Analysis of Tower Shadow Effects on the UAE Rotor Blades

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Down Wind?  
Tower Shadow?

• Does tower shadow effect blade aerodynamics?
• Does it effect bending moments?

• Can we trust predictive models developed to answer these questions?
• Experimental data is needed
UAE (Unsteady Aerodynamics Experiment)

- Turbine specifications
  - Grumman Wind Stream-33
  - 2 Blade
  - 10m Rotor Diameter
  - Rated Power 20 kW

- Hundreds of different configurations
  - Testing upwind and downwind rotors,
  - Testing faired and unfaired tower
  - Varying flow speed, rotational speed, yaw, coning, pitch and more

- Hundreds of different parameters
  - Flow field, pressure distributions, bending moments, accelerations, power, and more
Research Goals

1. Analyze the UAE data
2. Identify & understand tower shadow aerodynamics
3. Determine strengths and limitations of FAST
Tower Fairing

Dimensions:

S = 3.66m

t = 0.46m

C = 0.89m

t/C = 0.517
Experimental Description

**Upwind Baseline:**
- UC

**Downwind Baseline:**
- DC

**Downwind Fairied:**
- DF0 - $\theta = 0^\circ$
- DF10 - $\theta = 10^\circ$
- DF20 - $\theta = 20^\circ$

<table>
<thead>
<tr>
<th>Parameter</th>
<th>UC</th>
<th>DC</th>
<th>DF</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_\infty$ (m/s)</td>
<td>5-25</td>
<td>5-25</td>
<td>5-25</td>
</tr>
<tr>
<td>RPM</td>
<td>72</td>
<td>72</td>
<td>72</td>
</tr>
<tr>
<td>Rotor</td>
<td>Rigid</td>
<td>Teetered</td>
<td>Rigid</td>
</tr>
<tr>
<td>Cone Angle</td>
<td>0</td>
<td>3.4</td>
<td>3.4</td>
</tr>
</tbody>
</table>
Parameter Description

Measured Parameters
- Relative Flow Velocity: $V_{rel}$
- Relative Flow Angle: $\alpha_{rel}$
- Normal Force Coefficient: $C_n$
- Root Flap Bending Moment: $M_b$

Instrumentation
- Relative Flow Field: 5-hole Probes ($r/R=0.67$)
- Pressure Distributions: Pressure Taps ($r/R=0.63$)
- Bending Moments: Strain Gauges
FAST

- Fatigue, Aerodynamics, Structures, and Turbulence (FAST)
- Comprehensive aeroelastic simulator developed by NREL
- Modeled the UAE
- Compared modeled & experimental

- Faired tower modeled with low drag coefficient, C_d=0.25
- Unfaired tower modeled with default drag coefficients
Tower Fairing

Dimensions:

- $t = 0.46 \text{m}$
- $C = 0.89 \text{m}$
- $S = 3.66 \text{m}$
Relative Flow Velocity

- Both increase and decrease in velocity
- FAST only captures average velocity
Relative Flow Angle

- Shadow effects $\alpha_{\text{rel}}$ less than zero
- FAST under predicts shadow effect
Normal Force Coefficient

- Similar asymmetry
- FAST over predicts average $C_n$
Root Flap Bending Moment

- Wake affects RFBM
- FAST doesn’t predict bending well
Bending Mean

DC 10 m/s

\[ M_b \, [\text{kNm}] \]

\[ \psi \, [\text{deg}] \]

- UAE
- FAST
- UAE mean
- FAST mean

\[ M_b \, [\text{kNm}] \]

\[ V_\infty \, [\text{m/s}] \]

UC Mean

DF0 Mean
**Bending Range**

**DC 10 m/s**

- UAE
- FAST
- UAE Range
- FAST Range

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**UC Range**

**DF0 Range**
Conclusions

- Flow fields are unsteady & relative wake is asymmetric
- Tower shadow negatively influences root bending moments
- Fairing reduces tower shadow effects
- Fairing improvements are lost with yawed fairing
- FAST does not fully capture tower shadow complexities
Questions and Comments