Rapid questions – rapid prototyping – rapid answers: 3d printing in small wind turbine tests

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Bloomington, MN, USA, 04/10/2018
Our **people** behind the **success**
Question:
How to conduct load tests for a 3d printed wind turbine blade?

Prototype:
Small scale prototype 1:6 scale – bench and force platform

Answer:
.... It’s coming!* 😊

*Based on student project by Hippolyte Menestreau „Studies of a 3D-printed wind turbine blade”, Lodz University of Technology, January 2018.
Blade testing standard BS EN 61400-23:2014

Test procedure

- Mass/COG of the blade
- Natural frequencies of the blade
- Static load test
- Fatigue load test
Static test – design load case

Characteristics of a wind turbine stage

@ 18 m/s wind speed

Rotational speed range 300 rpm to 7100 rpm

Increment of 200 rpm between each test
Static test – design load case

Characteristics of a wind turbine stage

Maximum load at 3900 rpm @ wind speed of 18 m/s

1st flapwise at 4980 rpm
Characteristics of a wind turbine stage

Maximum load at 3900 rpm @ wind speed of 18 m/s

1st flapwise at 4980 rpm

Shear force distributions $F = f\left(\frac{r}{R}\right)$ @3900 rpm

Moment distributions $M = f\left(\frac{r}{R}\right)$ @3900 rpm

Static test – design load case
Static test – design load case

Whiffle-tree design

Ø0.4 mm nylon strings

2nd stage beam

1st stage beams

3D printed blade

Holder
Static test – design load case

Whiffle-tree design

Turnbuckle:
- to level the beam

2nd stage beam

Ø0,4 mm nylon strings

1st stage beams

3D printed blade

Holder
Turnbuckle: to level the beam
Counter-weight: to balance the beam

Static test – design load case

Whiffle-tree design

2nd stage beam
Ø0.4 mm nylon strings
Turnbuckle
Counter-weights
1st stage beams
3D printed blade
Holder
Static test — design load case

Whiffle-tree design

Turnbuckle:
  to level the beam

3d printing turnbuckle bolts and frame
Whiffle-tree design

Turnbuckle: to level the beam

Counter-weight: to balance the beam

Design with channels and holders for 3d printing

3d printing turnbuckle bolts and frame

Easy: rope slides into the channel

Secure: pin is locked between the holders

Fast: pin is knotted to the rope before assembly

Static test – design load case
Static test – design load case

Blade testing

<table>
<thead>
<tr>
<th>Mass (g)</th>
<th>Primary load (N)</th>
</tr>
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<tbody>
<tr>
<td>78</td>
<td>0.765</td>
</tr>
<tr>
<td>206</td>
<td>2.02</td>
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<td>12.2</td>
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<tr>
<td>1370</td>
<td>13.4</td>
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<tr>
<td>1490</td>
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<td>1540</td>
<td>15.1</td>
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<td>1620</td>
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<tr>
<td>2170</td>
<td>21.3</td>
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<tr>
<td>3430</td>
<td>33.6</td>
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</table>

Design load case

Nylon string was torn apart

... while 3d printed blade returned to its original shape!
Static test – design load case

Test results (deflection)

![Graph showing test results with different markers for Tip, Saddle 4, Saddle 3, and Saddle 2. The x-axis represents Primary mass (g) ranging from 0 to 2500, and the y-axis represents Blade deflection (cm) ranging from 0 to 5. The graph includes data points for each mass and deflection, showing the relationship between the two variables.]
Static test – design load case

Test results (deflection)

Stress – deflection @ Saddle 2

$y = 1870x$

Stress – deflection @ Saddle 3

$y = 904x$

$$\sigma_x = \frac{M \cdot Y_d}{I_x}$$
Test results (Young modulus)

\[ w(x)'' = \frac{M(x)}{E \cdot I_x} \]

\[ y = -7.4226x + 2.2341 \]

\[ R^2 = 0.90 \]

<table>
<thead>
<tr>
<th>Primary Load (N)</th>
<th>Radial distance (m)</th>
<th>0.11</th>
<th>0.14</th>
<th>0.16</th>
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</thead>
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<td>1.02</td>
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<td>1.11</td>
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<td>1.69</td>
<td>1.33</td>
<td>1.30</td>
<td></td>
</tr>
</tbody>
</table>

Average (GPa) 1.45 1.12 1.09

\( E = 1.95 \text{ GPa} \) – Young modulus of ABS material according to Zortrax
Nowadays...

**Rapid question:**
How much does a winglet increase power output of a small wind turbine?

**Rapid prototype:**
Small scale prototype 1:6 scale – wind tunnel

**Rapid answer:**
By about 2-3%
<24h fast track

- Preparing / modifying existing 3D model
- Generating code for 3D printer
- 3D printing (10-12 hours)
- Model finishing / support removal / polishing
- Wind tunnel test
- Wind tunnel warmup
- Results post-processing
<24h fast track

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<24h fast track

16:00 17:00 18:00 19:00 20:00 21:00 22:00 23:00 0:00 1:00 2:00 3:00 4:00 5:00 6:00 7:00 8:00 9:00 10:00 11:00 12:00 13:00 14:00

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16:00
Preparing / modifying existing 3D model
Generating code for 3D printer

18:00
20:00
21:00
22:00
23:00

24
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00

3D printing (10-12 hours)

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Results post-processing

Wind tunnel test

Wind tunnel warmup
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3d printing for lab test...

3d printed rotor, torquemeter and generator housings
<24h fast track

Preparing / modifying existing 3D model
Generating code for 3D printer

3D printing (10-12 hours)

Model finishing / support removal / polishing

Results post-processing

Wind tunnel test
Wind tunnel warmup
<24h fast track
Open field test to quantify real data

\[ C_{p_{\text{avg}}} = 0.65, \text{AF}=99\% \]

\[ C_{p_{\text{avg}}} = 0.75, \text{AF}=100\% \]

OPEN FIELD TEST

3D CFD

\[ \text{TSR}_{\text{avg}} = 6.76, V_{\text{avg}}=3.1 \text{ m/s} \]

\[ \text{TSR}_{\text{avg}} = 6.00, V_{\text{avg}}=5.0 \text{ m/s} \]

Algorithm for the innovative product development in the field of aerodynamics using multiple levels of numerical-experimental research integration
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