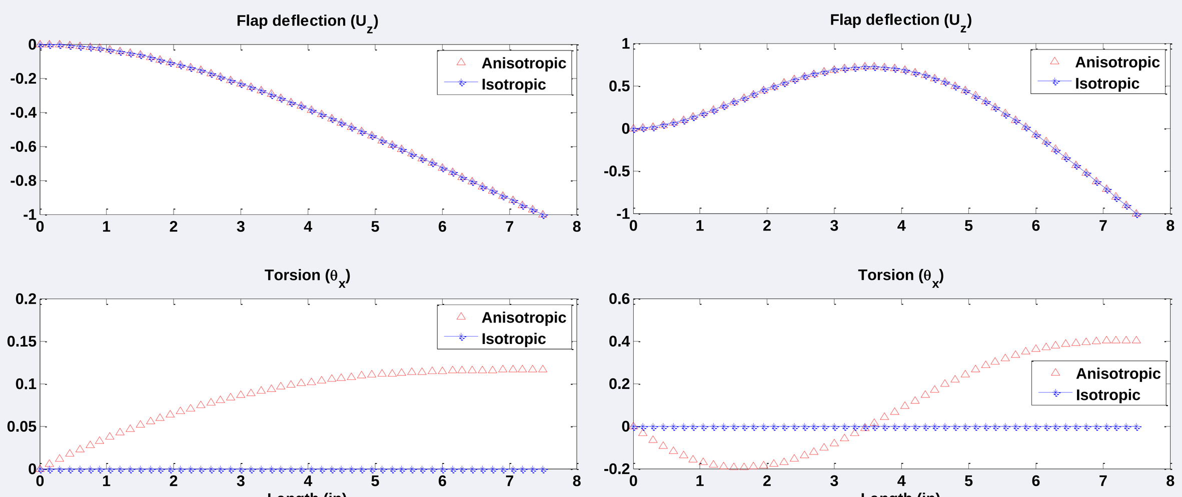


  - Natural frequencies (Hz) comparisons

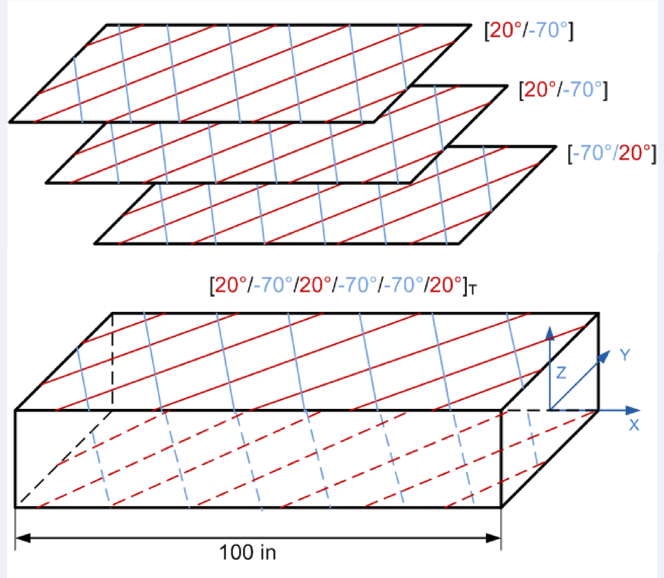
Mode	Isotropic [Hz]	Anisotropic [Hz]
1 (Flap)	70.6	52.6
2 (Edge)	210.3	209.9
3 (Flap)	436.5	327.3
4 (Flap)	1197.9	906.7
5 (Edge)	1304.8	1292.5
6 (Flap)	2282.9	1752.9

  - Mode shapes comparisons

1st Flap mode / 2nd Flap mode

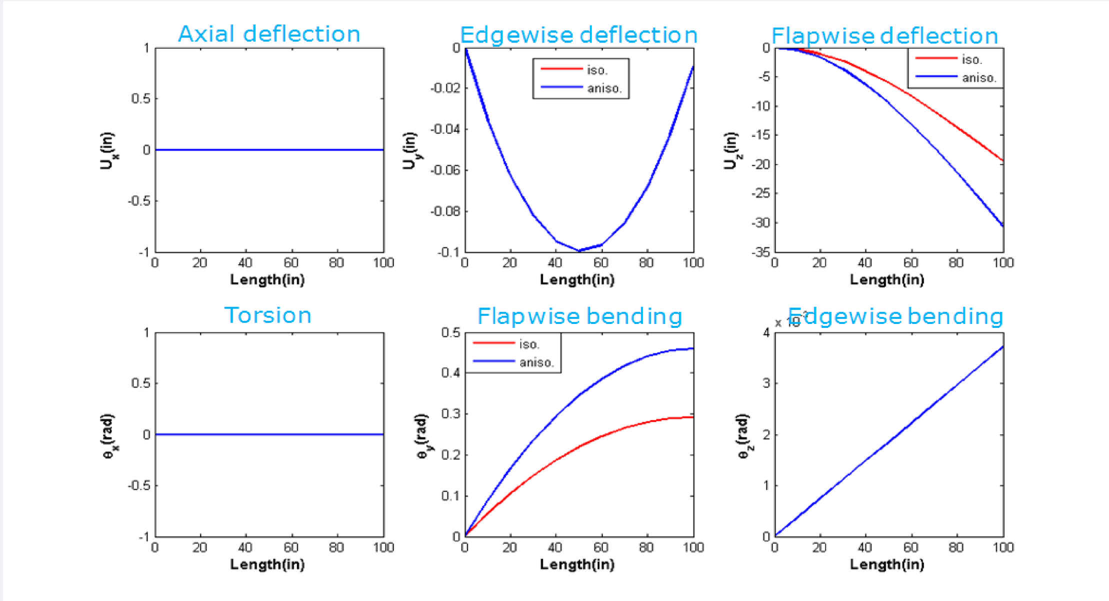


- Case II: Hodges *et al.* (1991)
  - Length of the beam: 100*in*
  - Graphite-Epoxy $[20°/-70°/20°/-70°/-70°/20°]_T$, rectangular box beam



$$[s]=\begin{bmatrix}S_{11}&0&0&S_{14}&0&0\\&S_{22}&0&0&S_{25}&0\\&&S_{33}&0&0&S_{36}\\&&&S_{44}&0&0\\&\text{sym.}&&&S_{55}&0\\&&&&&S_{66}\end{bmatrix}$$

  - Deflections and rotations

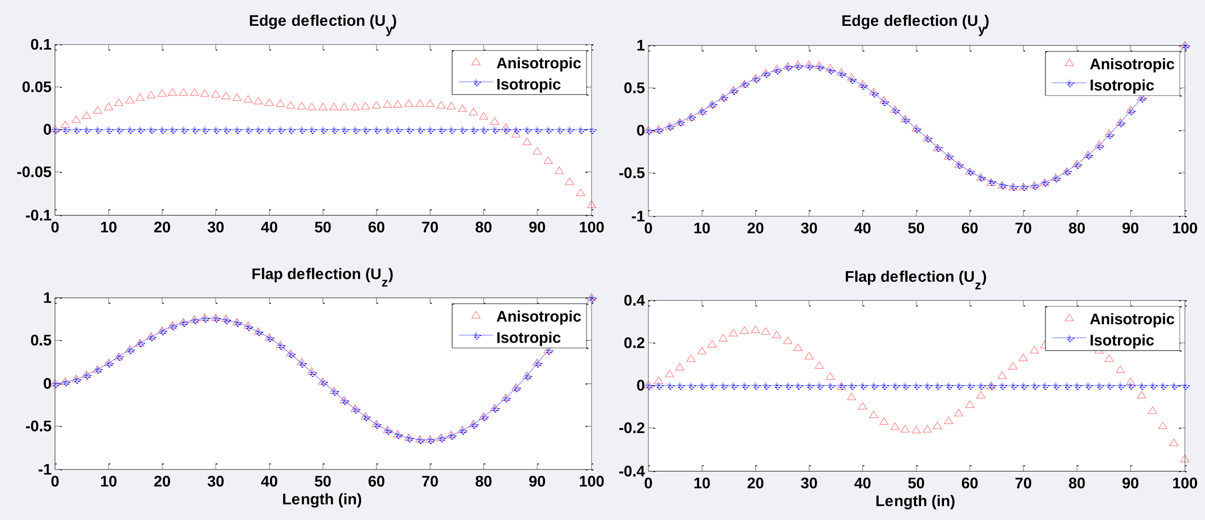


  - Natural frequencies comparisons

Mode	Isotropic [Hz]	Anisotropic [Hz]
1 (Flap)	3.69	2.95
2 (Edge)	6.43	5.09
3 (Flap)	23.12	18.44
4 (Flap)	40.23	31.84
5 (Edge)	64.53	51.59
6 (Flap)	112.22	87.95

  - Mode shapes comparisons

3rd Flap mode / 3rd Edge mode



Conclusions

- Steady deflections for isotropic and anisotropic cases
  - Anisotropic beam deflects more than isotropic beam.
- Natural frequencies and mode shapes
  - Natural frequencies with isotropic material are higher than the frequencies for anisotropic material.
  - More coupling effects are illustrated when anisotropic materials are considered.
    - For the case 1, torsion mode is coupled with flap mode.
    - For the case 2, edge mode is coupled with flap mode.

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