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Aerodynamic Design of NRT Blade

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Fully Constrained Inverse Design, $\frac{r}{R} <= 0.97$

- Given $\begin{cases} \Gamma'_{ss} = \Gamma'_{fs}, & \frac{r}{R} \in [0, 1] \\ C_{l_{ss}} = -0.4\frac{r}{R} + 0.9, & \frac{r}{R} \in [0, 0.97] \end{cases}$
- Solve for c/R and β
- $C_l = 0.7$ at mid-span, and 0.5 at tip
- Tends towards higher tip solidity and thickness
- stall margin

Constraints
Airfoil Placement
Algorithm
Geometry Results
Performance
Region II.5

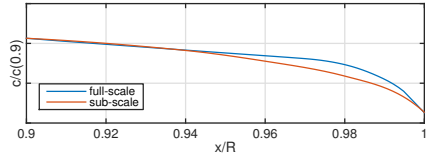
Objective Function, Γ'_{fs}

- Full-scale turbine model provided by manufacturer
- Modeled in WT_Perf
- 1.5 MW
- $\lambda = 9$
- smooth surface airfoil data from wind tunnel

Scaled Tip Design, $\frac{r}{R} > 0.97$

$$c(1)_{ss} = \frac{c(1)_{fs} c(0.9)_{ss}}{c(0.9)_{fs}}. \quad (1)$$

- Transition at 97% span matches chord at slope
- Only twist is adjusted to achieve target circulation



Requirement 5 Scaled Tip Design

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Blade Dimensions

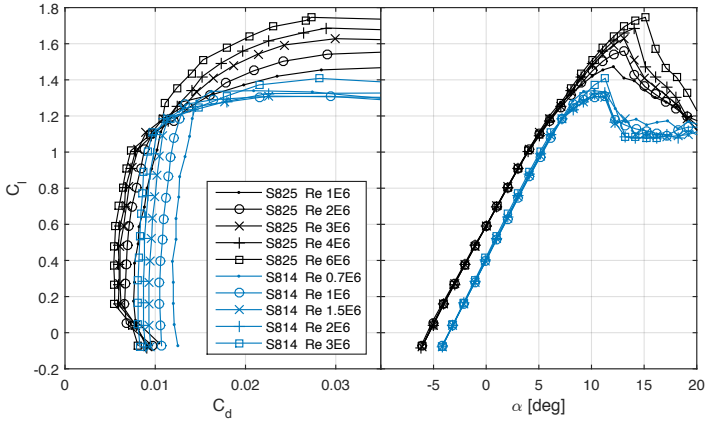
- $R = 13.5$ m
- $\beta_{max} = 12°$
- $c/R_{max} = 0.10$
- $c_{hub} = 0.5926$ m
- $r/R_{hub} = 0.0370$

Airfoil Locations

Pure Airfoil Locations.

Section	Shape	$\frac{r}{R}$
1	Circle	0.037
2	S814	0.27
3	S814/S825 XFoil	0.42
4	S825	[0.49,1]

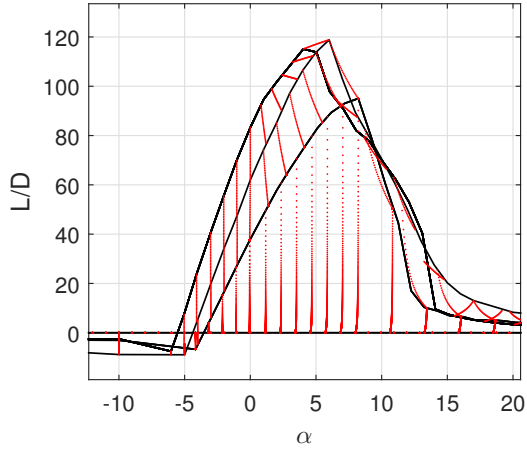
Aerodynamic Data



Requirement 6 Design for Analysis

L/D Interpolation

- Airfoil polars in blended regions are found from interpolation operating on thickness and L/D ratio



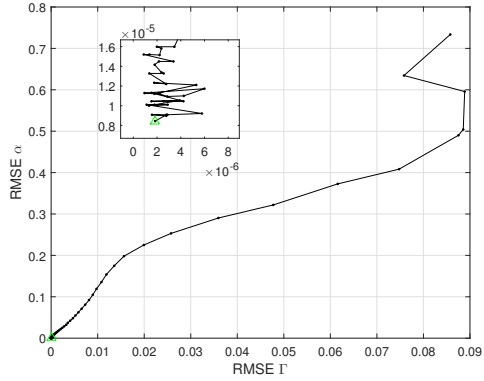
Algorithm

- blade geometry initiated from $a = 1/3$ solution
- WT_Perf is run
- residuals for circulation and angle of attack (corresponding to C_l) are calculated
- residuals are proportional to chord and twist iteration

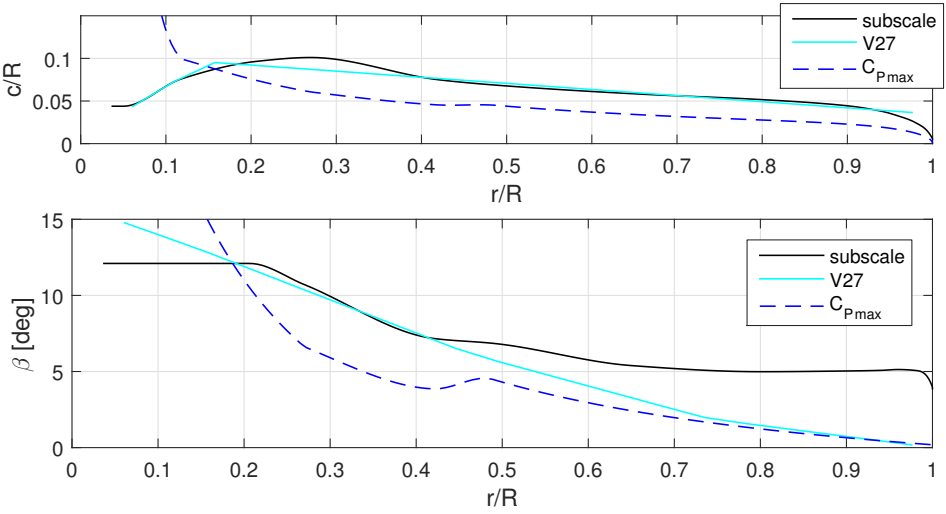
$$c/R_{i+1} = c/R_i - k_1\, r_\Gamma$$

$$\beta_{i+1} = \beta_i + k_2\, r_\alpha$$

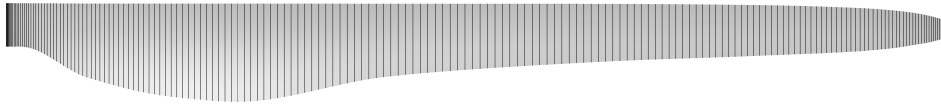
- new blade with modified chord and twist rerun until converged



Geometry



Chord and twist distributions for new NRT blade.



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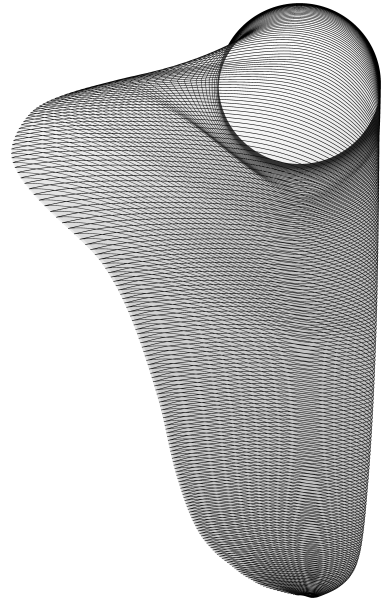
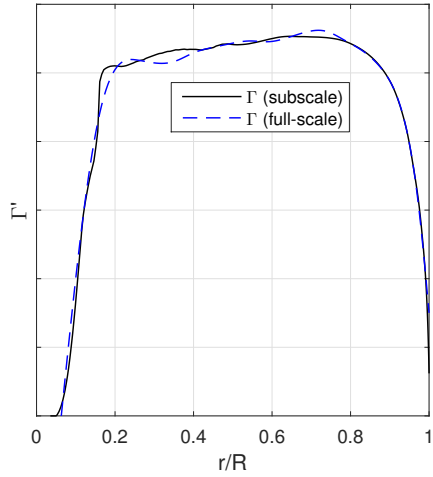


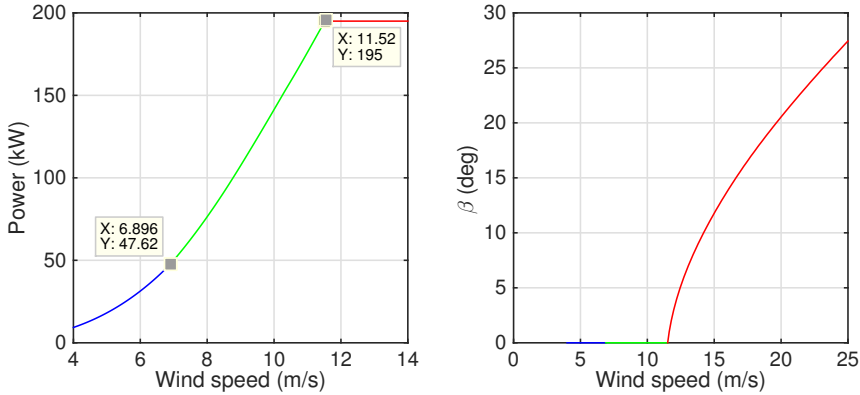
Circulation



Requirement 2

$$\Gamma' = \Gamma'_s$$

Performance



Power curve for NRT rotor design and pitch schedule.

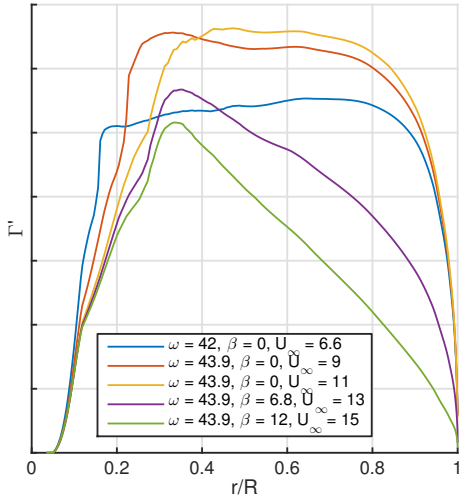
Performance

D [m]	λ_{R2}	σ [%]	P_{rated} [kW]	$C_{P_{R2}}$	$C_{T_{R2}}$	Pr(R2)	Pr(R2.5)	Pr(R3)	cf	AEP [GWh]
27	9	6.1	195	0.470	0.867	0.387	0.415	0.037	0.30	0.51

Requirement 1,3

$\lambda = 9, \quad C_P = 0.47$, 3% less than full-scale

Region 2.5


Γ'
r/R
0
0.2
0.4
0.6
0.8
1
ω = 42, β = 0, U∞ = 6.6
ω = 43.9, β = 0, U∞ = 9
ω = 43.9, β = 0, U∞ = 11
ω = 43.9, β = 6.8, U∞ = 13
ω = 43.9, β = 12, U∞ = 15

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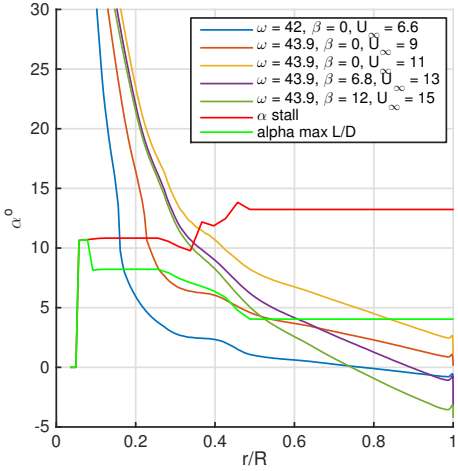
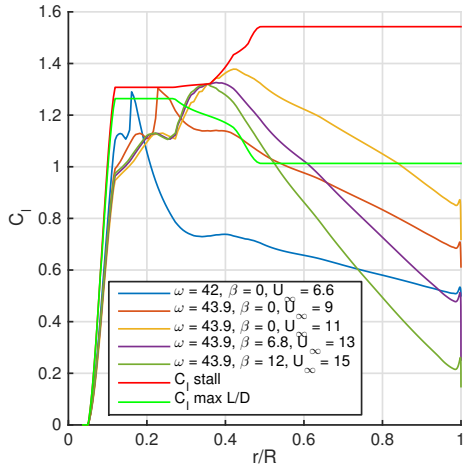
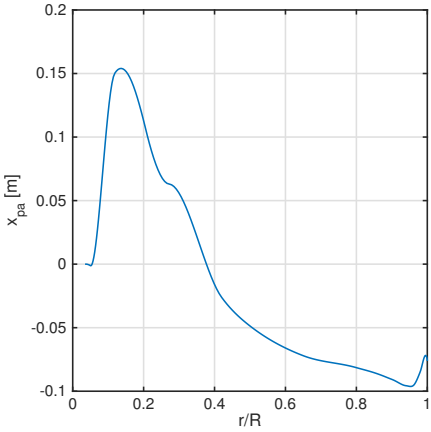
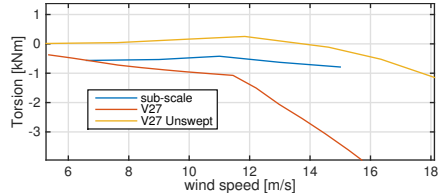




Blade Sweep


0.2
0.15
0.1
0.05
0
-0.05
-0.1
x_{pa} [m]
0
0.2
0.4
0.6
0.8
1
r/R


1
0
-1
-2
-3
Torsion [kNm]
6
8
10
12
14
16
18
wind speed [m/s]
sub-scale
V27
V27 Unswept

Conclusions

- inverse design tool implemented
- design tool used to find blade geometry
- blade geometry creates scaled wake based on shed vorticity
- all requirements met except dynamic loading (gust repsonse)
- 3D CFD has begun examining root region