Land-based Downwind Wind Turbine Optimization

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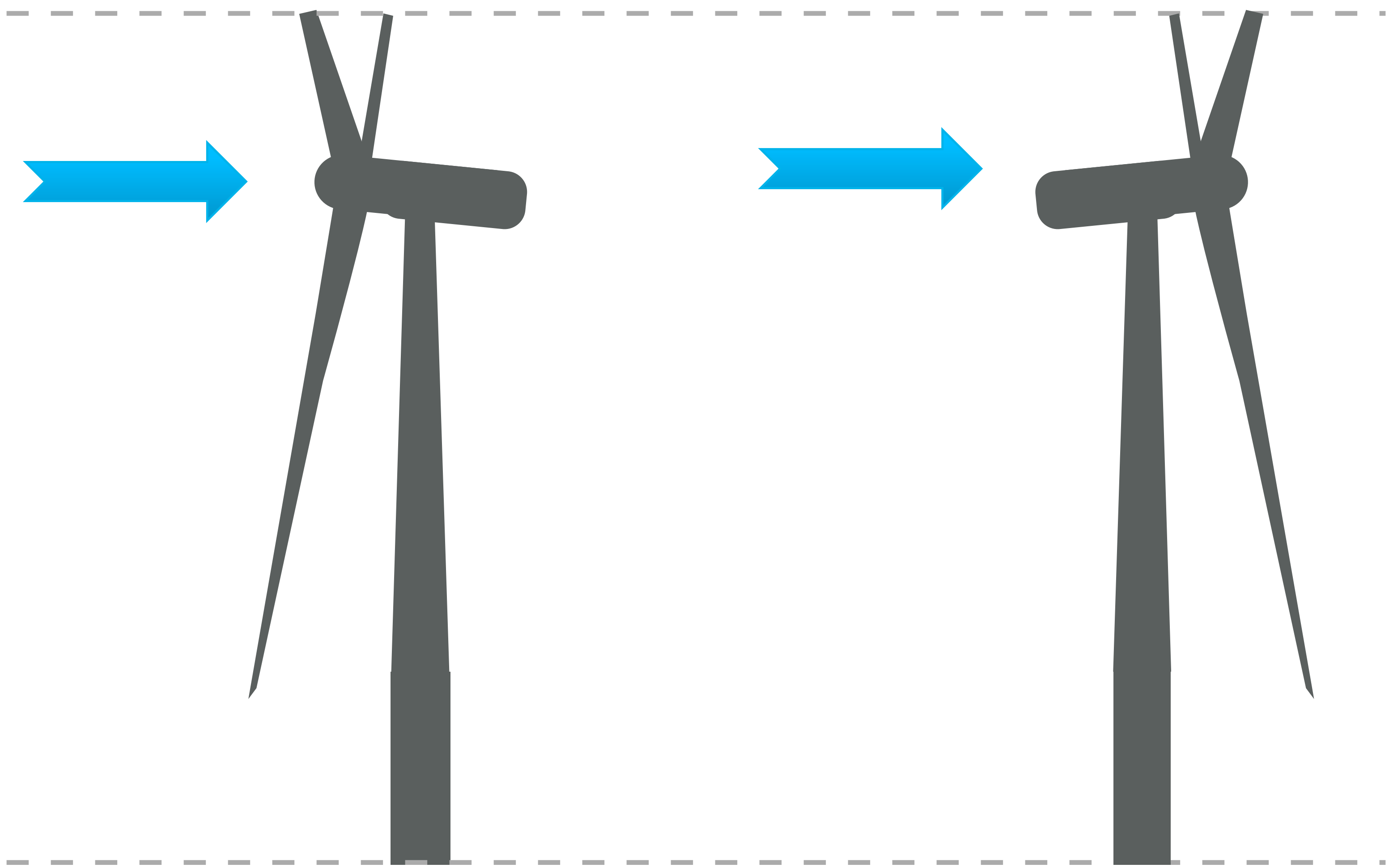
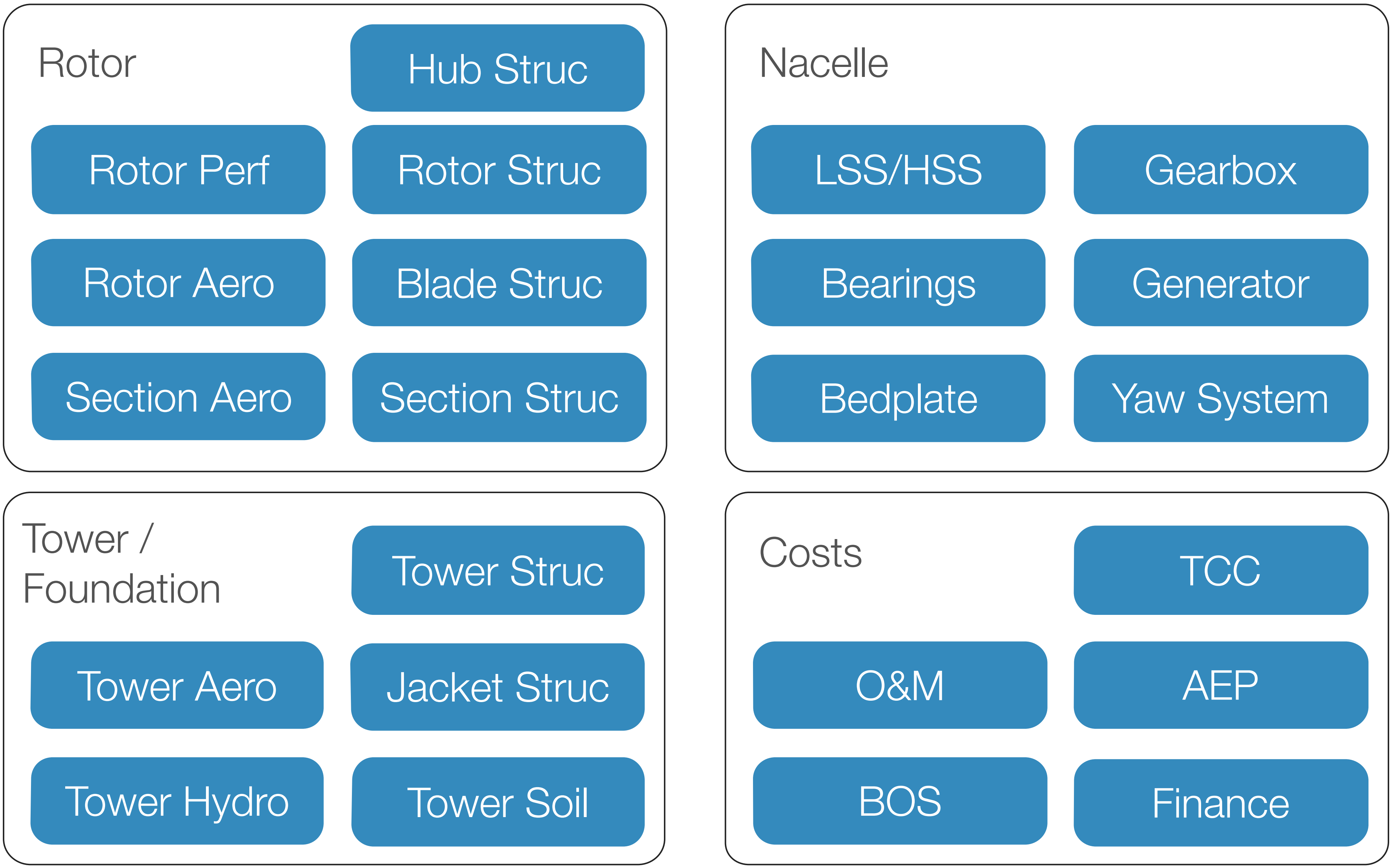
Downwind wind turbines may be advantageous at large scales because of the relaxed tower-strike constraint



WISDEM: Wind-Plant Integrated System Design and Engineering Model



A coupled, multidisciplinary approach

Discipline	Theory
Blade aerodynamics	Blade element momentum
Blade structures	Beam finite element, classical laminate theory
Tower aerodynamics	Power-wind profile, cylinder drag
Tower structures	Beam finite element, Eurocode and GL
Nacelle	Physics-based component models, Univ. of Sunderland
Cost	mass-based TCC, new BOS

35 design variables

Rotor

- chord distribution
- twist distribution
- spar-cap thickness distribution
- aft panel thickness distribution
- blade precurve distribution
- tip-speed ratio in Region 2

Nacelle

- bedplate I-beam dimensions
- low speed shaft lengths

Tower

- tower diameters
- tower wall thicknesses
- tower waist location
- tower height

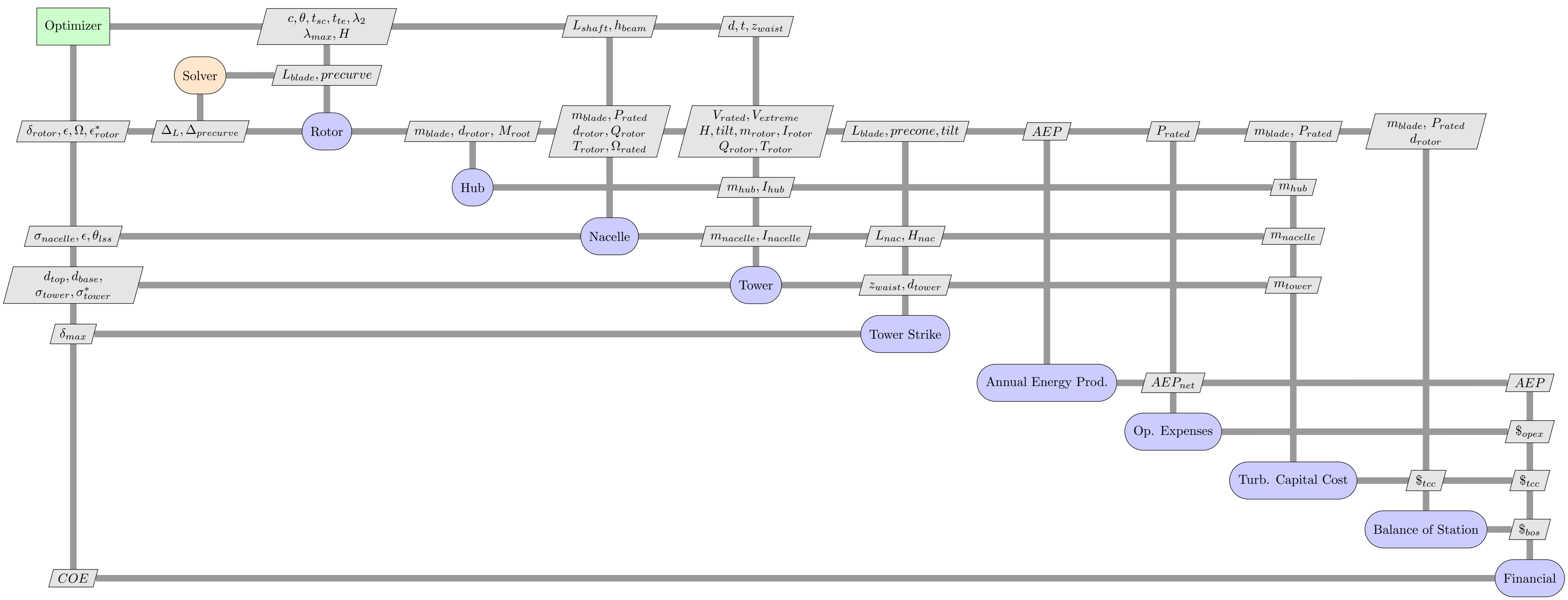
100+ constraints

r	n	t	
■		■	Natural Frequencies (resonance)
■	■		Deflections (tower strike, ground strike, bedplate)
■	■	■	Ultimate Stress/Strain (max wind and max thrust)
■		■	Buckling (panel, shell, global)
■		■	Fatigue Damage
■			Max Tip-Speed
■		■	Transportation
		■	Welding and Manufacturing

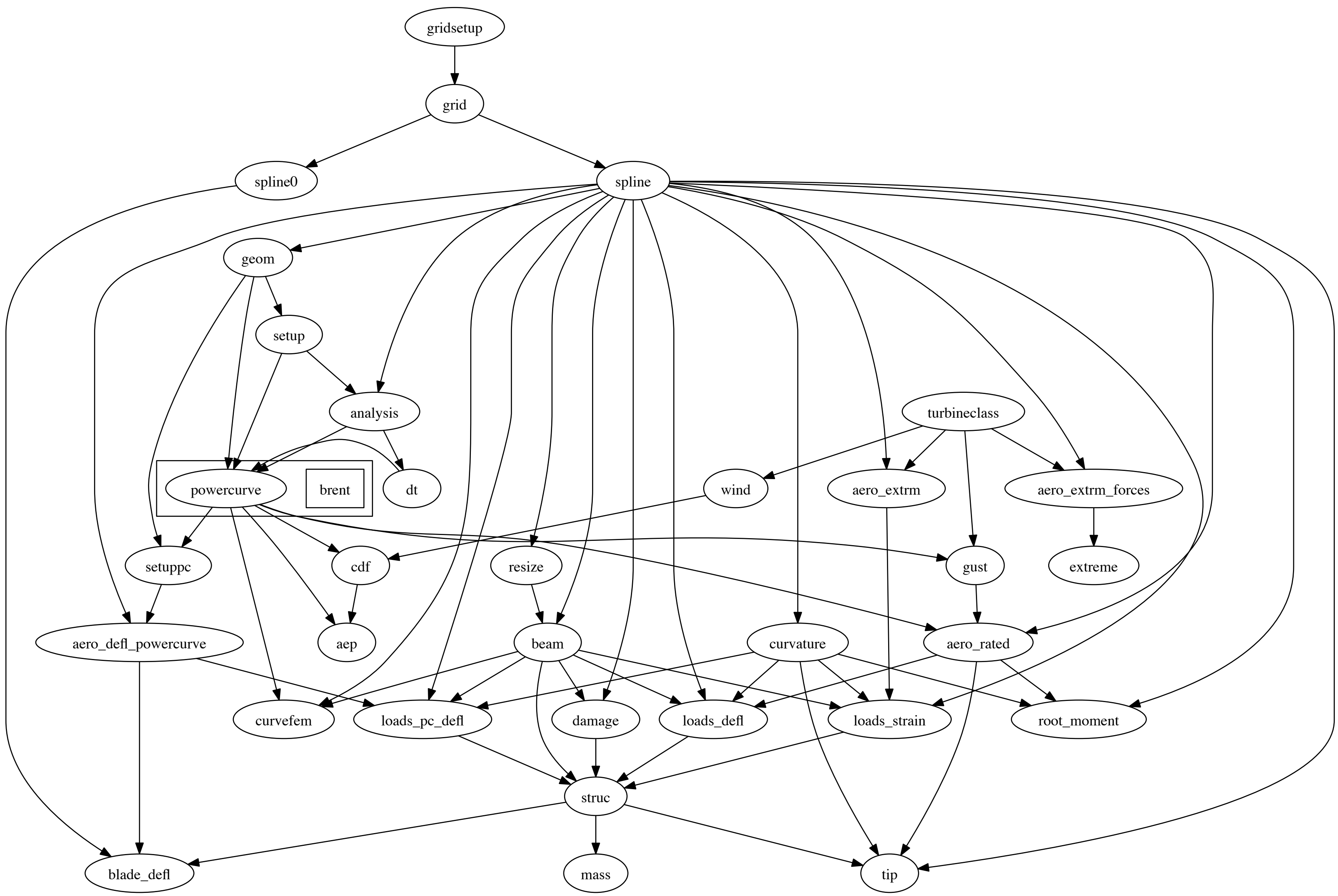
Several specific additions/modifications were made for this downwind study

- Converged aero/structural response
- Reductions in AEP due to blade curvature/deflection
- CurveFEM used to find natural frequencies of curved blades

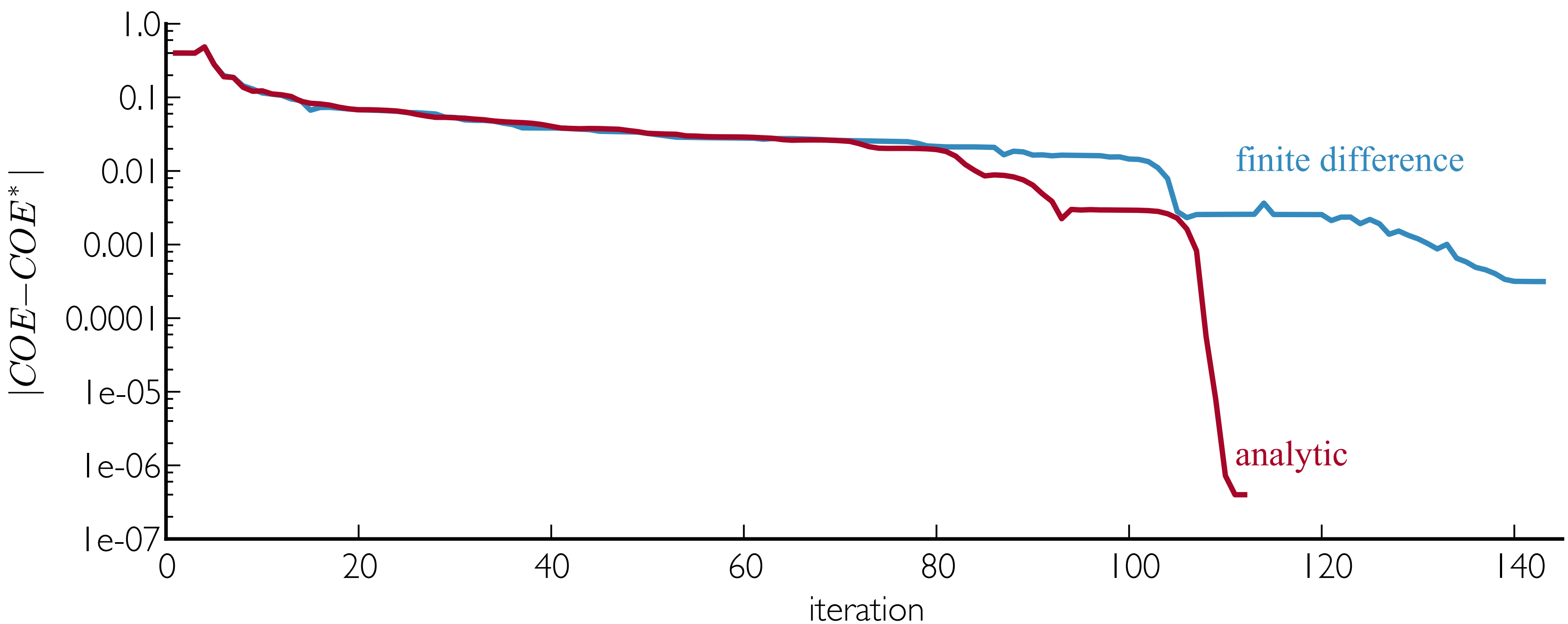
OpenMDAO facilitates coupled gradients across 102 components



The dependence graph for the rotor contained the most complexity including nested solvers

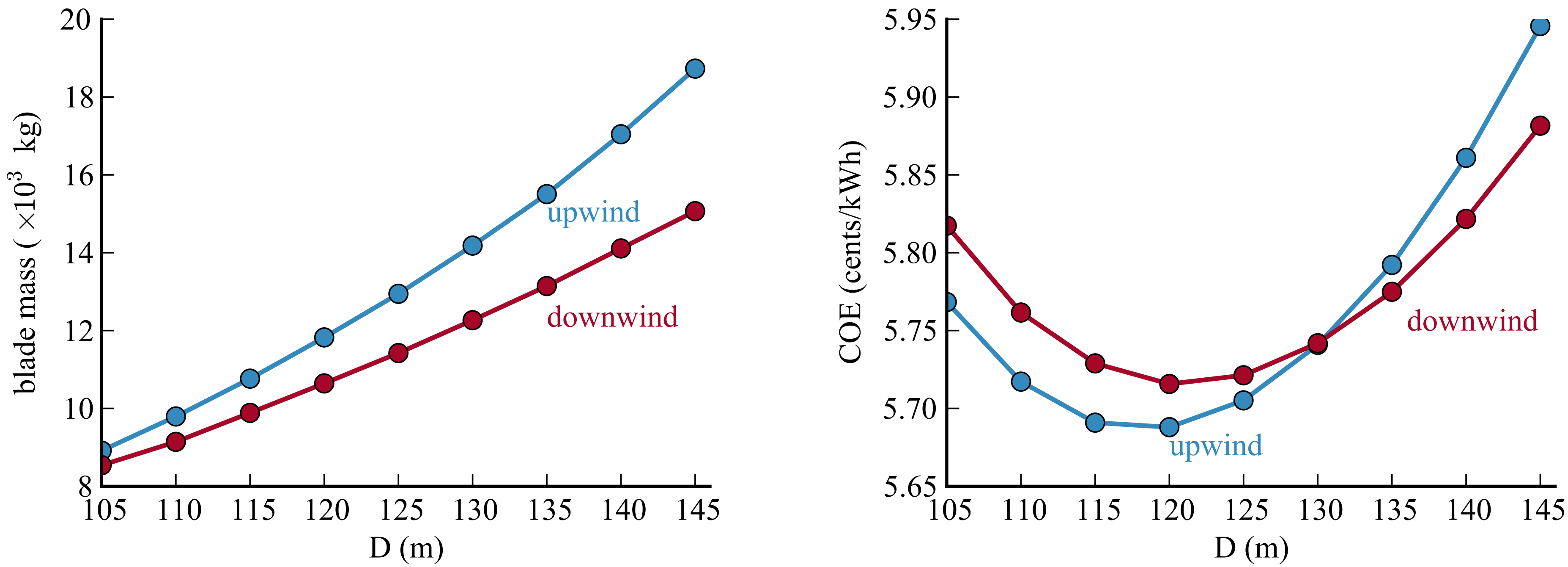


Analytic gradients allow for quicker and more robust convergence



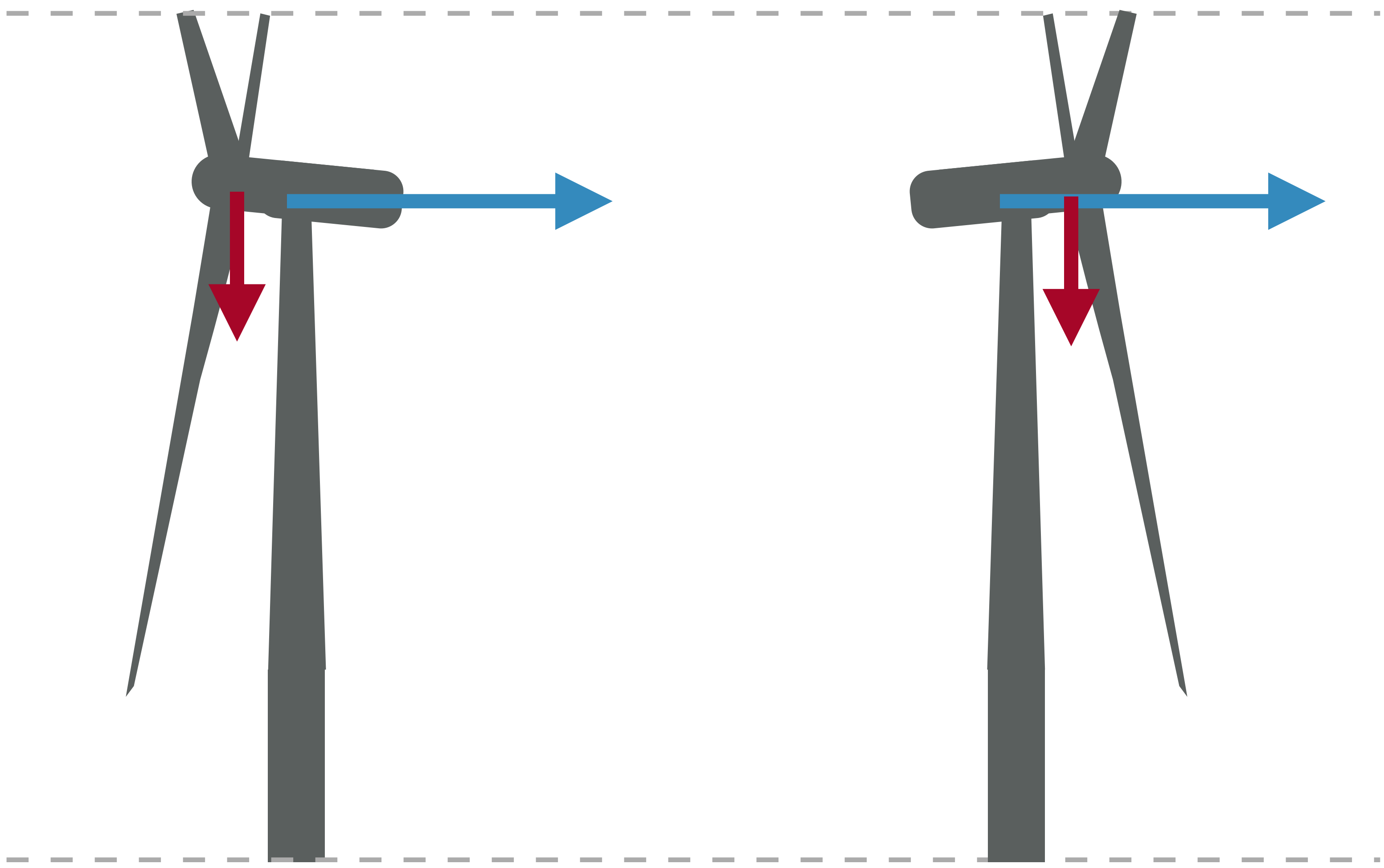
	Finite-difference	Analytic
Run time (hours)	5.43	1.11

Class I, 5-MW—negligible benefit for downwind designs

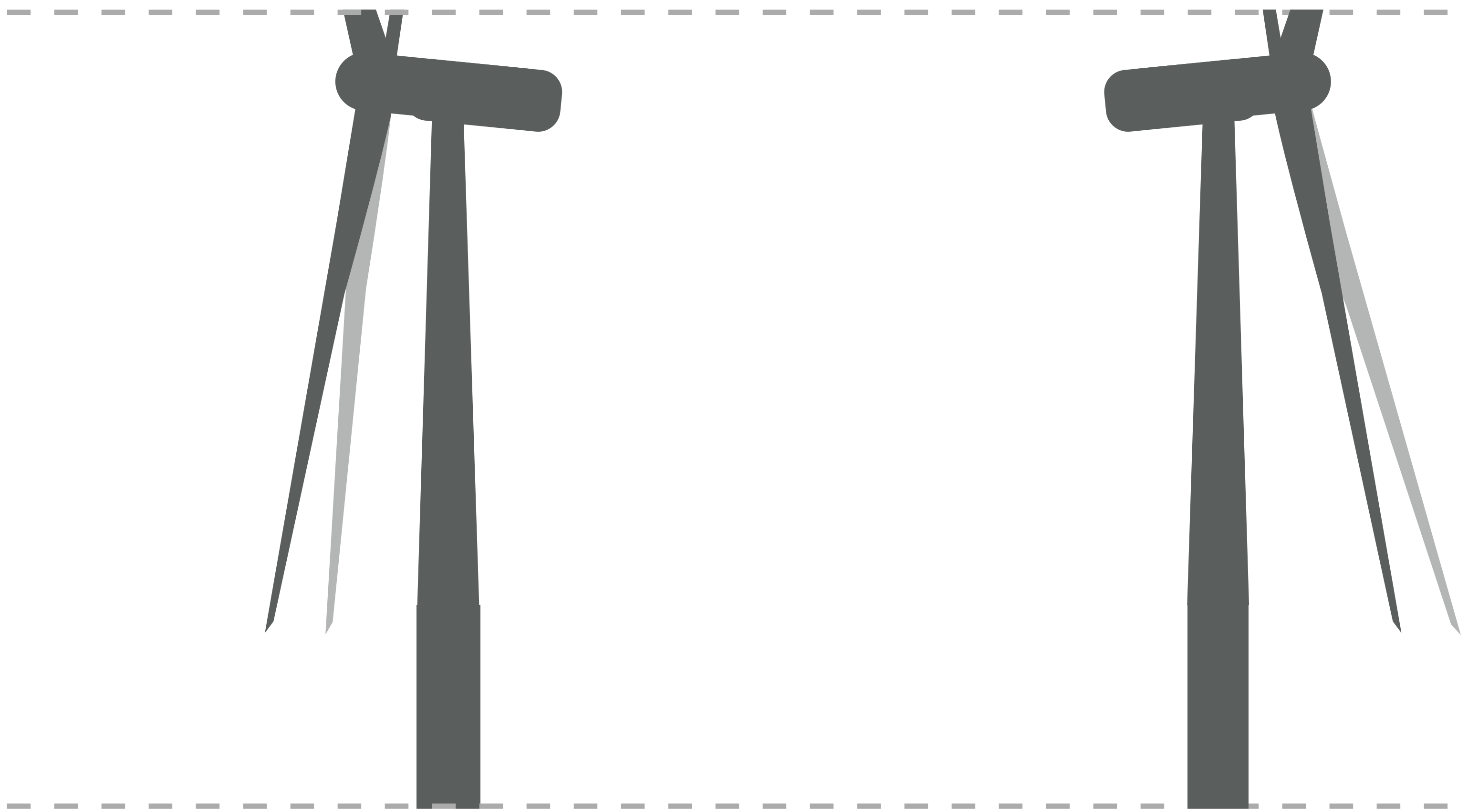


Blade mass savings was limited because survival wind speed was dominant constraint.

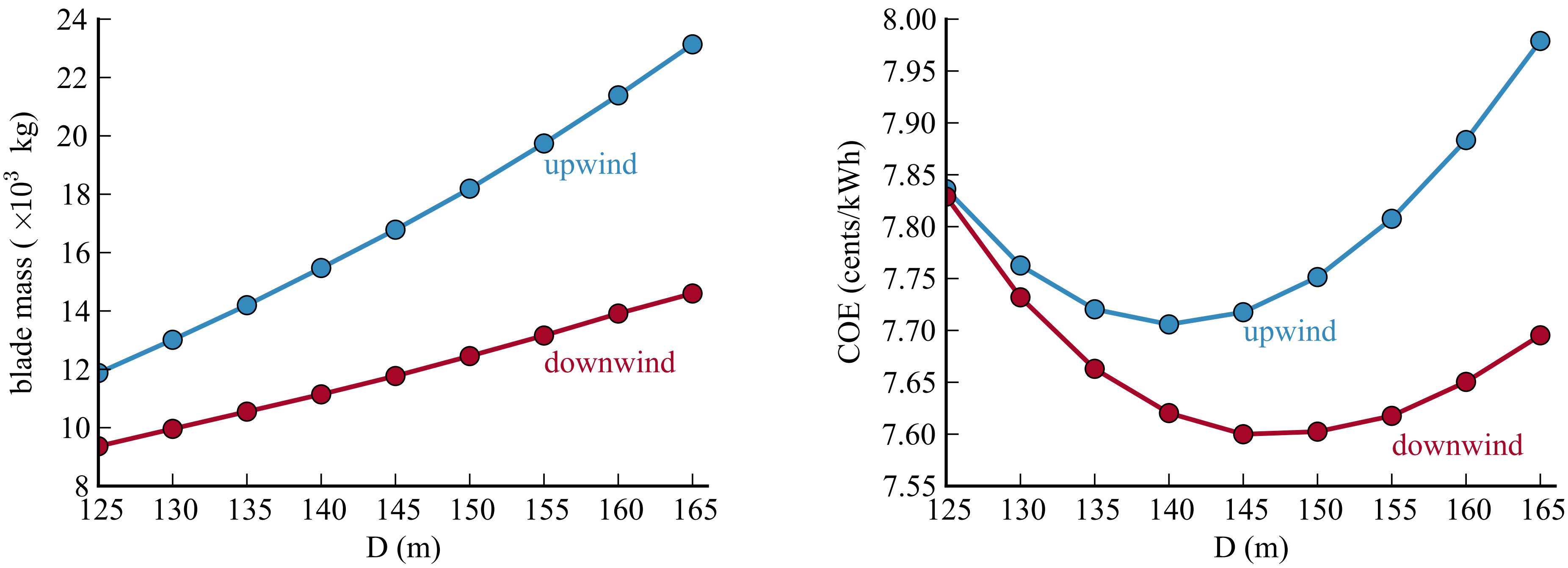
The cost savings for lighter blades were offset by a heavier tower



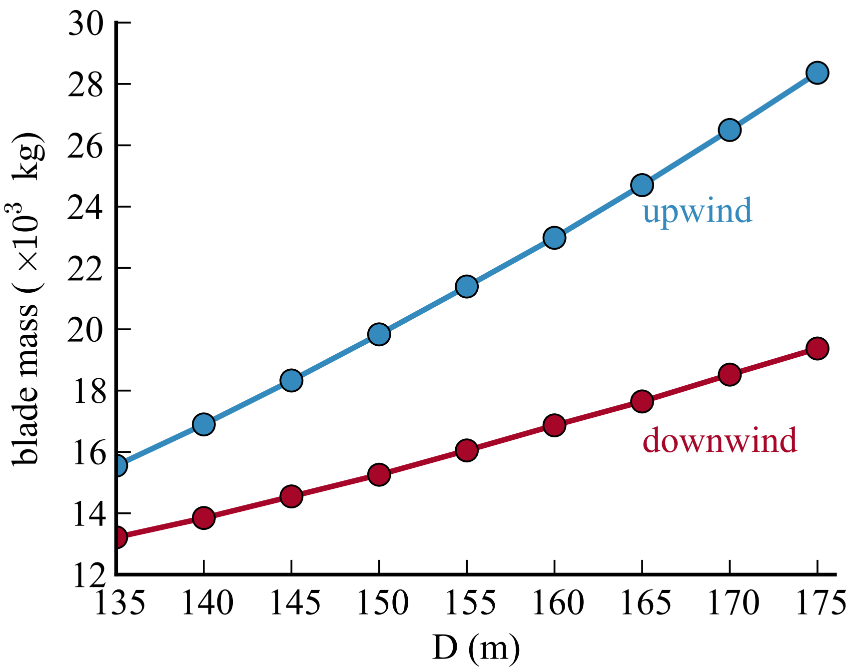
AEP was slighter lower for downwind designs

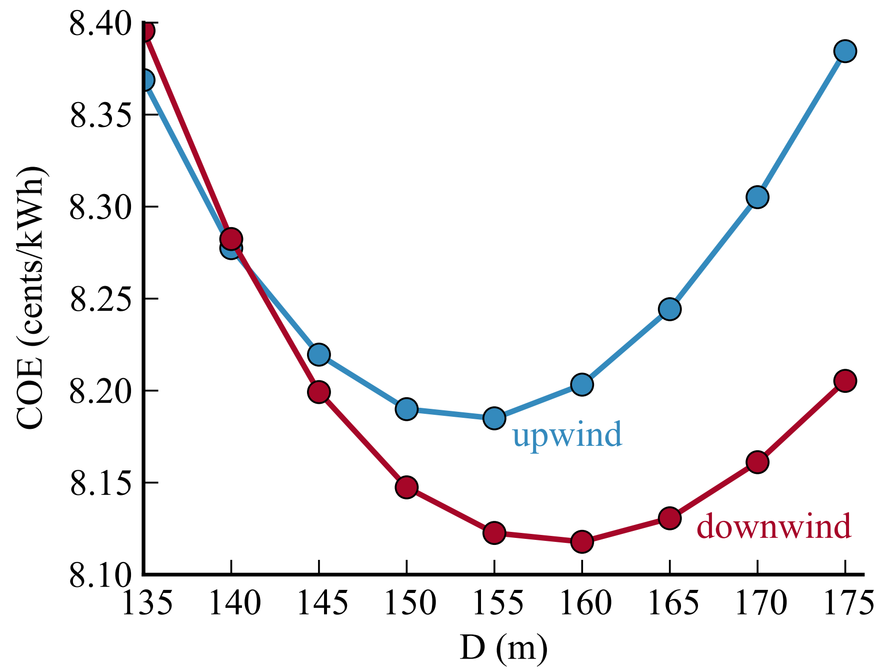


Class III, 5-MW—blade mass savings of around 30%

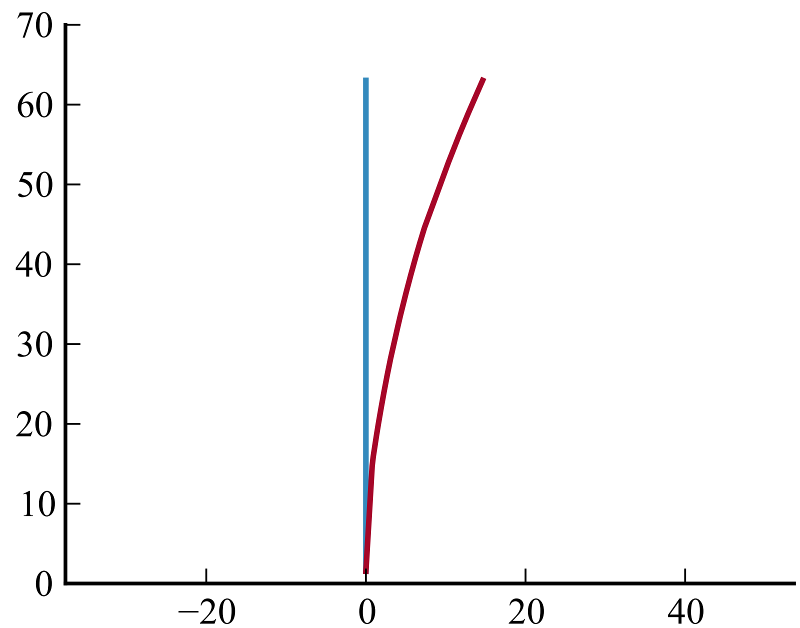


Class I, 7-MW—results were similar but tower design is limiting factor





Highly downwind precurved bladed did not appear to be advantageous



	Straight blade	Curved blade
max strain at rated (microstrain)	1,336	841
max strain at survival (microstrain)	3,001	2,872
1st flap freq (Hz)	0.961	0.848
1st edge freq (Hz)	1.15	1.08
AEP (MWh)	19,560	18,802

Conclusions

- Downwind rotors allowed for blade mass reductions of around 10-30%
- Downwind configurations were potentially advantageous for sites with lower wind speeds, and for turbines with higher power ratings
- For very large turbines, efficient tower design is critical
- Optimal precurved blades were curved upwind