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# Analysis of Tower Shadow Effects on the UAE Rotor Blades

Carlos Noyes (Graduate Student)

Chao Qin (Research Associate)

Eric Loth (Professor)

Scott Schreck (Principal Engineer)



# 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



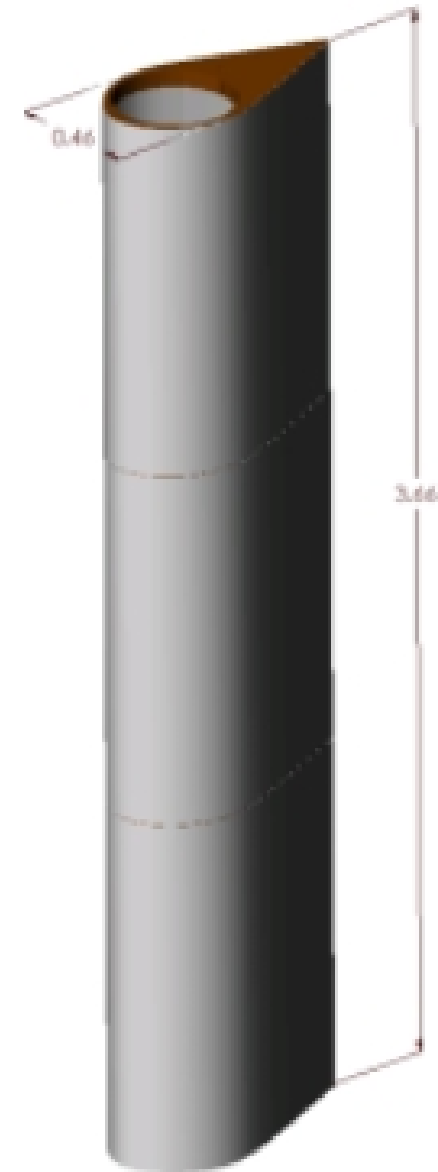
Dimensions:

$$S=3.66\text{m}$$

$$t=0.46\text{m}$$

$$C=0.89\text{m}$$

$$t/C=0.517$$



# Experimental Description

Upwind Baseline:

UC

Downwind Faired:

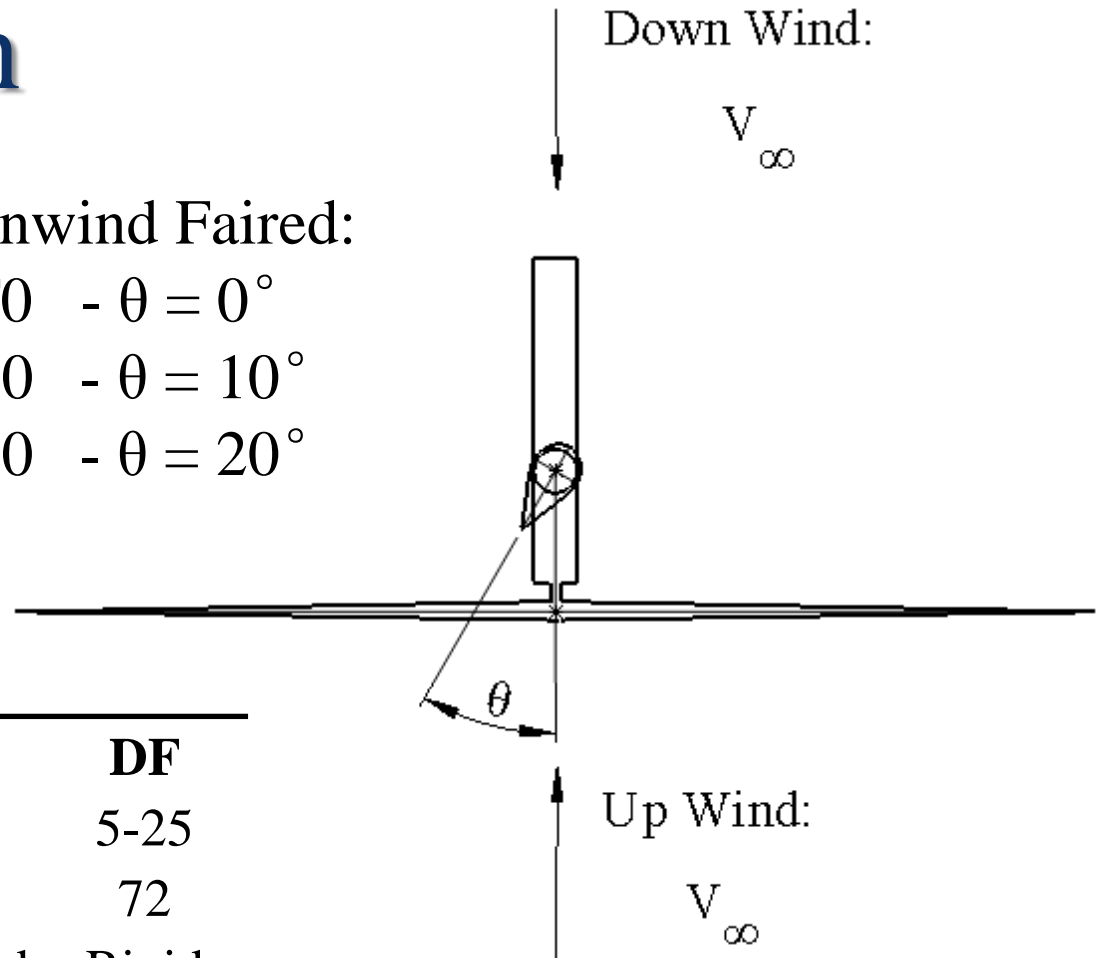
DF0 -  $\theta = 0^\circ$

DF10 -  $\theta = 10^\circ$

DF20 -  $\theta = 20^\circ$

Downwind Baseline:

DC



|                                    | <b>UC</b> | <b>DC</b> | <b>DF</b> |
|------------------------------------|-----------|-----------|-----------|
| <b><math>V_\infty</math> (m/s)</b> | 5-25      | 5-25      | 5-25      |
| <b>RPM</b>                         | 72        | 72        | 72        |
| <b>Rotor</b>                       | Rigid     | Teetered  | Rigid     |
| <b>Cone Angle</b>                  | 0         | 3.4       | 3.4       |

# Parameter Description

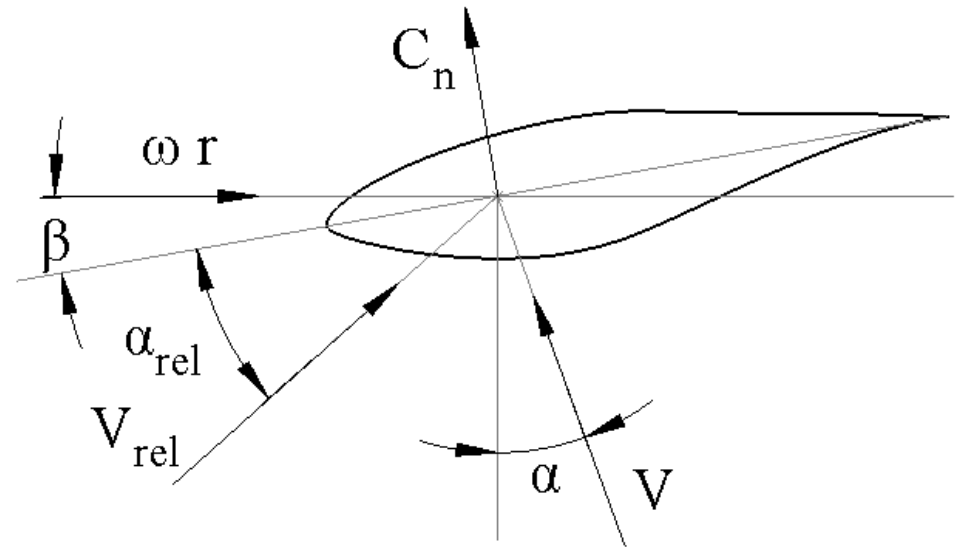
## Measured Parameters

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 ( $r/R=0.63$ )

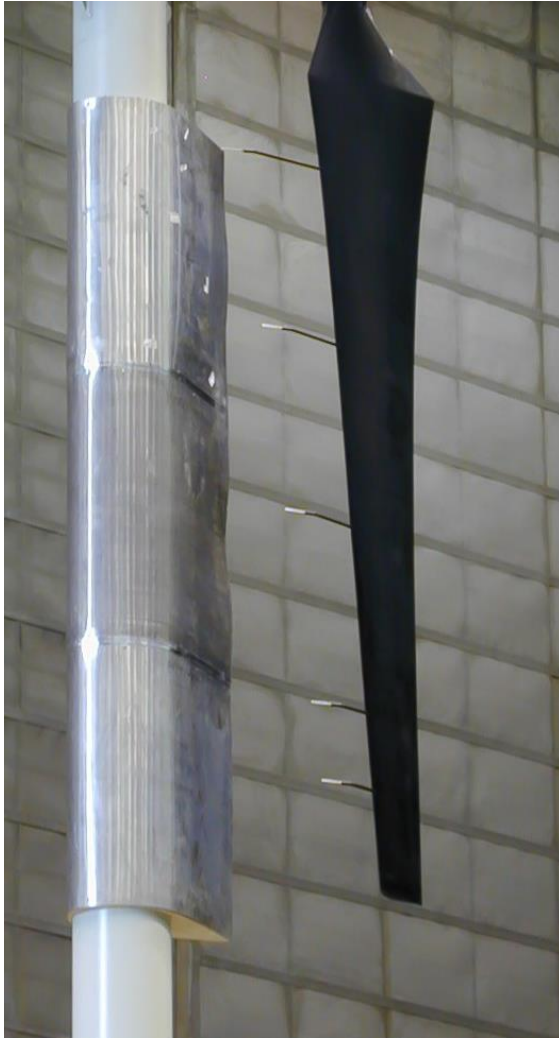
Bending Moments: Strain Gauges

# 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

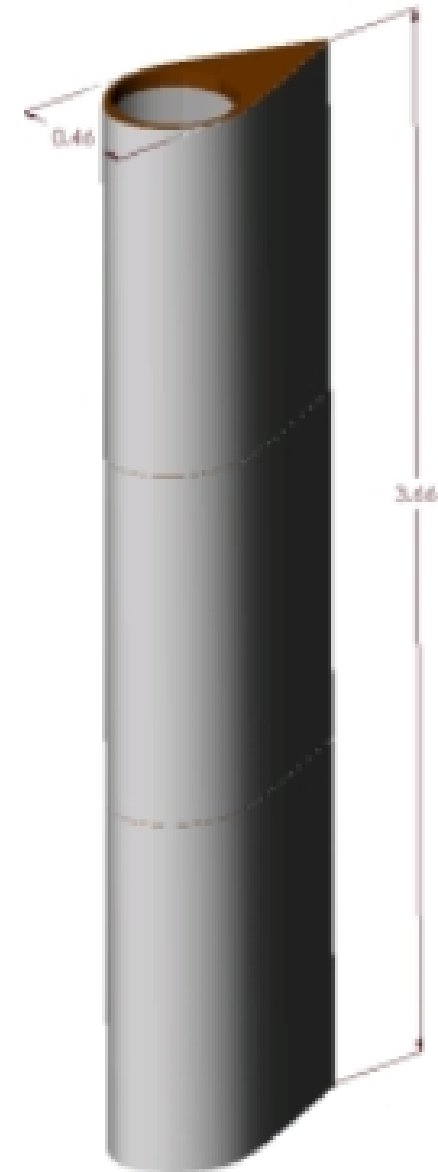


Dimensions:

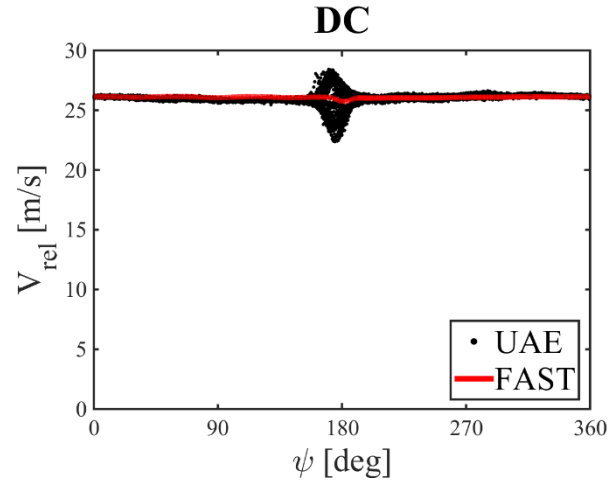
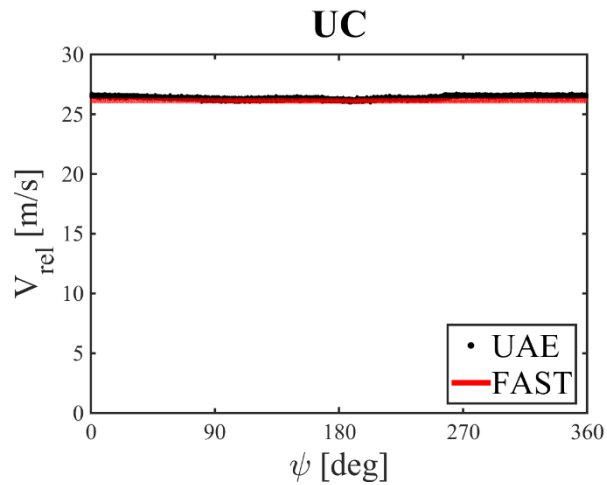
$$t=0.46\text{m}$$

$$C=0.89\text{m}$$

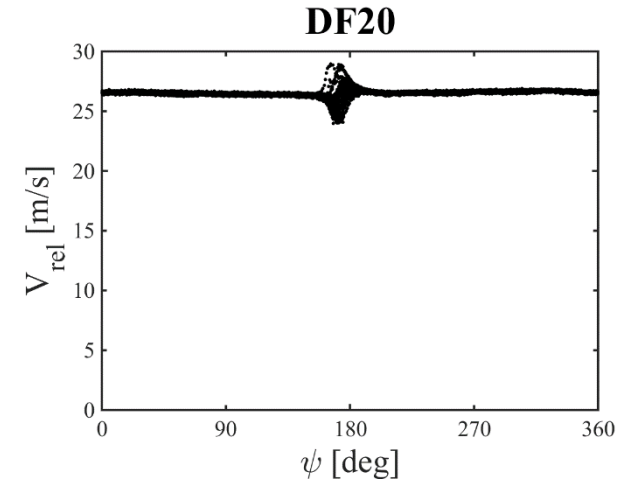
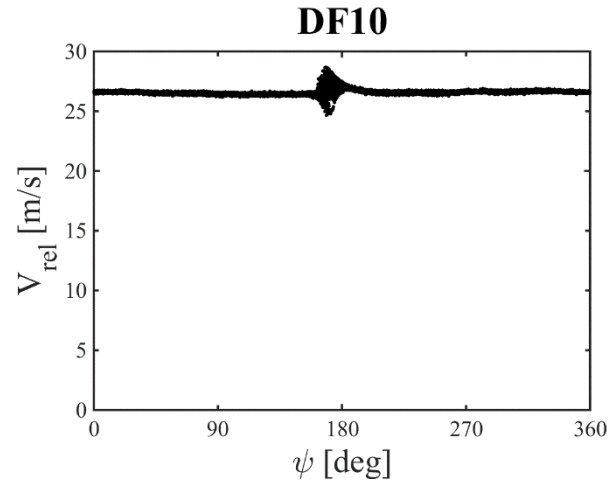
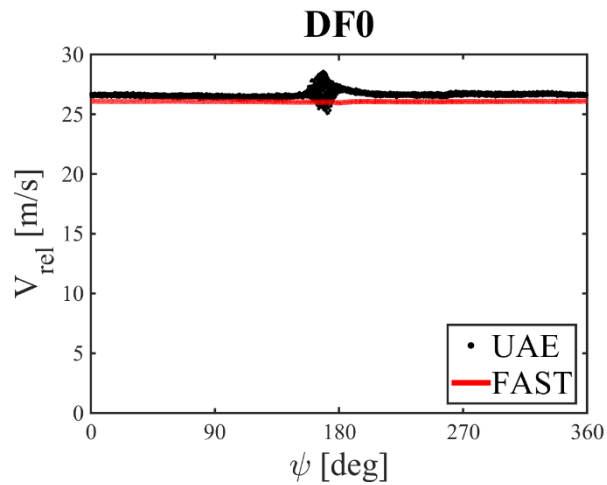
$$S=3.66\text{m}$$



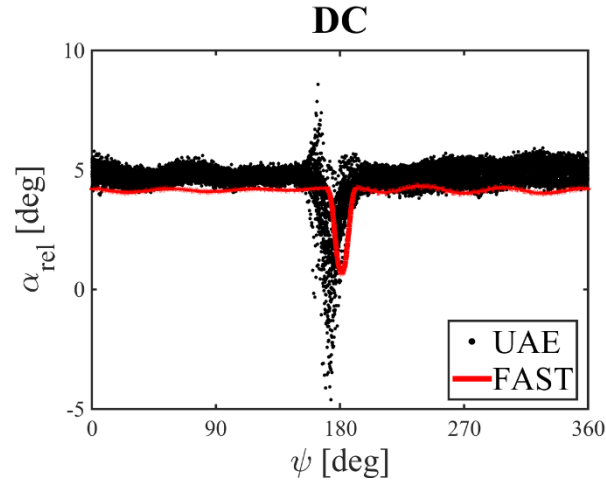
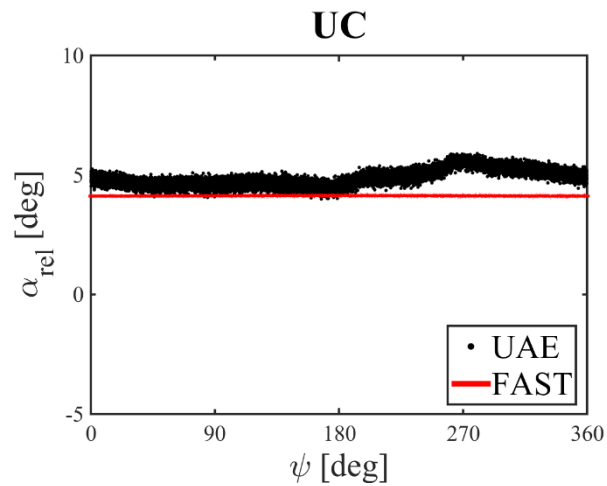
# Relative Flow Velocity



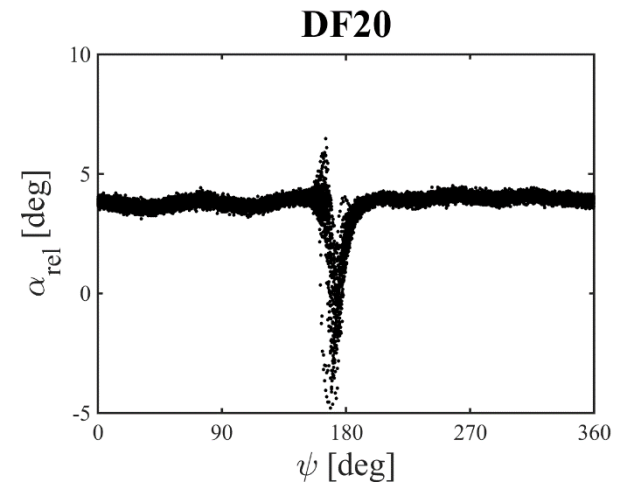
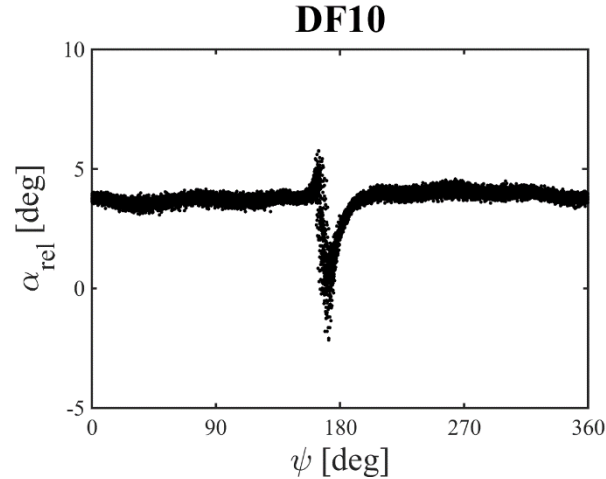
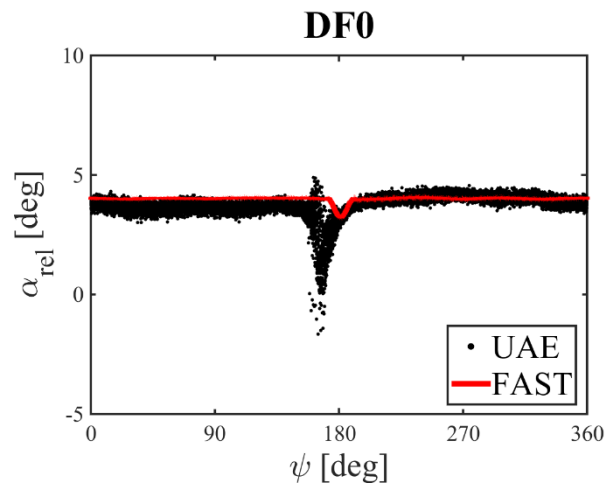
- Both increase and decrease in velocity
- FAST only captures average velocity



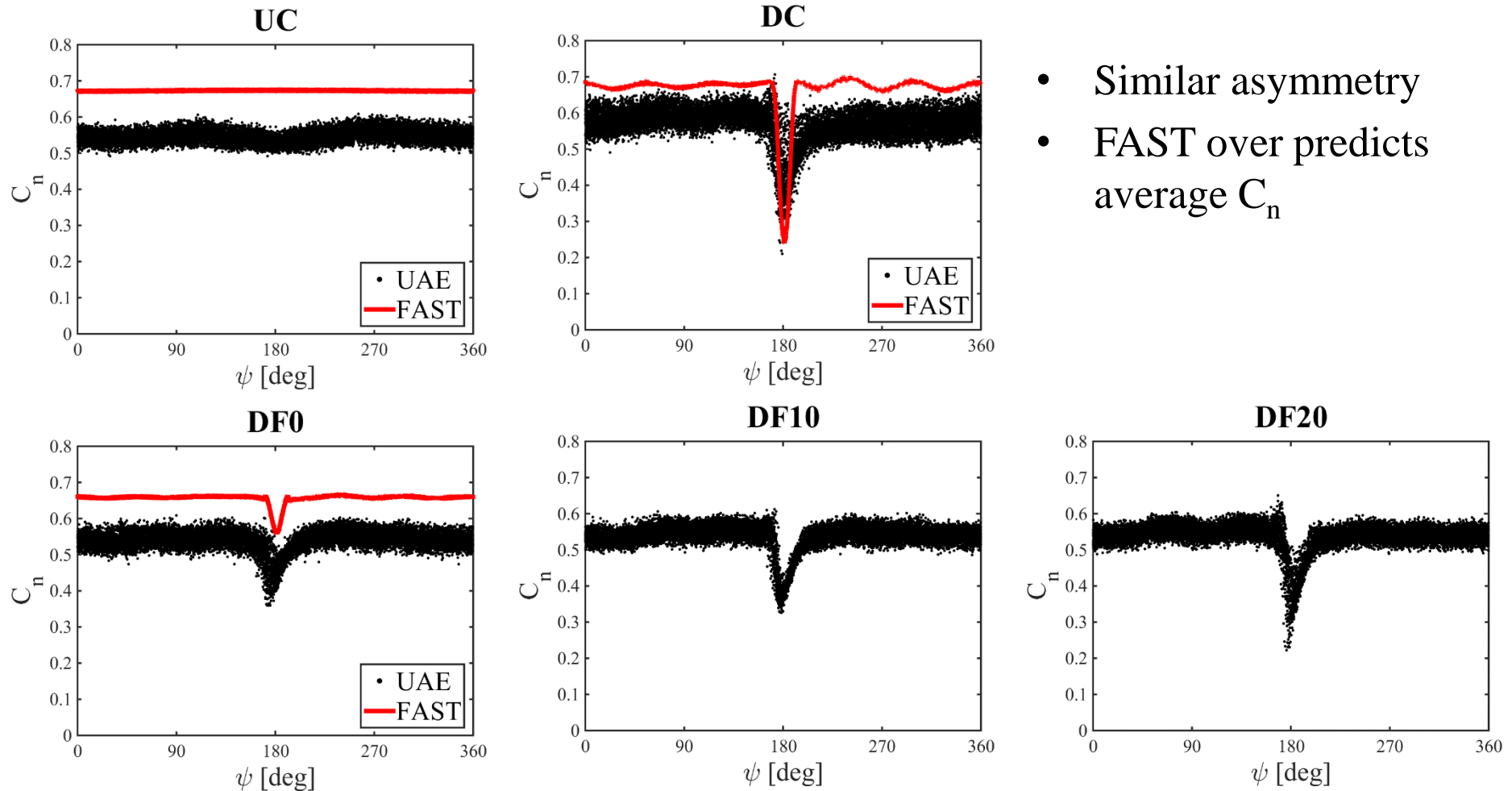
# Relative Flow Angle



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

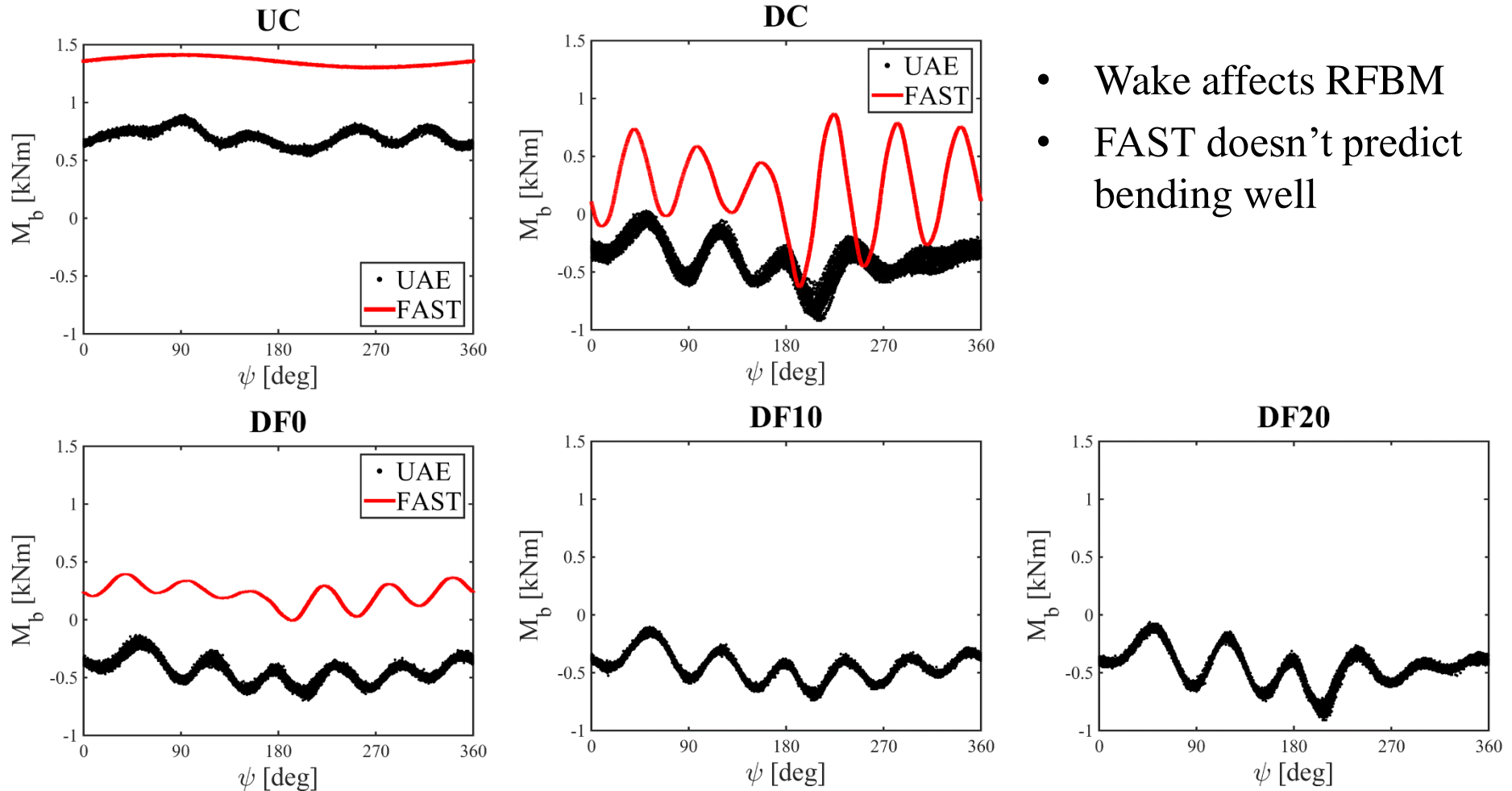


# Normal Force Coefficient



- Similar asymmetry
- FAST over predicts average  $C_n$

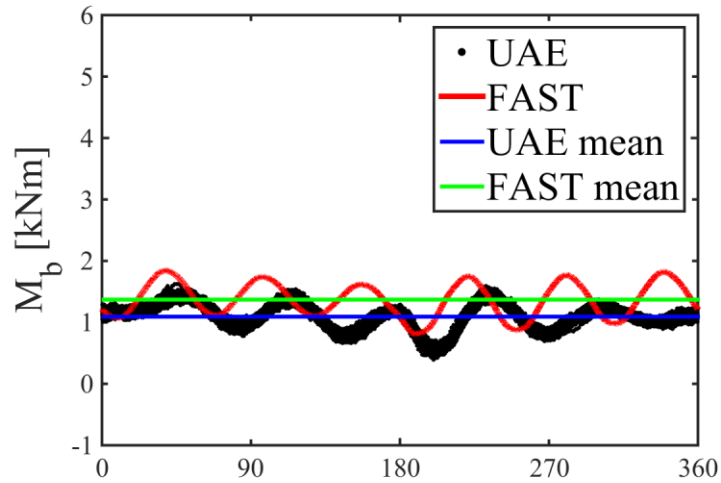
# Root Flap Bending Moment



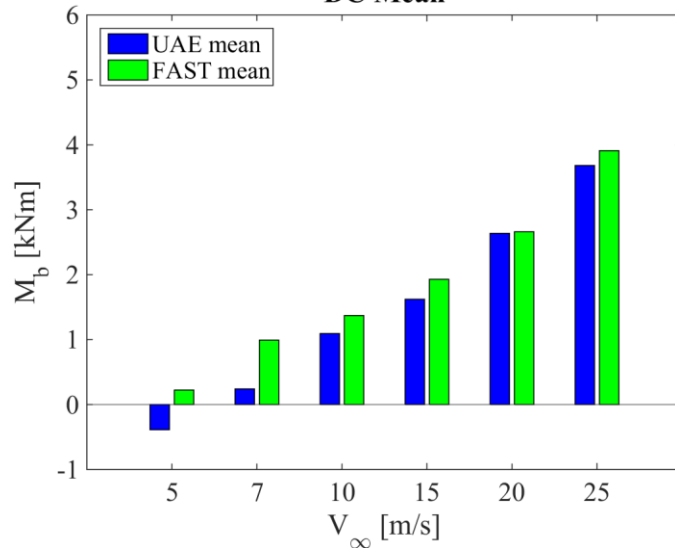
- Wake affects RFBM
- FAST doesn't predict bending well

# Bending Mean

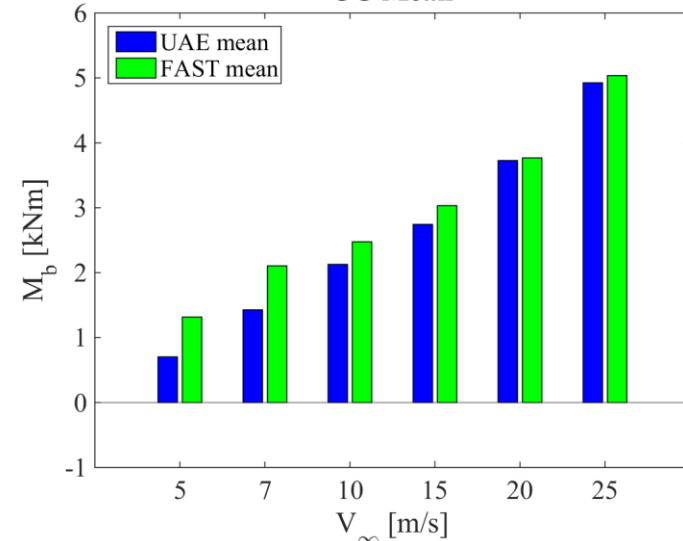
DC 10 m/s



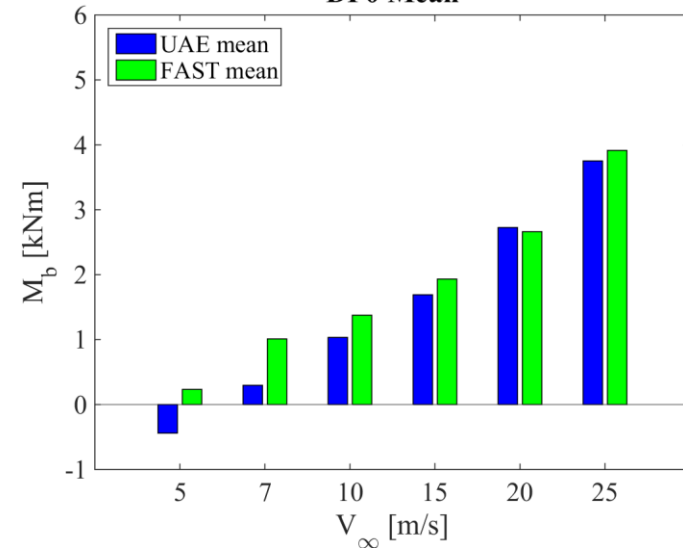
DC Mean



UC Mean

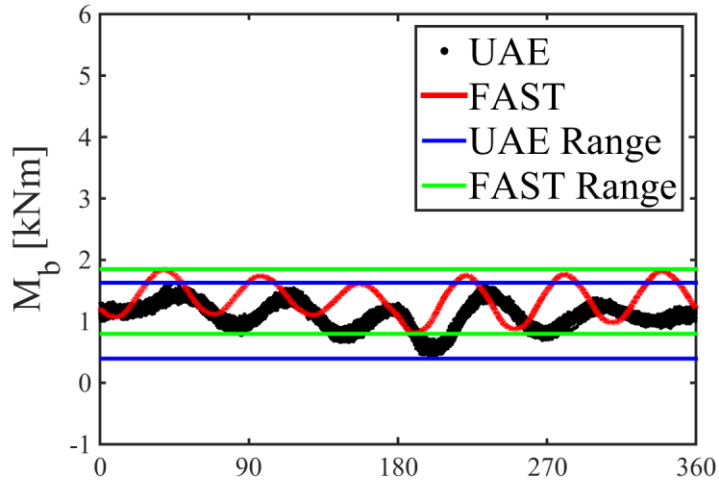


DF0 Mean

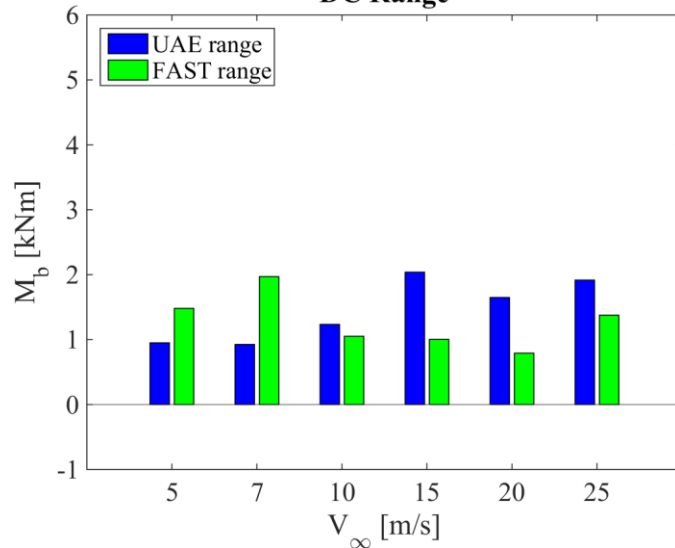


# Bending Range

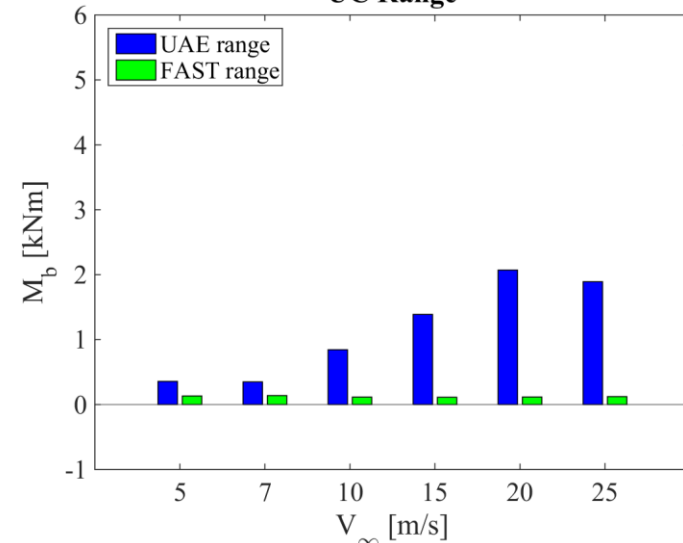
DC 10 m/s



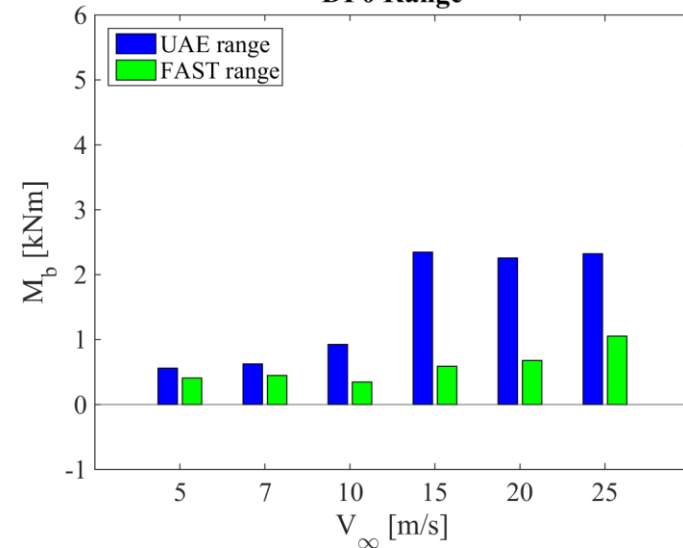
$\psi$  [deg]  
DC Range



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*