Preliminary Design of Low Specific Power Rotors

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Specific Power Trends

$$S_P = \frac{P}{\pi R^2}$$

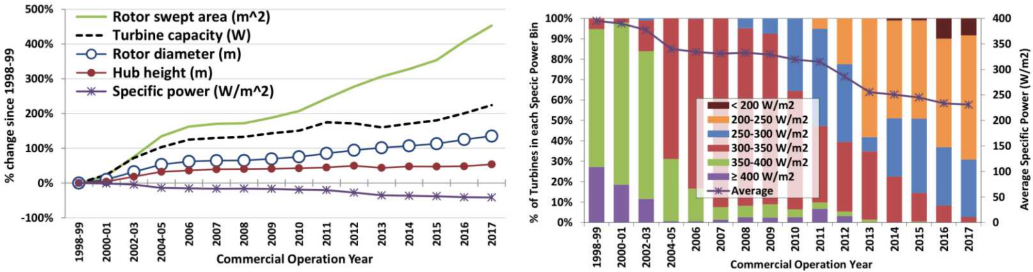
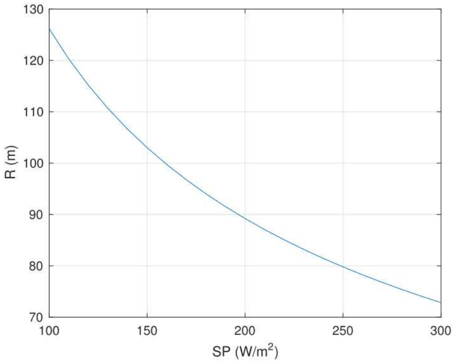


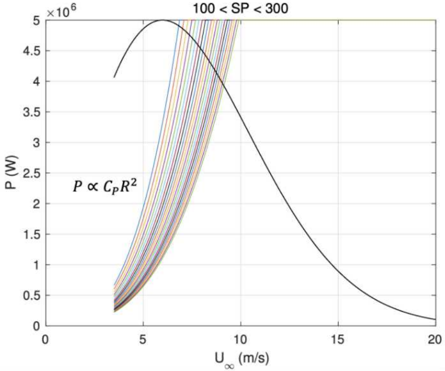
Figure 1: Specific power trends for new USA land-based installations, Bollinger [1]

225 W/m^2 is the average new machine!

Why?

Power Curve, 5 MW Example

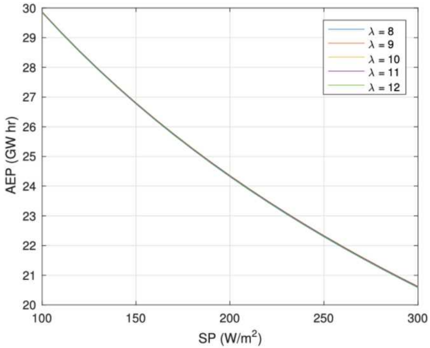




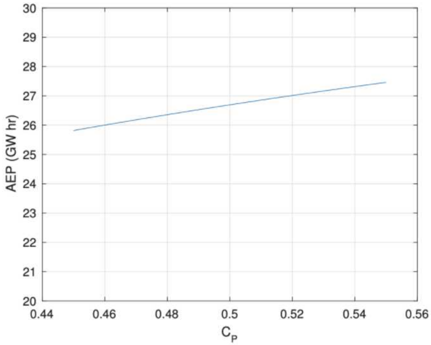
Explanation 1

more energy and higher capacity factor from the same generator
more consistent and predictable output

AEP, 5 MW Example



30 % AEP increase



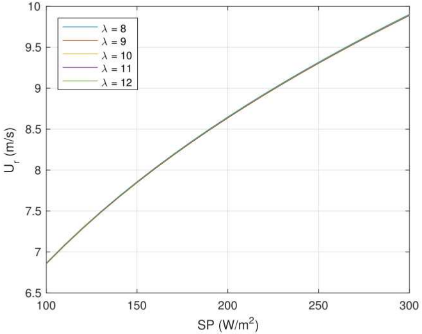
2.6 % AEP increase

Explanation 2

AEP more sensitive to specific power

Rated Wind Speed

$$U_r = \sqrt[3]{\frac{2\,S_P}{\rho C_P}}$$



Explanation 3

DLC 1.4 can be run at lower rated wind speed

Spar Mass

$$m = (k)(\frac{\rho}{E})(\frac{R^2}{t^2})(\frac{R}{\delta})(M_{\text{root}})$$

$$M_{\text{root}} = C_M \frac{1}{2} \rho U_r^2 \pi R^3$$

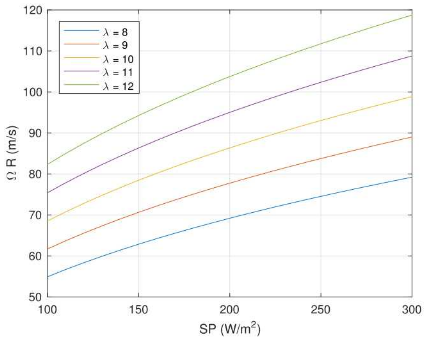
held constant	spar mass scaling
load shape, material, slenderness, δ, S_P	R^4
load shape, material, slenderness, $\frac{\delta}{R}$, S_P	R^3
load shape, material, slenderness, δ	$R^{2.67}$
load shape, material, slenderness, $\frac{\delta}{R}$	$R^{1.67}$

Explanation 3

spar mass may scale as well as $R^{1.67}$ for same percent percent tip deflection
longer blades on the same generator are lighter than expected

Tip Speed

$$\Omega_r R = \lambda U_r$$



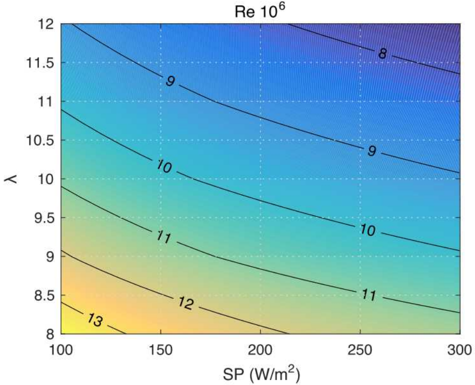
Explanation 4

quieter rotors and less erosion, or higher λ

Knowledge gaps and problems with low S_P

Reynolds Numbers, 5 MW Example

$$Re \approx \frac{16\pi\rho R U_r}{9B\mu C_l \lambda}$$



Knowledge Gap 1

open source high Re airfoils

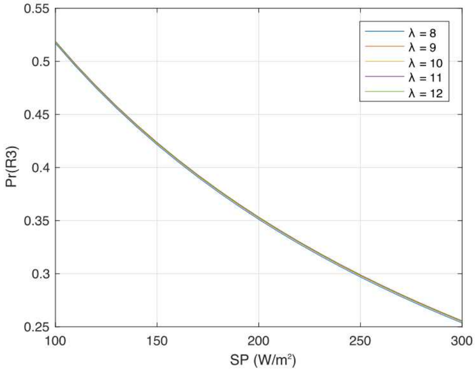
Sandia Centrifuge for High Re Airfoil Design?

ΩR= 160 m/s

Re = 11,200,000 for 1 m chord

DTU Rotating Test Rig

Pitch Duty Cycle



Knowledge Gap 2

reliability of pitch actuators with greater use

Prebend

- to realize the most benefits in mass savings, constant $\frac{\delta}{R}$, which means δ increases
- bridges, tunnels, and turning radii
- thick molds and tall manufacturing buildings

Figure 2: Griffin [2]

Knowledge Gap 3

manufacturing and logistics

Low Cost Carbon Fiber

Material	UTS(MPa)/$/kg	%	UCS(MPa)/$/kg	%	E(GPa)/$/kg	%
Industry Baseline	147.6	100	-100.3	100	9.6	100
Heavy-Tow (full-utilization)	180.0	122	-156.9	156	19.2	200
Heavy-Tow (current)	137.0	93	-119.4	119	14.6	152

Figure 3: Ennis [3]

Knowledge Gap 4

new materials

Why Lower S_P?

- higher cf
- predictable output
- lower rated wind speeds
- reduced loads/deflection for DLC 1.4
- spar mass scaling as low as $R^{1.67}$ instead of R^3
- quieter and less erosion, or higher λ

Challenges for the Future

- high Re airfoils
- greater pitch actuation
- greater prebend and length presents manufacturing and logistics challenges
- new materials
- other rotor technologies

References

- Mark Bolinger et al. "Trends Analysis of Low-SP Turbines". In: *Sandia Blade Workshop*. Lawrence Berkeley National Laboratory and National Renewable Energy Laboratory. 2018.
- Dayton Griffin, Patrick Gillman, and Ryan Wiser. *R&D Pathways for Supersized Wind Turbine Blades*. Tech. rep. 10080081-HOU-R-01. DNVGL and Lawrence Berkeley National Laboratory, 2019.
- Brandon Ennis et al. *Optimized Carbon Fiber Composites for Wind Turbine Blades*. Tech. rep. Sandia, Oakridge, and Montana State, 2019.