How appropriate are sales power curves on complex or forested sites?

Tomas Blodau

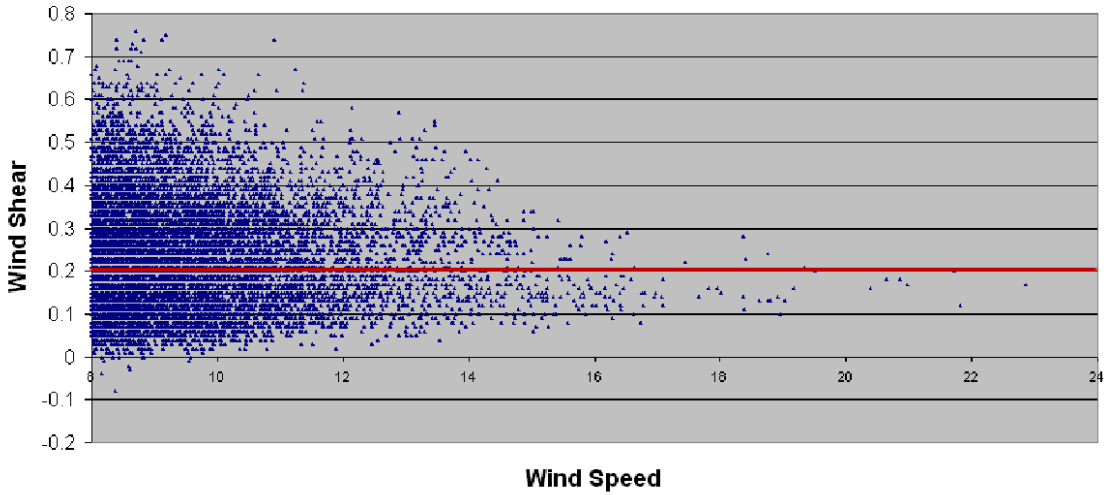
July 2nd 2012

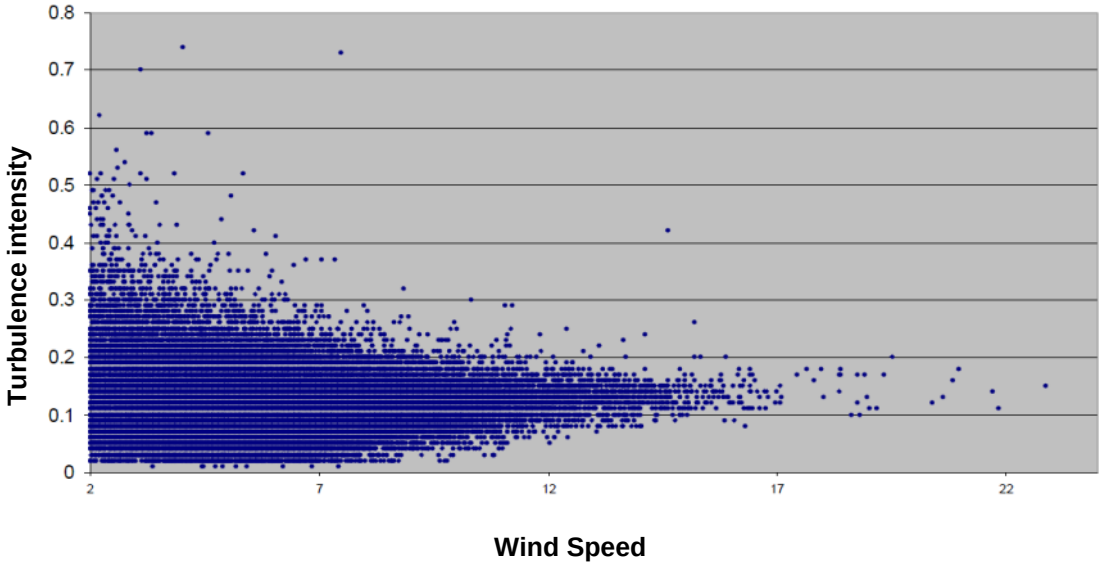
Agenda

- Rotor Aerodynamics
- PC Measurement Analysis
- Alternative Techniques for PC Measurement
- Summary

Rotor Aerodynamics

Variable Site Conditions



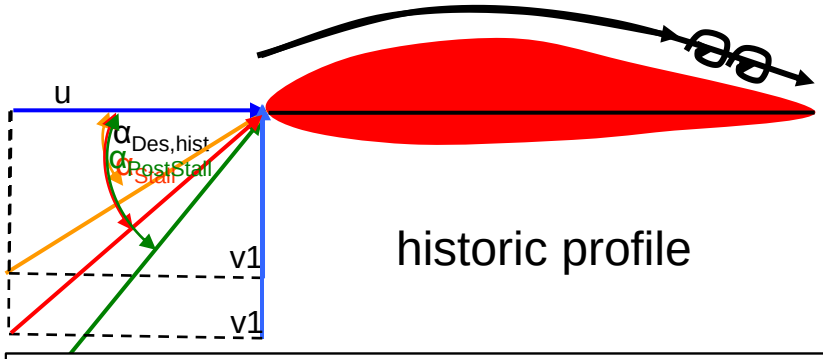


All sites show varying wind conditions

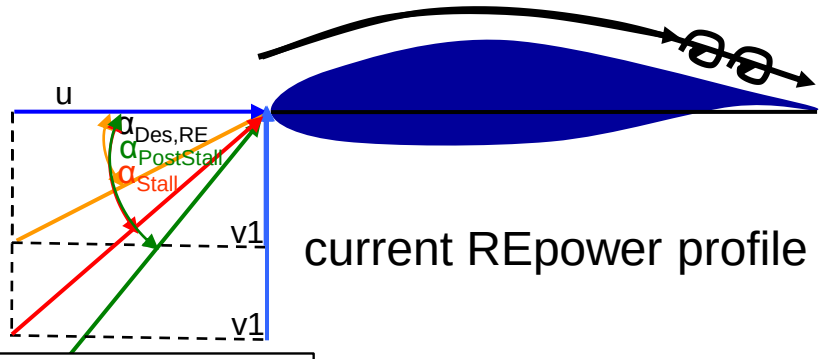
Turbine design needs to account for this.

Rotor Aerodynamics

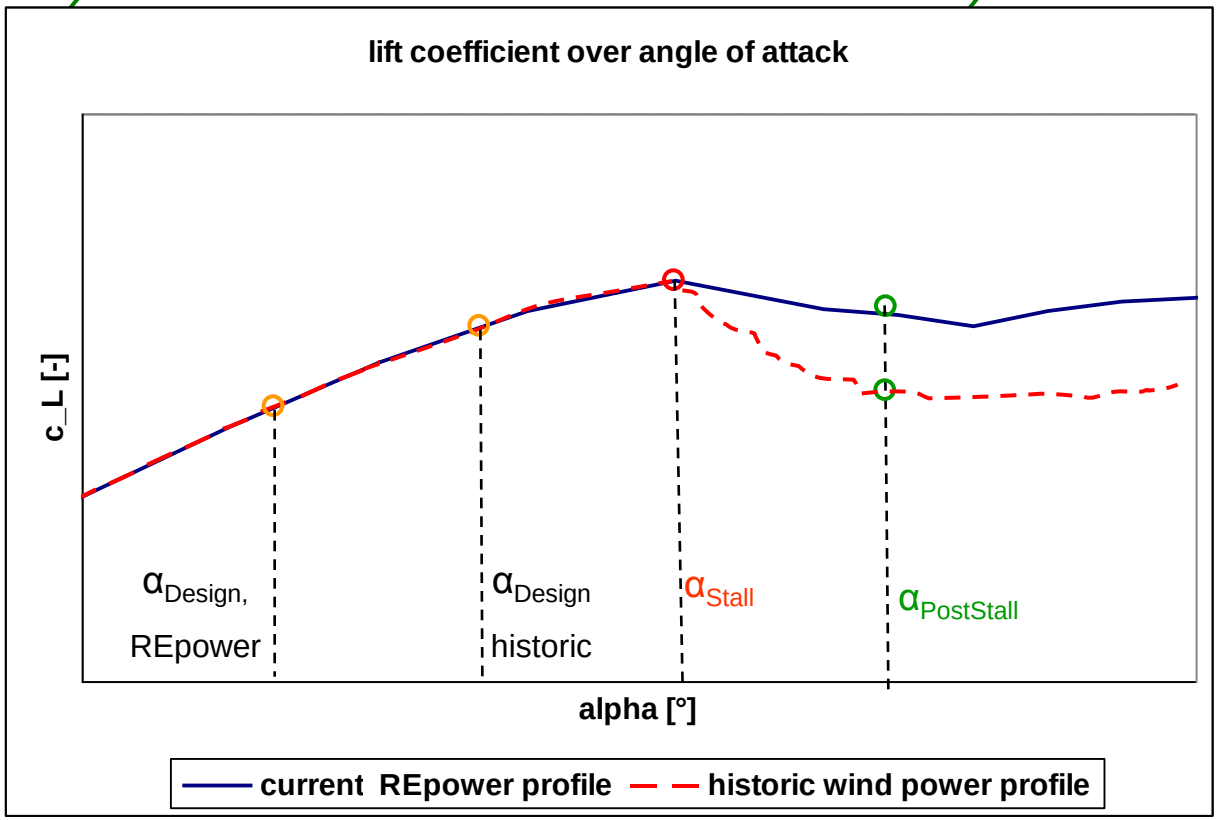
Influence of profile properties



historic profile



current REpower profile



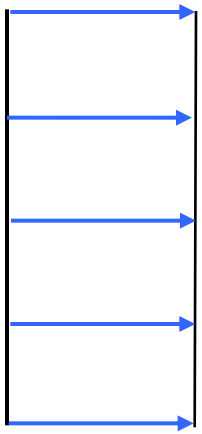
$$\text{Lift} = \rho/2\ A\ c_L\ v_r^2$$

REpowers philosophy is to have a sufficient angle margin to stall.

smooth stall behaviour.

Rotor Aerodynamics

Airfoil characteristics

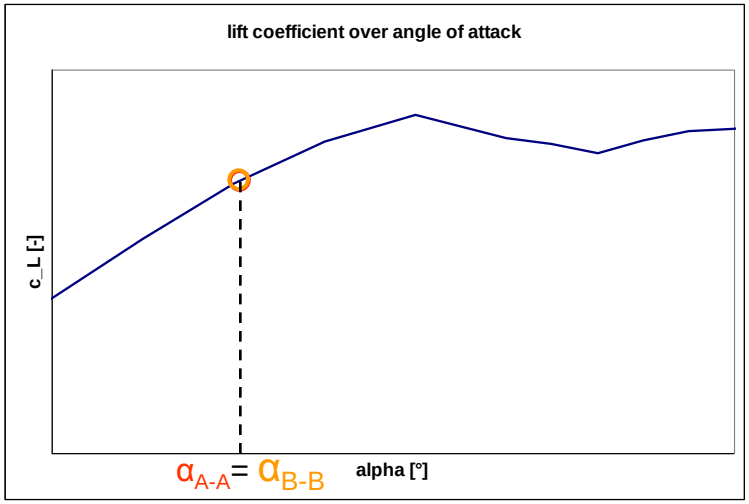


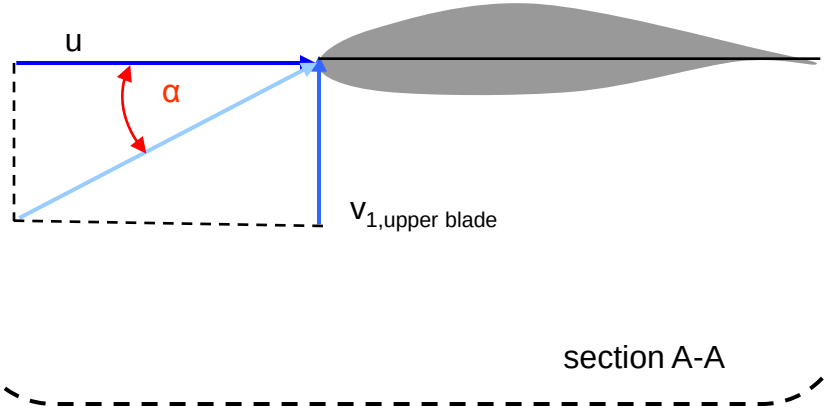
no shear

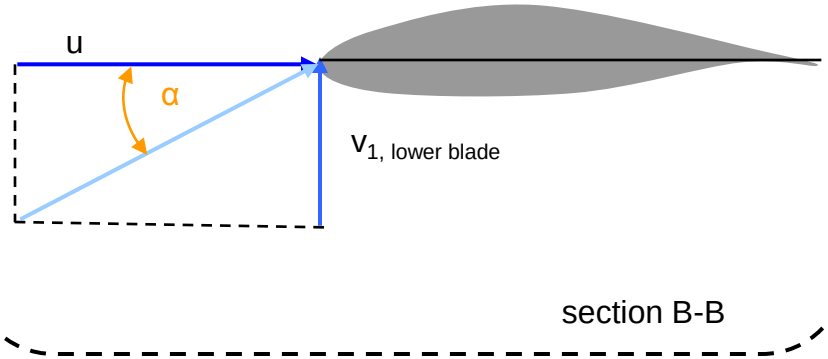
$V_{1,HH}$ = const

section A-A

section B-B

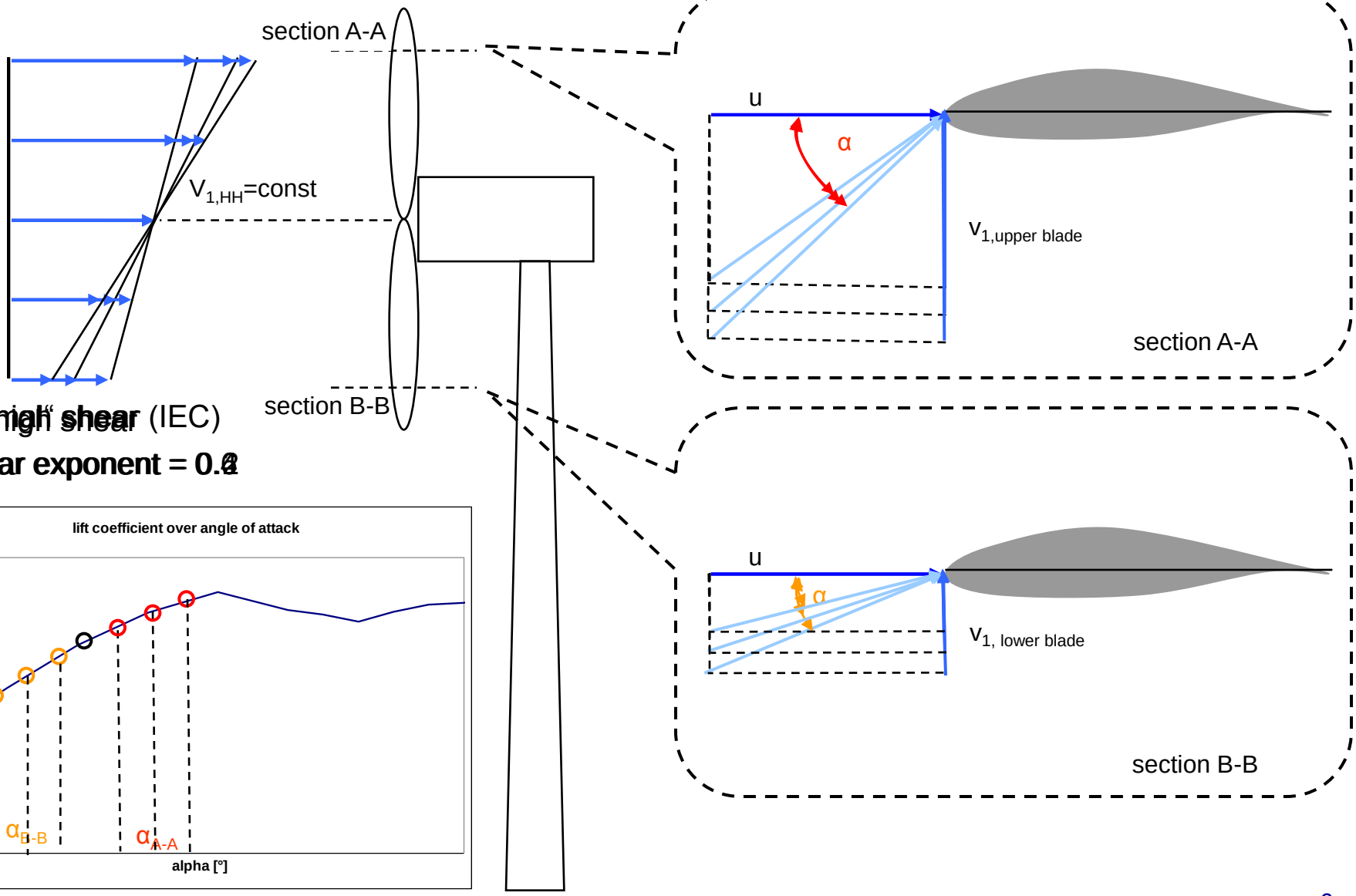






Rotor Aerodynamics

Airfoil characteristics – shear influence



normal shear (IEC)

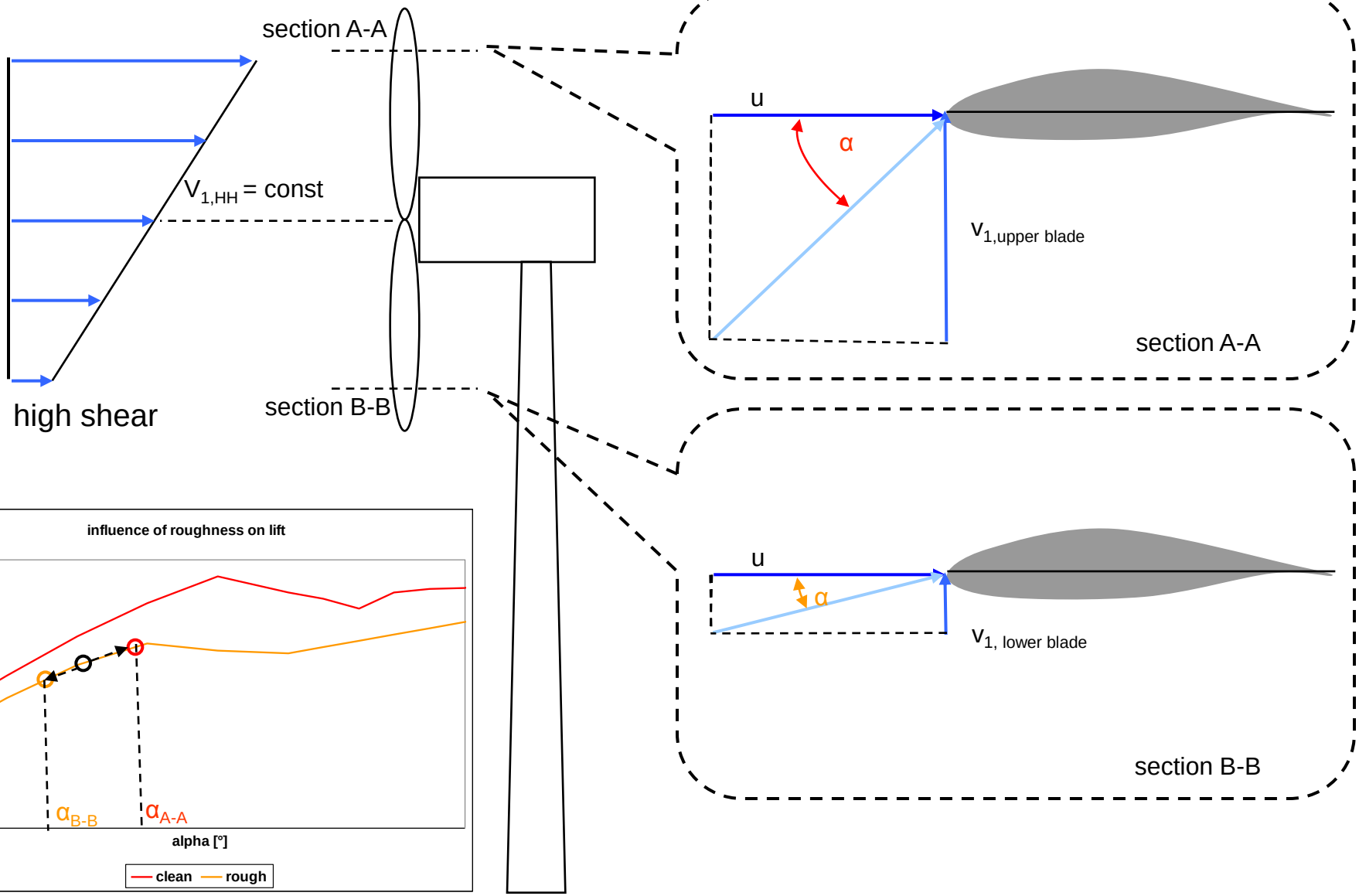
shear exponent = 0.2

very high shear

shear exponent = 0.4

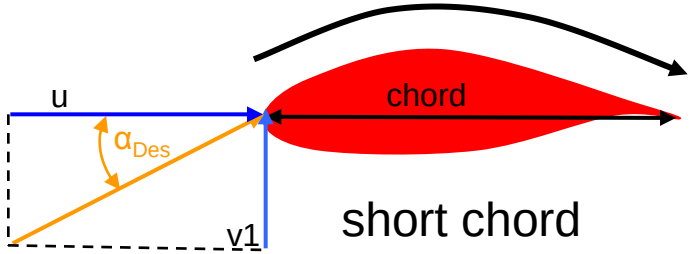
Rotor Aerodynamics

Airfoil characteristics – roughness influence

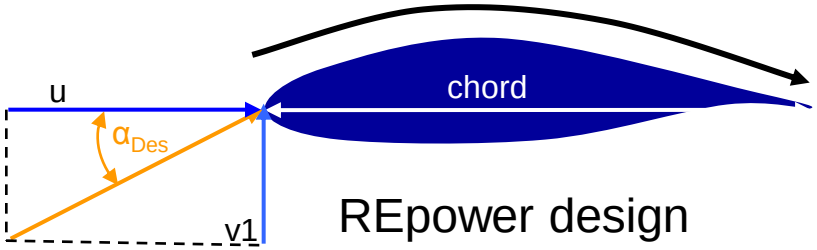


Rotor Aerodynamics

Stall power and aerodynamic safety factor



short chord
(slender blade design)



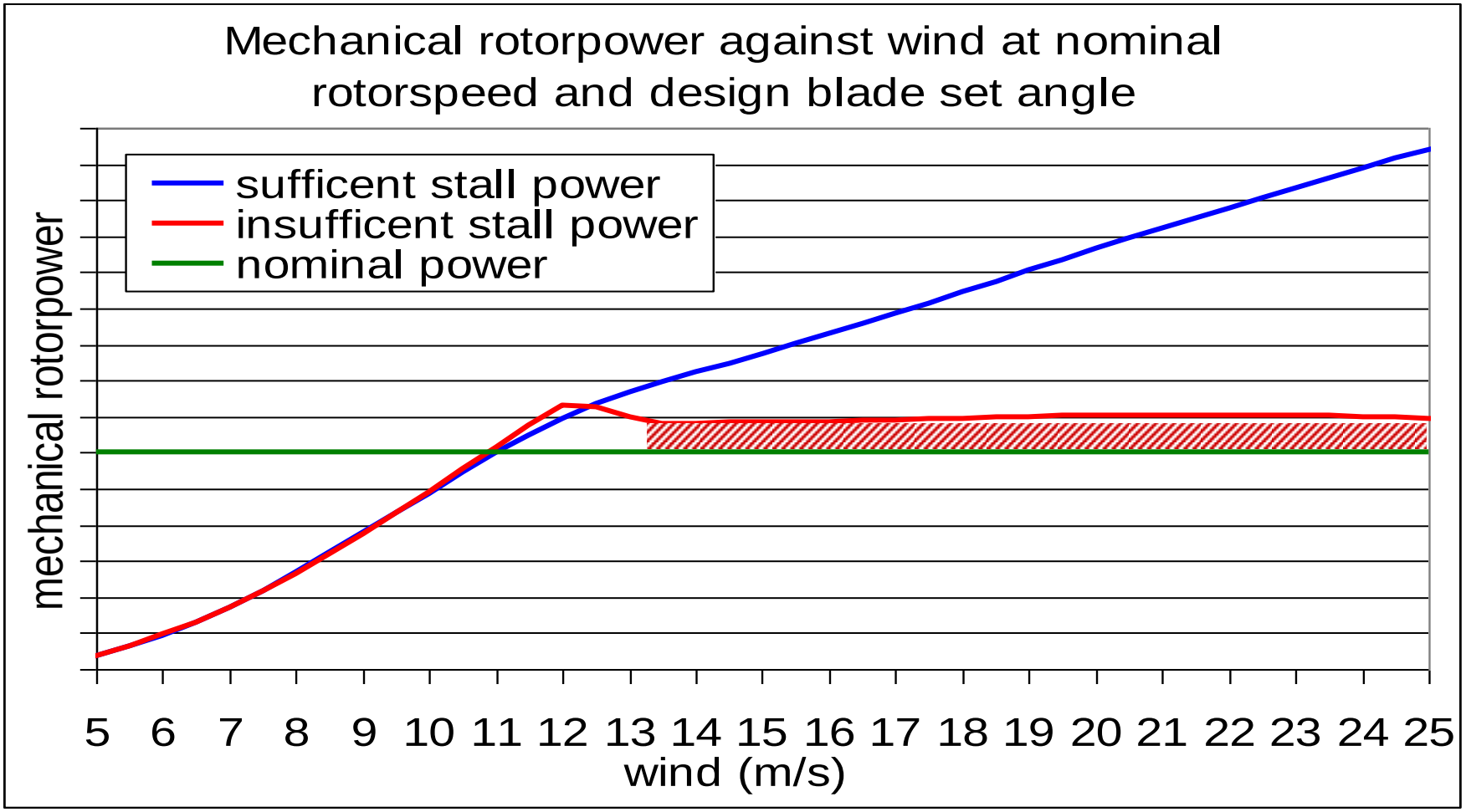
REpower design

$$\text{Lift} = \rho/2\ A\ c_L\ v_r^2$$

$$A = f(\ldots,\text{chord})$$

Chord	↓
Profile Thickness	↑
Contamination Sensitivity	↑
Stall Power	↓
Loads	↓

Stall power and aerodynamic safety factor

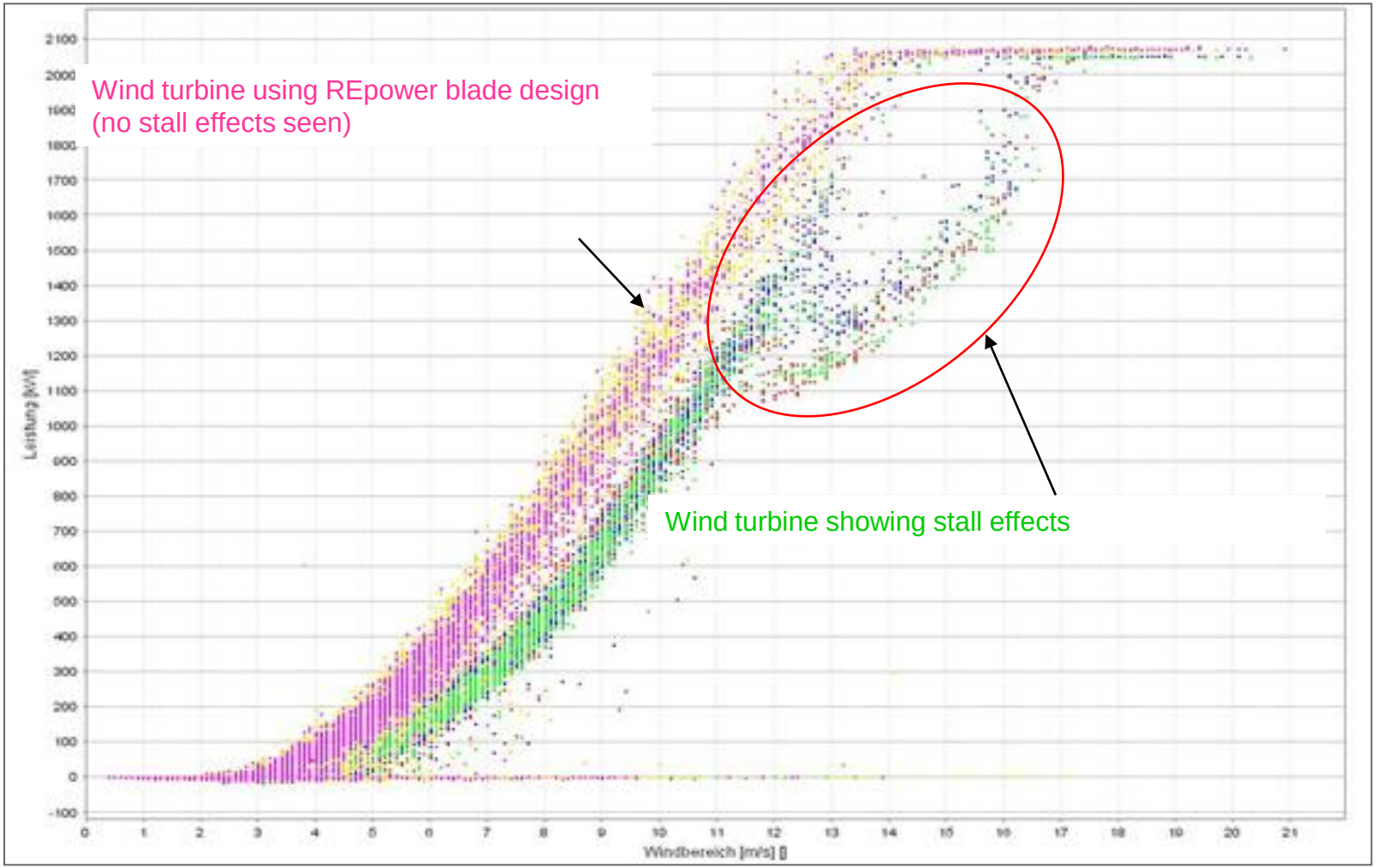


For high performance under varying conditions

REpower blades are designed with high Aerodynamic Safety Factors

Rotor Aerodynamics

Aerodynamic safety factors



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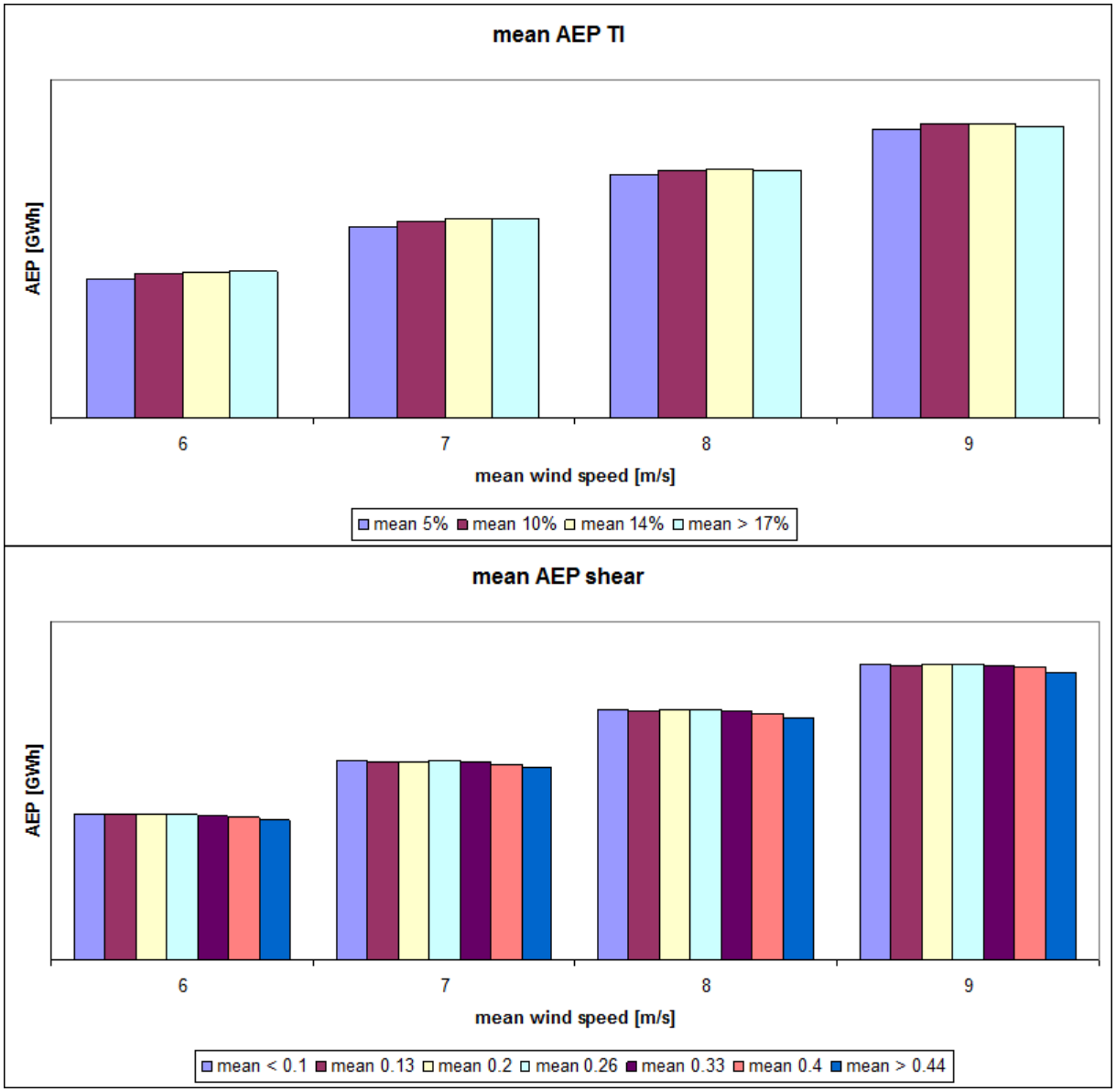
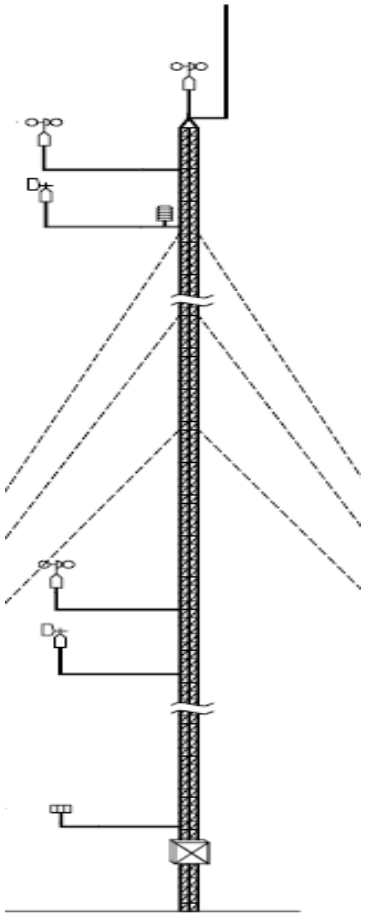
PC Measurement Analysis

Measured power curves - practice



PC Measurement Analysis

Power curve verification reference list



GL Garrad Hassan	Model	Number of measurements	Number of measured turbines	Ratio EMAEP/GAEP [%]
MD70	Standard	5	2	98.9% min / max results 96.9 – 100.8
MD77	Standard	6	2	99.2% min / max results 96.1 – 103.2
MM70	Standard	2	2	101.9% min / max results 101.2 – 103.3
MM82	Standard	8	8	100.9% min / max results 96.4 – 106.8
	Plus Option	1	1	
	Evolution	6	5	
MM92	Standard	1	1	100.0% min / max results 98.2 – 102.1
	Evolution	6	5	
3.4M104	Standard	3	3	100.4% min / max results 99.6 – 100.1
5M	Standard	1	1	100.9% min / max results n/a – n/a
6M	Standard	1	1	101.2% min / max results n/a – n/a
MD70 MD77 MM70 5M 6M MM82 MM92 3.4M104		40	31	100.4% min / max results 96.1 – 106.8

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Alternative Techniques for PC Measurement

Power curve verification today

Met mast is industry standard and is required by the IEC 61400-12-1.

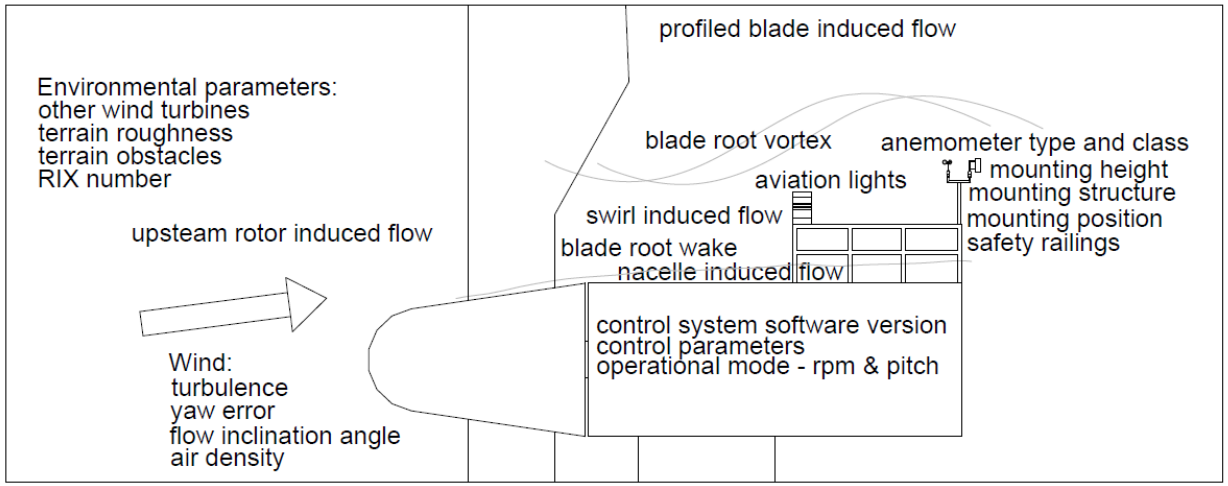
Alternative Techniques for PC Measurement

Power curve verification

Nacelle Anemometer

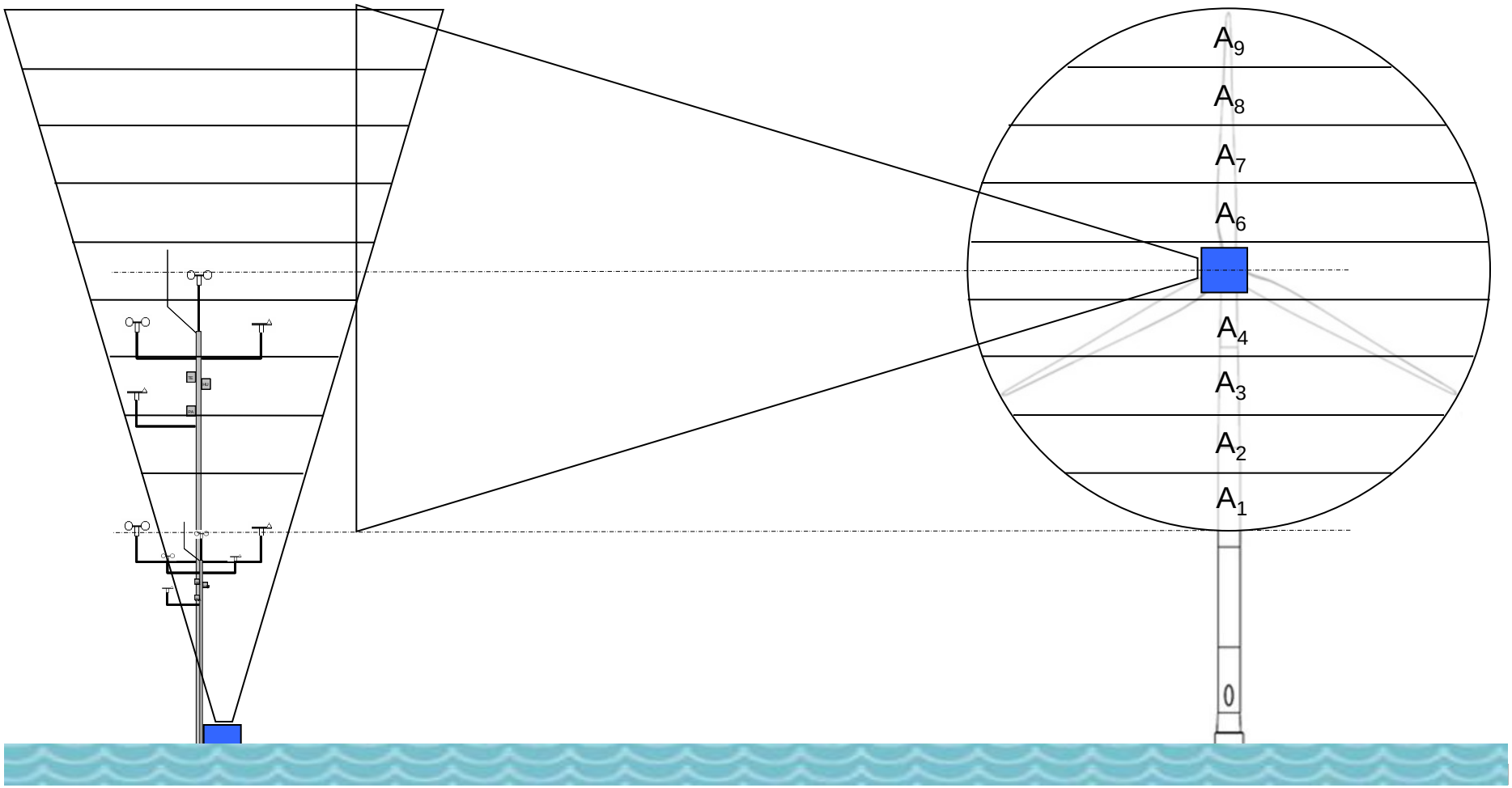
IEC 61400-12-2 nearly complete (FDIS)

Very high uncertainty approach: 15 to 20% uncertainty



Alternative Techniques for PC Measurement Power Curve Measurements – Anticipated Development

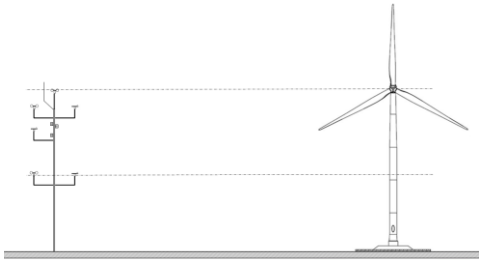
1. Current Status

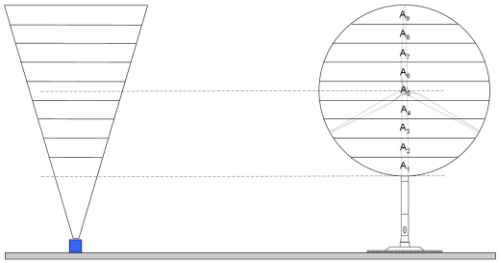


Power curve verification

Sample comparisons show promising results:

Normalized AEP compared to guaranteed power curve (100 %)		
Met mast	**LiDAR (Hub height)**	**LiDAR (Equivalent wind speed)**
103.5 %	102.7 %	101.1 %
100.0 %	99.4	99.0





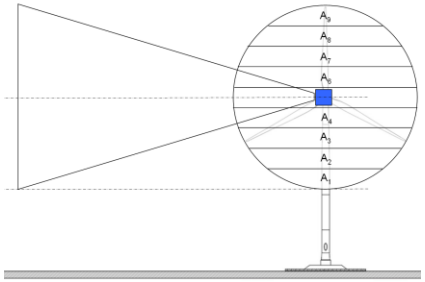
Alternative Techniques for PC Measurement

Power curve verification future

Stand alone ground based LiDAR will be acceptable

Further in the future

nacelle based LiDAR (of special interest offshore)



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Summary

Wind conditions are highly variable on all sites

Good aerodynamic blade design can handle highly variable conditions

Power curve measurement show stable results for a wide variety of conditions