Structural Analysis of Wind Turbine Blades

2nd Supergen Wind Educational Seminar
Manchester – 04 Mar 2009

Paul Bonnet – Geoff Dutton
Energy Research Unit
Rutherford Appleton Laboratory – STFC
[1] Approach
[2] Achievements so far
[4] Longer term work
[1] Approach:
OBJECTIVES

- Finite element analysis models for large wind turbine blades

- For the analysis of the impact on the blade structure of different materials, blade construction options, turbine configurations, aerodynamic features, control options…
**STRATEGY**

- parametric processor tool for the creation & running of the FE model

Better for sensitivity analyses, flexibility, documenting, re-usability…
Wind Energy Technologies

aerofoil shape

Composite materials, fibre angles, glass fibre, carbon, layups...
REALISATION

- Python script for the automation of the Abaqus FE package
  - Fully parametric & automated
  - Can easily call routines and data files from outside Abaqus for input or output
# Rotor & operating conditions variables

B = 3                         # Number of blades (-)
upwindrotor = 1               # Rotor location relative to tower (1 = upwind / 0 = downwind)
clockwiserotation = 1         # Rotation direction seen by wind (1 = clockwise / 0 = anti-clockwise)
rotoroverhang = 5.0           # Rotor overhang from tower centreline (m)
rotortilt = 5.0               # Rotor axis tilt angle - positive values increase tower clearance
#     (deg)
rotorcone = -2.5              # Rotor cone angle - positive values increase tower clearance (deg)
offsetroot = 1.5              # Offset from hub axis to blade root (m)
avimuth = 0.0                 # Blade #1 azimuth position (0 = vertical upwards) (deg)
controlscheme = 1             # Rotor RPM & pitch regulation (0 = none / 1 = regulation) (-)
cyclicscheme = 0              # RPM & pitch regulation type (0 = collective / 1 = cyclic) (-)
setazimuthamplitude = 5.0     # Peak-to-peak set angle change over azimuth for cyclic scheme (deg)
rotorrpm = 12.1               # Rotor angular velocity for unregulated control (rev/min)
setangle = 4.6                # Blade set angle for unregulated control (>0 moves LE upwind) (deg)

# Look-up table data for collective/cyclic pitch control scheme

controlwindrotor = [0.0, 10.5, 25.0]    # Hub wind speed table for rotor speed (m/s)
controlrotorspeed = [0.0, 12.13, 12.13] # Rotor speed table (rpm)
controlwindset = [0.0, 11.0, 12.0, 14.0, 16.0, 18.0, 20.0, 22.0, 24.0, 25.0]    # Hub wind speed table for blade set angle (m/s)
controlsetangle = [0.0, 0.0, 3.84, 8.59, 12.0, 14.9, 17.8, 20.1, 22.3, 23.5]    # Blade set angle table (deg)

# Blade sectional data

numbersamesections = 2

distrootsections = [0.0, 1.3667, 4.1, 6.8333, 10.25, 14.35, 18.45, 22.55, 26.65, 30.75, 34.85, 38.95, 43.05, 47.15, 51.25, 54.6667, 57.4, 60.1333, 61.5]

lengthchord = [3.5, 3.6, 3.854, 4.167, 4.557, 4.652, 4.458, 4.249, 4.007, 3.748, 3.502, 3.256, 3.01, 2.764, 2.518, 2.313, 2.086, 1.419, 0.2]

twist = [13.308, 13.308, 13.308, 13.308, 13.0, 11.6, 10.162, 9.011, 7.795, 6.544, 5.361, 4.188, 3.2, 2.319, 1.526, 0.863, 0.4, 0.106, 0.0]

thicknesses = [100.0, 97.0, 80.0, 64.5, 49.7, 40.0, 34.6, 30.0, 26.0, 23.0, 21.0, 19.8, 18.9, 18.2, 18.0, 18.0, 18.0, 18.0, 18.0]

ratiopitchaxis = [0.50, 0.49, 0.46, 0.43, 0.395, 0.375, 0.375, 0.375, 0.375, 0.375, 0.375, 0.375, 0.375, 0.375, 0.375, 0.375, 0.375, 0.375, 0.375, 0.375]


# Glue & shear-webs geometry

longlimittsshwbindice = 0    # Shear-web limits definition (1 = by section index / 0 = by radius)
thresholdratioshw = 0.05     # ratio of sizeelementlongitudinal as length definition threshold
shwLEsections = range(1,16)  # Indices of distrootsections between which LE shear-web is present
shwTEsections = range(1,16)  # Indices of distrootsections between which TE shear-web is present
shwLEstart = 1.3667         # (m)
shwLEend = 58.0             # (m)
[2] Achievements so far:
Script can create meshes of different densities by the push of a button
Can create model geometries for different internal configurations...
... and external configurations (list of aerofoil names along the span is 1 parameter)
For different layups
Script can calculate and apply fully distributed aero load
Can run a stiffness analysis to produce e.g. the blade stiffness distribution along the span…
... or a non-linear operational load analysis of a 36m blade for gravity + centrifugal + aero load, at e.g. 18rpm and +23deg pitch angle

Root moments (Nm) against blade azimuth angle (deg)
[azimuth = 0deg is vertical upwards]
Validation of TSA measurements of blade construction defects on a 4.5m blade
Development of a 2MW 36m blade model

Practically no layup information…

…but mass & stiffness info available from 2MW Exemplar GH Bladed Model
Development of a 2MW 36m blade model
Development of a 2MW 36m blade model
Development of a 2MW 36m blade model
Development of a 2MW 36m blade model
Development of a 5MW 61m blade model

Here we had some layup information available as well as mass & stiffness targets

⇒ limitations of the layup info in terms of overall mass & 3D spar cap stress profile

⇒ this was improved by modifying the layup
Layup grids:
Development of a 5MW 61m blade model

Distribution of edgewise stiffness along blade

- Exemplar Data
- Current Model
- 2 per. Mov. Avg. (Current Model)
Development of a 5MW 61m blade model

Distribution of flapwise stiffness along blade
Development of a 5MW 61m blade model

Distribution of torsional stiffness along blade
Development of a 5MW 61m blade model
Development of a 5MW 61m blade model

Distribution of chordwise centre of gravity location along blade
[3] Work underway:
Modelling of the dual-axis fatigue test loading developed by NaREC – using constant resonant masses (CRM)
Modelling of the dual-axis fatigue test loading developed by NaREC – using constant resonant masses (CRM)
Modelling of the dual-axis fatigue test loading developed by NaREC – using constant resonant masses (CRM)
Modelling of the dual-axis fatigue test loading developed by NaREC – using constant resonant masses (CRM)

> Strain animation…
Comparison of different materials (collaboration with U. Manchester) 
application of material data from baseline glass/epoxy material, HiperTex glass fibre with 
baseline epoxy, baseline glass with nano-particles reinforced epoxy

### Isotropic materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Foam</th>
<th>Steel</th>
<th>Glue_Hysol_EA_9309_2NA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal thickness (m)</td>
<td>0.02</td>
<td>0.01</td>
<td>1</td>
</tr>
<tr>
<td>Density (kg/m³)</td>
<td>45</td>
<td>7850</td>
<td>1100</td>
</tr>
<tr>
<td>Young's Modulus E (N/m²)</td>
<td>2.600E+09</td>
<td>2.100E+11</td>
<td>2.343E+09</td>
</tr>
<tr>
<td>Poisson's Ratio (-)</td>
<td>0.3</td>
<td>0.28</td>
<td>0.385</td>
</tr>
</tbody>
</table>

### Anisotropic composites

<table>
<thead>
<tr>
<th>Material</th>
<th>GFRP_UD</th>
<th>GFRP_pm45</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal thickness (m)</td>
<td>0.0026</td>
<td>0.001</td>
</tr>
<tr>
<td>Density (kg/m³)</td>
<td>1950</td>
<td>1950</td>
</tr>
<tr>
<td>Longitudinal Young's Modulus E1 (N/m²)</td>
<td>3.807E+10</td>
<td>1.190E+10</td>
</tr>
<tr>
<td>Transverse Young's Modulus E2 (N/m²)</td>
<td>1.053E+10</td>
<td>1.190E+10</td>
</tr>
<tr>
<td>In-plane Poisson's Ratio (-)</td>
<td>0.18</td>
<td>0.55</td>
</tr>
<tr>
<td>In-plane shear modulus G12 (N/m²)</td>
<td>3.840E+09</td>
<td>1.129E+10</td>
</tr>
<tr>
<td>Out-of-plane longitudinal shear modulus G13 (N/m²)</td>
<td>3.840E+09</td>
<td>1.129E+10</td>
</tr>
<tr>
<td>Out-of-plane transverse shear modulus G23 (N/m²)</td>
<td>3.840E+09</td>
<td>1.129E+10</td>
</tr>
</tbody>
</table>
[4] Longer term work:
Look at smart blade concepts:
e.g. static structural analysis of blade with aerodynamic flaps, deformable trailing edge, flap/twist coupling, active or passive devices

Figure 14. Design and mounting of the actuators.
Barlas & van Kuijik 2007
Thanks!

Discussion