Large-eddy simulation of SWiFT turbines in different wind directions

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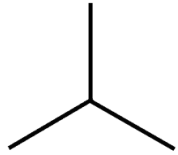
SWiFT Experimental Campaign

- Understand complex wake flows
- Highly instrumented blades and new blade designs, new measurement technologies
- Better understanding of scaling effects so results are relevant to MW turbines
- Followup to blade load distribution, shear, and TI study

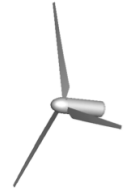
VWiS: A high fidelity simulation tool

- Virtual Wind Simulator (VWiS) developed St. Anthony Falls Lab, University of Minnesota
- Incompressible continuity and Navier-Stokes equations
- Second-order central differencing; Second-order fractional step
- Large-eddy simulation with dynamic subgrid scale model
- Actuator disks, actuator lines, actuator surfaces and geometry resolving
- Capable of curvilinear immersed boundary method, complex terrains and an elastic blade

Actuator disk



Actuator line



Actuator surface

Geometry–resolving

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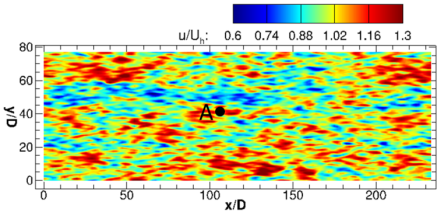
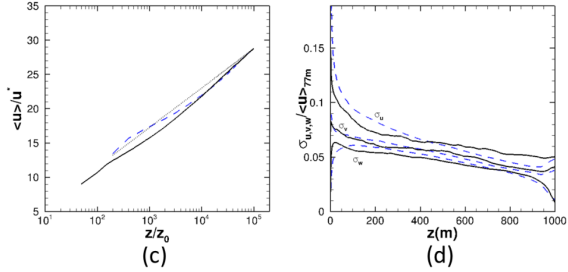
Turbulent Inflow Precursor

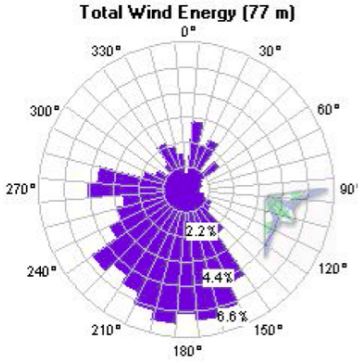
- (a) Coarse grid periodic simulation
- (b) Fine grid simulation using inflow interpolated from coarse grid simulation



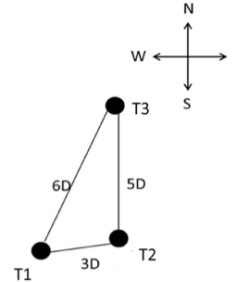


6 Simulation Cases

- $\lambda = 9$ (Region II), 4.7 (Region III)
- Wind Direction South, South-West, and West



(a)



(b)

Simulation Parameters

Table 2. Numerical set-up for SWiFT site characterization cases.

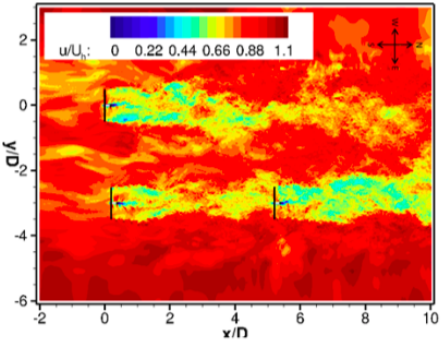
	S4.7† (S9)	W4.7 (W9)	SW4.7 (SW9)
$L_x(D) \times L_y(D) \times L_z(D)$	$12 \times 77 \times 37$	$10 \times 77 \times 37$	$12 \times 77 \times 37$
$N_x \times N_y \times N_z$	$1201 \times 561 \times 256$	$1001 \times 686 \times 256$	$1201 \times 685 \times 256$
$\delta t(D/U_h)$	1.4×10^{-3} (7×10^{-4})	1.4×10^{-3} (7×10^{-4})	1.4×10^{-3} (7×10^{-4})
Average time $(2\pi/\Omega^{\ddagger})$	81 (115)	64 (115)	64 (115)

† S4.7 represents SWiFT site characterization cases with wind blowing from the south and tip-speed ratio 4.7, which is the same for all other similar abbreviations in this table.

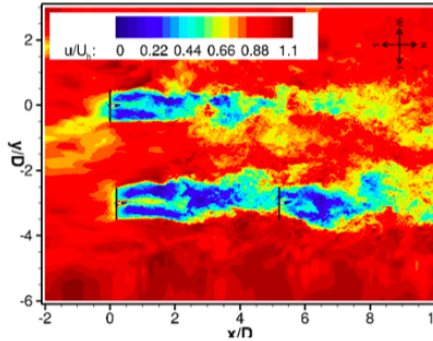
‡ Ω is the rotational speed of the turbine facing the free wind.

Instantaneous Velocity Field - South

S



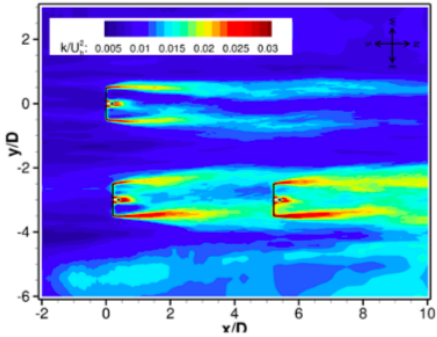
TSR=4.7, U_h=13.4 m/s



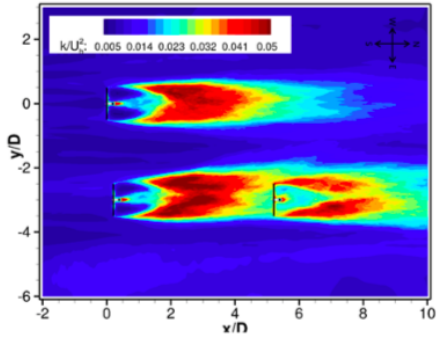
TSR=9, U_h=6.9 m/s

Turbulent Kinetic Energy - South

S



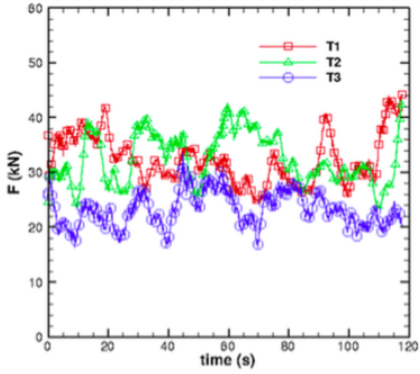
TSR=4.7, U_h=13.4 m/s



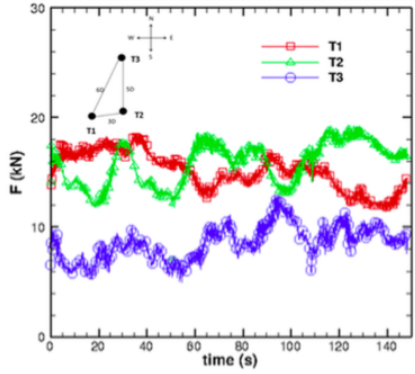
TSR=9, U_h=6.9 m/s

Thrust Force - South

S



TSR=4.7, U_h=13.4 m/s



TSR=9, U_h=6.9 m/s

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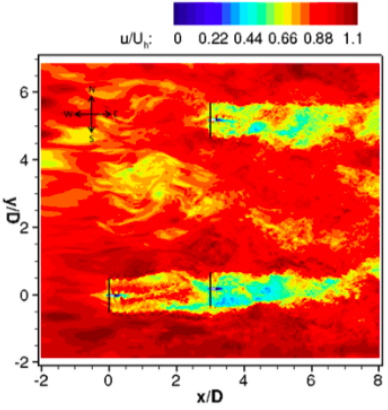
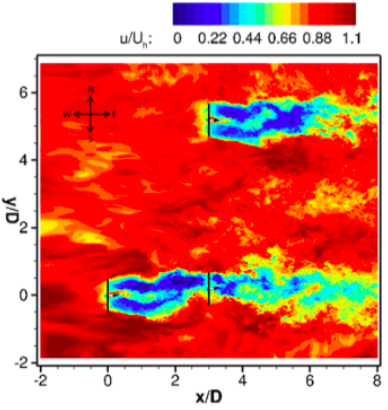
Instantaneous Velocity Field - West

W



TSR=4.7, U_h=13.4 m/s



TSR=9, U_h=6.9 m/s

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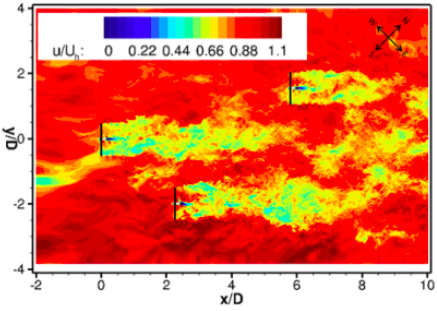
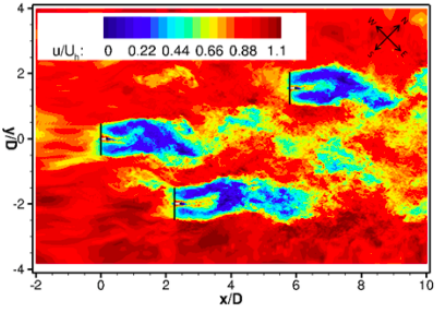
Instantaneous Velocity Field - South-West

SW



TSR=4.7, U_h=13.4 m/s



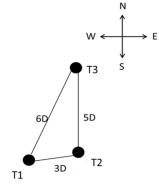
TSR=9, U_h=6.9 m/s

Array Performance

Table 3. Power and axial force coefficients and root-mean-square (rms) of the coefficients for SWiFT site characterization cases.

Case	Turbine	C_P	rms of C_P (%)	C_T	rms of C_T (%)	Averaged C_P †	Averaged rms of C_P (%) ‡
S4.7	T1	0.251	19.92	0.345	13.33	0.22	19.50
	T2	0.255	20.00	0.349	14.33		
	T3	0.156	18.59	0.249	13.25		
S9	T1	0.445	16.63	0.607	11.20	0.38	20.08
	T2	0.478	18.62	0.634	12.93		
	T3	0.212	25.00	0.344	18.02		
W4.7	T1	0.362	19.61	0.441	14.06	0.27	19.85
	T2	0.170	20.59	0.267	14.98		
	T3	0.279	19.35	0.371	13.74		
W9	T1	0.542	16.97	0.696	11.49	0.35	22.22
	T2	0.082	35.37	0.162	27.16		
	T3	0.426	14.32	0.592	9.97		
SW4.7	T1	0.218	15.60	0.315	11.11	0.25	15.87
	T2	0.284	15.49	0.376	10.90		
	T3	0.254	16.53	0.348	11.49		
SW9	T1	0.389	15.42	0.557	10.23	0.45	15.02
	T2	0.500	15.00	0.661	9.98		
	T3	0.458	14.63	0.662	9.36		

† Average of the C_P in the third column over three turbines for each case.
‡ Average of the rms of C_P in the fourth column over three turbines for each case.



Conclusions

- $\lambda = 9$, Region II
  - TKE rapidly expanded to entire wake width
  - Downwind turbines have significantly higher fluctuations in C_P and C_T
  - Wake meandering was observed
- $\lambda = 4.7$, Region III
  - Unsteady thrust force on upwind and downwind turbines were equal
- Blockage effect on T2 in SW wind