Validation of the Response of the

Wind Harvester™ Model 3.1 VAWT

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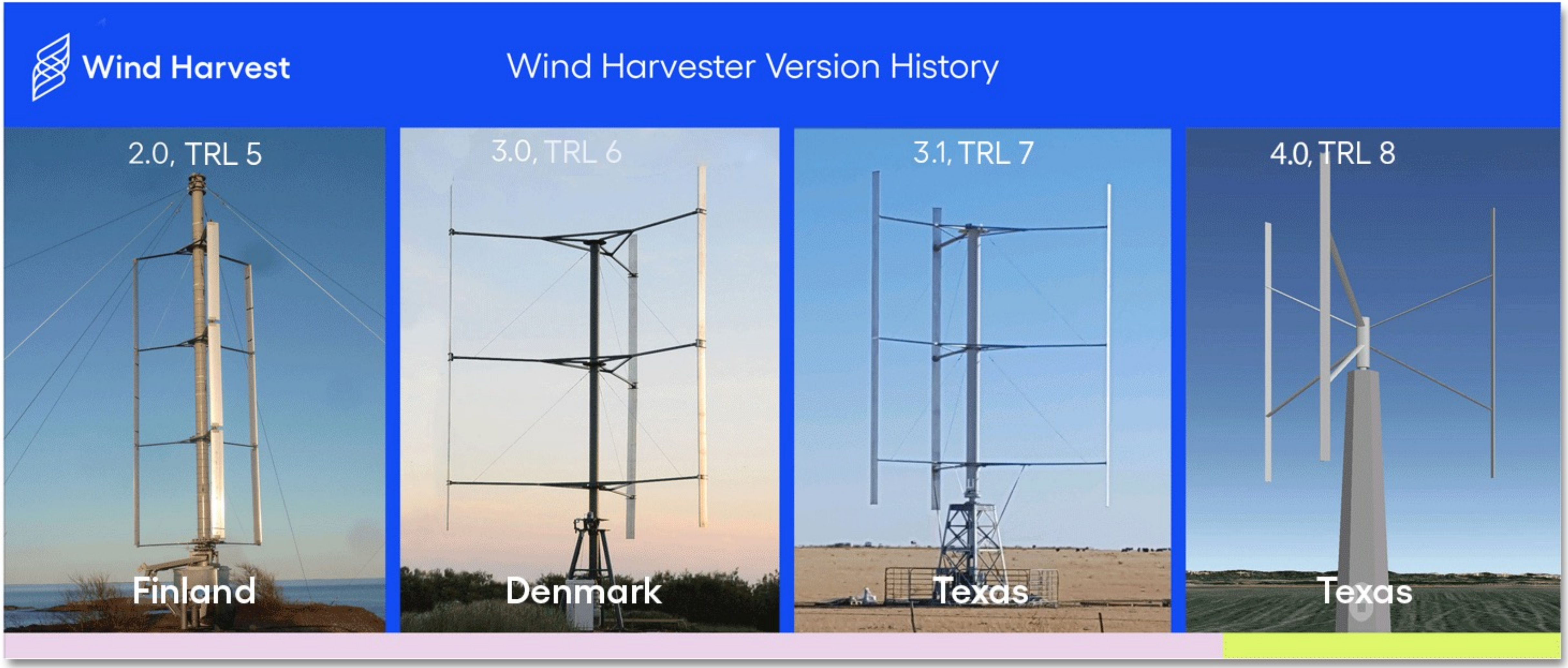
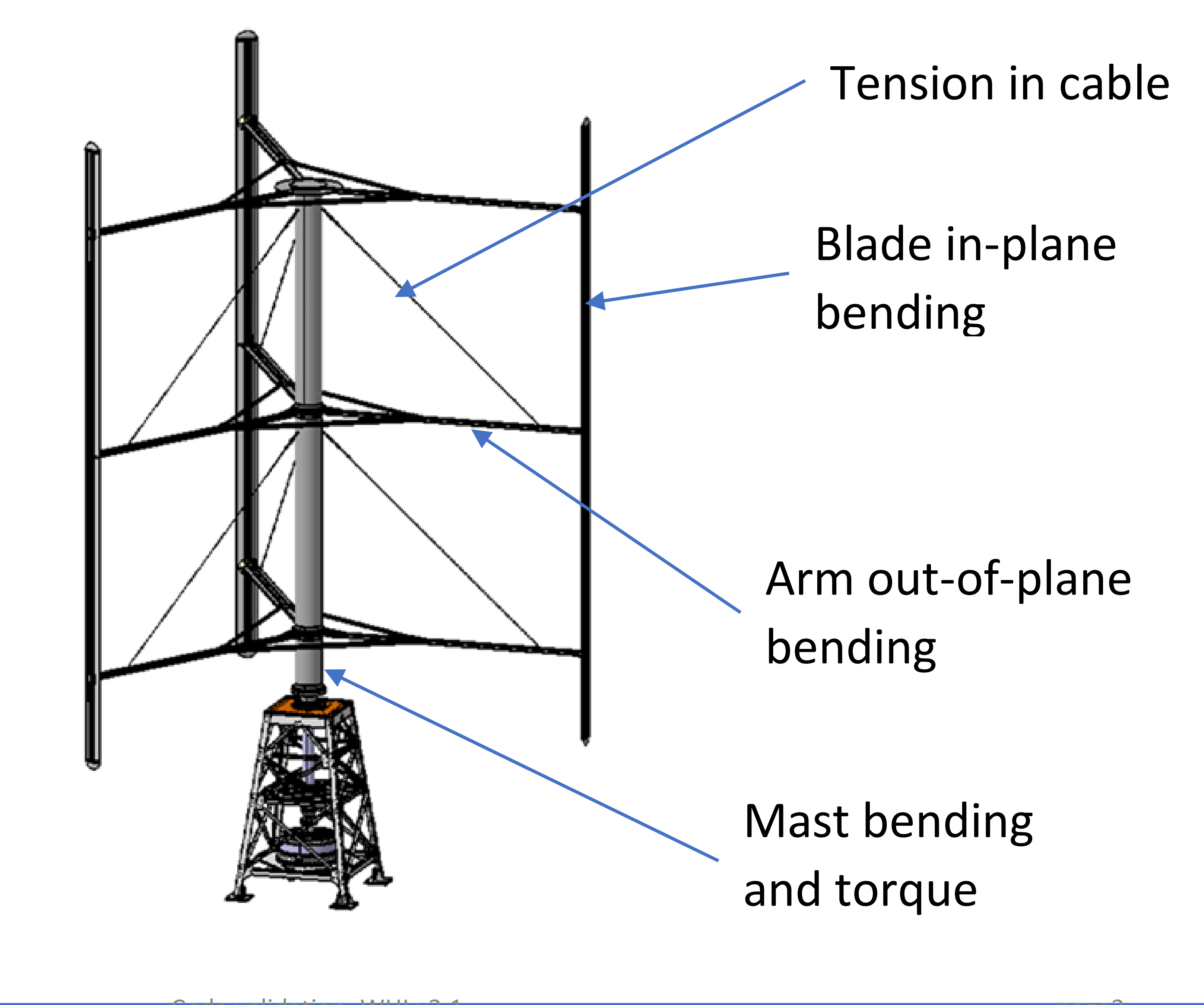
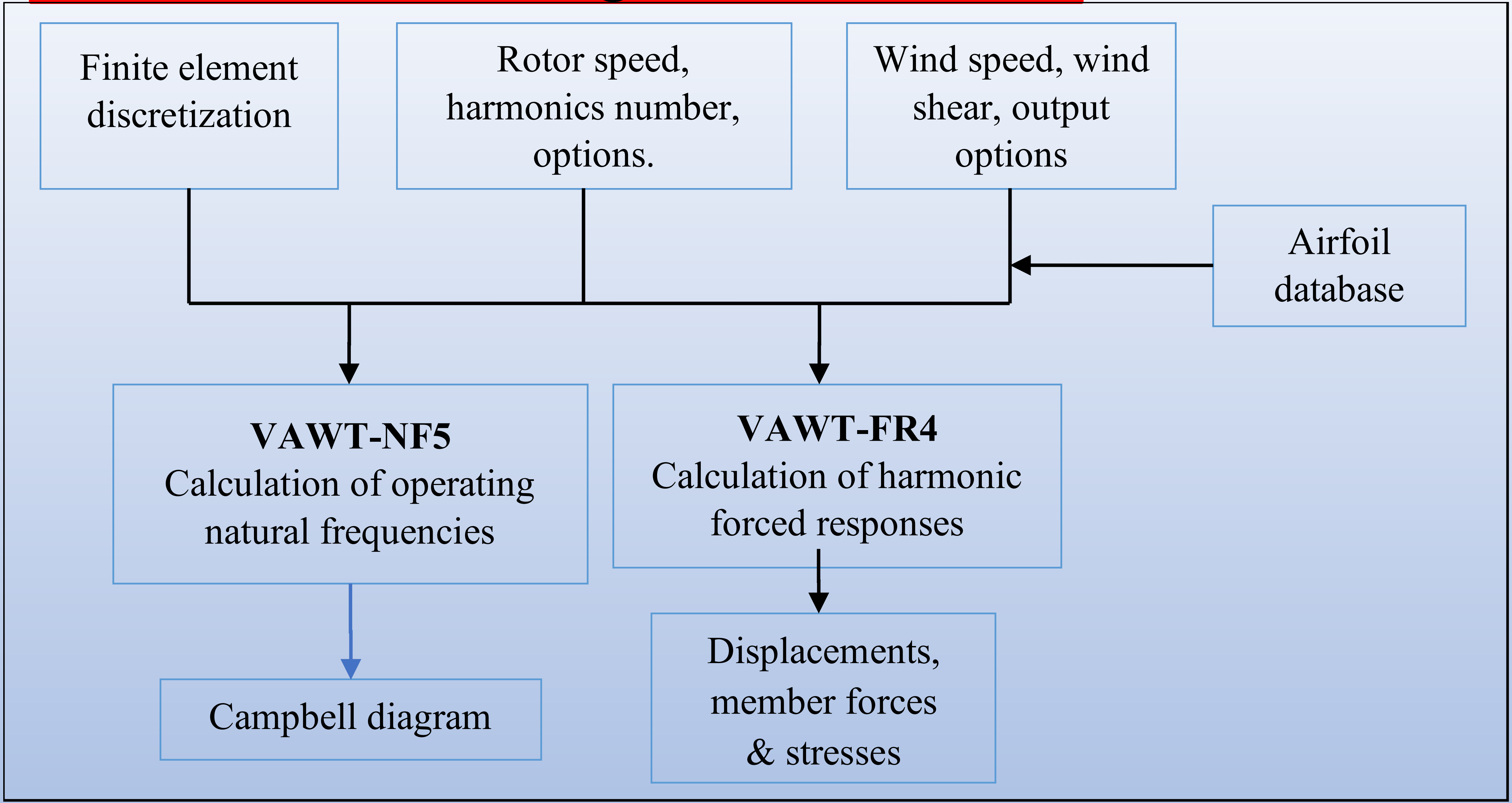

Wind Harvest
Wind Harvester Version History
2.0, TRL 5
Finland
3.0, TRL 6
Denmark
3.1, TRL 7
Texas
4.0, TRL 8
Texas

Instrumentation & Testing

- 168m2 rotor
- 6061T6 Al blades
- 70kW capacity
- Various fixed rotor speeds.
- Range of wind speeds and tip speed ratios



Eole Suite - Modeling Tools - 1



Eole Suite Modeling Tools - 2

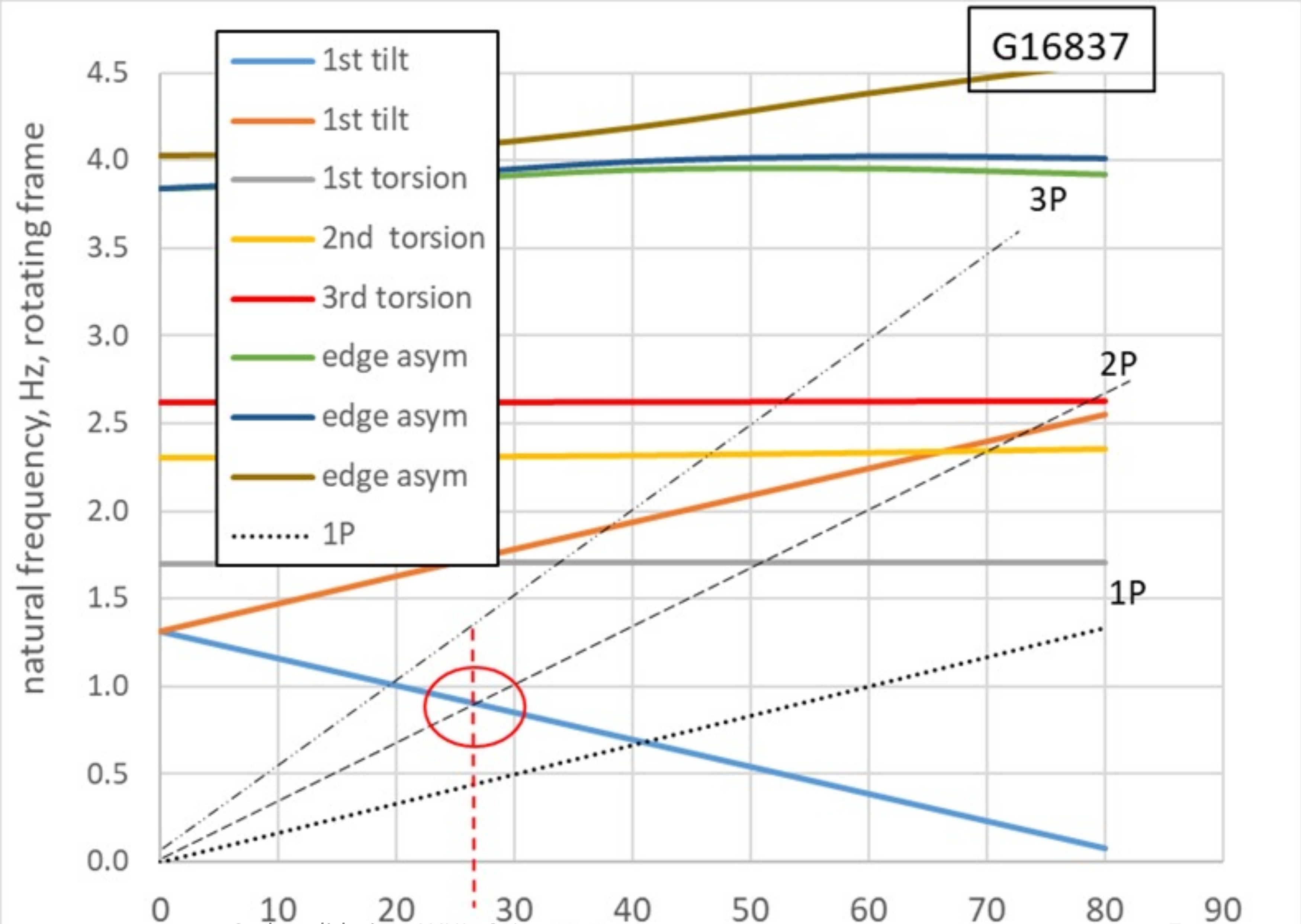
- Finite element (beam) model. In FORTRAN.
- Includes Double Multiple Stream-Tube (DMST) routine for aero loads.
- Based on early codes at Sandia National Labs.
- Steady state, frequency response at harmonics.
- Uses natural mode shapes as generalized coordinates.
- This reduces run times and aids in understanding response.

Objectives of Testing Model 3.1

- Measure power from prototype
- Detect any resonant operating conditions, compare with predictions
- Measure stresses/member forces in a range of operating conditions.
- Compare measured (harmonic) forces vs. predicted values.
- Assess accuracy of aero/structural models
- Gain confidence in model use for peak and fatigue loads

Campbell Diagram

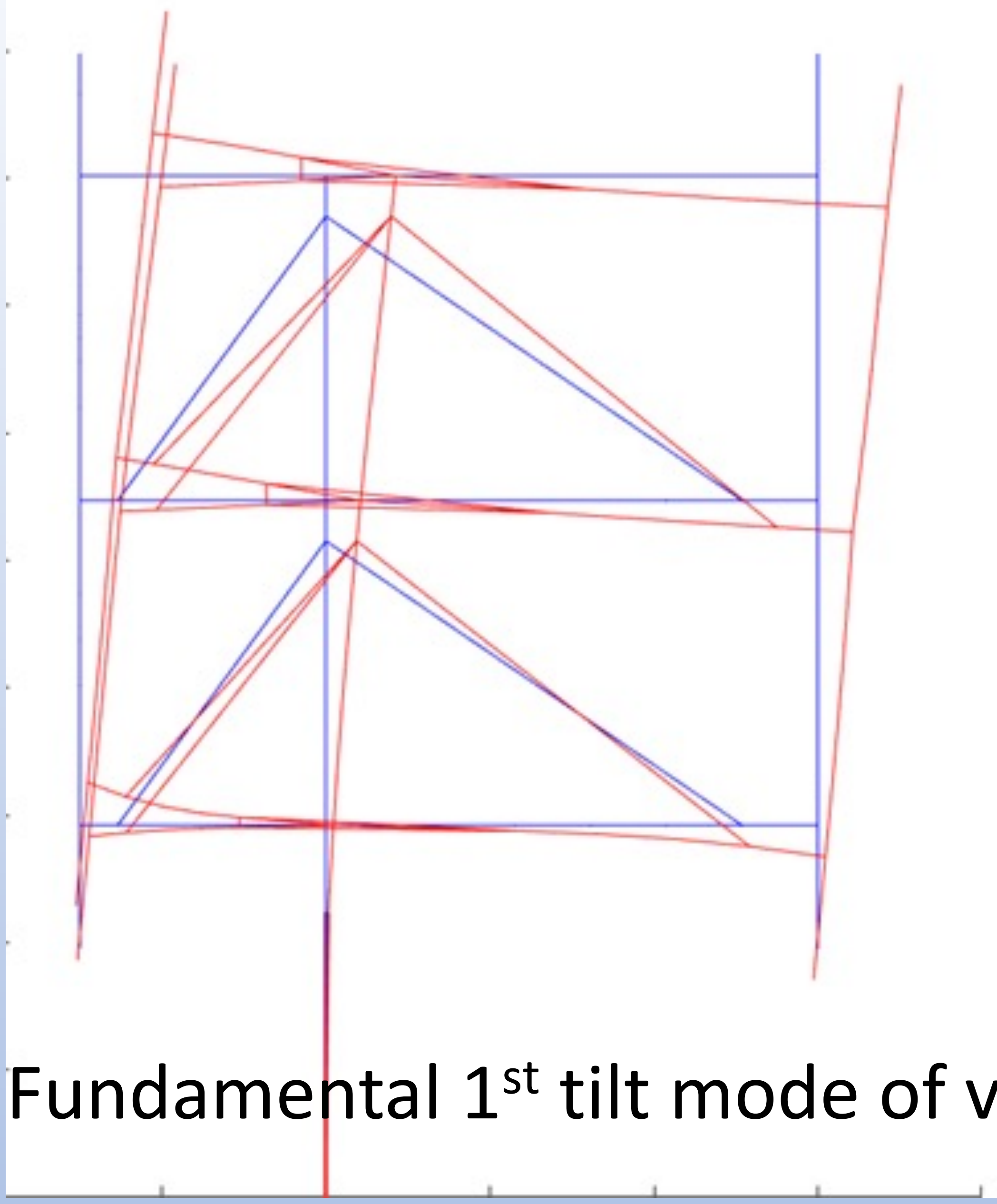
- Not all crossings are critical/resonant.
- The model predicted the 2P crossing at 26 rpm to be critical.
- The 30-60 rpm operating range was free of critical crossings.



Natural Modes

This mode is excited by the 2P harmonic loads at 26 rpm.

The 3-blade configuration means that most of the crossings on the Campbell diagram are not critical.

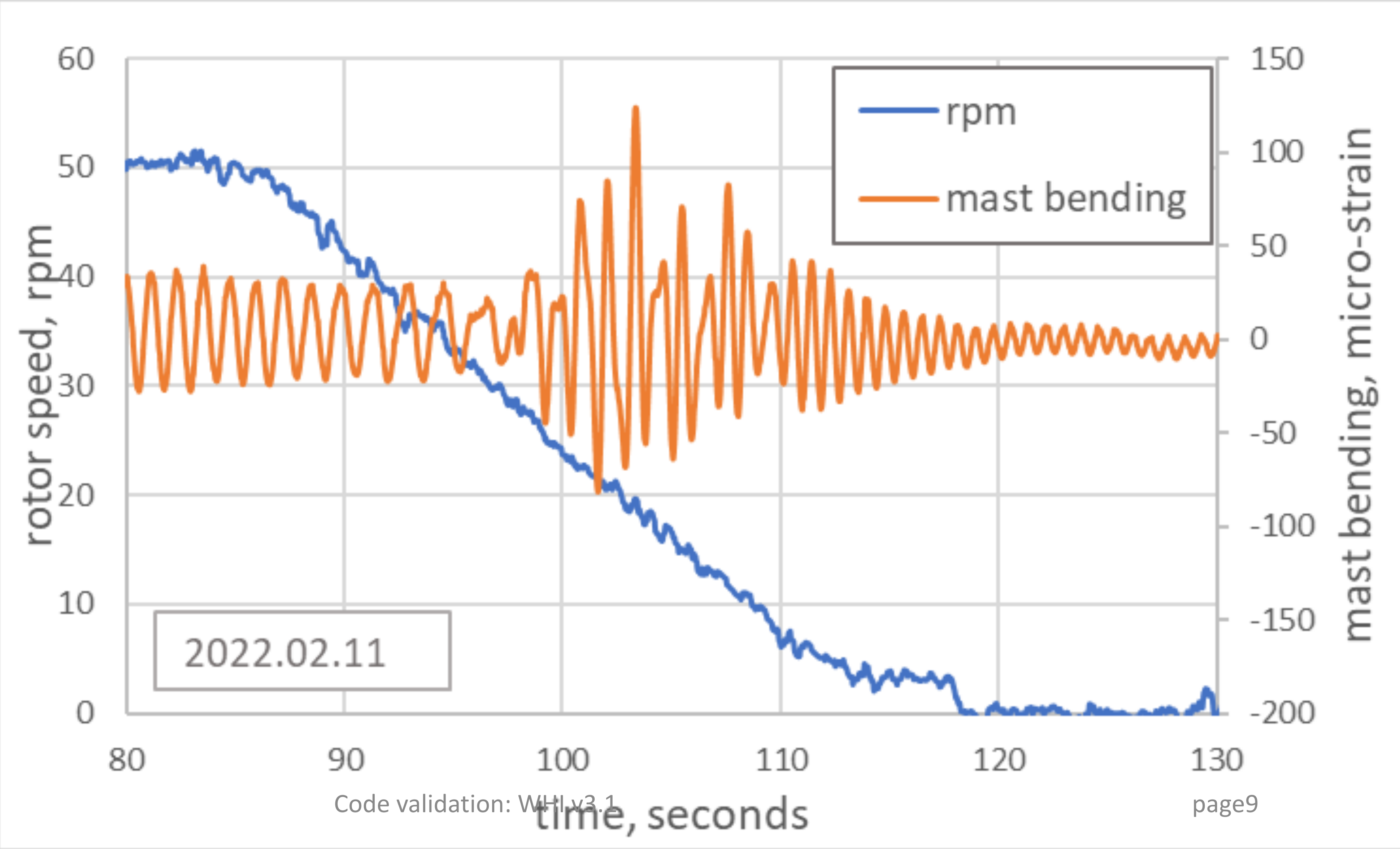


Fundamental 1st tilt mode of v3.1

Confirmation of Critical Crossing

This braking sequence shows increased mast bending between 25 and 30 rpm.

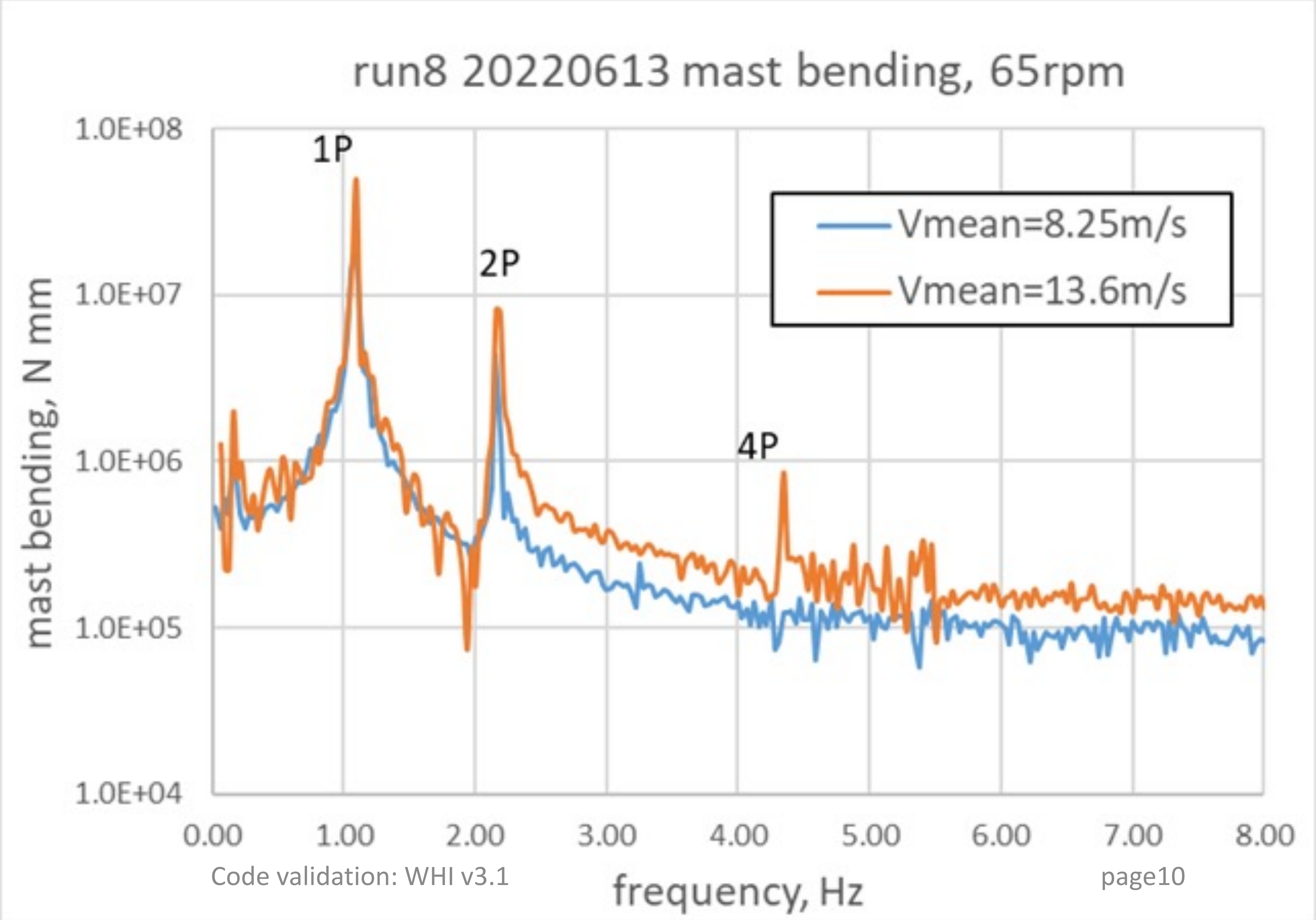
The model prediction of a critical crossing at 26 rpm was confirmed.



Frequency Spectrum from Mast Bending

This response is dominated by the 1P harmonic.

How does the amplitude compare with the model prediction?

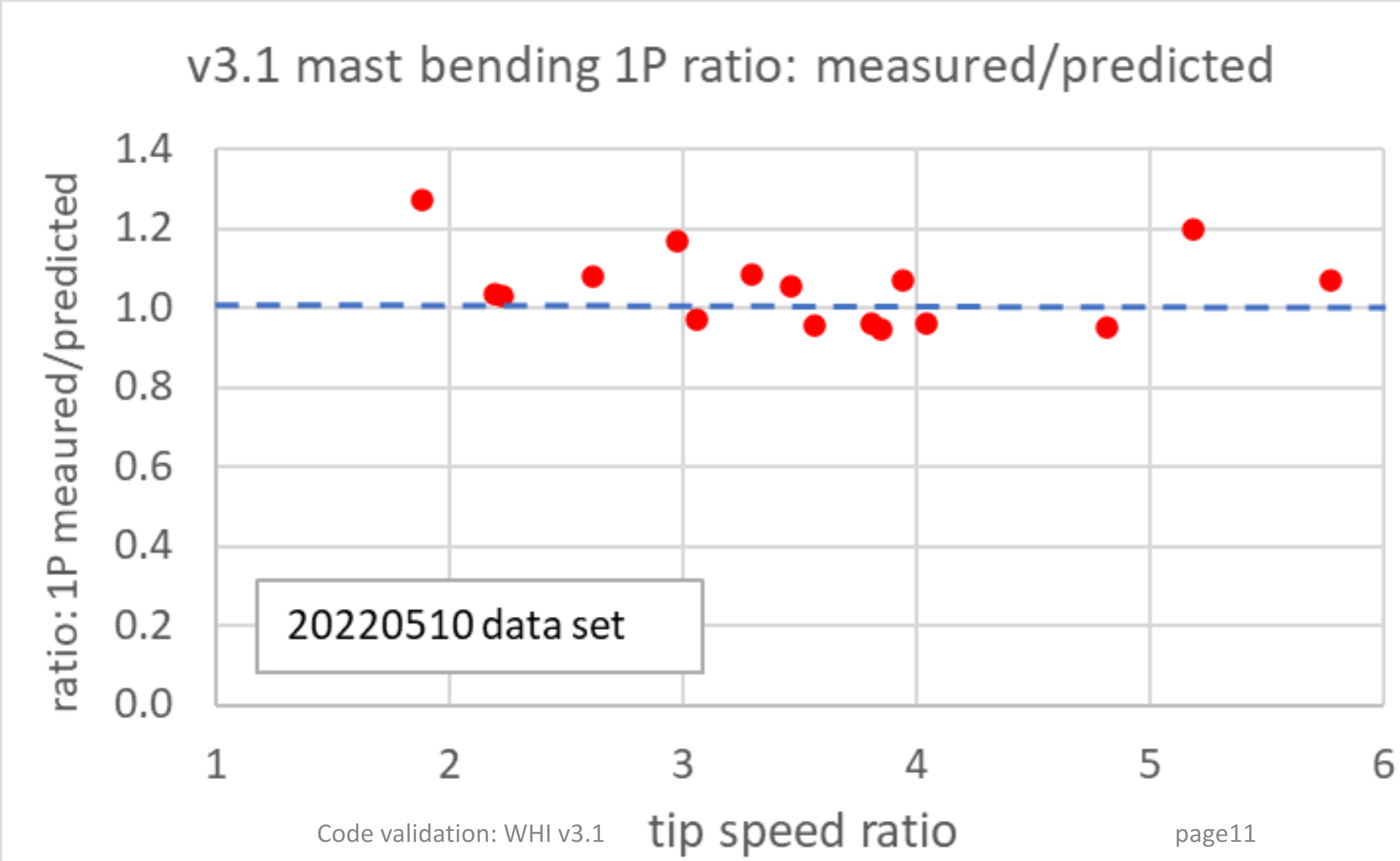


Comparison with Model - Mast Bending

Here is the ratio of measured to predicted 1P mast bending amplitude over a range of tip speed ratios.

A ratio of 1.0 indicates perfect agreement.

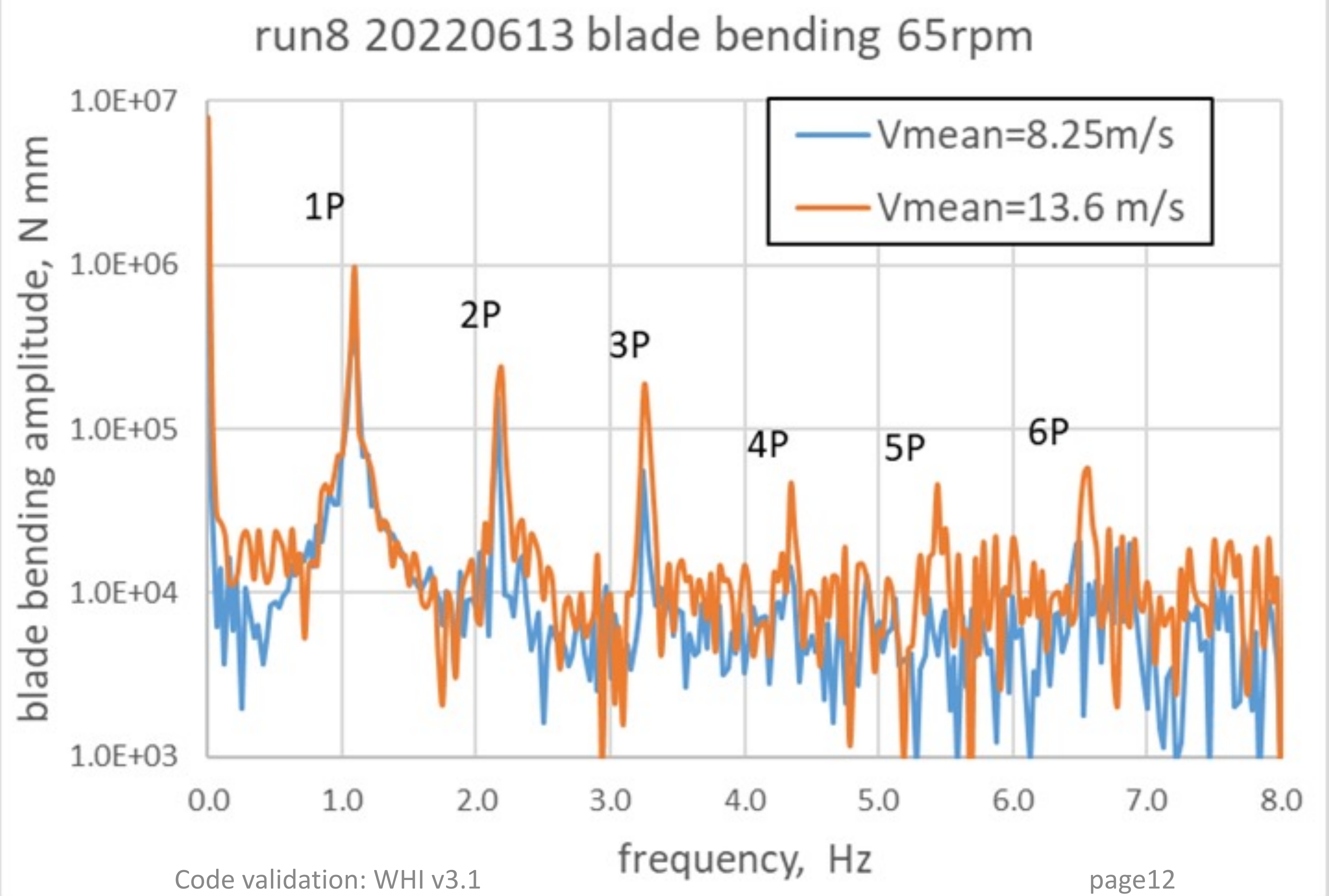
Result: mostly very good.



Frequency Spectrum from Blade Bending

Again it is dominated by 1P.

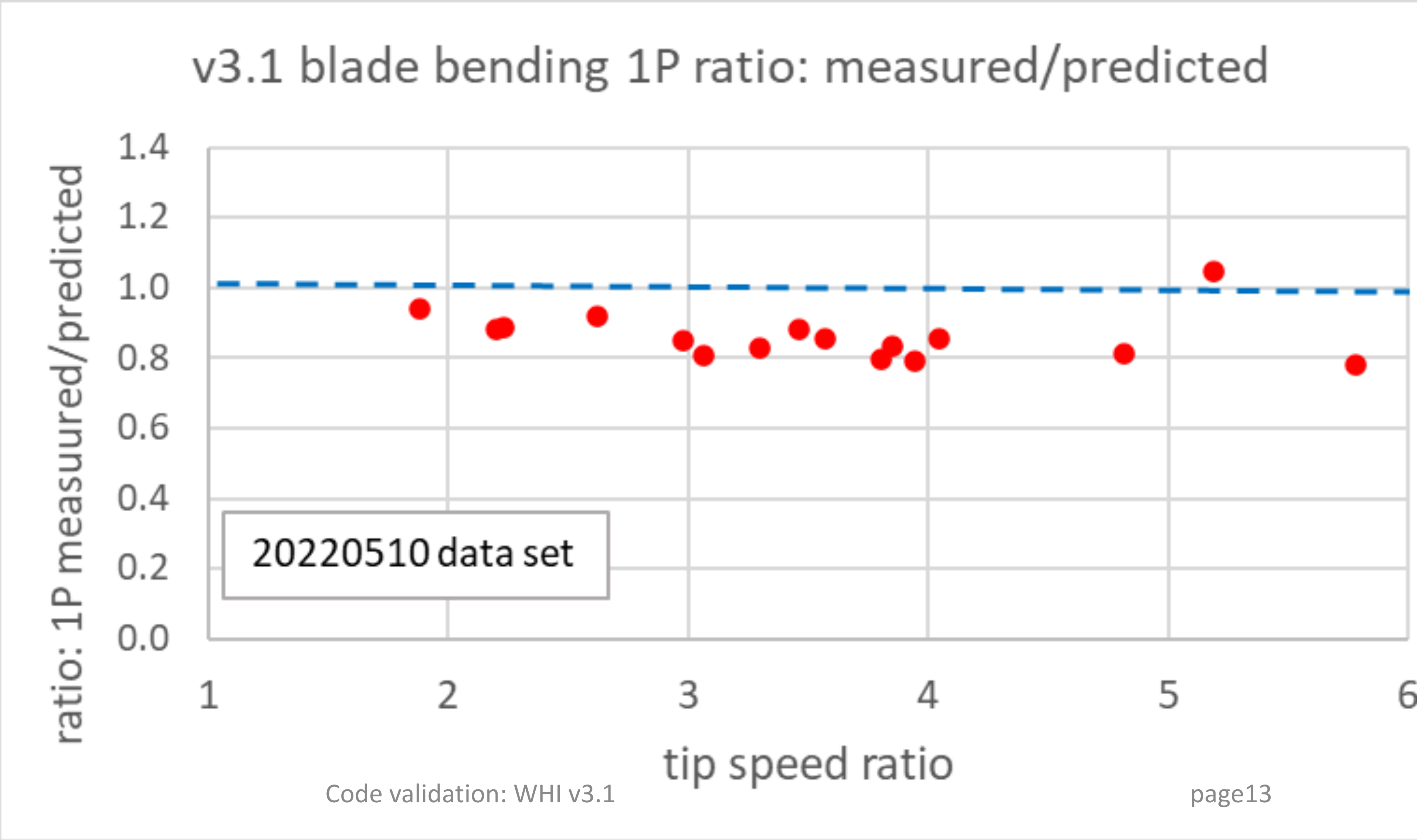
But there are some high harmonics – as high as 6P.



Comparison with Model - Blade Bending

In general, the measured 1P amplitudes are 10% lower than the predicted values.

This is still an encouraging result.



High Frequencies in Field Data

- Some field response shows considerable high frequency response.
- Such as 4P, 5P, & 6P in blade bending.
- It is also seen in the arm bending.
- One reason for this may be the shadow on the downwind blade.
- The DMST model was modified to include the downwind shadow effect.

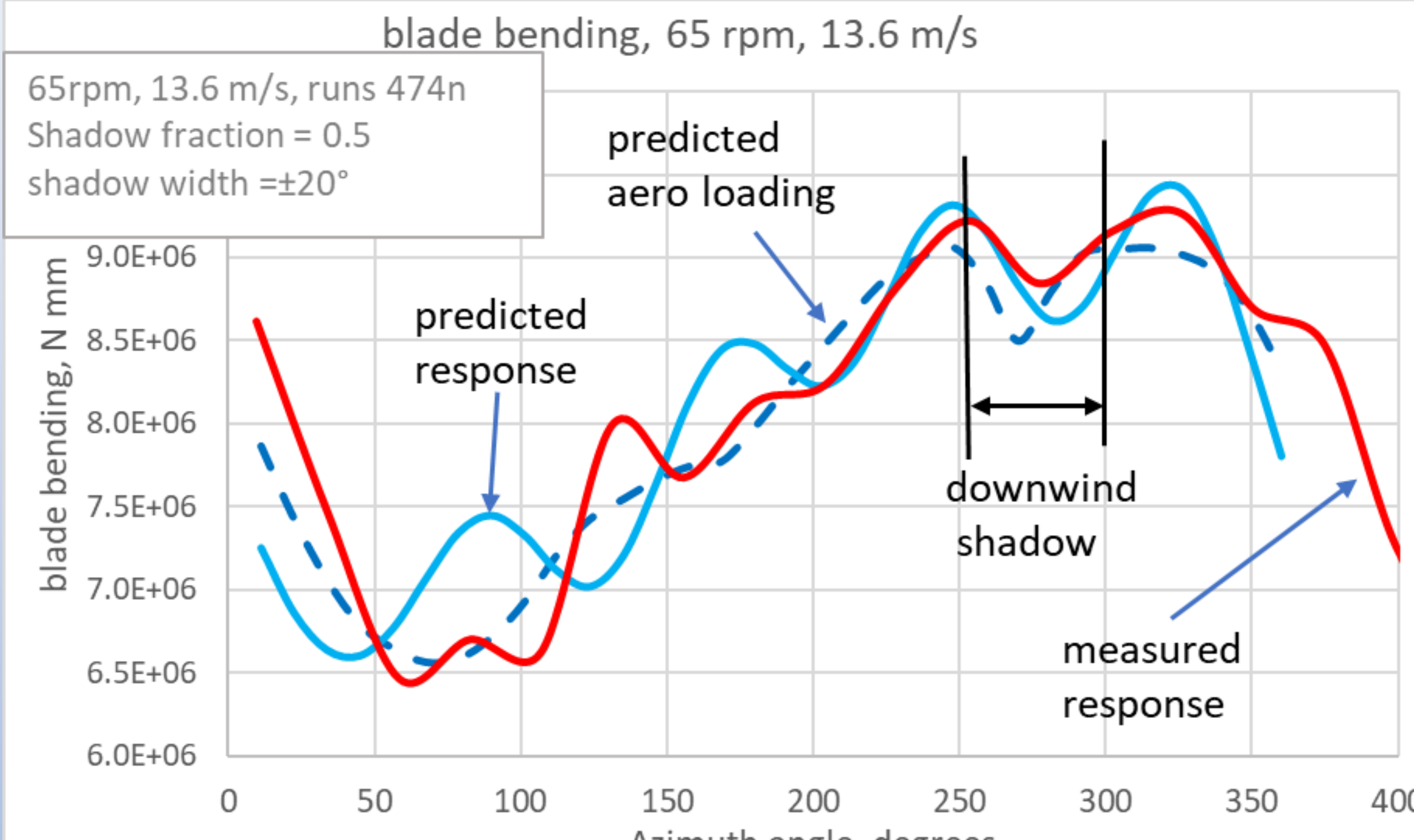
Effect of Downwind Shadow

A repeated impulse can be represented by a series of harmonic loads.

This was incorporated into the model.

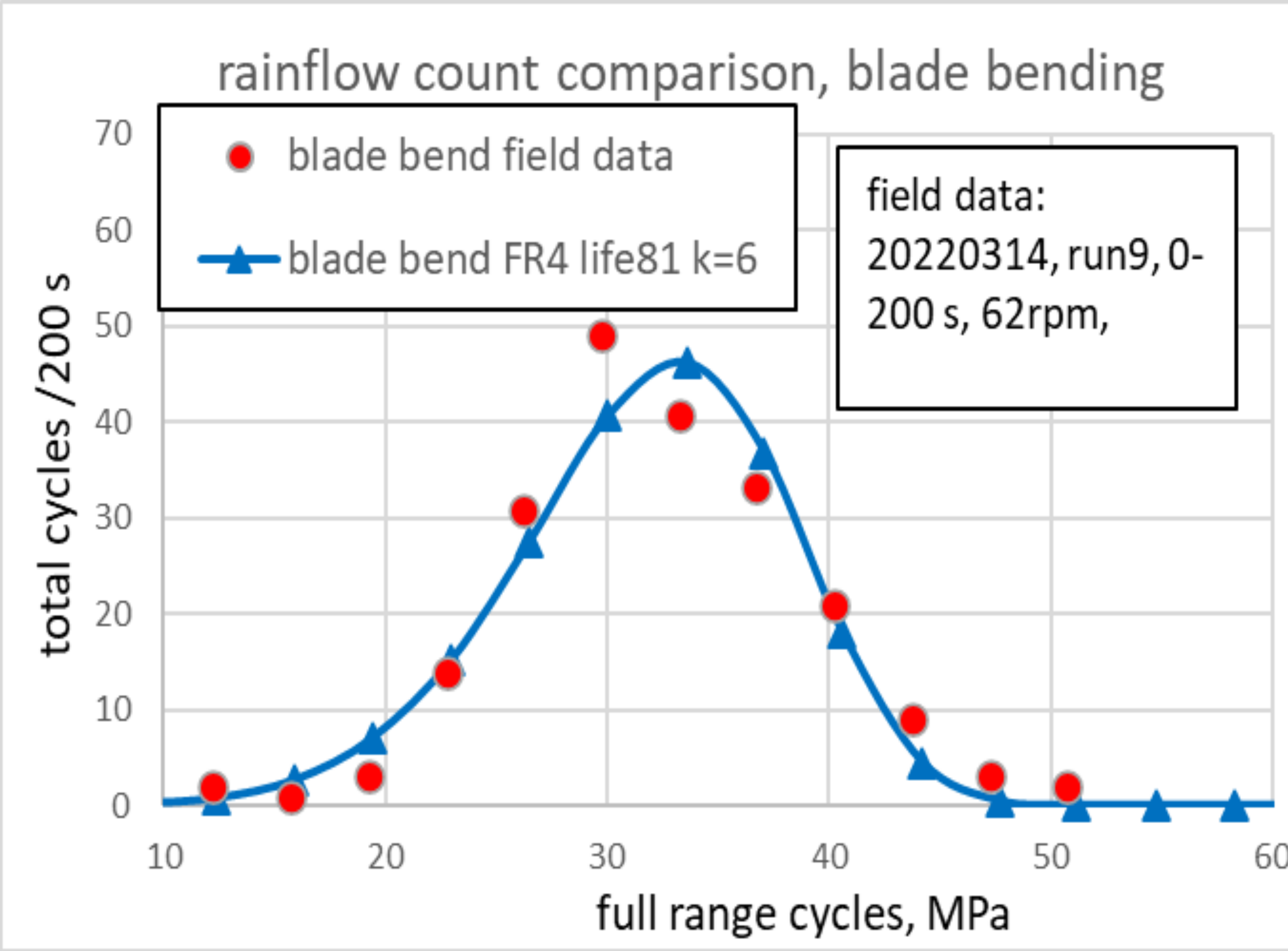
The measured response was slightly different for each revolution. A typical revolution is shown.

The predicted response agreed well with the higher frequencies observed in the field data.



Fatigue Analysis Field vs. Model

- Field data are rainflow counted to identify fatigue cycles.
- Material SN data used to calculate fatigue life.
- The predicted rms of cyclic loads from FR4 code used to predict histogram of fatigue cycles.
- Based on Sandia LIFE code.



Summary

- The Eole suite of codes – steady state, modal coordinates, frequency response - has been largely validated.
- The resonance at a critical 2P frequency crossing has been confirmed.
- No other resonant conditions appear in the operating range of rpm.
- The measured amplitudes of the dominant 1P cycle in mast and blade bending agree well with predicted values over a range of tip speed ratios.
- The higher harmonics present in some field data are likely due to downwind shadow which can be included in the model.
- The predicted fatigue cycles agree well with field data.