Frequency Considerations with FAST Modeling

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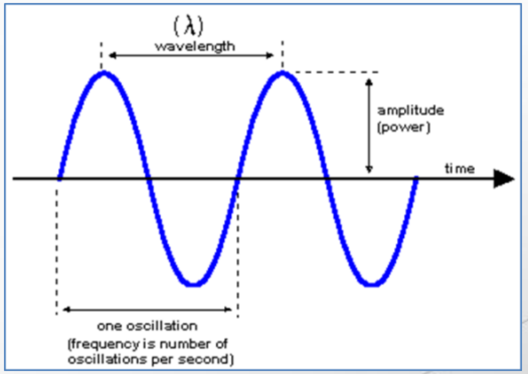
Natural Frequencies

- Natural frequency- frequency at which a system tends to oscillate in the absence of any driving or damping force.
- Tower & Blades.
- New Wind Turbine Design.
- Retrofit- Tower, Blades, RPM.
- **Natural Frequencies can have a large impact on Ultimate and Fatigue Loads.**



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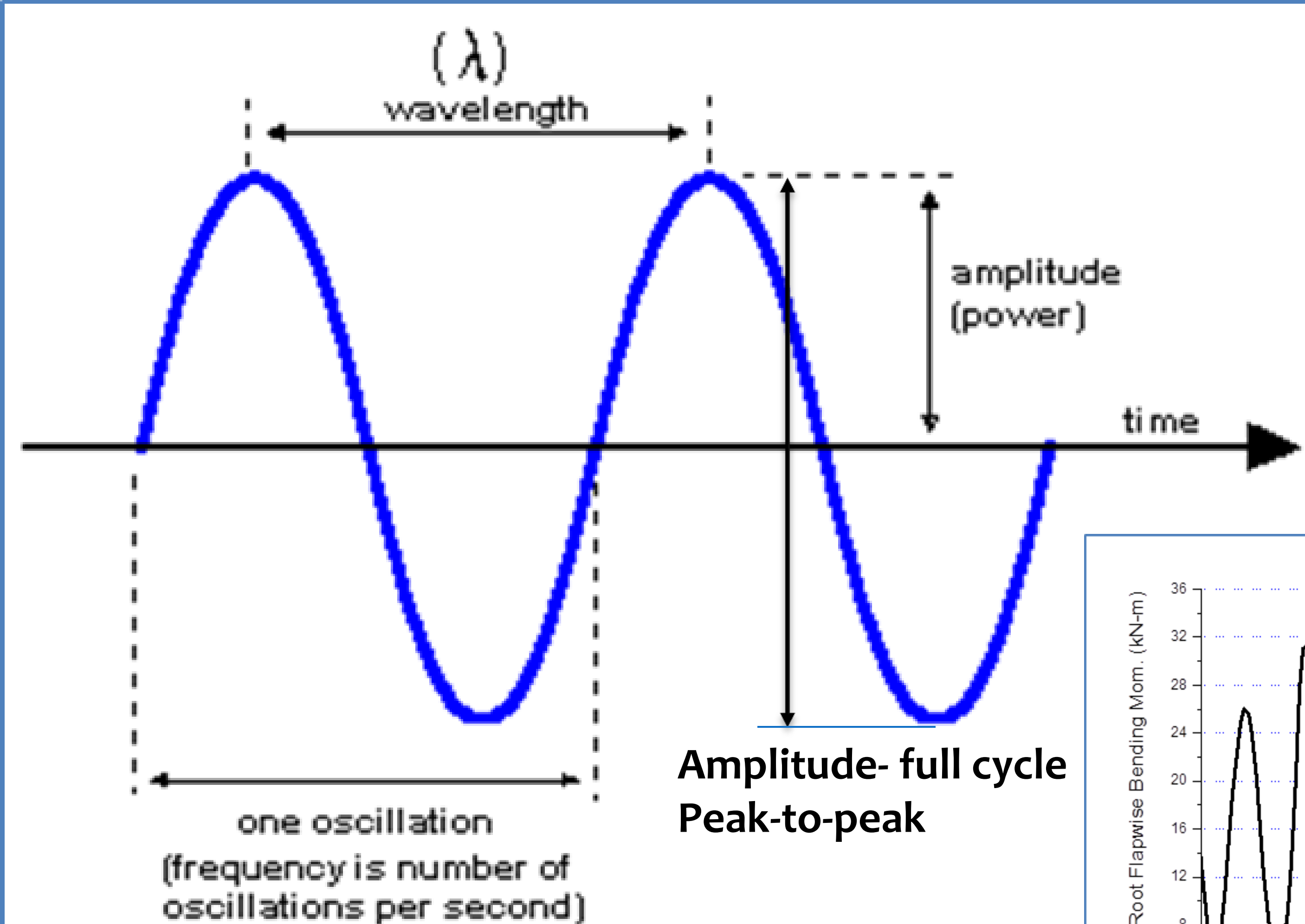
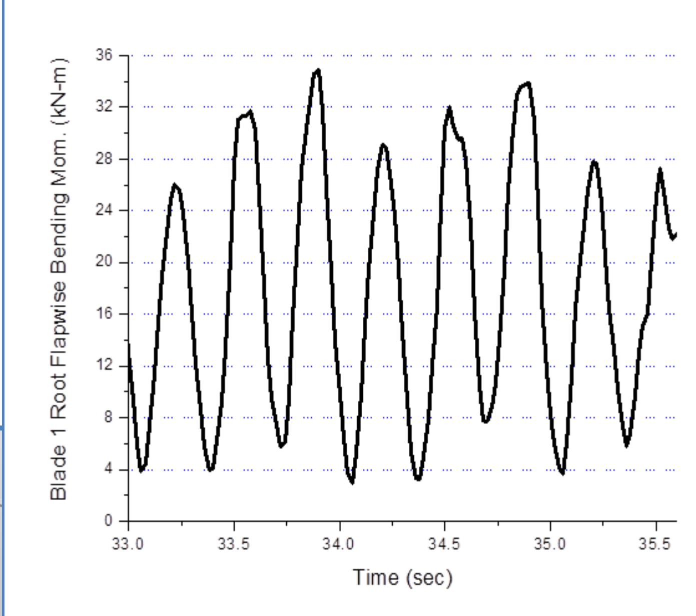
Natural Frequencies

* Natural frequencies need to be considered in the design and manufacturing of wind turbines.
* We consider materials- steels, fiberglass, etc.
* Shapes, Diameter & Wall Thickness.
* Material properties + geometry + RPM → Natural Frequencies.

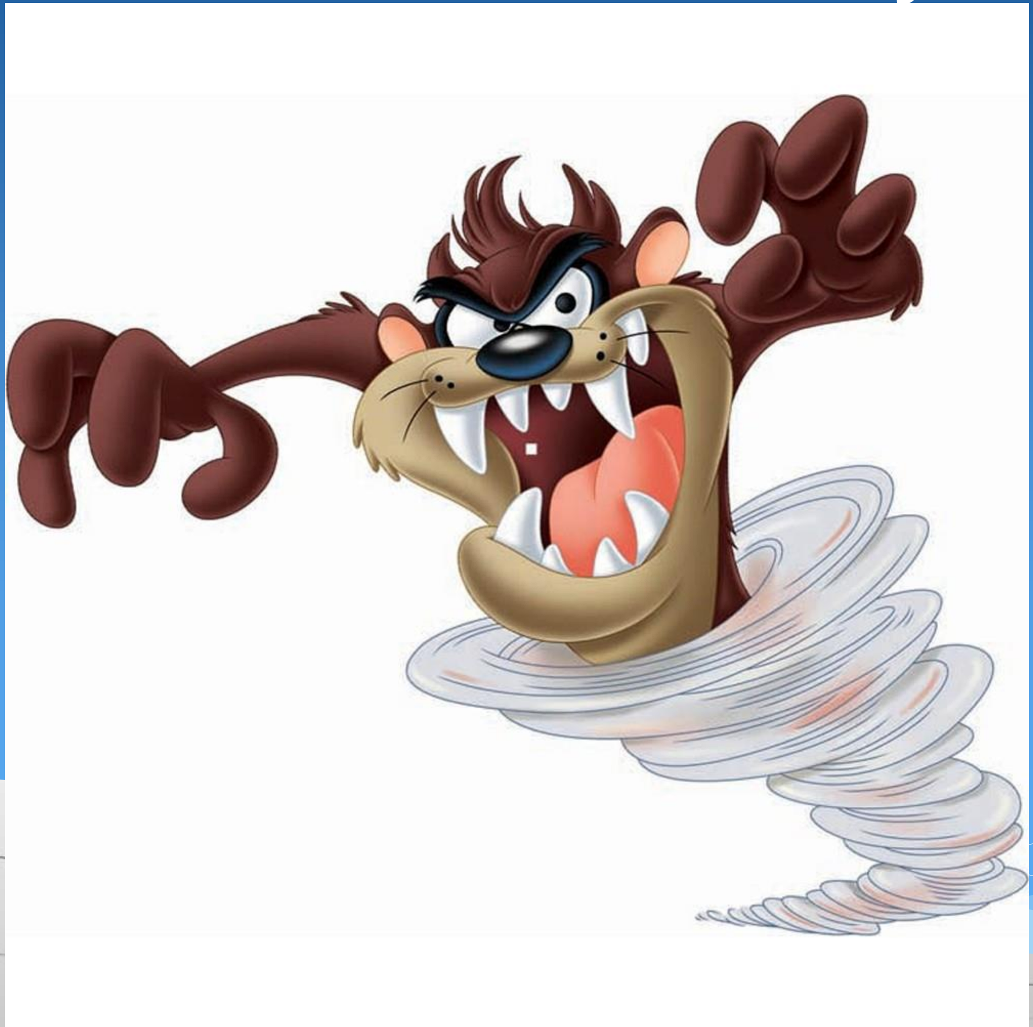
Sine Wave- Freq. (cycles/sec = Hz)



Amplitude- full cycle
Peak-to-peak



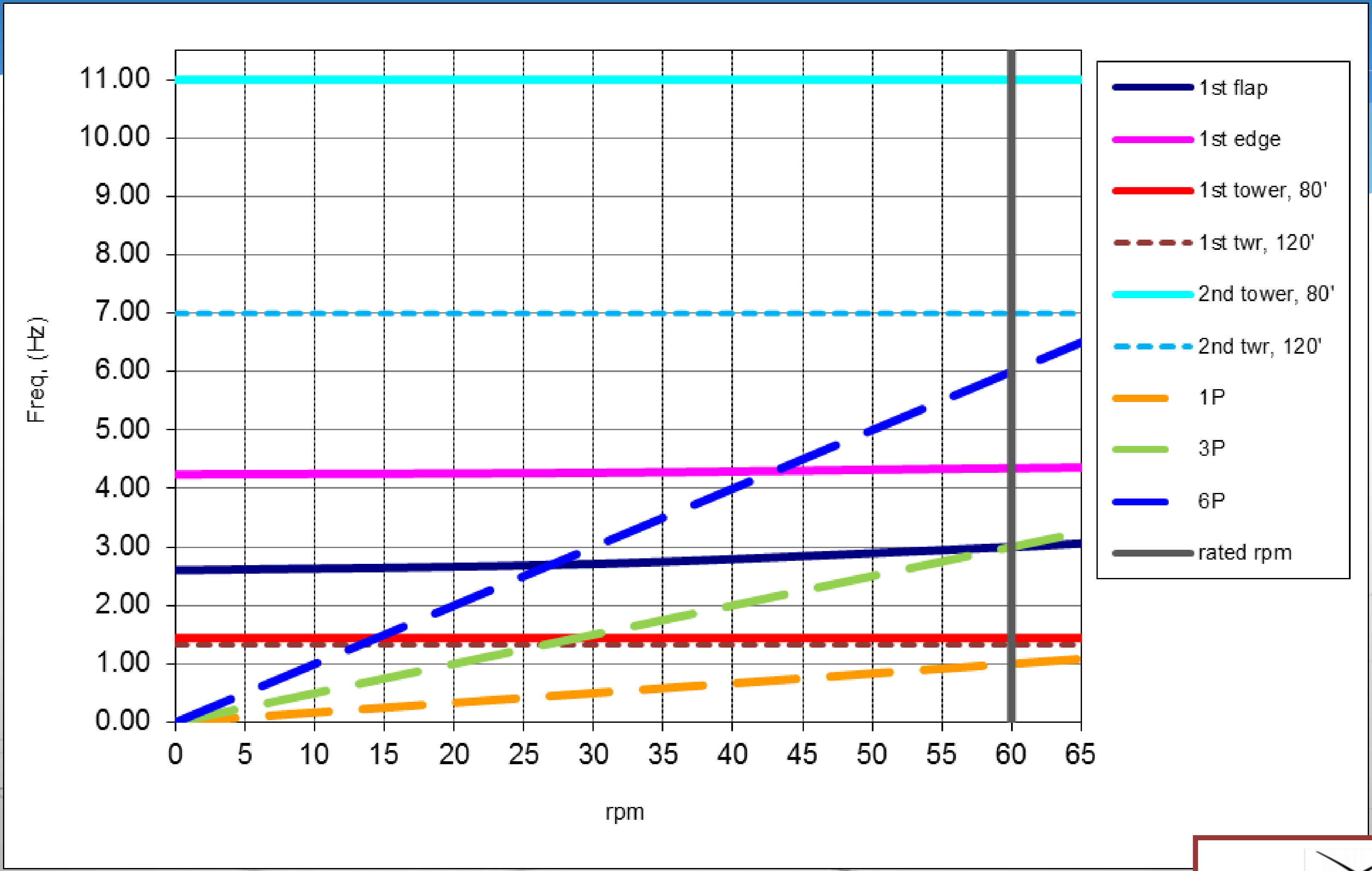
Frequencies can get wild- choose carefully.



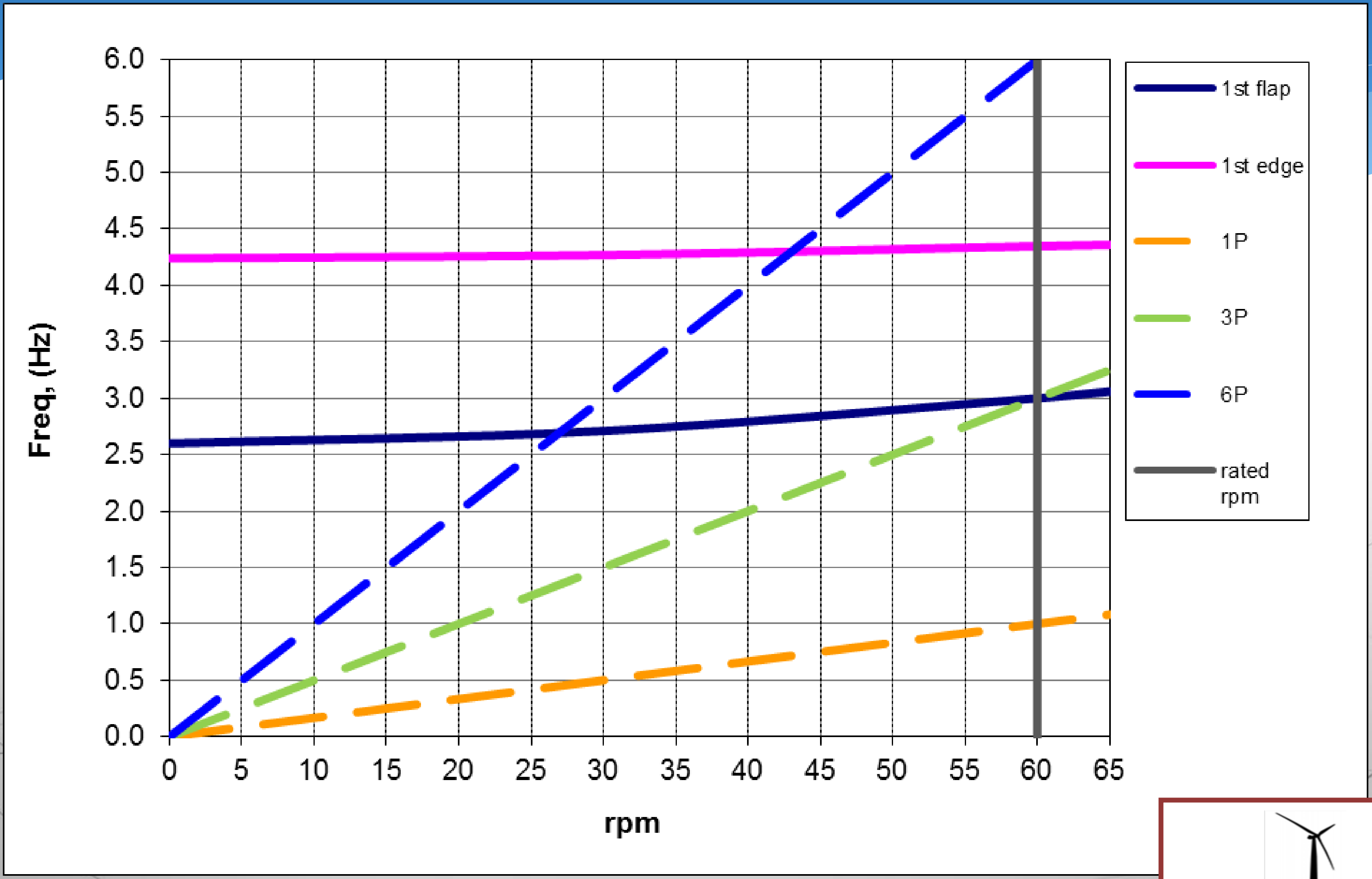
Sensitivity Study

- Have you seen a tower shake? RPM excites a tower freq. Skystream 3.7 (300 rpm = 5.0 Hz = 2nd tower mode)
- How Sensitive are Blade Root Bending Moments to Blade Frequencies?
- Begin with an existing FAST model of a 3-bladed, constant rpm (60 rpm) turbine.
- Model the Tower as “rigid”. Focus on the Blades.
- Use BModes to get the frequencies and mode shapes of the blade- tune the blade to have a 1st flap of 3.00 Hz at 60 rpm. 3.00 Hz = 1st flap= 3P . This is a Bad Place to be! How Bad?
- Purposely model a Bad Blade Freq. to see how bad it really is.

Campbell Diagram- complex



Campbell Diagram- simple



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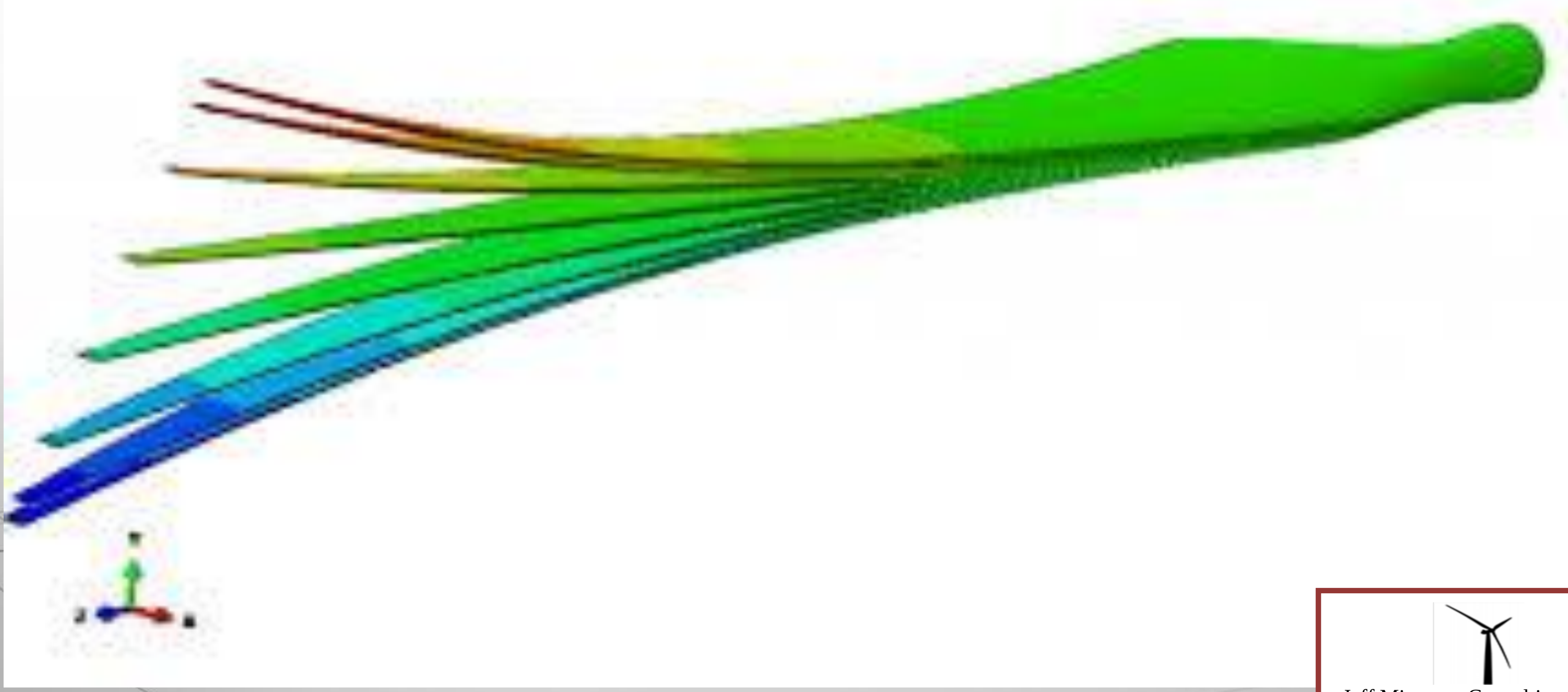
Blade Root Flapwise Bending Moments



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Sensitivity Study- FAST sims

- Run Turbulent Wind at 20 m/s→ at 4, 6, … 24 m/s (mean wind speed). Downwind configuration.
- 0.30 TwrShad - Tower-shadow velocity deficit (-)
- 0.70 ShadHWid - Tower-shadow half width (m)
- 1.70 T_Shad_Refpt - Tower-shadow reference point (m)
- 1- Blades with a 1st flap = 3.00 Hz at 60 rpm (at 3P)
- 2- Blades with 1st flap = 3.15 Hz (5% higher, 5% rule)
- 3- Blades with 1st flap = 3.30 Hz (10% higher)
- 4- Same as #1 = 3.00 Hz, upwind configuration.

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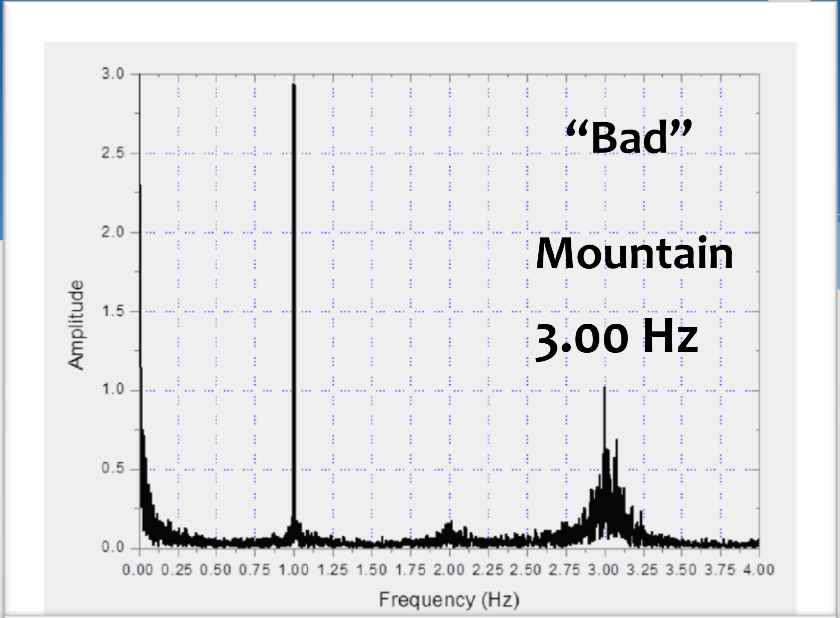
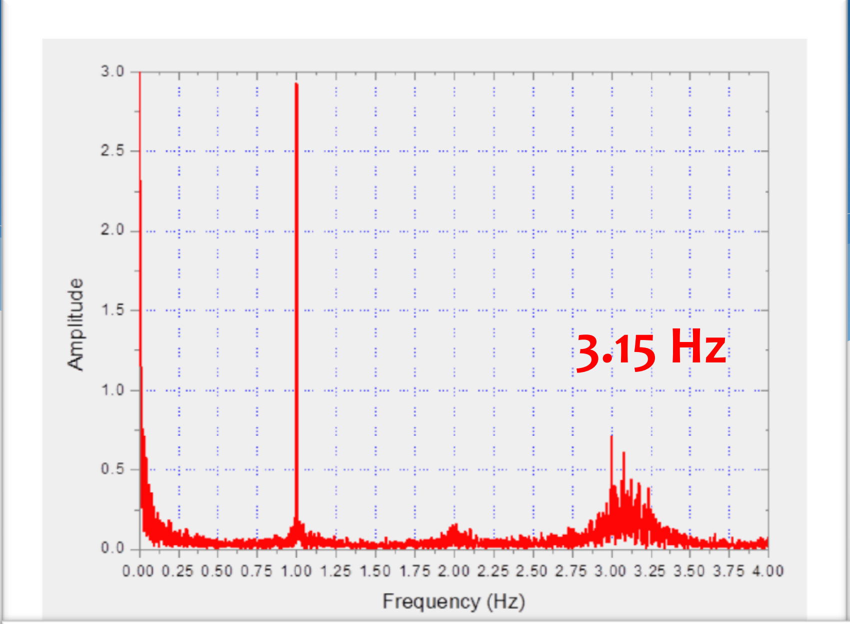
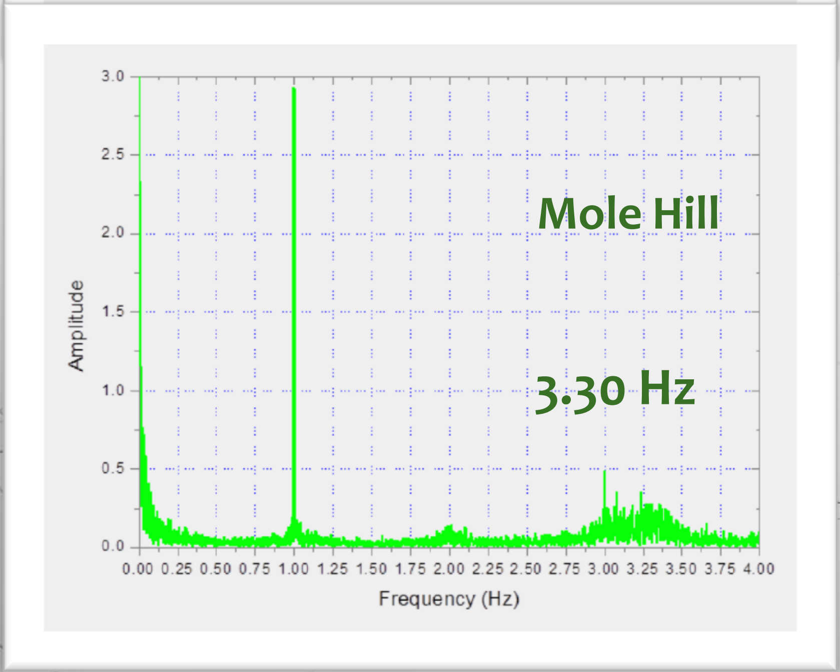
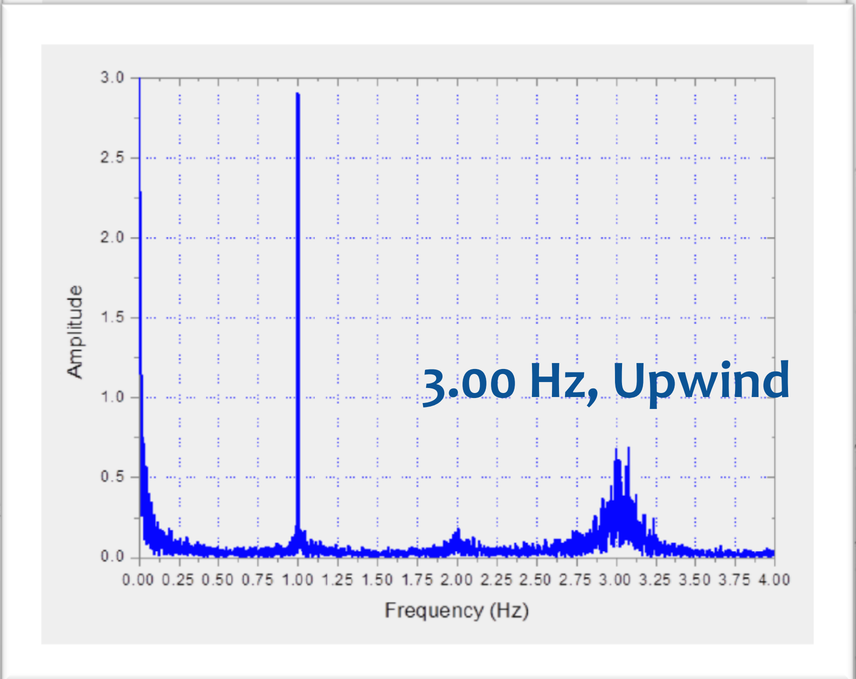
FAST Results @ 20m/s Turb.- FFT

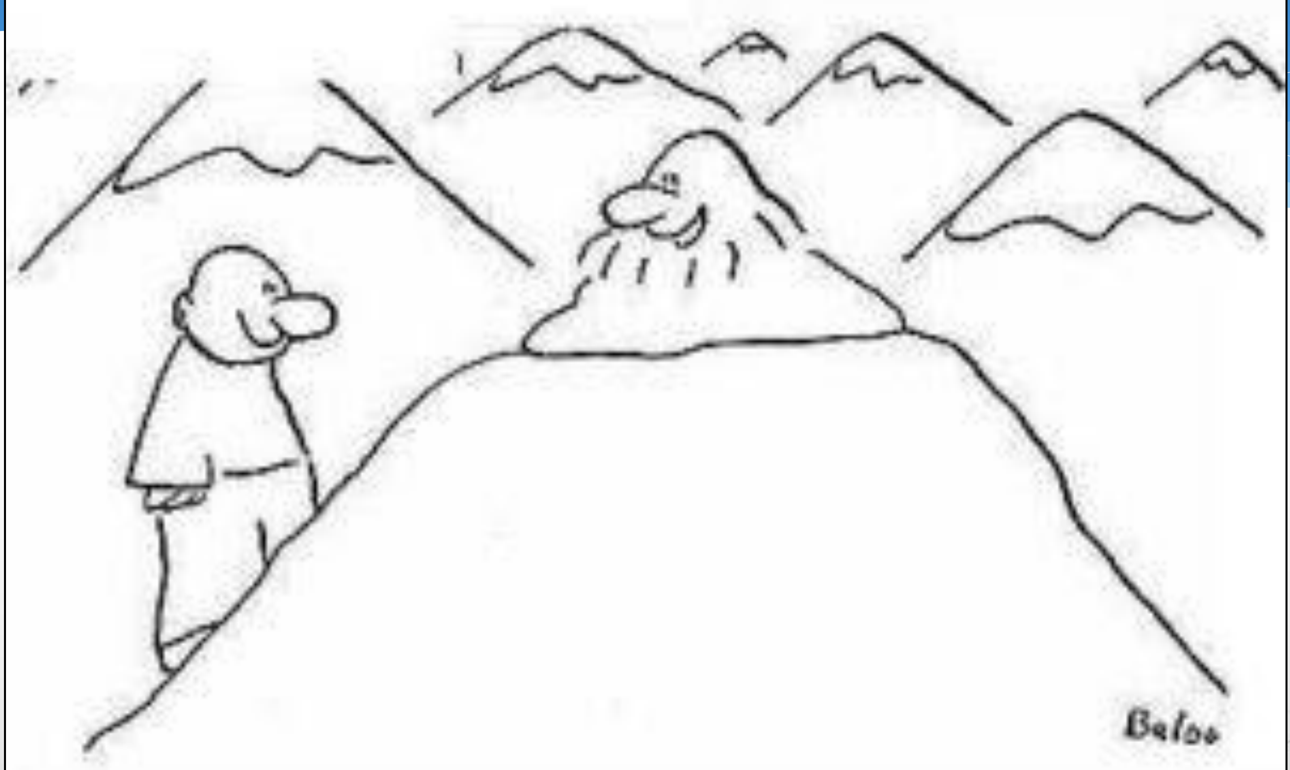








3.00 Hz = mountain
3.30 Hz = molehill



"Why, thank you — I made it out of a molehill."

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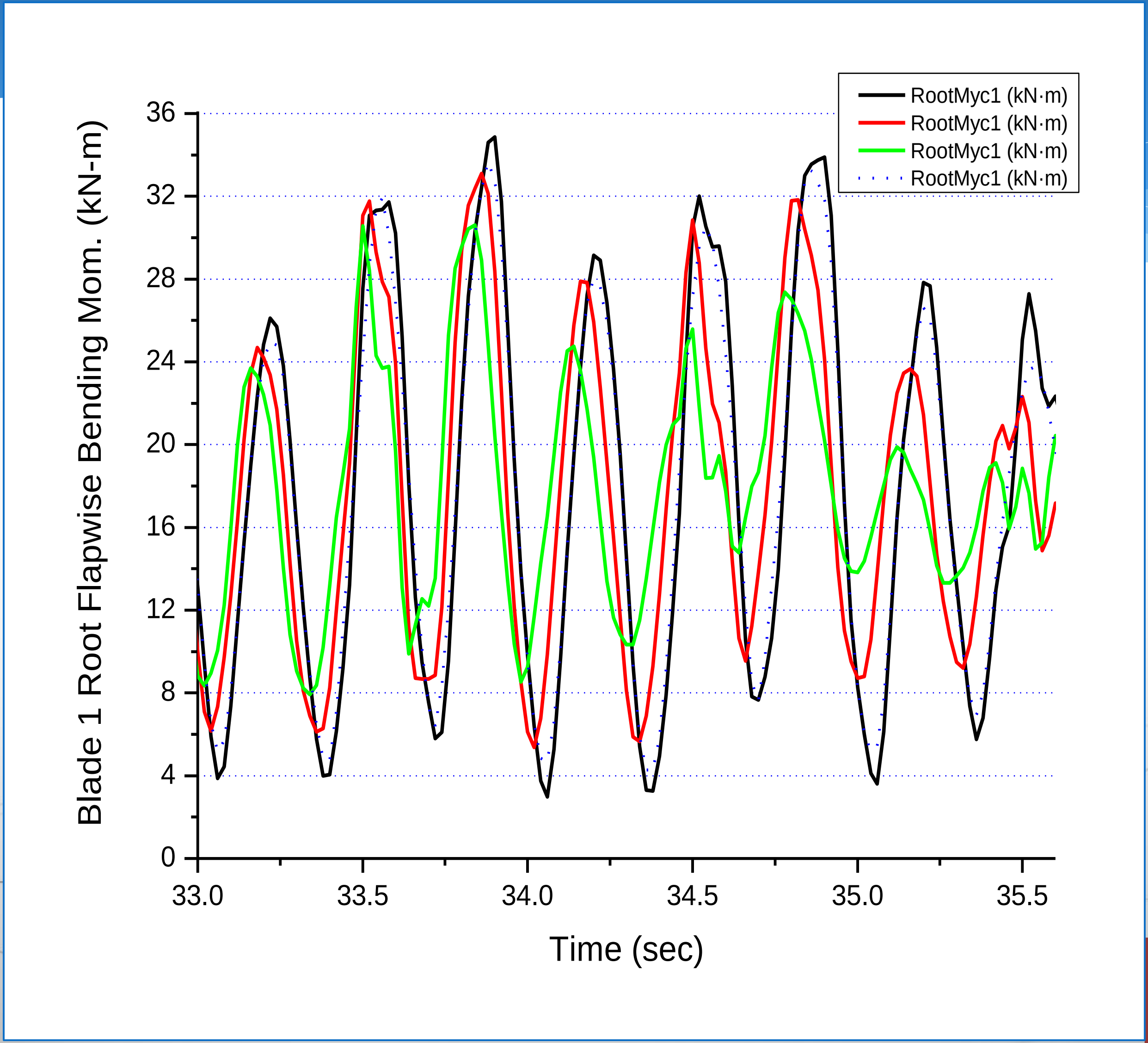
Time Series Output @ 20 m/s



3.00 Hz
3.15 Hz
3.30 Hz
3.00 Hz Up

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Look at 4, 6, … 24 m/s Turb.

* We've looked at 20 m/s turb. Do these trends continue with all winds?
* Run the 4 diff. FAST models in turbulent winds with mean wind speeds of 4, 6, … 24 m/s.
* Ultimate Loads- Blade Root Bending Moment.
* Fatigue Loads.

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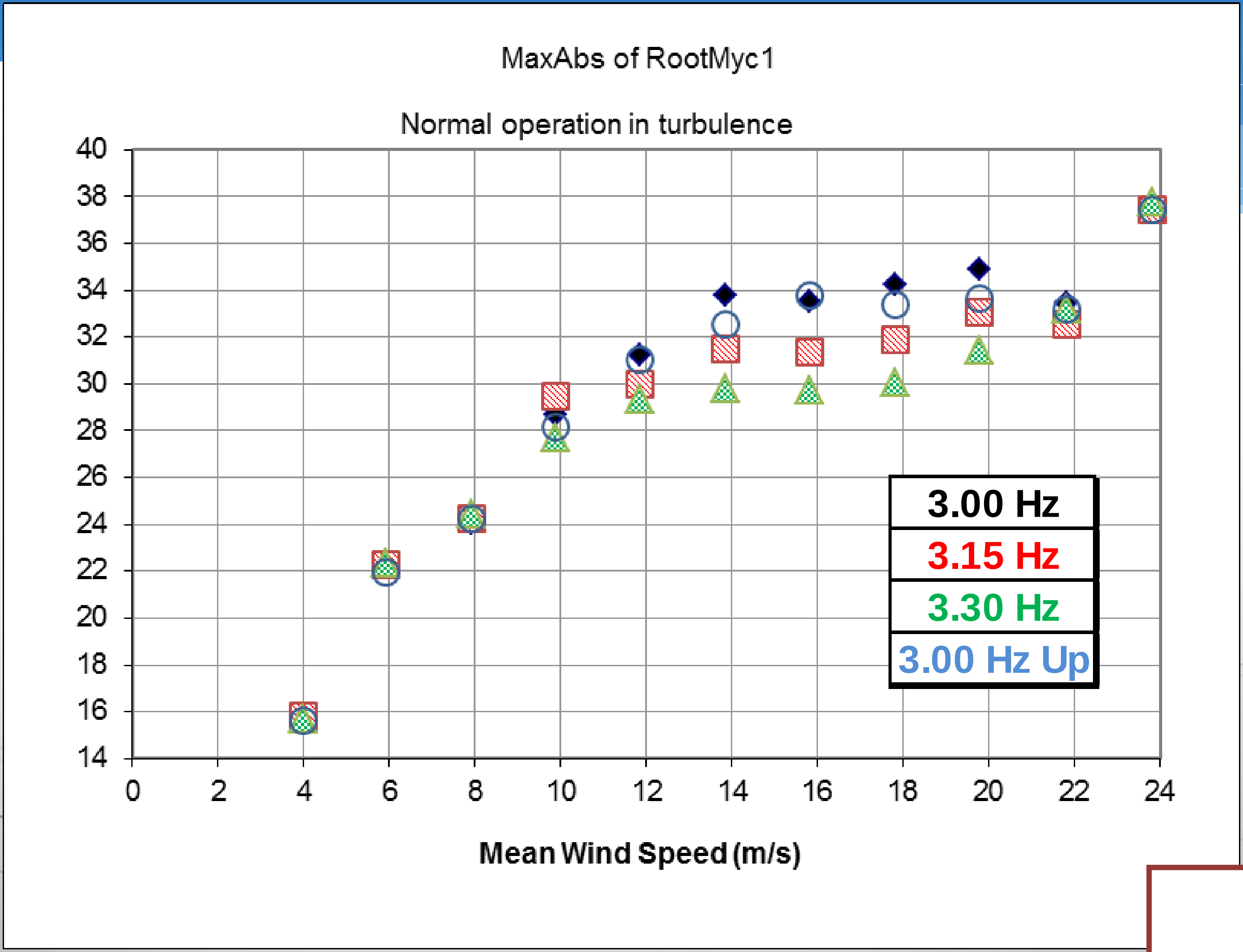
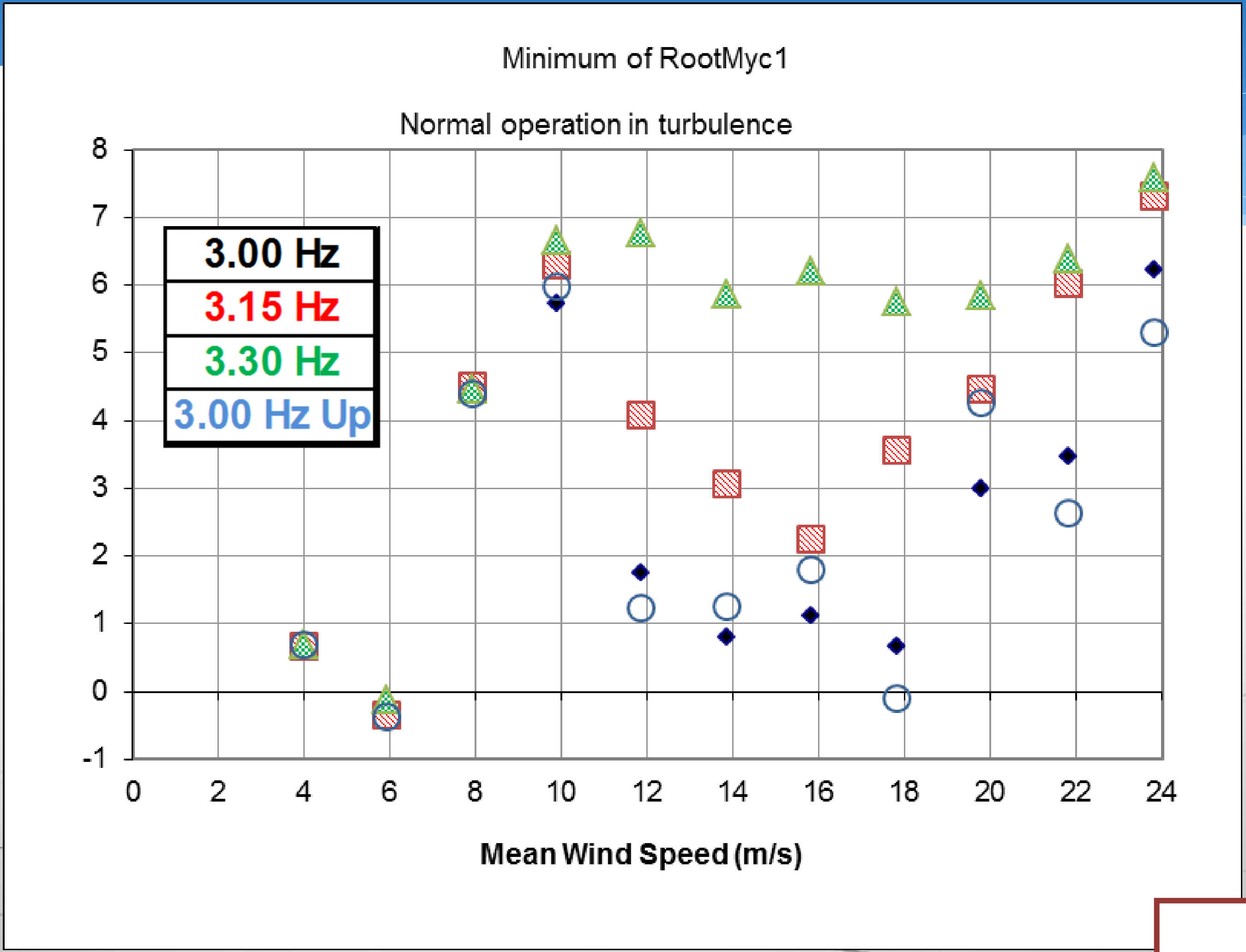
Ultimate Blade Flap Moment



Minimum Blade Flap Moment



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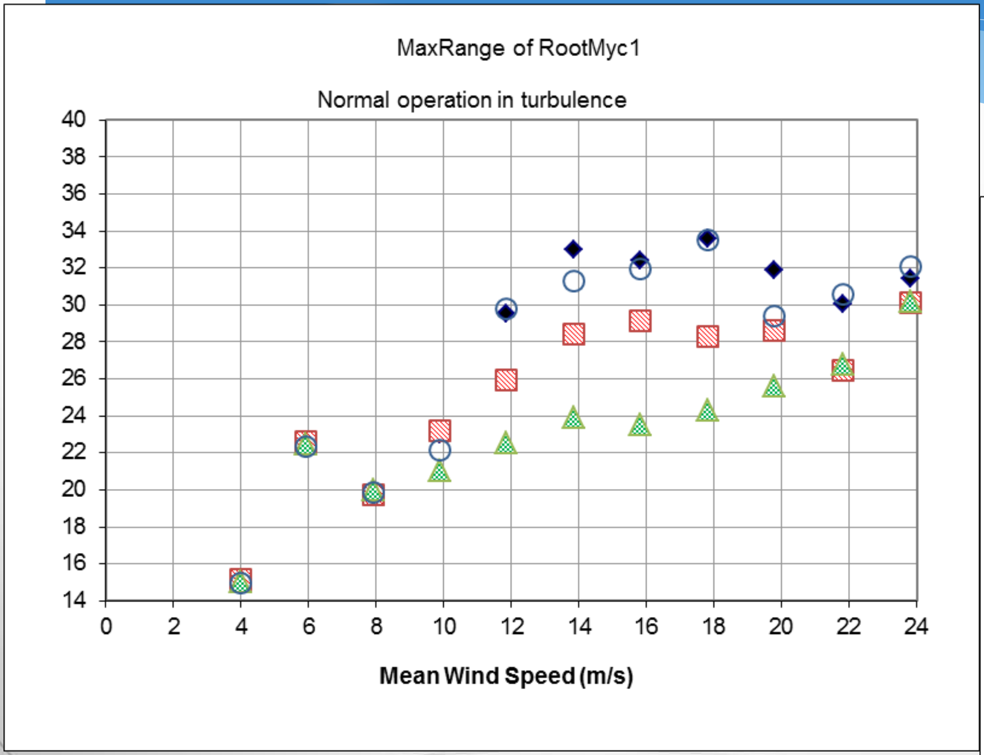
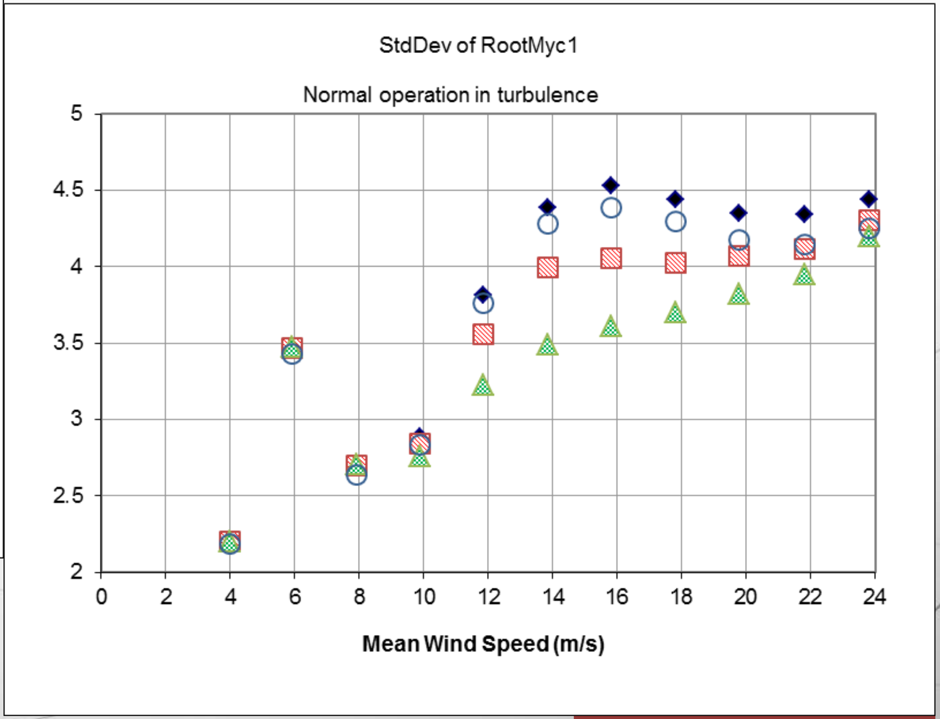
Max. Range & Std. Dev.
Blade Flap Moment

3.00 Hz
3.15 Hz
3.30 Hz
3.00 Hz Up





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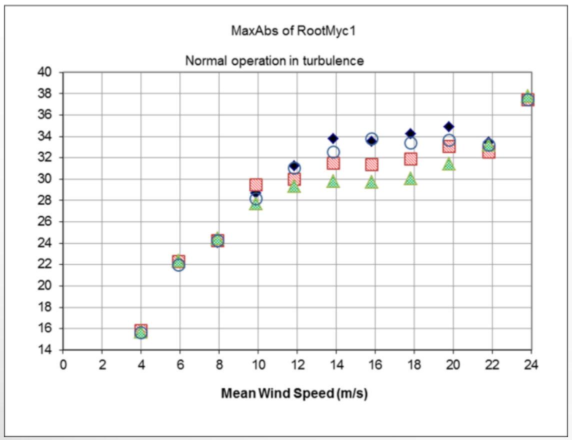
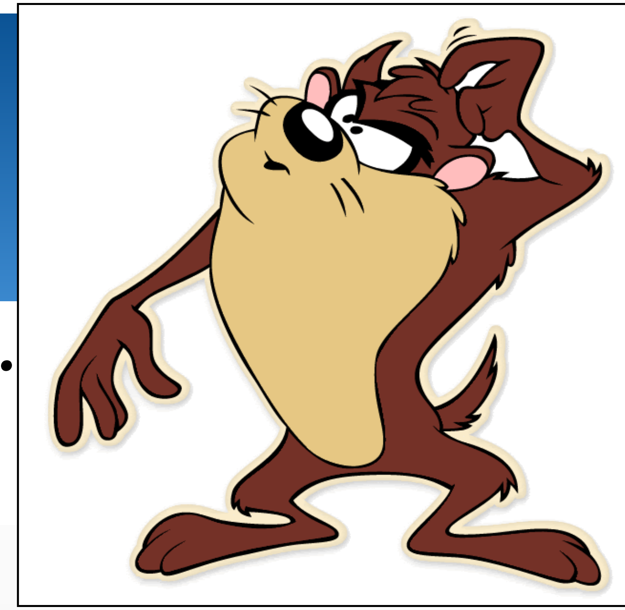
What does it mean?

* <u>Ultimate Loads-</u> All 4 blades have approx. the same peak load (at 24 m/s turb.)





* <u>Fatigue-</u> The 3.00 Hz blade (both upwind and downwind) has the highest highs, lowest lows, largest max. range and std. deviation. Most Fatigue?
* <u>Fatigue-</u> Calculate Damage Equivalent Loads (DEL's)

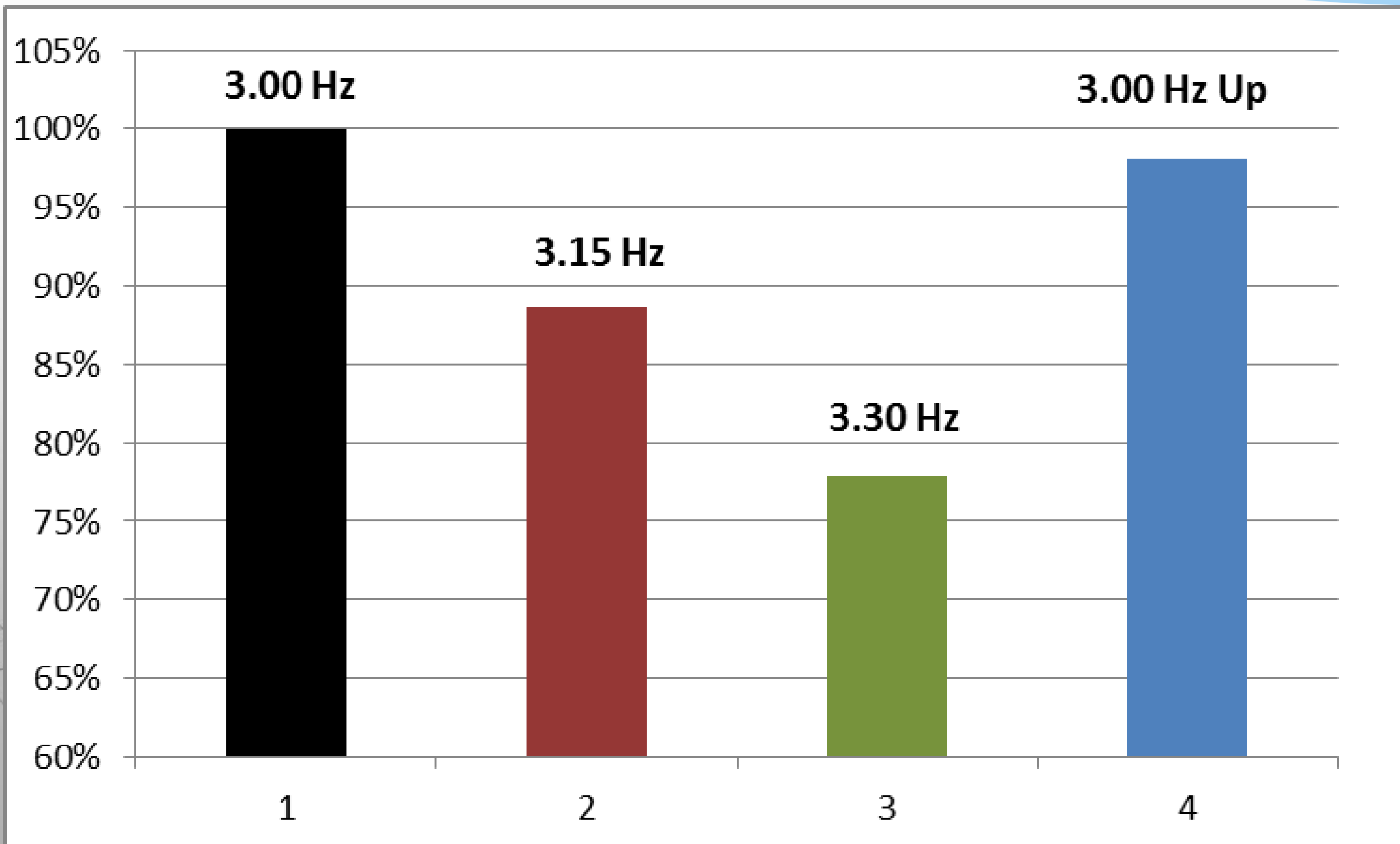
Fatigue- DEL's
Damage Equiv. Loads

* Use FAST outputs- 11 sims for each of the 4 blade configurations: 4 to 24 m/s turb.
* Run CRUNCH- get rainflow counts of the cycles (output from FAST) at each of the mean wind speeds.
* Use a Rayleigh Distribution for Wind Speed, Class 2 wind (8.5 m/s average).
* Calculate the DEL's for each of the 4 blade configurations.

Fatigue- DEL's

	DEL	Normalized
1	21.49	100%
2	19.04	89%
3	16.73	78%
4	21.09	98%

Higher DEL = more damage



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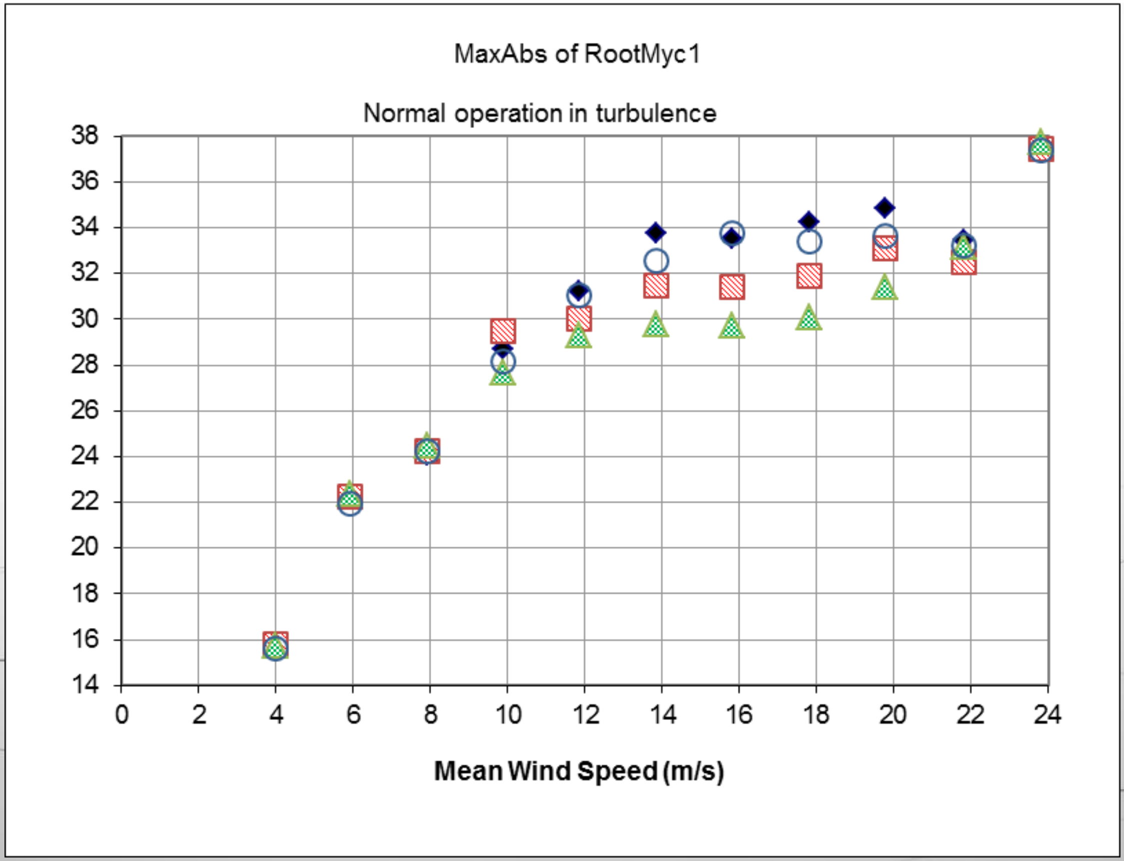
Conclusions- Ultimate

* **The 3P (3.00 Hz) blade has the highest Ultimate loads at 12 – 20 m/s, but all 4 blades (3.00, 3.15, 3.30 & 3.00 Up) have the same Ultimate Load at 24 m/s. Control system- brake, pitching?**



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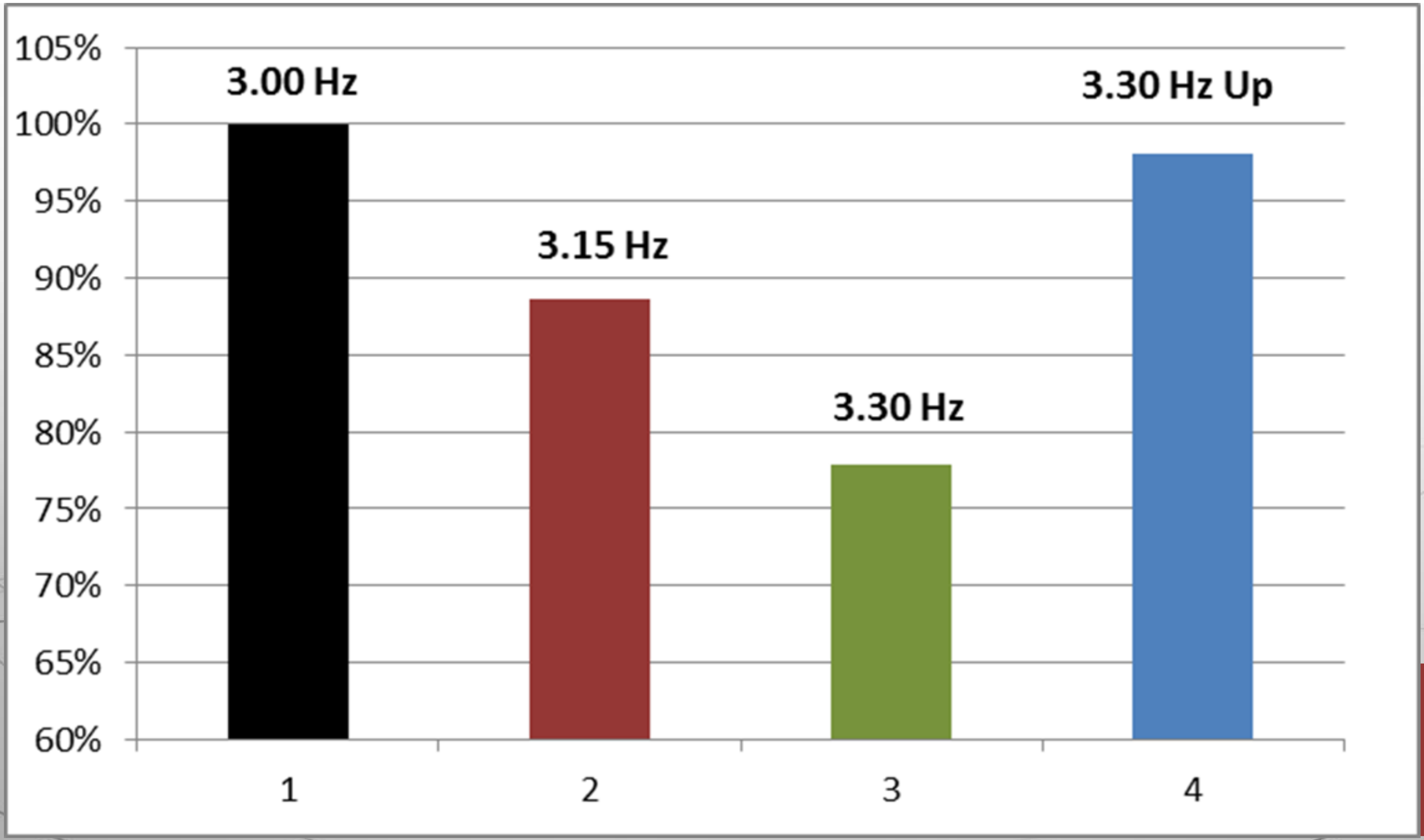
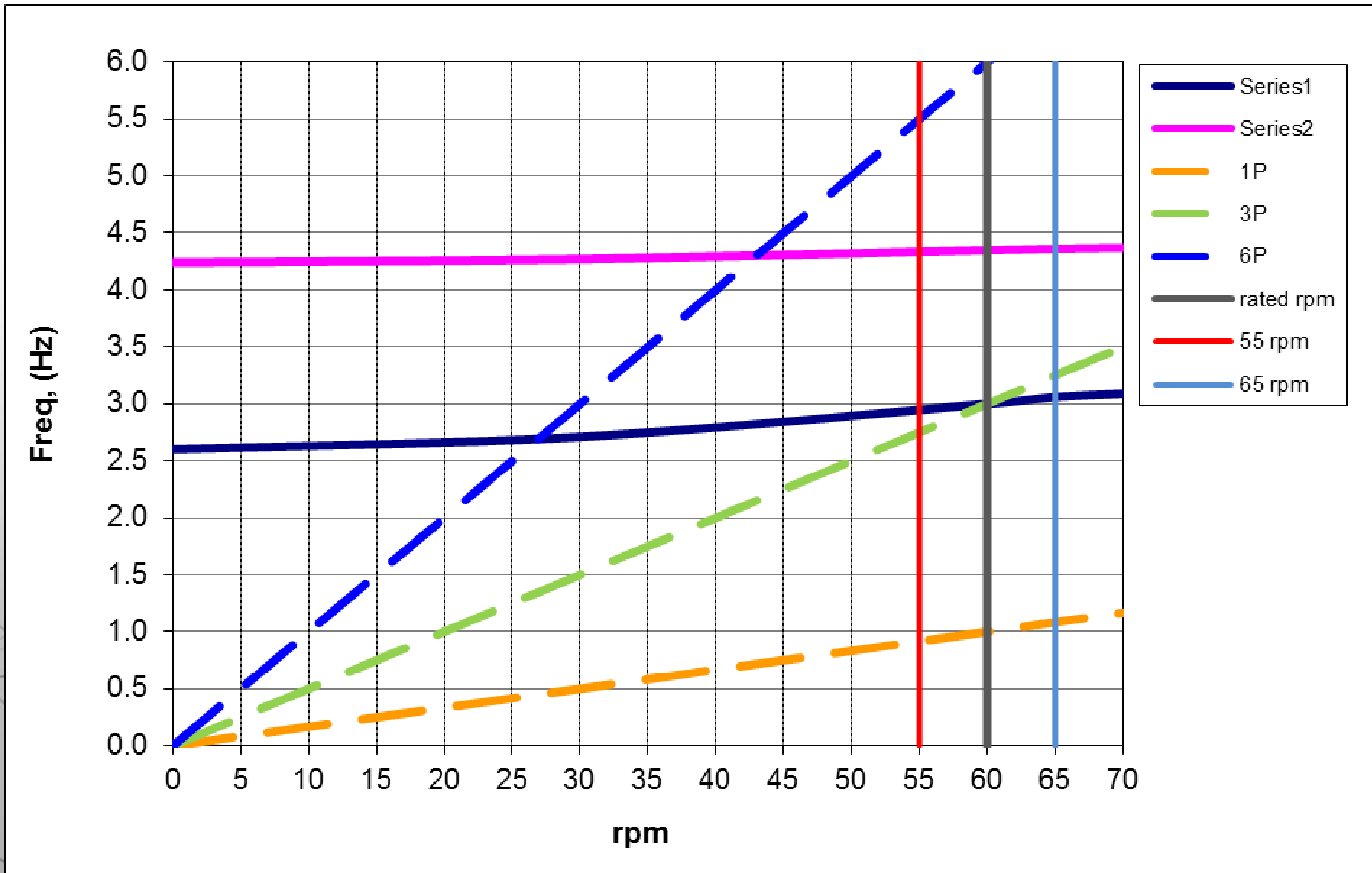
Conclusions- Fatigue

* The 3.00 Hz blade is the worst Downwind & Upwind.
* The 3.30 Hz (10%) blade is a lot better than the 3.15 Hz (5%) blade. 5% rule is maybe a 10% rule?



What If ?

- What if you wanted to use a 3.00 Hz blade on your 60 rpm turbine? Maybe you can.
- Can you operate at 55 rpm? 65 rpm?



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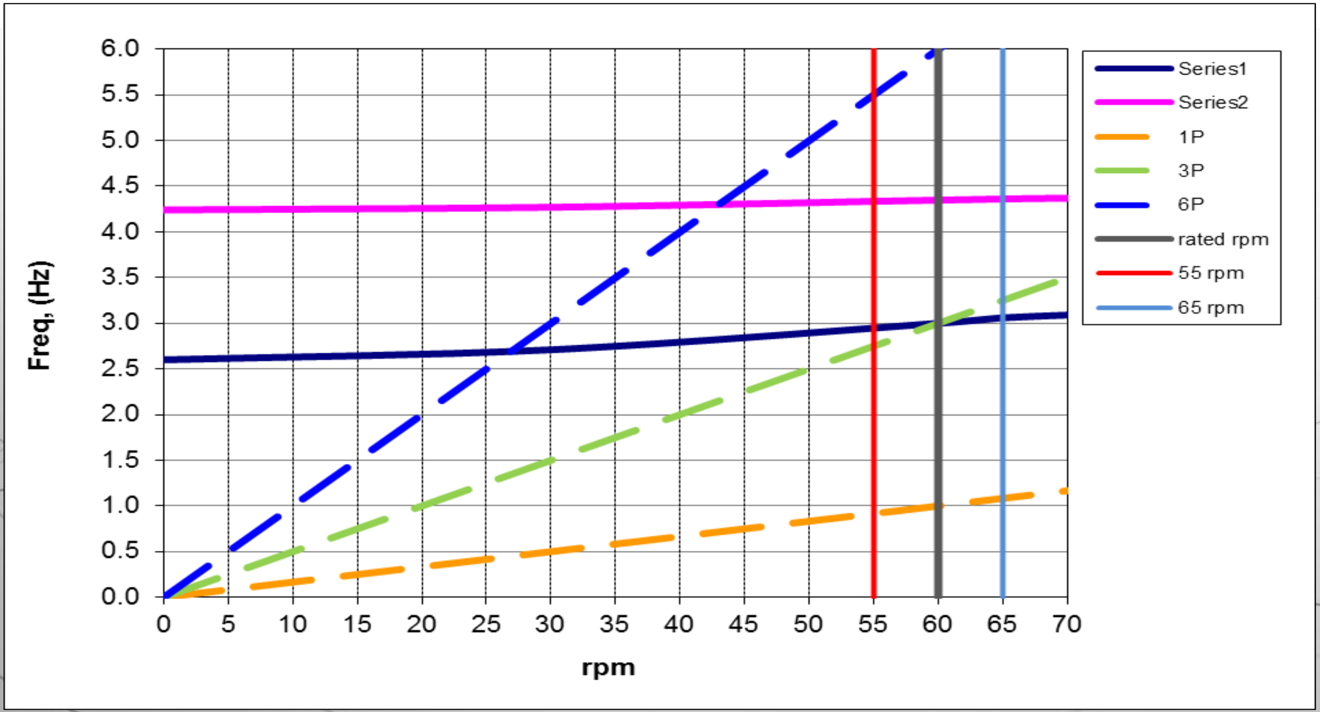
What If ?

* 55 rpm? 65 rpm?
* A FAST Model can help! May need to modify the generator or pitch the blades to optimize power, reduce loads, etc.
* Changing the operating rpm can transform the 3.00 Hz "mountain" into a "molehill".



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FAST Conclusions

- **A FAST model of your wind turbine is a very useful tool.**
- **FAST can assist with initial turbine design as well as retrofits.**
- **With FAST, you can try different configurations prior to manufacturing/purchasing. Determine a best design.**
- **FAST is a necessary tool for running IEC simulations for Turbine Certification.**

Contact


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