Comparison of linear and non-linear blade model predictions in Bladed to measurement data from GE 6MW wind turbine

Will Collier

10 November 2016

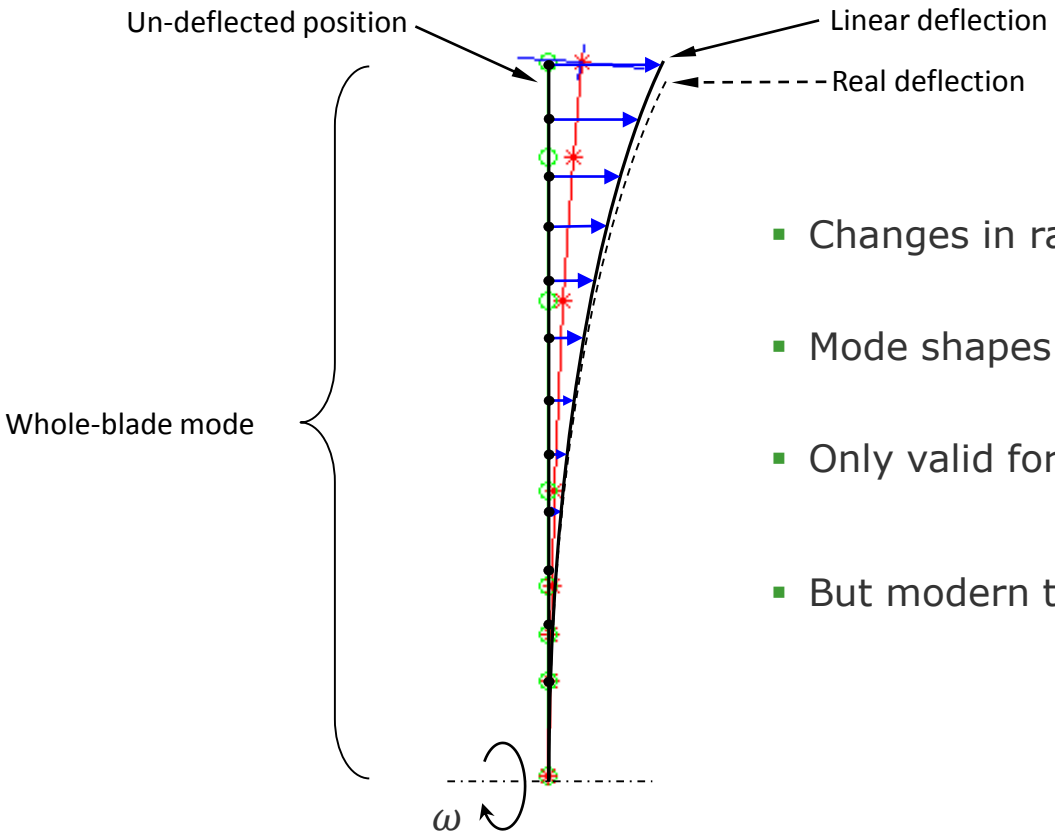
Contents

- Introduction
  - Non-linear blade model in Bladed
  - The turbine, environment and Bladed models
- Results
  - Power curve
  - Loads on blade, hub, tower
- Conclusions

Contents

- Introduction
  - Non-linear blade model in Bladed
  - The turbine, environment and Bladed models
- Results
  - Power curve
  - Loads on blade, hub, tower
- Conclusions

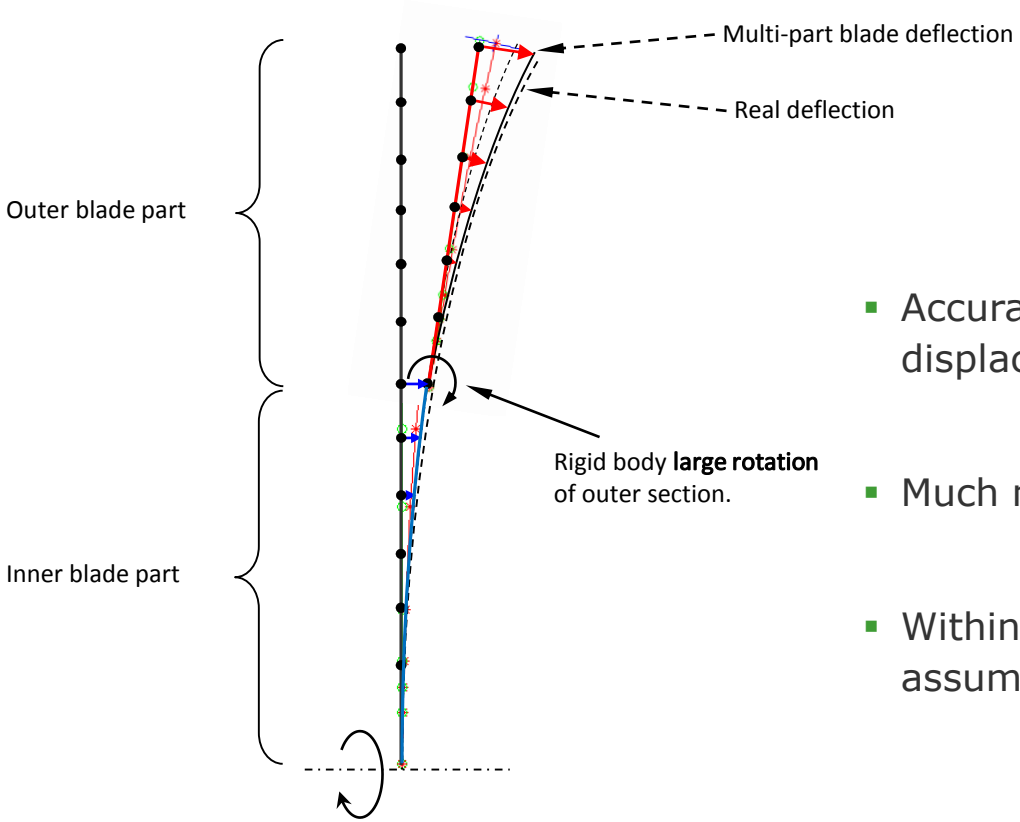
Linear blade model



- Changes in radial position not accounted for
- Mode shapes only correct for the undeflected blade
- Only valid for small deflections
- But modern turbine blades have large deflections!

Multi-part blade

- Blade is several modal bodies



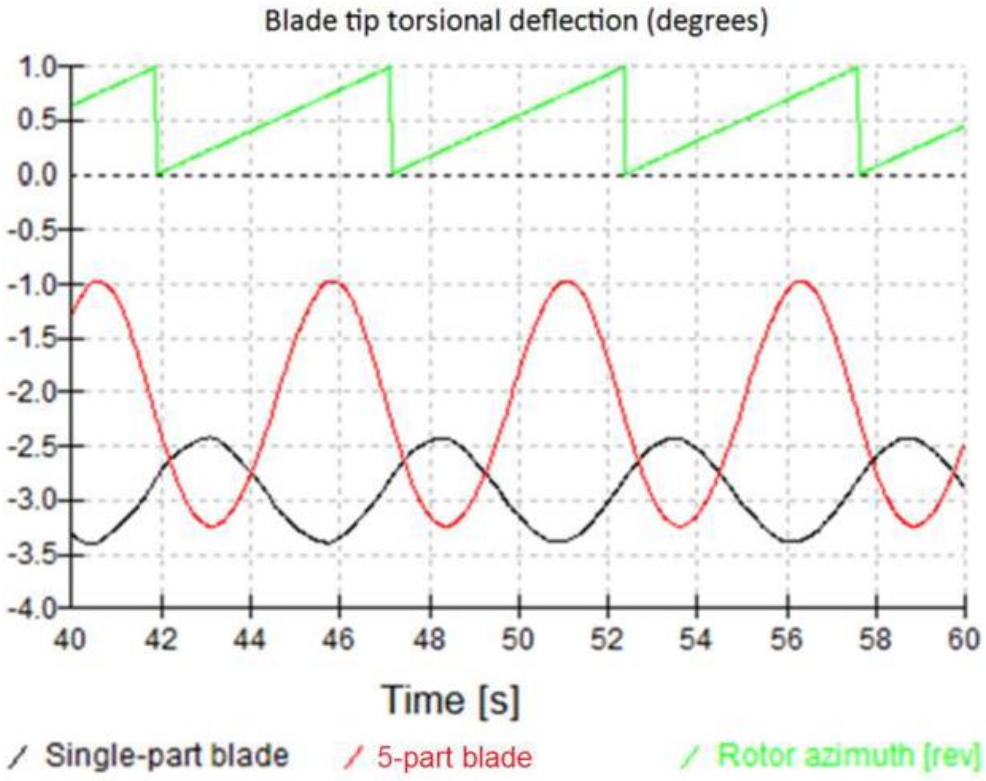
- Accurate model of large (non-linear) displacement, including radial displacement
- Much more accurate torsion prediction
- Within each blade part, small deflection assumption remains valid

The Bladed models

- Full turbine model defined by GE

- **Single-part blade**
  - 9 modes to include 1st torsional

- **Multi-part blade**
  - 5 blade parts, each with 8 modes

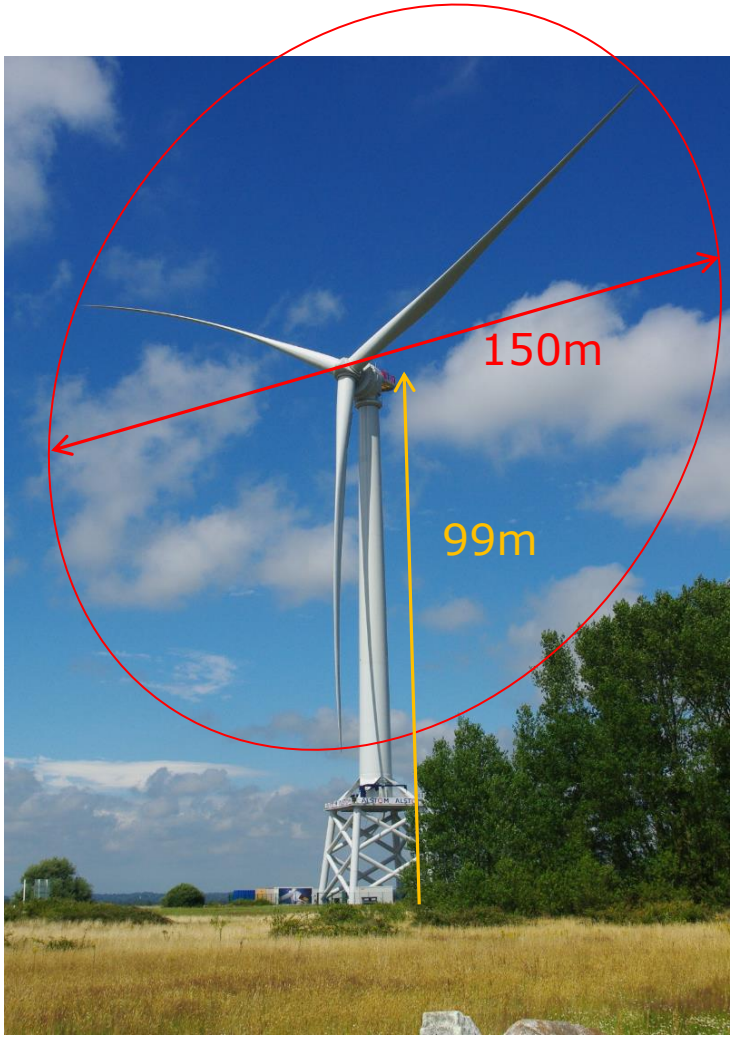


Aim of study

- **Aim**
  - Compare “single-part” and “multi-part” blade model results to measurements from GE Haliade 6MW turbine
    - Power
    - Loads
    - Blade deflection

The turbine

- GE Haliade 6MW (onshore prototype)
- LM blade 73.5m
- Direct drive



The environment

- Data collection
  - Wind speed and TI measured near turbine (2D away)
    - Wind speed 5-15m/s and filtered for TI = 10-12%
  - Wind shear and air density measured for each wind bin
  - Strain gauges at blade root, main shaft, tower base
  - Blade deflection measured with ground-based laser

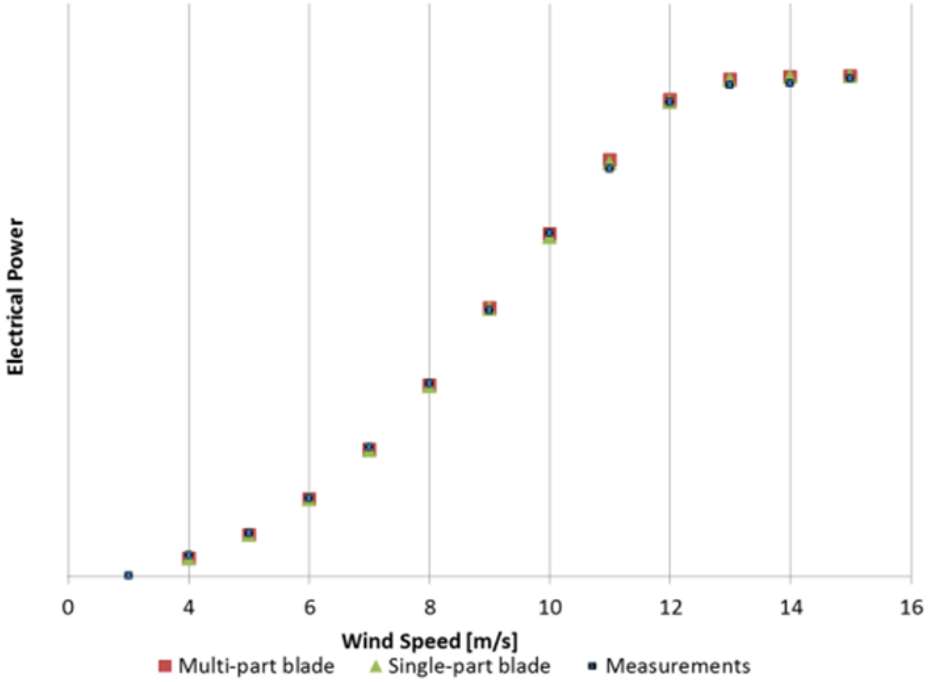
- Bladed wind inputs
  - Measured speed, shear and air density
  - Kaimal turbulence TI = 11%
  - Upflow = 0^{o}
  - 6 turbulence seeds (yaw -8, 0, 8)

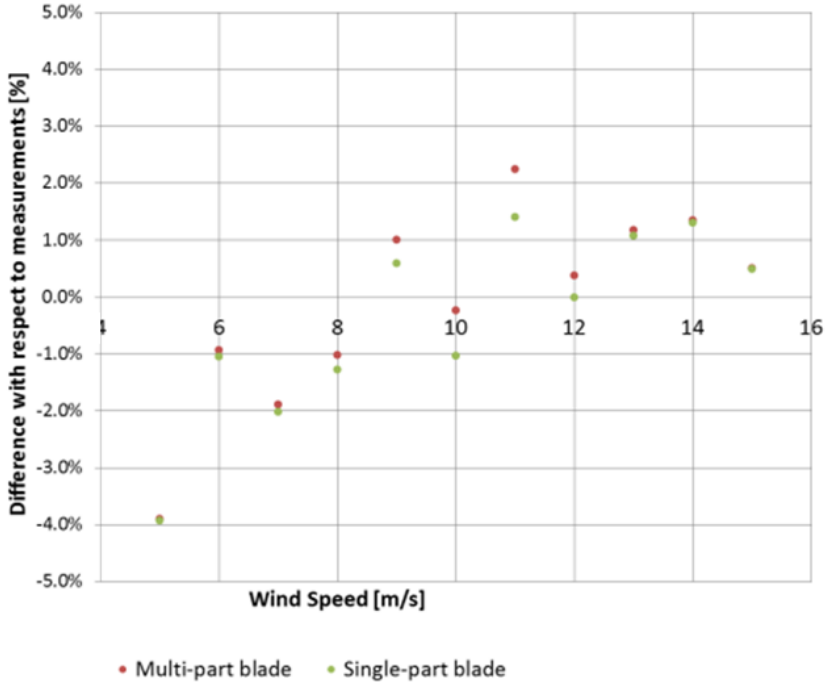
Contents

- Introduction
  - Non-linear blade model in Bladed
  - The turbine, environment and Bladed models
- Results
  - Power curve
  - Loads on blade, hub, tower
- Conclusions

Results – power curve

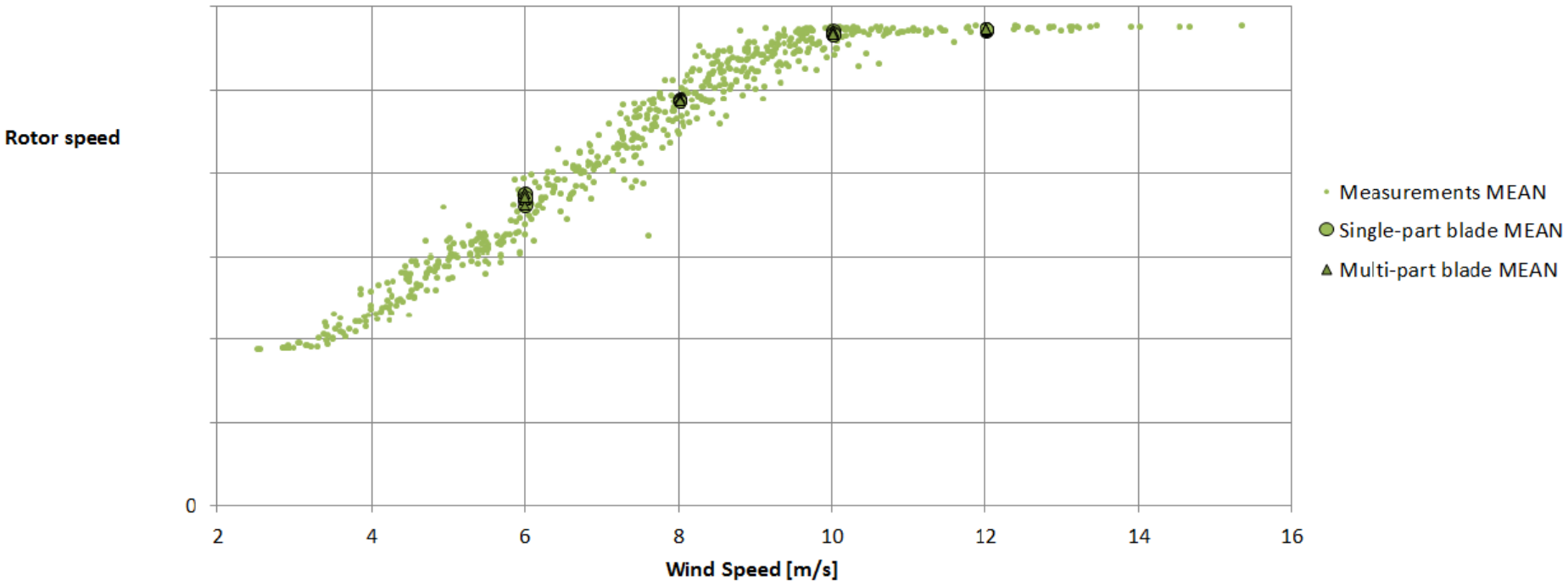
- Electrical power prediction relative to measurements – generally within 2%





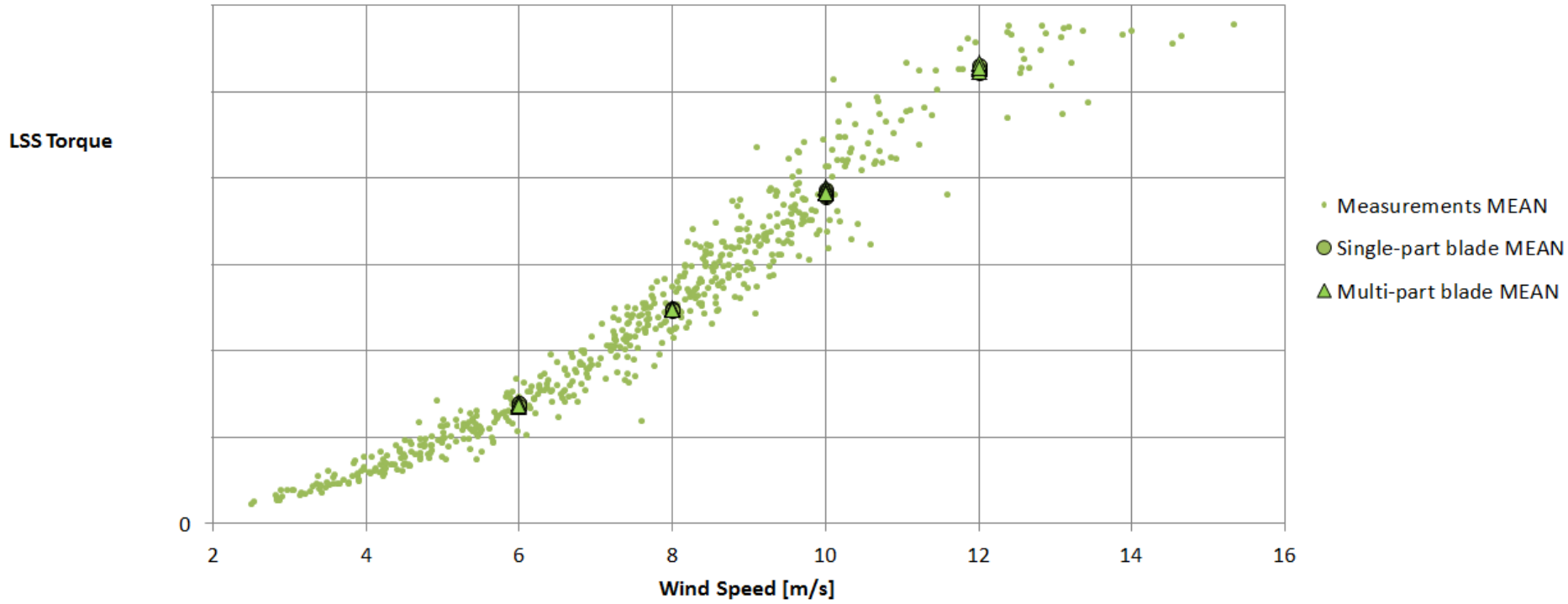
Results – loads (operating point)

- Check match in operating point
- Rotor speed mean values match well



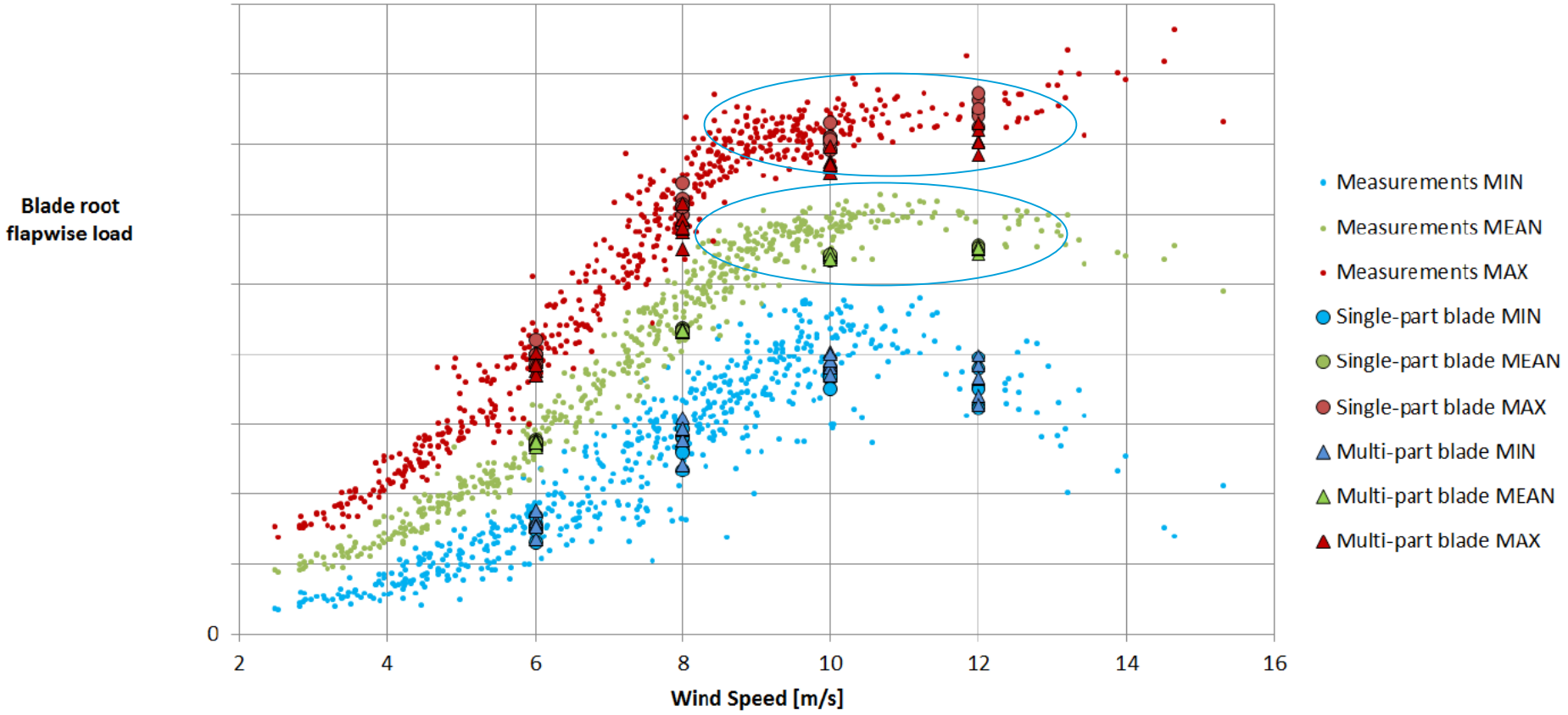
Results – loads (operating point)

- Check match in operating point
- Shaft torque mean values match well



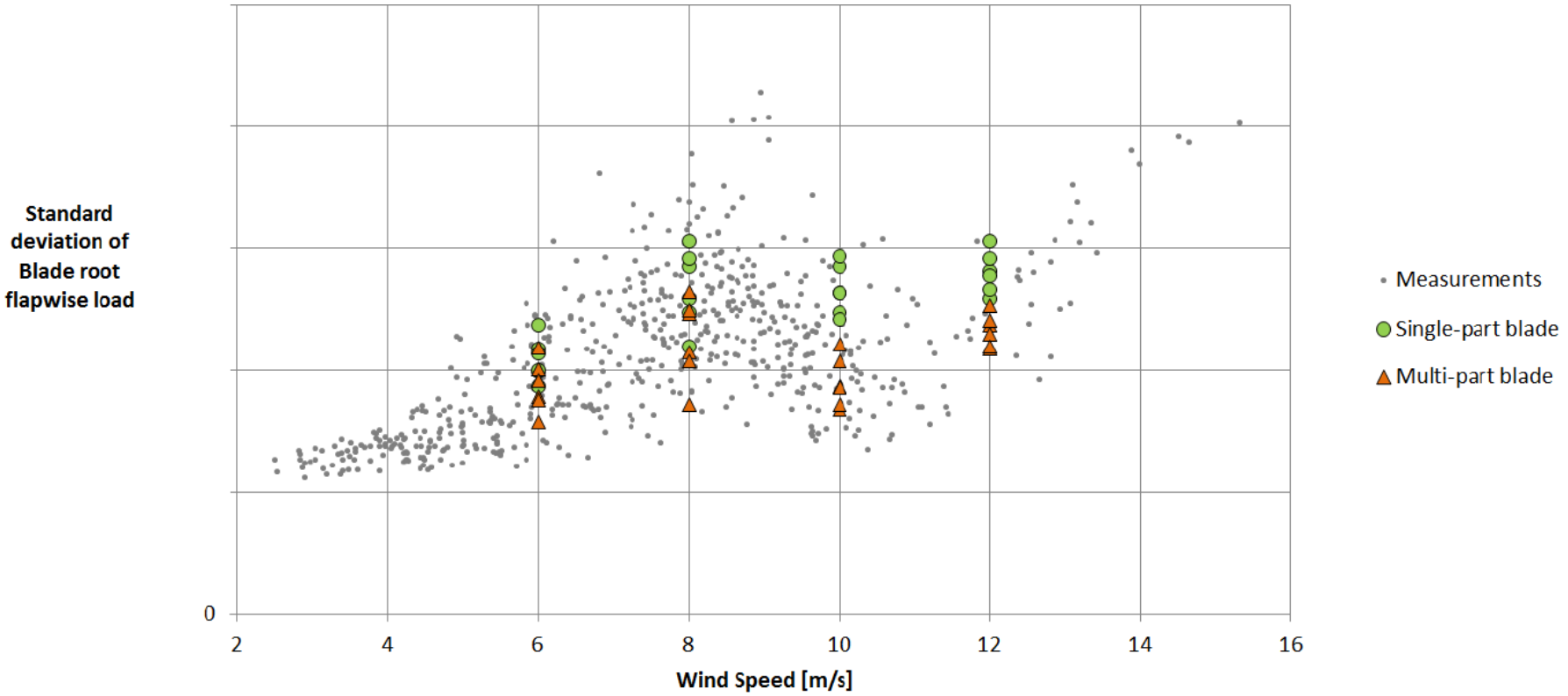
Results – blade flapwise loads

- Blade flapwise loads **Min, Mean, Max**
  - Offset in mean value between simulation and measurements



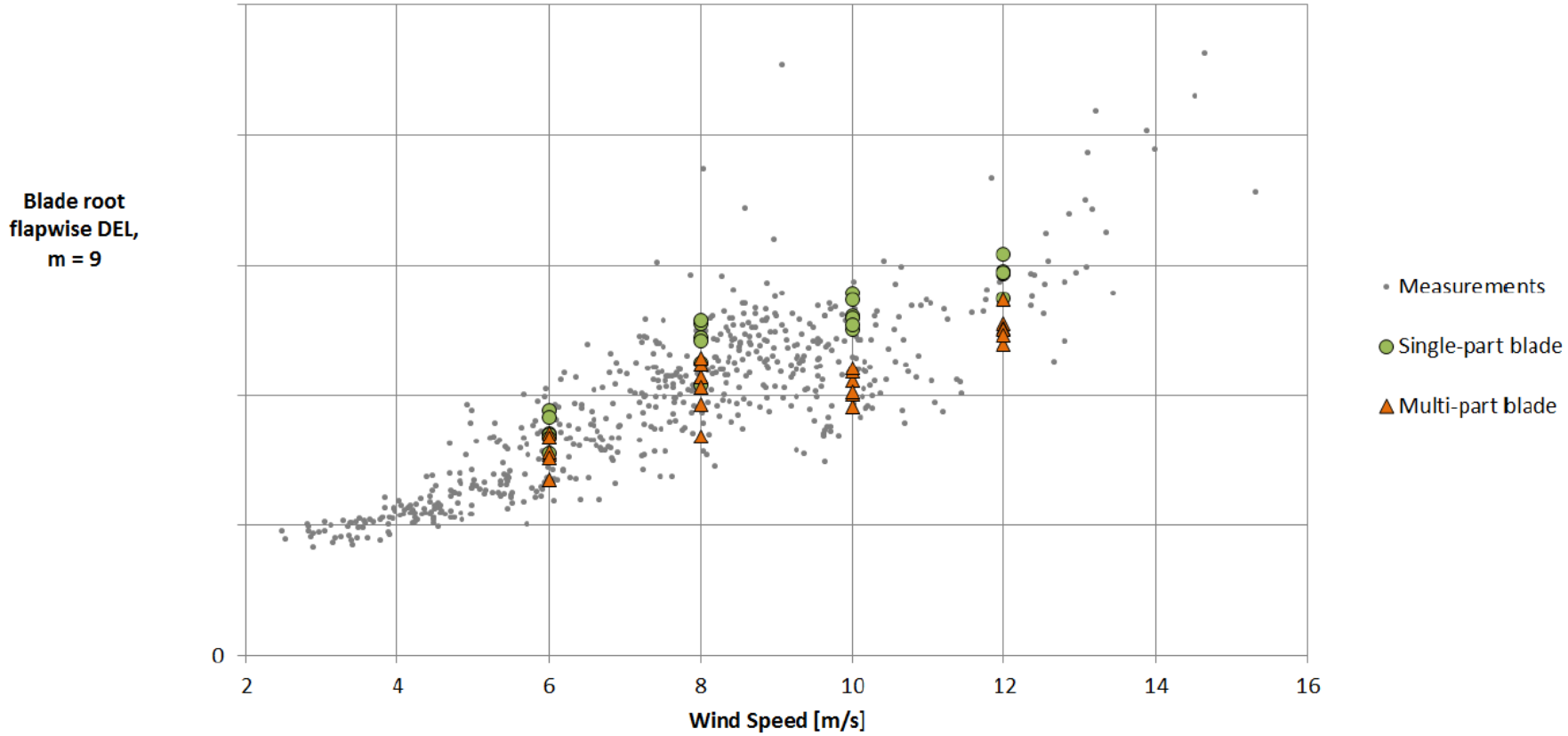
Results – blade flapwise loads

- Blade flapwise loads **standard deviation**
  - Good match suggesting range is well captured



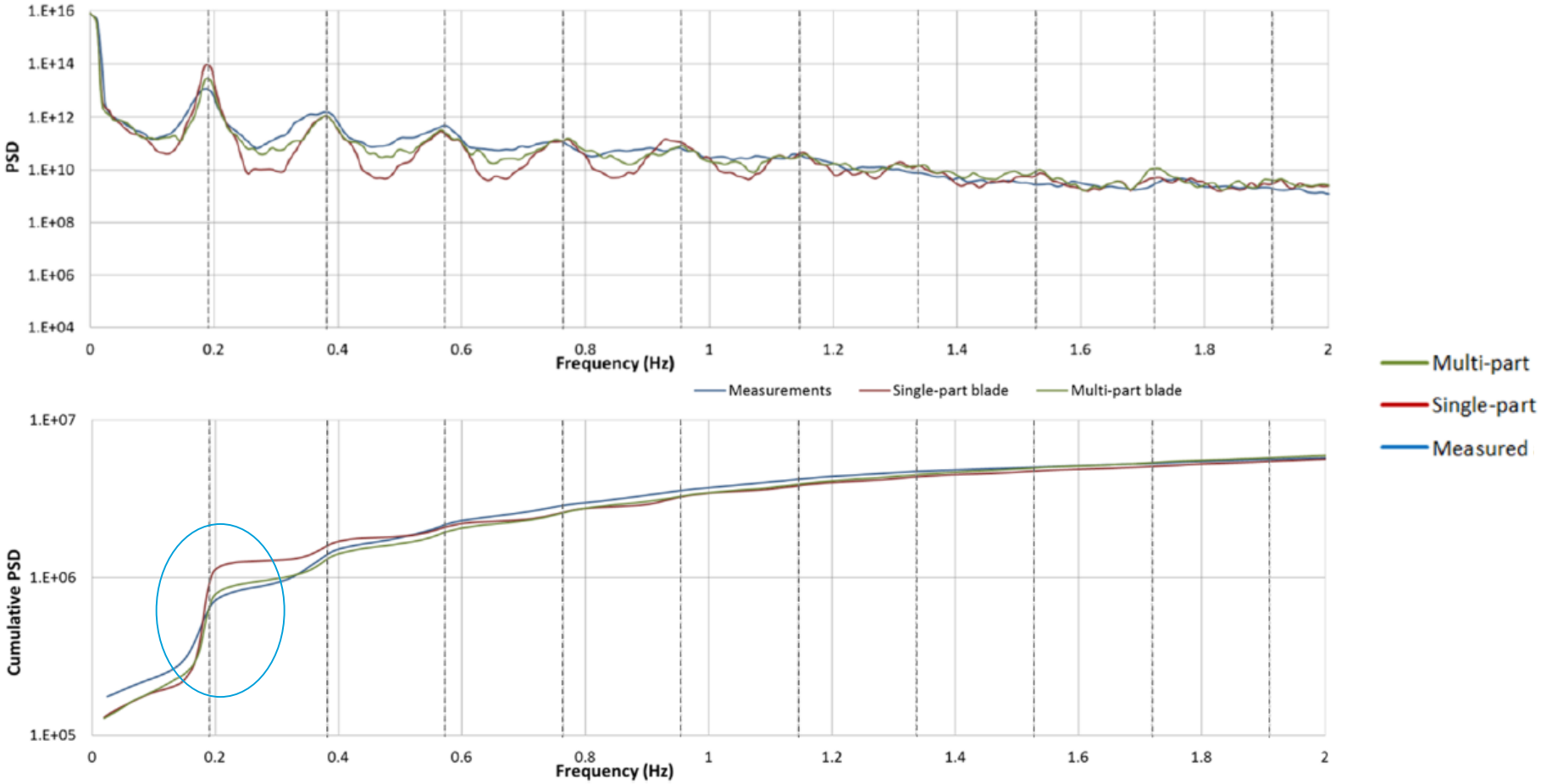
Results – blade flapwise loads

- Blade flapwise loads **DEL**
  - Multi-part centred in cloud of measurements. Single-part near top.



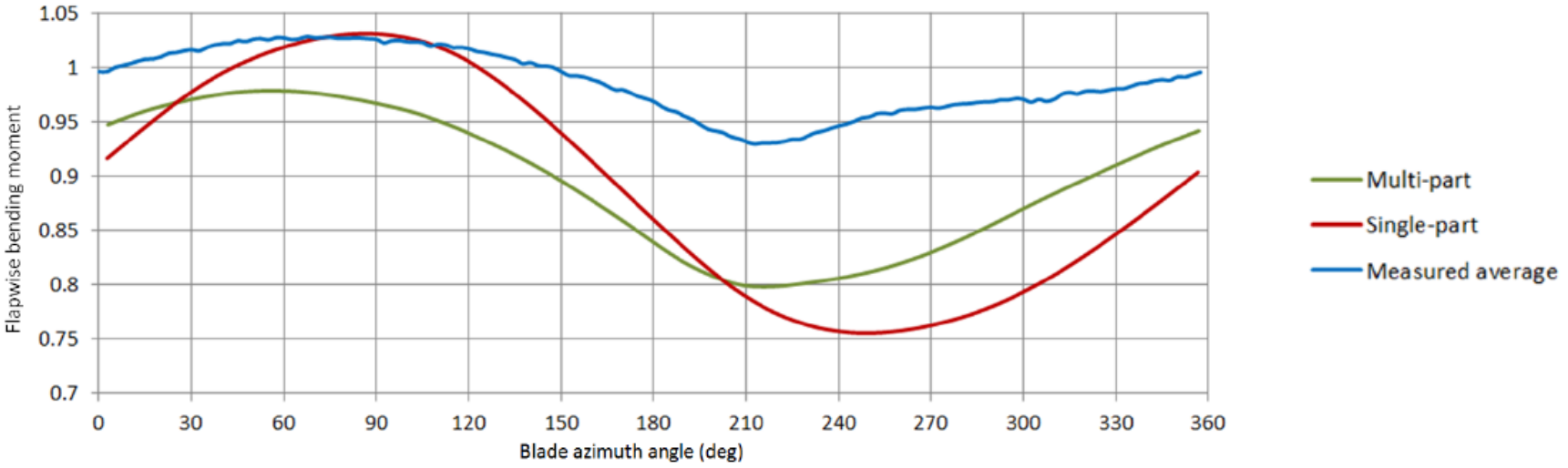
Results – blade flapwise loads

- Blade flapwise loads **PSD** – main difference at 1p



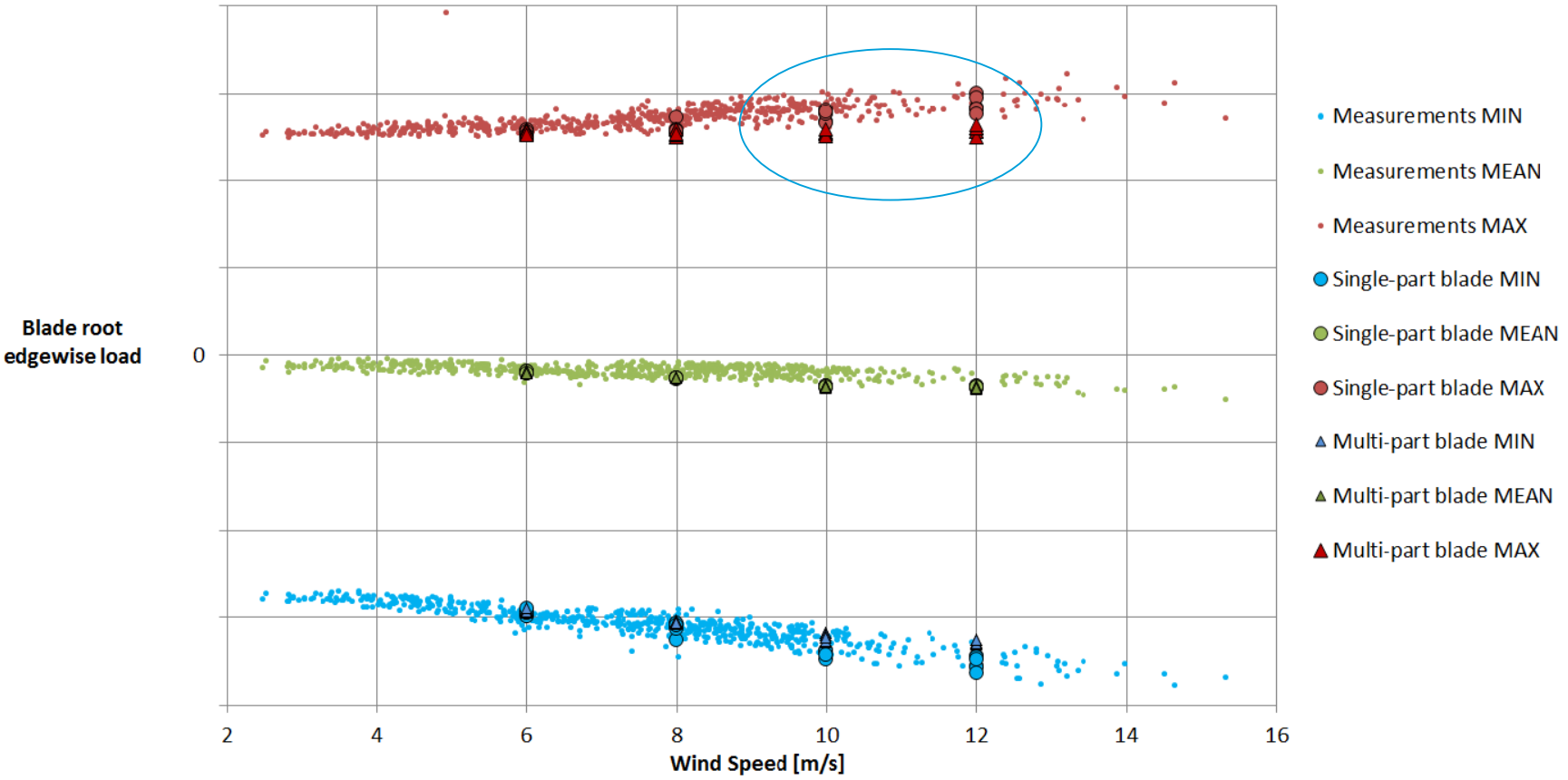
Results – blade flapwise loads

- Blade flapwise load **periodic component**
  - Multi-part matches better in phase and amplitude



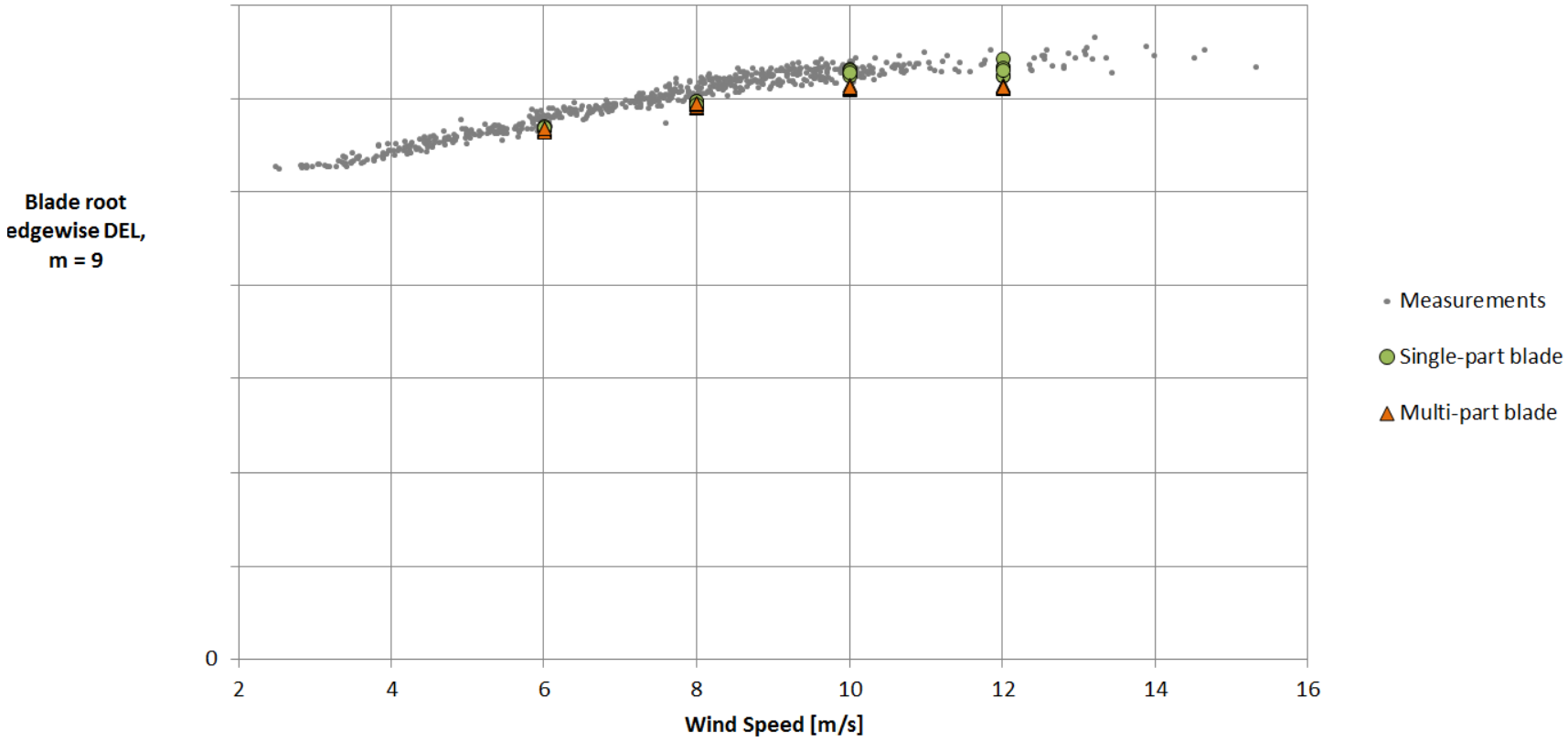
Results – blade edgewise loads

- Blade edgewise loads **Min, Mean, Max**
  - Good match generally. Single-part matches max loads better



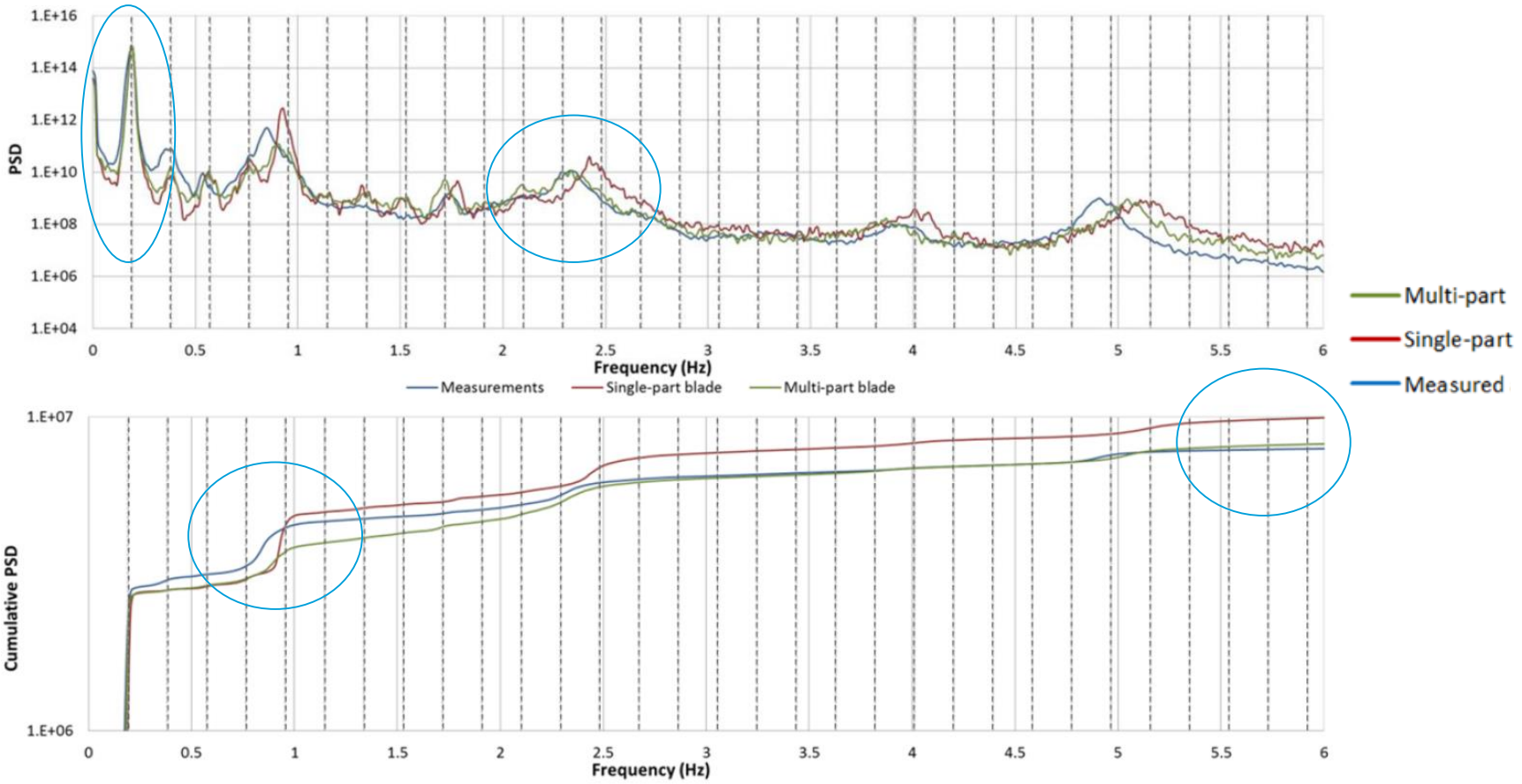
Results – blade edgewise loads

- Blade edgewise loads **DEL**
  - Single-part slightly closer to measurements



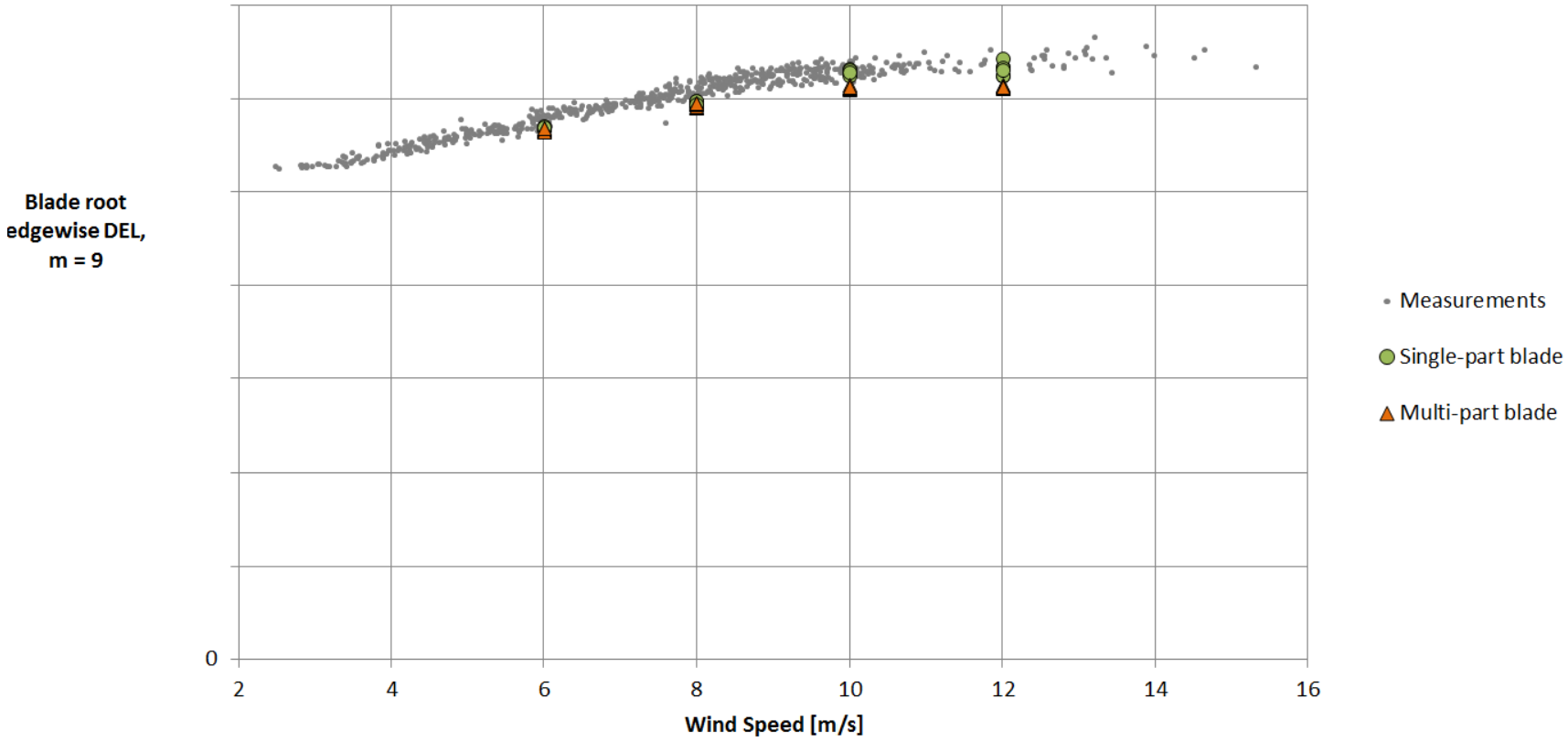
Results – blade edgewise loads

- Blade edgewise loads **PSD**
  - Multi-part dynamic response looks better (contradicts DELs)



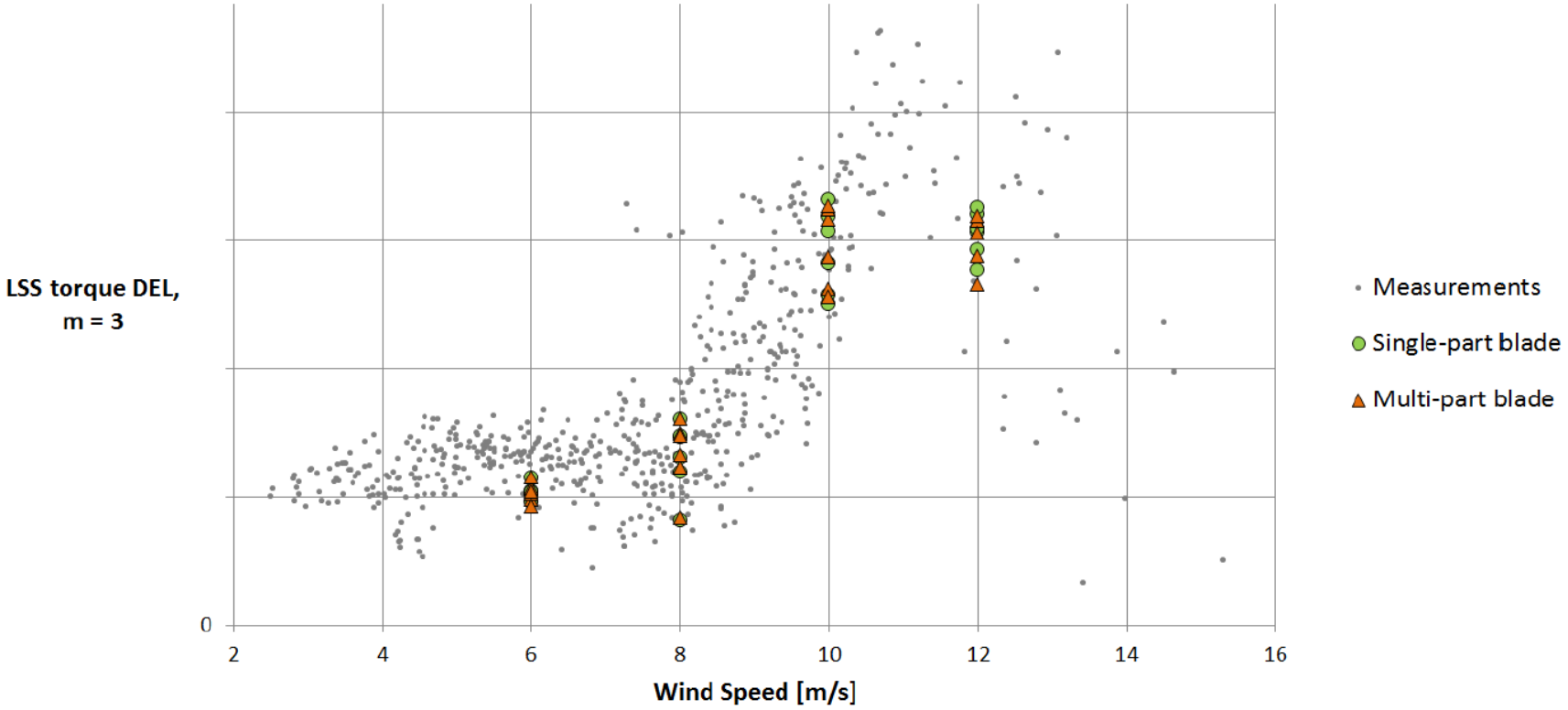
Results – blade edgewise loads

- Blade edgewise loads **DEL**
  - Single-part slightly closer to measurements



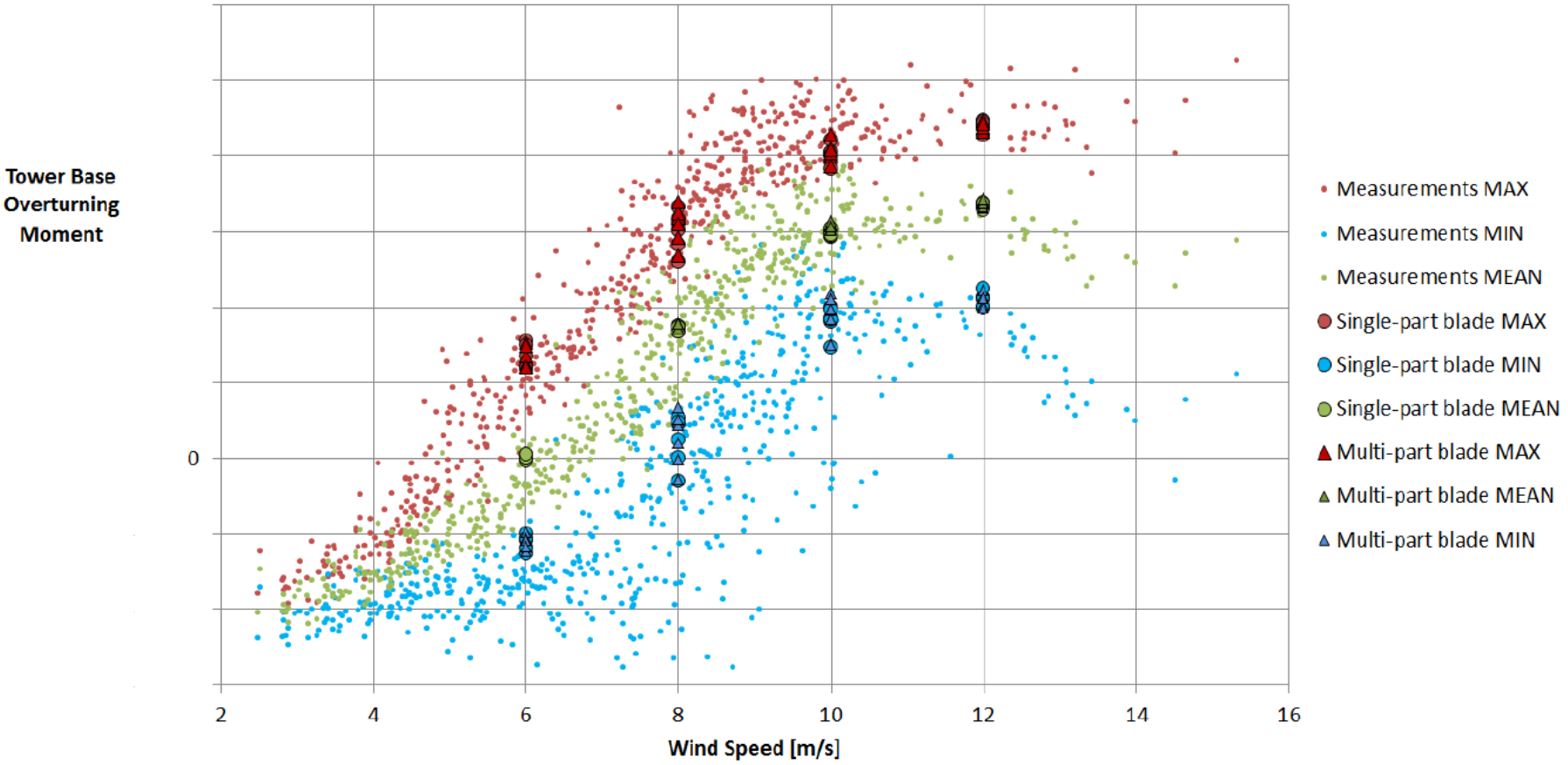
Results – shaft torque loads

- Good match in LSS **DELs**



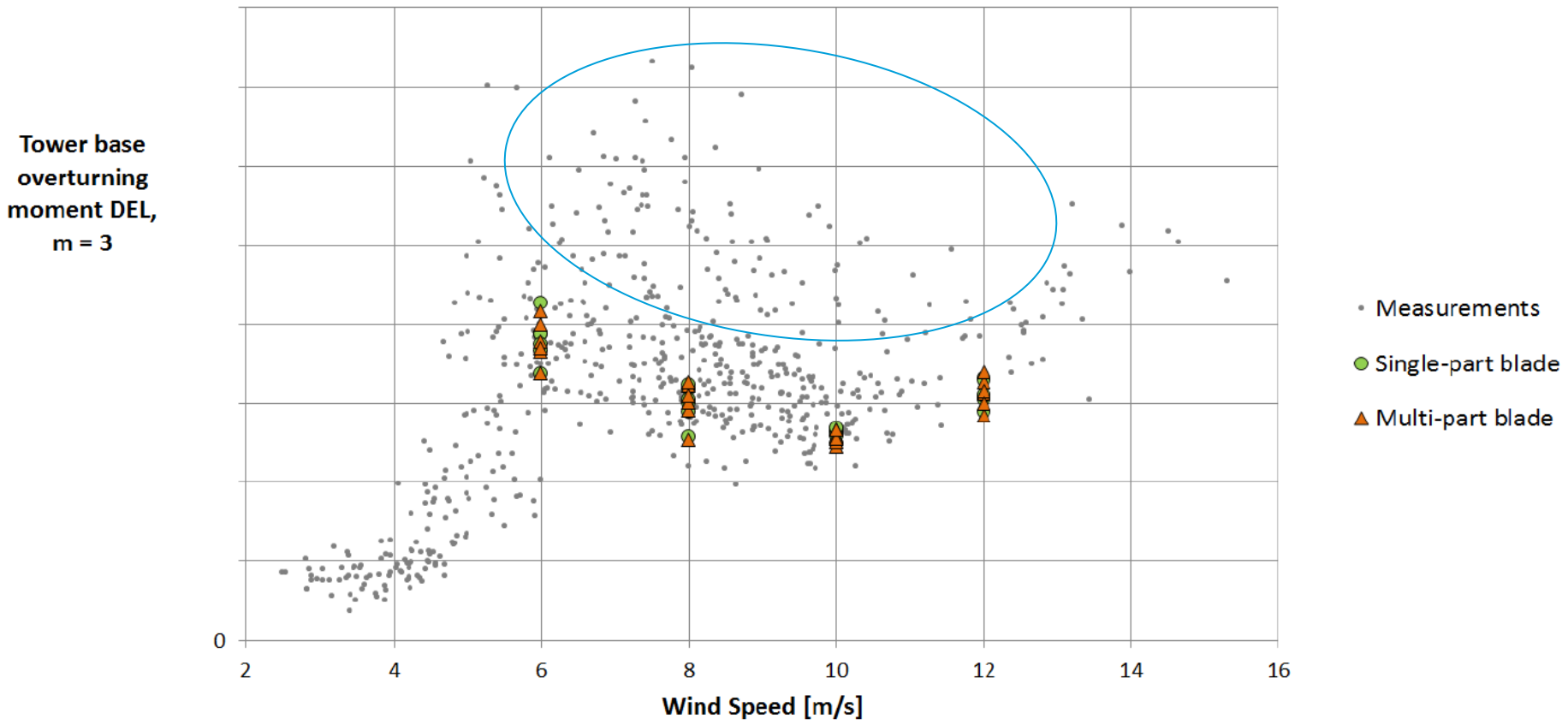
Results – tower base loads

- Good match in tower **Min, Mean, Max**



Results – tower base loads

- Ok match in tower **DELs** – not capturing highest values



Contents

- Introduction
  - Non-linear blade model in Bladed
  - The turbine, environment and Bladed models
- Results
  - Power curve
  - Loads on blade, hub, tower
- Conclusions

Conclusions

- Single-part and multi-part both generally show a good match to measurement power, loads and blade deflection
- Measured power generally within 2% of simulated
- Blade flapwise loads matched better to measurements with multi-part
  - periodic load is a contributor to differences
- Blade edgewise DELs closer to measurements for single-part
  - dynamic response of multi-part looks better
  - other factors? (Aerodynamics, wind inflow conditions etc.)