National Renewable Energy Laboratory
Innovation for Our Energy Future

Power Performance Testing
IEC 61400-12-1 1st edition

NWTC

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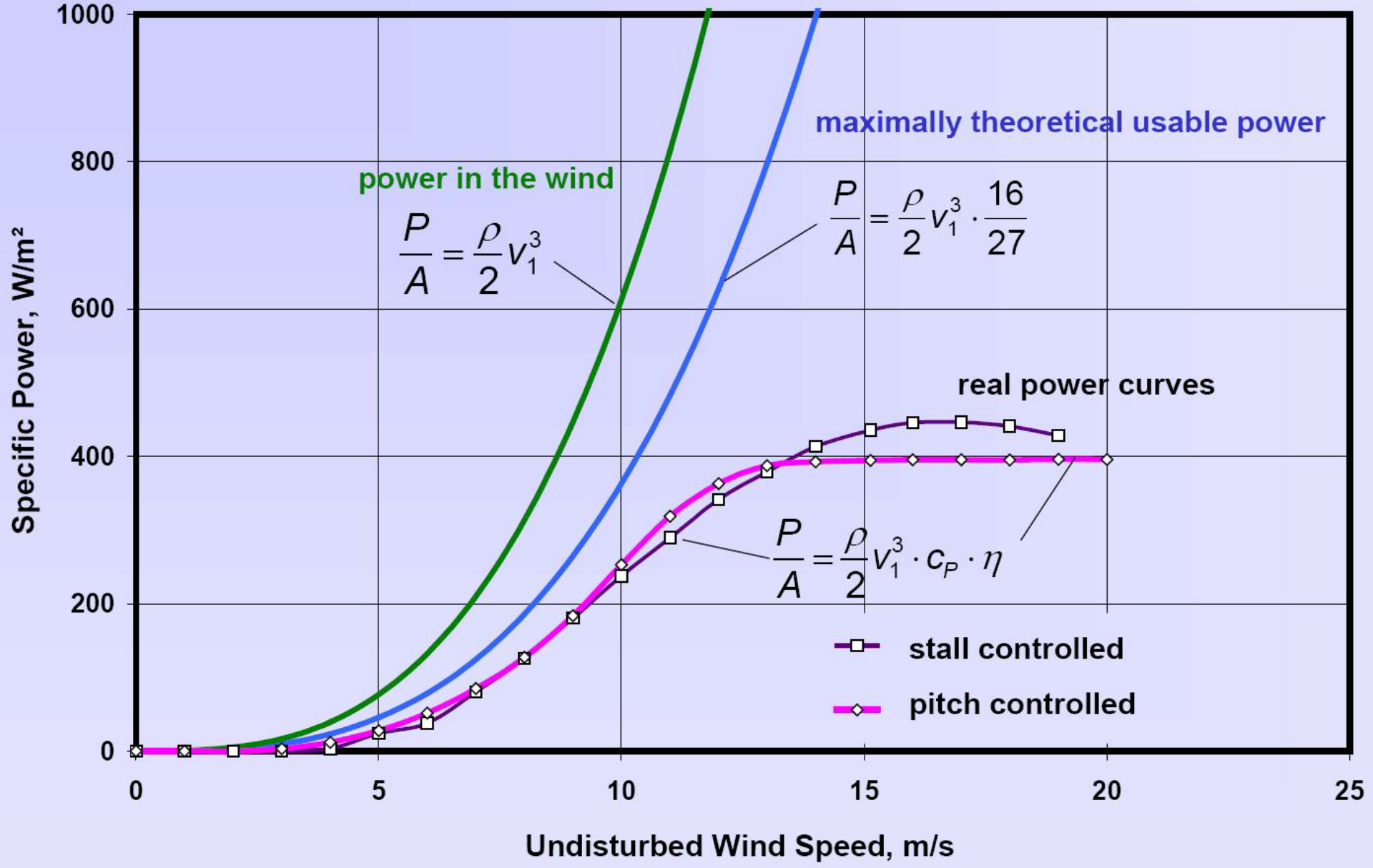
20 October 2009

9:00 – 9:30am

Power curve



Source DEWI: http://www.exportinitiative.de/media/article005913/dewi_klug_kanada_englisch_28032006.pdf

Results of Power Performance test

- Output of the turbine vs. wind speed
- Overall efficiency of turbine (power coefficient)
- Estimate the **A**nnual **E**nergy **P**roduction of turbine

Objective of Power Performance Tests

- Required for certification
- Independent check of manufacturer's claimed turbine performance

Objective of IEC Standard

- Basis for comparing different Wind Turbines
- Minimize uncertainty in test
- Improve repeatability between sites

Annex H: Power performance testing of small wind turbines

How Does NREL Test Power Performance?

1. Obtain test information on test turbine
2. Select, Develop, & Assess test site
   - Determine preliminary measurement sector
   - Prepare for site calibration, if required
3. Test preparation
   - Write test plan
   - Check out instruments in the lab
4. Readiness check
   - Sign documents
   - Commissioning
   - Safety review
5. Start test

Conduct Power Performance Test

6. Analysis
   - Analyze data on weekly/monthly basis
   - Report on progress
   - Identify and correct problems
   - Determine when sufficient data has been obtained
   - Keep to documented procedure
   - Keep test log
7. Test Report & review
   - Write test report
   - Send report to client
   - Review test with participants

Power Performance - Instruments

Instruments on Met Tower

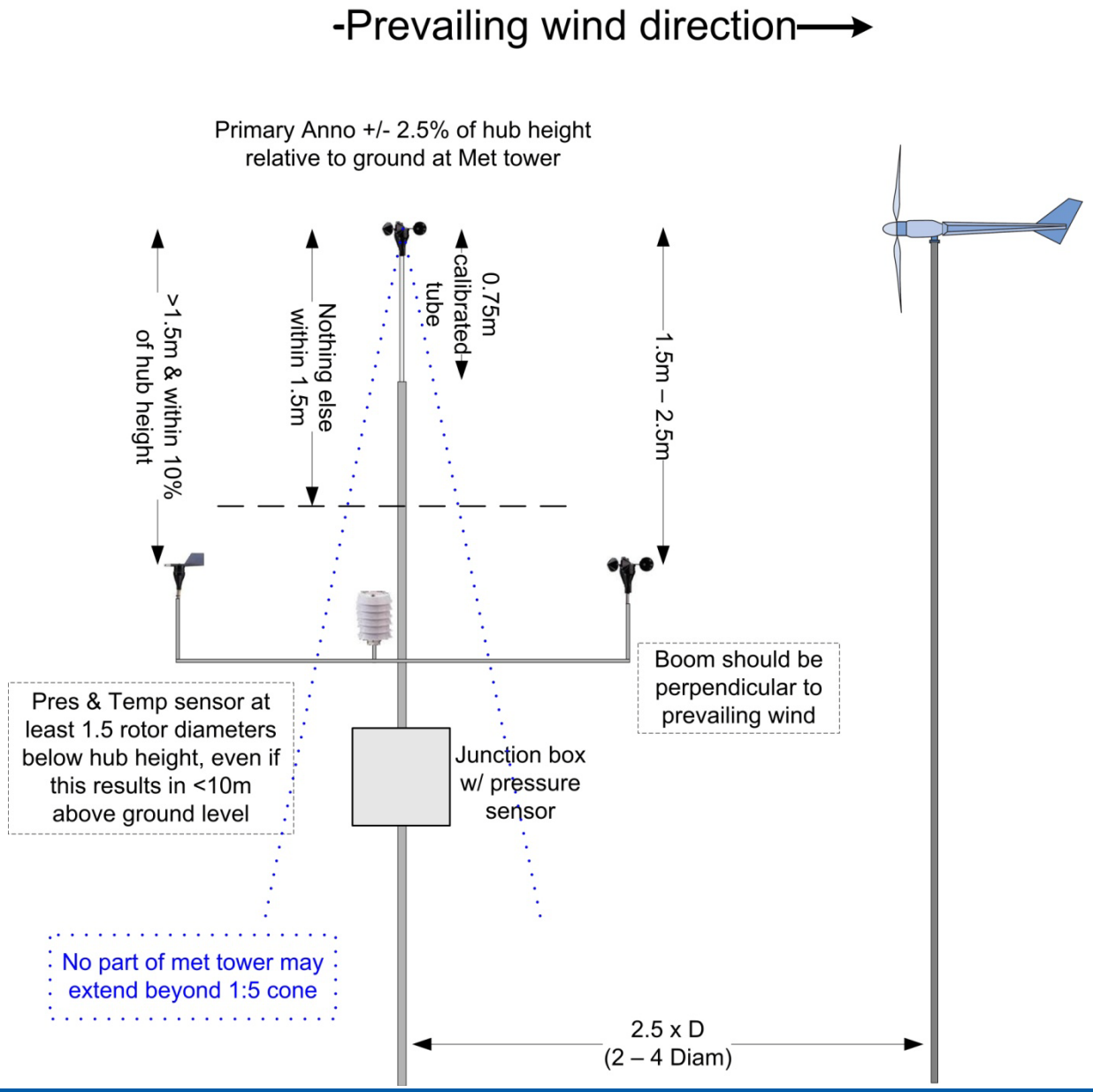
- Primary Anemometer – CLASS 1
- Reference Anemometer
- Wind Vane
- Air Pressure Transducer
- Shielded Air Temperature Sensor
- Rain indicator
- Datalogger/DAS

Instruments at Turbine

- Power Transducer
- Turbine Available Signal
- Turbine On-line Signal
- Nacelle anemometer (optional)

Power Performance - Instruments

Power Performance - Instruments



Power Performance - measurements

RPM

Turbine status signal(s)

1Hz or higher

- Mean
- Standard deviation
- Maximum
- Minimum

Power Performance - measurements

1min data sets

10min per 0.5m/s bin

1m/s below cut-in to 14m/s

Database for cutout hysteresis

Databases for special operating condition

For furling turbine, database should characterize performance when turbine is furled.

Power Performance – Data Rejection

External conditions exceeds operating range

Turbine in faulted state

Manually shut down (test or maintenance)

Test equipment failure or degradation (e.g. icing)

Wind direction outside measurement sector(s)

- Wind direction outside completed site calibration sector(s)

Clearly report any other rejection criteria.

Power Performance – Data Normalization

Site Average air density

Sea Level air density

$$\rho_{10min} = \frac{B_{10min}}{R_0 \cdot T_{10min}}$$

where

ρ_{10min} is the derived 10 min averaged air density;

T_{10min} is the measured absolute air temperature averaged over 10 min;

B_{10min} is the measured air pressure averaged over 10 min;

R_0 is the gas constant of dry air 287,05 J/(kg × K).

For Stall regulated wind turbines:

For a stall-regulated wind turbine with constant pitch and constant rotational speed, data normalization shall be applied to the measured power output according to the equation:

$$P_n = P_{10min} \cdot \frac{\rho_0}{\rho_{10min}} \quad (2)$$

where

P_n is the normalized power output;

P_{10min} is the measured power averaged over 10 min;

ρ_0 is the reference air density.

Power Performance - Binning

"Method of Bins"

Using **0.5m/s bins**, calculate the mean, normalized:

- Wind speed
- Power output

Power Performance – Power Coefficient

$$C_{P,i} = \frac{P_i}{\frac{1}{2}\rho_0 A V_i^3}$$

where

$C_{P,i}$ is the power coefficient in bin i;

V_i is the normalized and averaged wind speed in bin i;

P_i is the normalized and averaged power output in bin i;

A is the swept area of the wind turbine rotor;

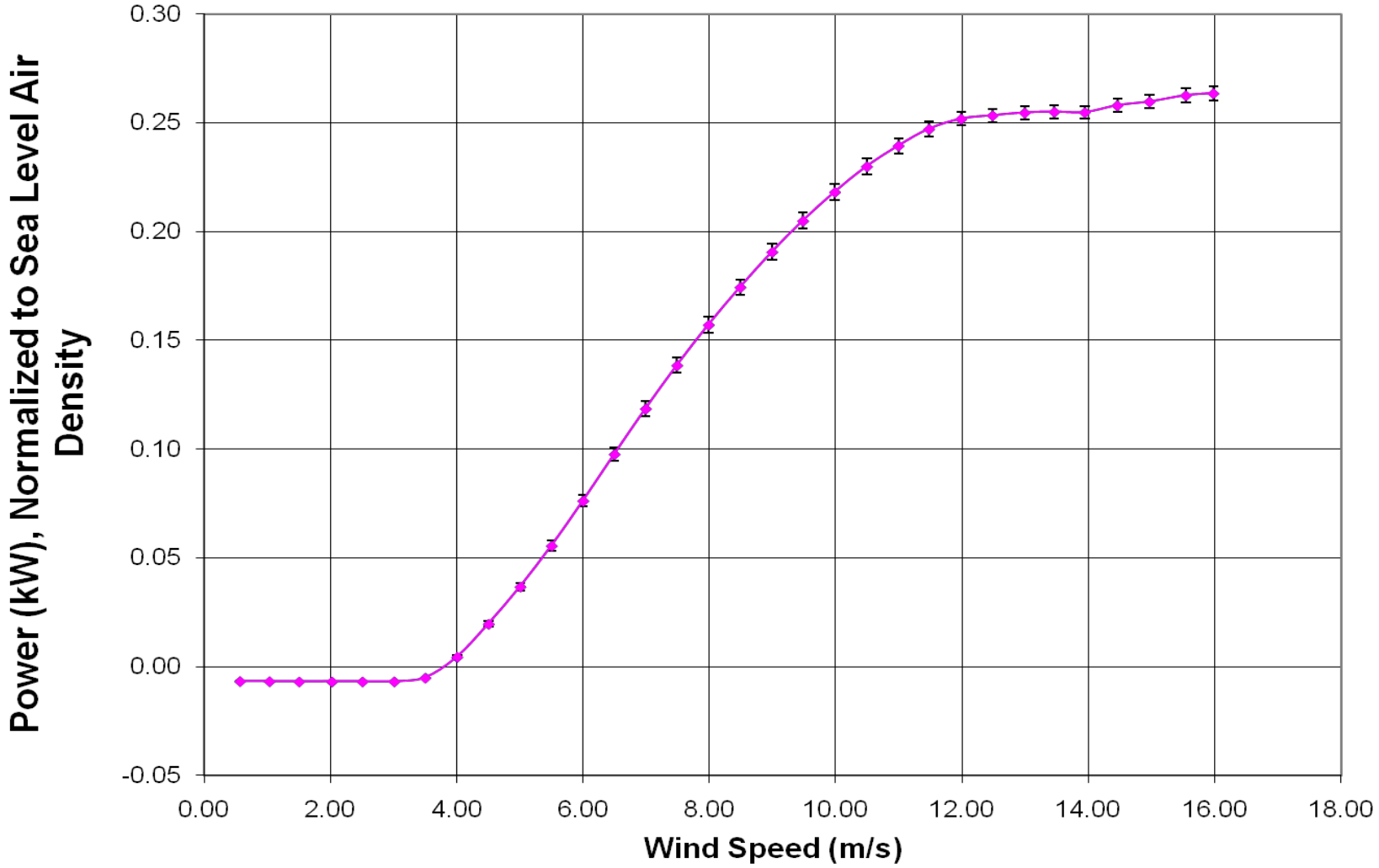
ρ_0 is the reference air density.

Power Performance - Results

- Power Curve (real power vs. wind speed)
  - normalized to sea-level density
  - normalized to site average density
- Power Coefficient Curve
- Wind Turbulence Intensity Scatter Plot
- Tables of data binned by wind speed
  - normalized wind speed
  - normalized output power
  - uncertainty
- Tables of calculated Annual Energy Production

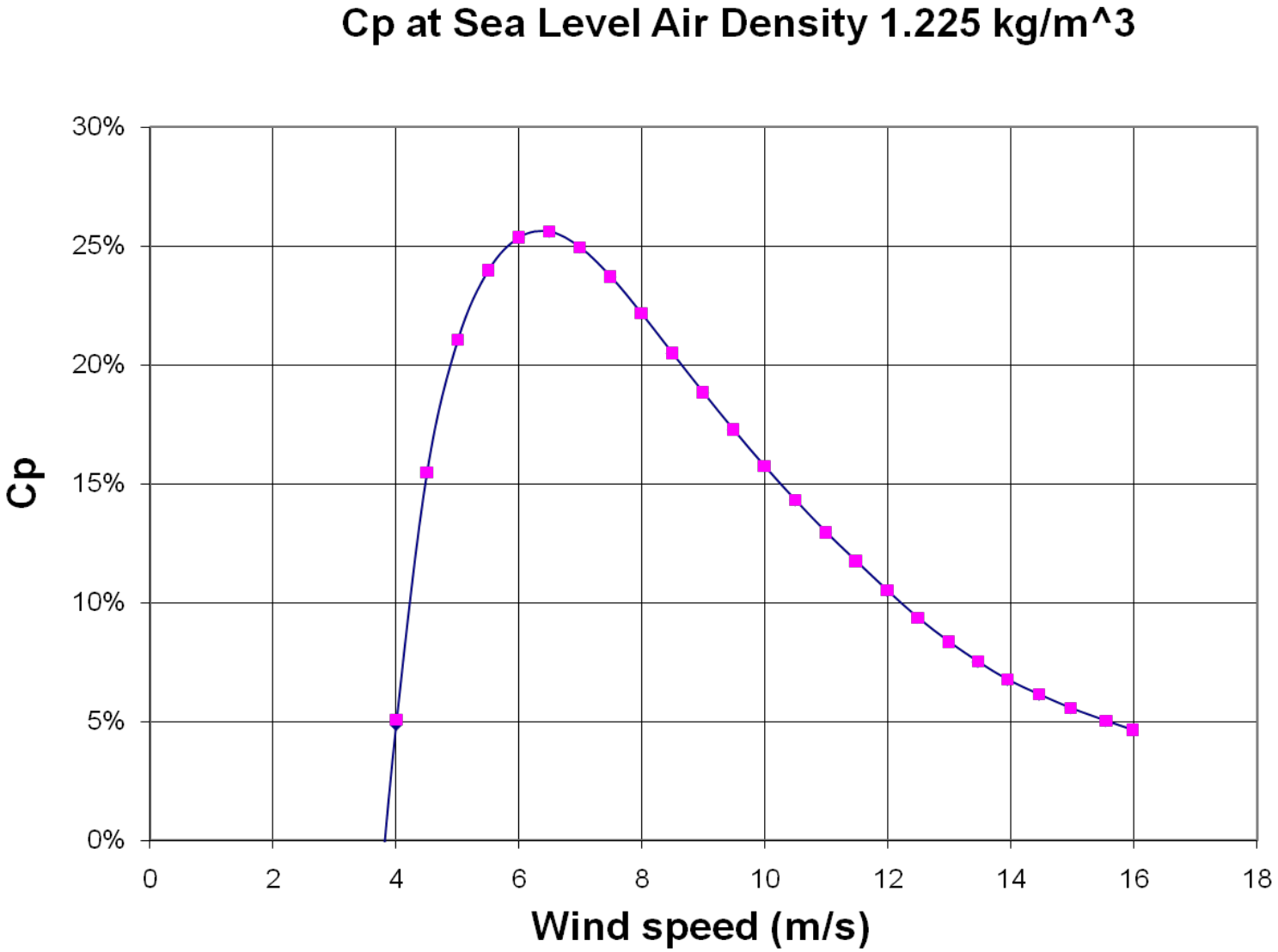
Power Performance - Results

Power Curve (real power vs. wind speed)
- normalized to sea-level density



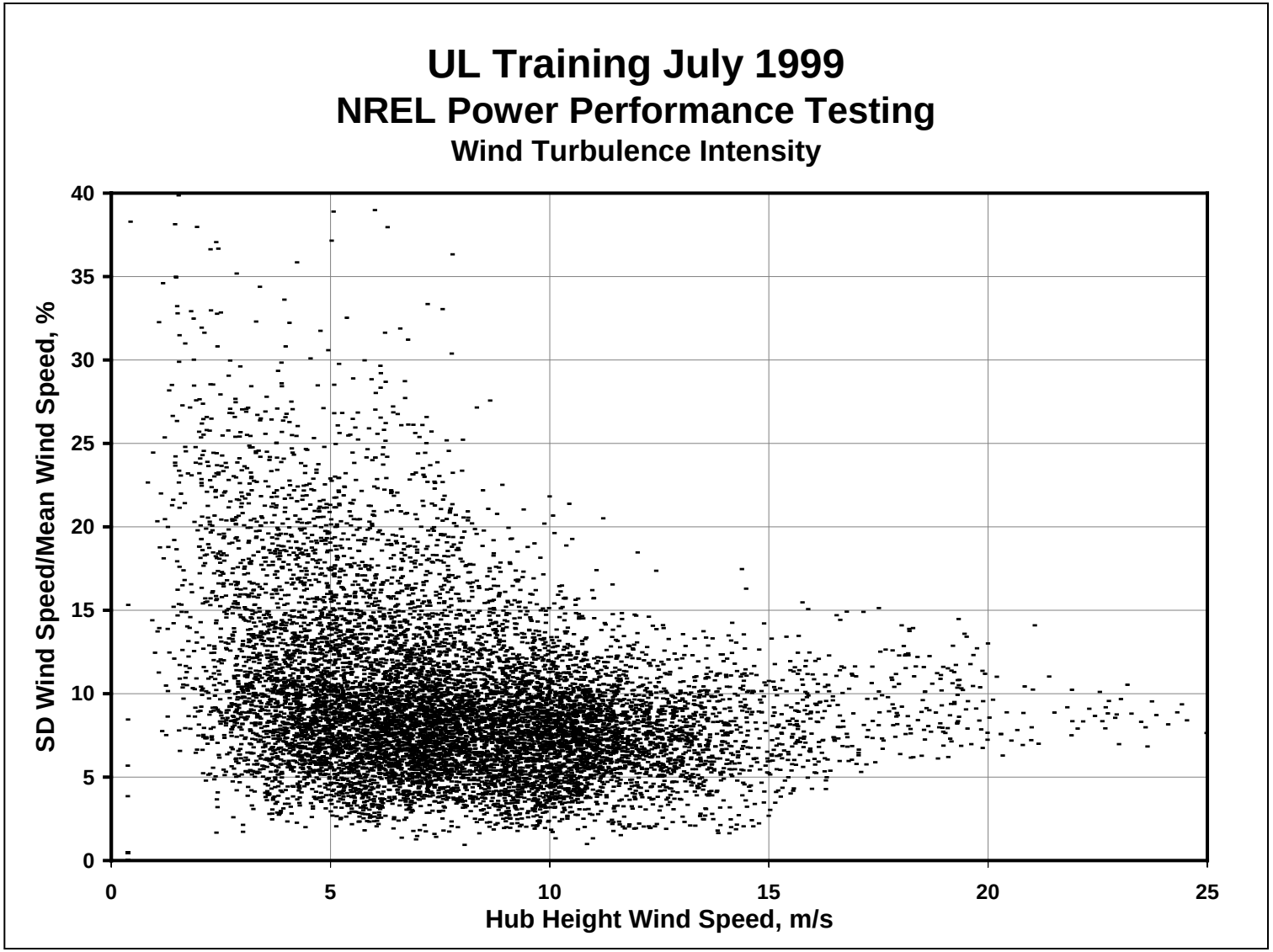
Power Performance - Results

Power Coefficient Curve



Power Performance - Results

Wind Turbulence Intensity Scatter Plot



Power Performance - Results

Tables of data binned by wind speed

Measured power curve, database A (All valid data)							
	Reference air density:		1.225 kg/m^3				
Bin Number	Hub height wind speed m/s	Power output (kW)	Cp	Number Data Sets	Category A Standard Uncertainty (kW)	Category B Standard Uncertainty (kW)	Combined Standard Uncertainty (kW)
1	0.57	-0.01	-26.562	177	0.000	0.000	0.000
2	1.03	-0.01	-4.410	658	0.000	0.000	0.000
3	1.50	-0.01	-1.460	1181	0.000	0.000	0.000
4	2.02	-0.01	-0.597	1503	0.000	0.000	0.000
5	2.51	-0.01	-0.313	2229	0.000	0.000	0.000
6	3.01	-0.01	-0.180	2882	0.000	0.000	0.000
7	3.50	-0.01	-0.085	3107	0.000	0.000	0.000
8	4.00	0.00	0.049	3404	0.000	0.001	0.001
9	4.50	0.02	0.155	3352	0.000	0.001	0.001
10	5.01	0.04	0.211	4242	0.000	0.002	0.002
11	5.50	0.06	0.240	4845	0.000	0.002	0.002
12	6.00	0.08	0.254	4918	0.000	0.003	0.003
13	6.50	0.10	0.256	4616	0.000	0.003	0.003
14	6.99	0.12	0.249	3853	0.000	0.003	0.003
15	7.49	0.14	0.237	3267	0.000	0.003	0.003
16	7.99	0.16	0.222	2545	0.000	0.004	0.004
17	8.49	0.17	0.205	2109	0.000	0.004	0.004
18	8.99	0.19	0.188	1727	0.000	0.004	0.004

Power Performance - Results

Tables of calculated Annual Energy Production

Estimated annual energy production, database A (all valid data)					
Reference air density:	1.225	kg/m^3			
Cut-out wind speed:	25.00	m/s			
Hub height annual average wind speed (Rayleigh) m/s	**AEP-measured MWh**	**Standard Uncertainty in AEP-measured**		**AEP-extrapolated MWh**	**Complete if AEP measured is at least 95% of AEP extrapolated**
		MWh	**%**		
4	0.258	0.011	4%	0.258	Complete
5	0.499	0.015	3%	0.500	Complete
6	0.733	0.018	3%	0.742	Complete
7	0.925	0.020	2%	0.963	Complete
8	1.054	0.021	2%	1.154	Incomplete
9	1.122	0.021	2%	1.311	Incomplete
10	1.141	0.020	2%	1.434	Incomplete
11	1.124	0.019	2%	1.524	Incomplete

How does NREL Confirm Accuracy?

- Instrument calibrations by accredited laboratories
- In-lab equipment checks
- In-field equipment checks
- Data validity checks
- Proficiency testing (Round Robins)