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Scaled Experiments at SWiFT

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Outline

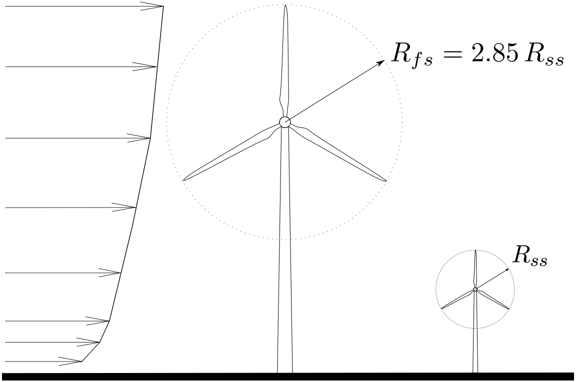
- Consideration of Inflow in Relation to Height and Size of Rotors
- Scaled Wake and NRT Design
- Other Topics

Scaling Perspective

- Wind turbines will continue to become larger
- Wind turbine designs can be scaled up or down, but not every dimensionless parameter can be kept constant
- Determine which dimensionless parameters are most important for research goals

Inflow Conditions

- Data from TTU 200 m meteorological tower
- Compare probability of subscale and full-scale inflow conditions



Scaled Inflow

shear

$$\tau^* = \frac{U_t - U_b}{U_h} \tag{1}$$

turbulence intensity

$$TI = \frac{\sigma(U_h)}{\overline{U}_h} \tag{2}$$

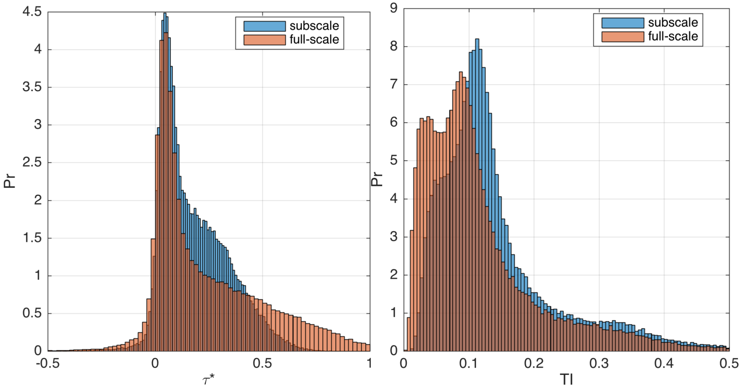
veer

$$V = \theta_t - \theta_b \tag{3}$$

lateral turbulence intensity

$$LTI = \frac{\sigma(\theta_h)}{\overline{\theta}_h} \tag{4}$$

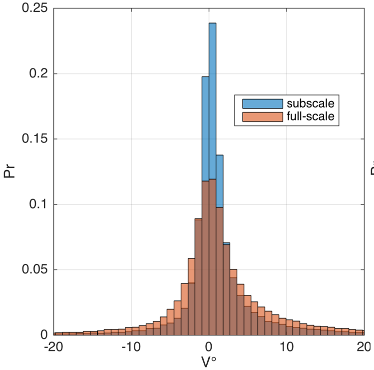
SWiFT Wind Resource

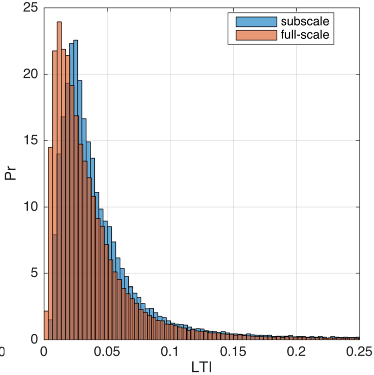


shear has equal modes

turbulence has equal ranges

SWiFT Wind Resource

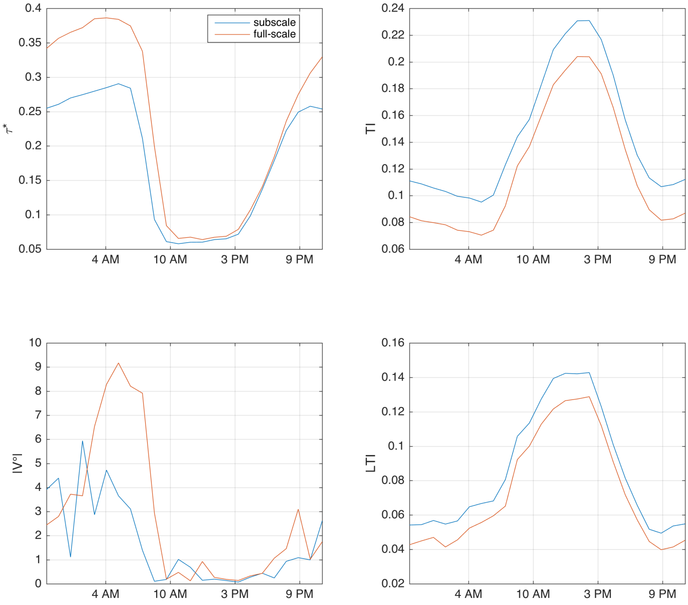




0 V_{ss} more common

higher TI_{ss} causes more $\sigma(\theta_{ss})$

SWiFT Average Day



Inflow Conclusions

- Inflow conditions may not be equal at same instant of time
- May need to wait longer for rarer event at subscale
- Range of TI, V, and LTI equivalent
- Late morning and afternoon average shear and veer are equal between scales
- Full-scale turbines occasionally see higher shear above 75% (Pr = 4%)

Blade Design and Functional Scaling

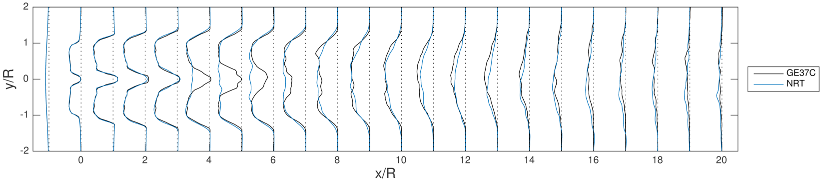
✓ Designed to Scale

- $\Gamma'(\frac{r}{R})$ the spatial distribution of dimensionless, bound circulation to shed equal trailing circulation
- Equal $\Gamma'(\frac{r}{R})$ between scales also means equal induction and thrust coefficient ($a(\frac{r}{R})$ and C_T), and the axial velocity of the near wake
- Tip-speed-ratio, λ, for equal tip vortex spacing and parallel streamlines
- Equal initial conditions for velocity field in wake
- Consideration of inflow and location in ABL

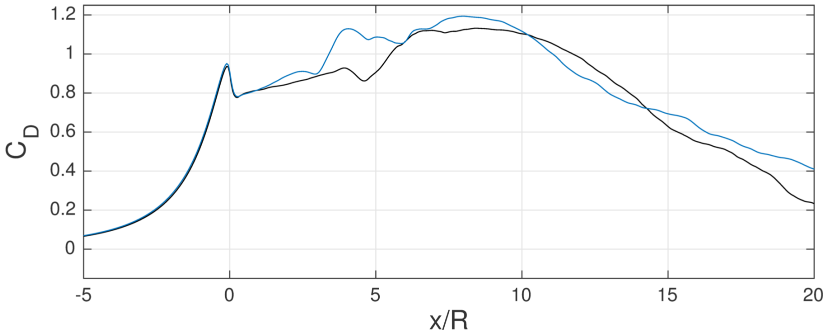
✗ Not Designed to Scale

- Re_c, Re_D, L/D, C_P, geometry, aeroelasticity, above parameters outside Region 2

Average Axial Velocity



Momentum Recovery



NRT Conclusions

- Parameters were chosen to create scaled wake of GE 1.5 MW machine
- NRT scaled wake experiments will confirm Γ', λ, a, C_T, are important to wake structure

Other Topics

- Re_c and Re_D
- Near wake is created by a distribution of forces, sufficient to create equal far wake mixing and recovery?
- Turbulence intensity created largest differences in wake recovery in LES

Table: Wake Reynolds Number, Re_D

scale	$Re_D \times 10^{-6}$	U_∞ (R2)	D (m)
subscale	7–12	4–8	27
full-scale	23–38	5–8	77

Aeroelasticity

- Lock Number: ratio of aerodynamic to inertial forces
- Similarly, time rate of change of circulation
- Would create equal gust response

$$C_{l_\alpha} \frac{c}{R} \frac{h_0}{R} \left(\frac{\omega_h}{\Omega} \right)^2 \lambda^2 = K \tag{5}$$

Aeroacoustics

- Tip and airfoil self-noise acoustic power: $SWL \propto (\Omega R)^5$
- NRT designed to have same max tip-speed as full-scale (≈ 74 m/s)

Conclusions

- NRT designed to create scaled wake
- One design cannot do it all
- Scaling is always important as blades continue to become larger
- Range of inflow conditions well represented at SWiFT