Static Balancing of Small Composite Turbine Rotors

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Wind Turbine Rotor Balancing

- Current balancing technique
  - Pitch offset
    - Actively vary pitch to offset bending moments on rotor
    - Can reduce energy capture
  - Little information on proprietary methods in literature

- Why is balancing important?
  - Excessive noise
  - Safety in populated areas
  - Improved reliability and return on investment (ROI)
  - Could lead to gearbox fatigue failures

Need for Balancing: Comparison

- Car Wheel
  - 700 RPM on the freeway (100 km/h)
- 5g is smallest typical balance mass
  - Assume accuracy of wheel balance is ± 2.5g

- Shake force is **<u>1.5%</u>** of wheel weight
  - This is deemed acceptable

Need For Balancing Continued

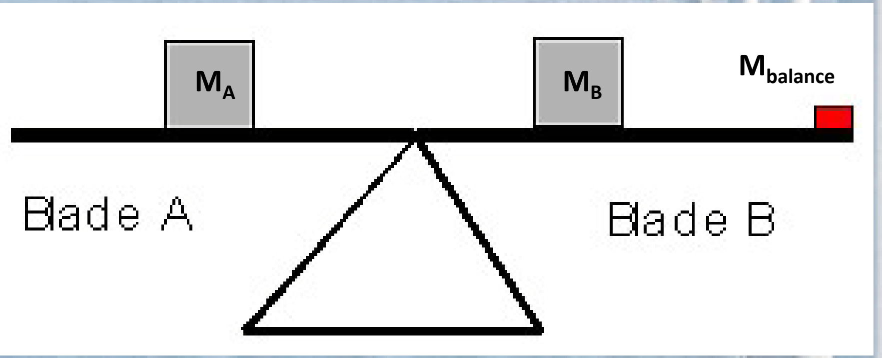
- Vestas V90
  - Shake force per blade up to 11.5 kN of due to construction tolerance alone
    - Approx. 3% of rotor weight
  - Uneven Aerodynamic loads
  - Wind gusts

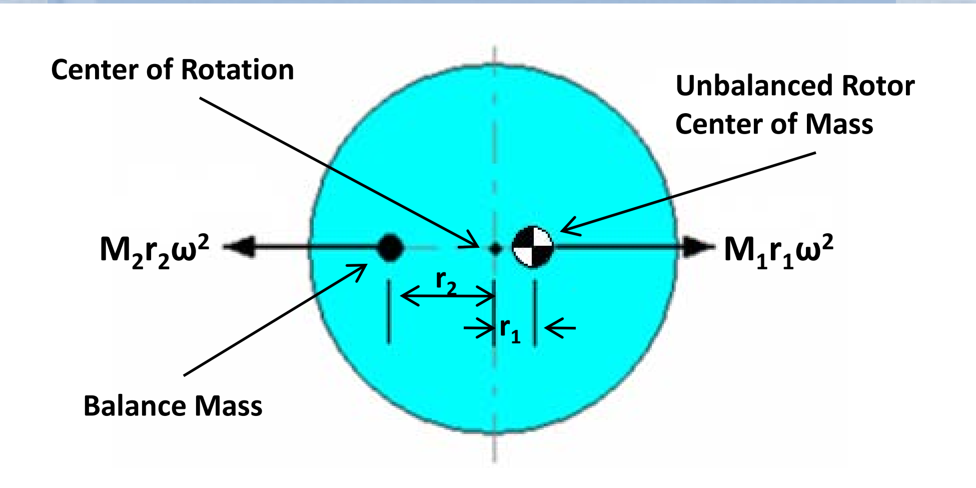
- Bergey Excel 10
  - A 1% blade weight tolerance at 400 RPM could cause an 360 N shake force
  - 60% of rotor weight

Static and Dynamic Balancing

- Static
  - Matching R*x*M of each rotating part while stationary
    - Safe
    - Not as accurate
    - Relatively economical in terms of space and cost

- Dynamic
  - Matching R*x*M*x*ω^2 by rotating the part with a variable speed motor
    - Very accurate
    - Expensive
    - Requires more space
    - Impractical for wind turbine rotor





Static Balancing

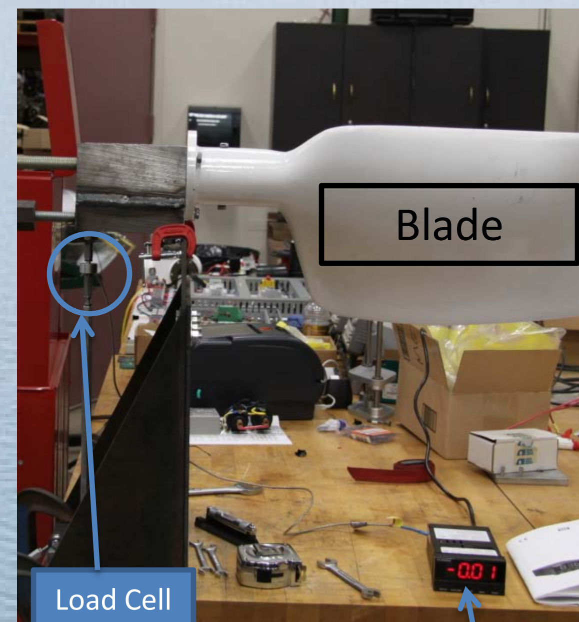
Method 1: Full rotor

– Match mass moments of all blades and hub simultaneously

Top View

Method 2: Single blade

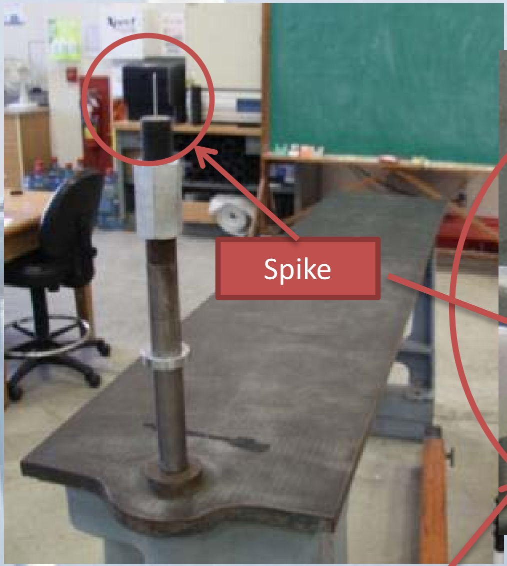
– Match mass moments of all blades to the same value sequentially

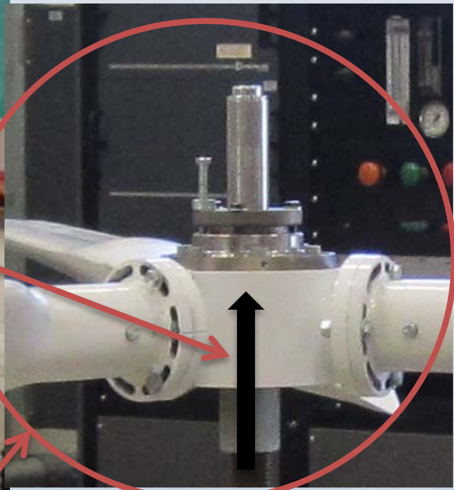


Load Cell Readout

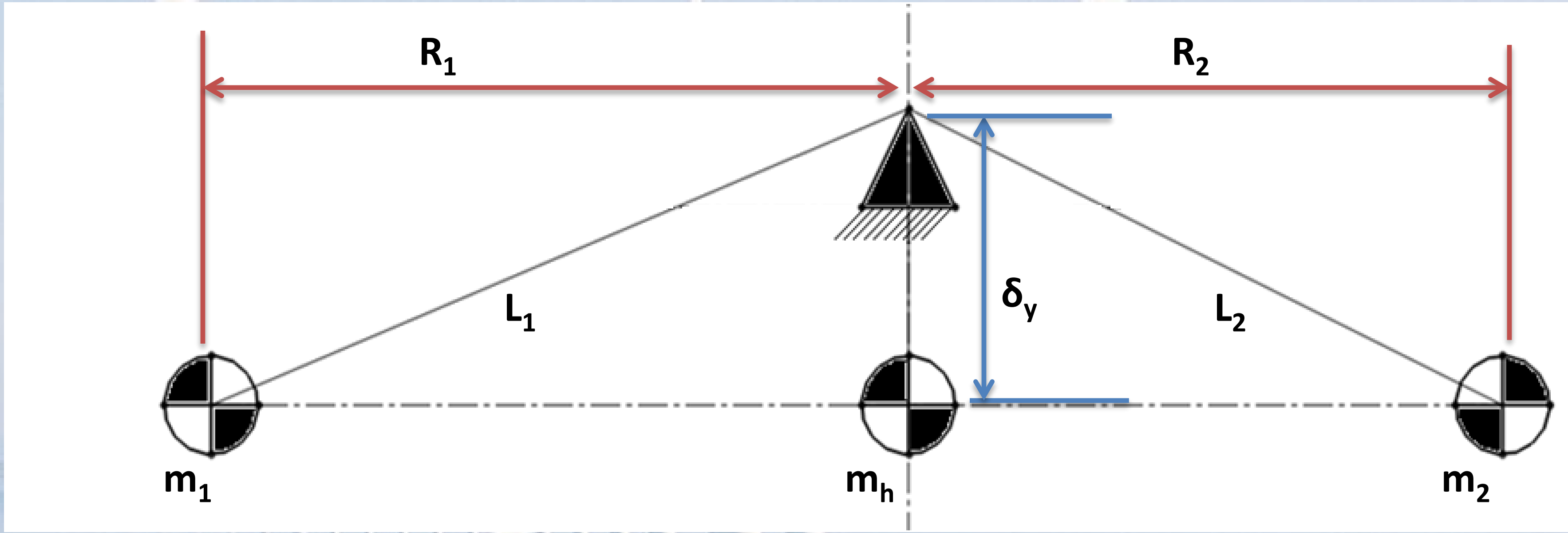
Method 1: Full Rotor

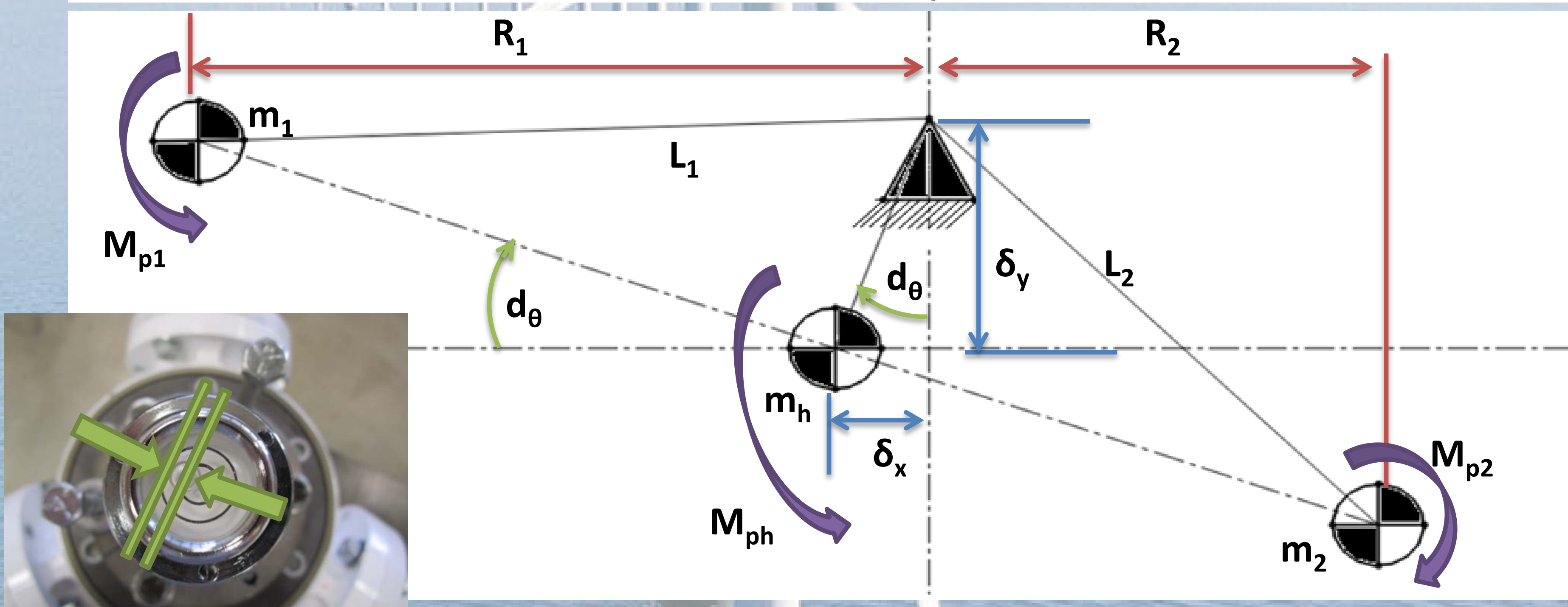
- Full rotor is balanced on a spike or “frictionless” point
- Very sensitive
- Requires space the size of rotor swept area



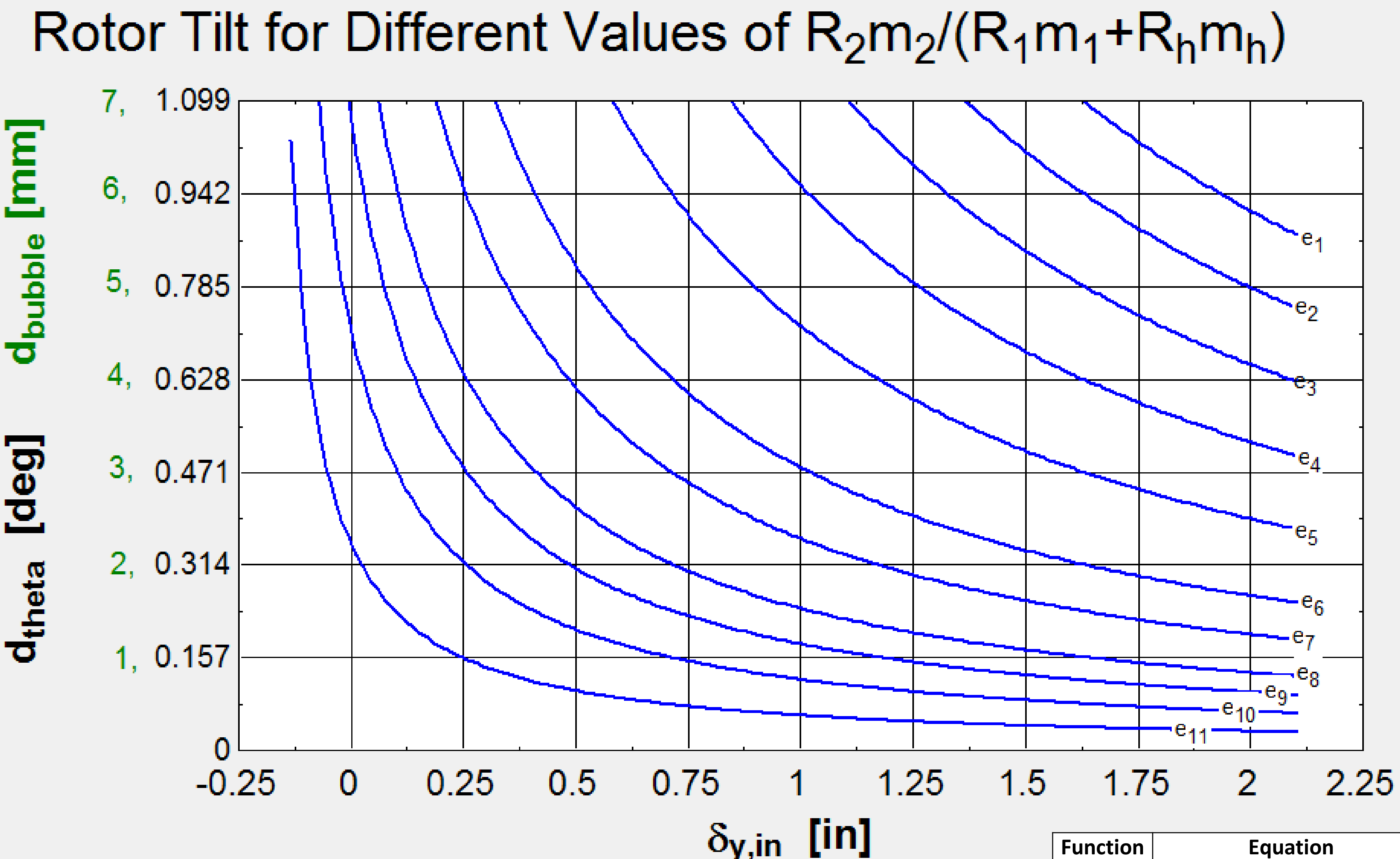


Full Rotor Method Formulation





Analysis of Full Rotor Error and Sensitivity



Function	Equation
e_1	$B = 0.000299*d_\theta + 1.00408$
e_2	$B = 0.000298*d_\theta + 1.00350$
e_3	$B = 0.000297*d_\theta + 1.00292$

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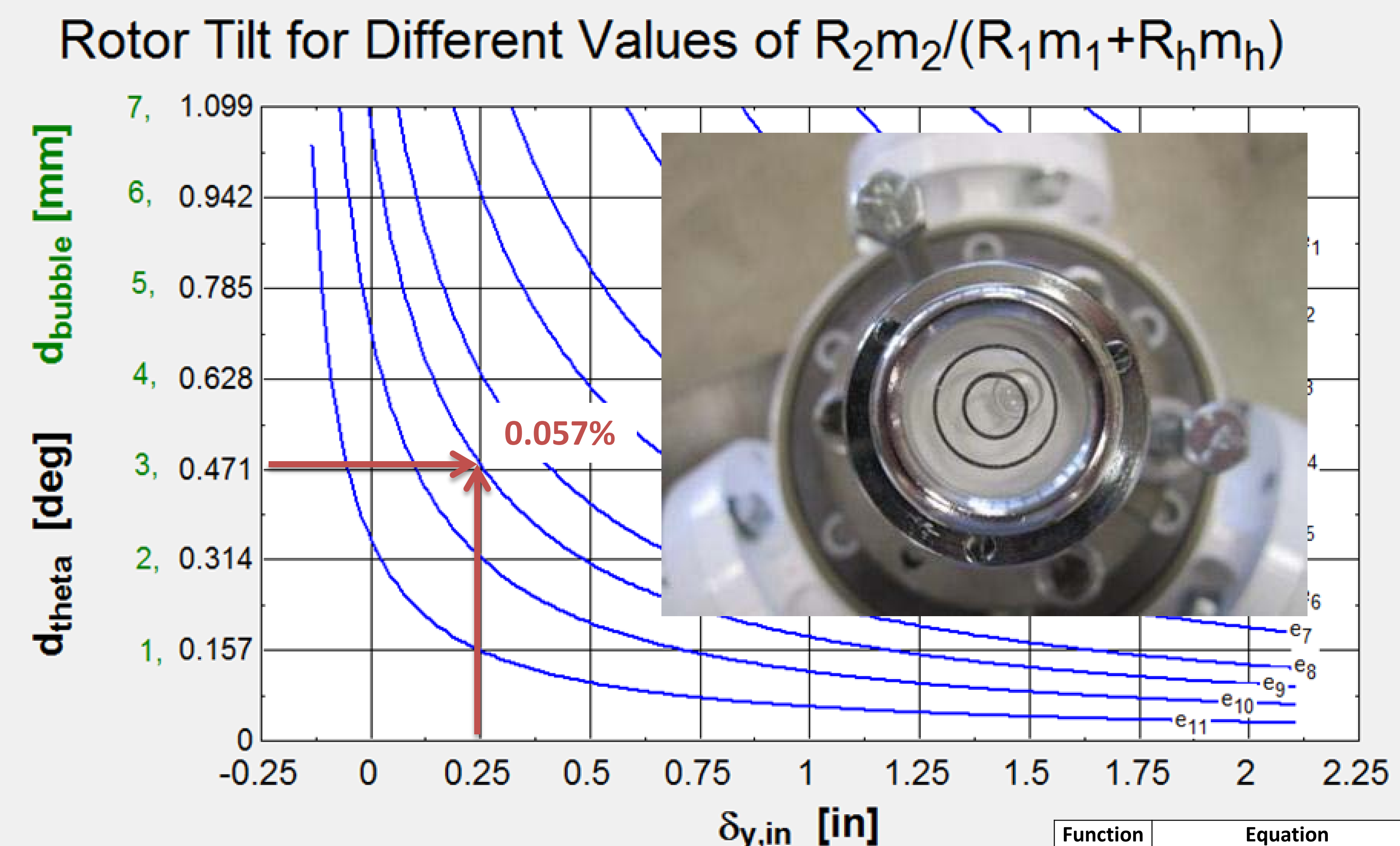

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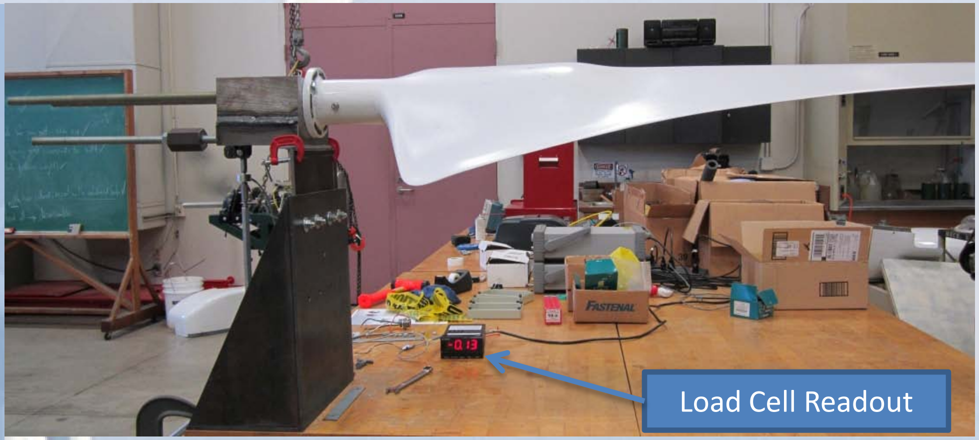
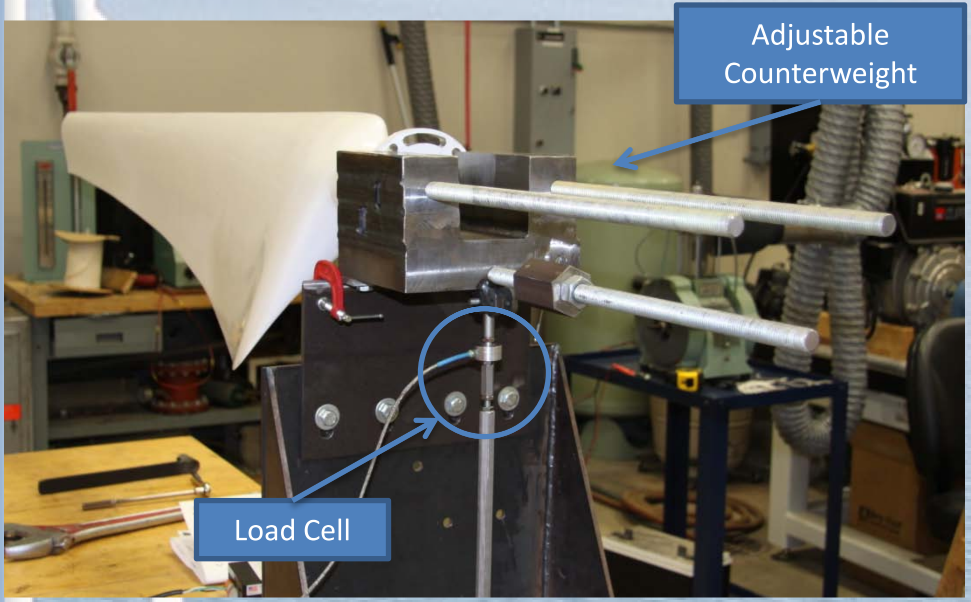
Full Rotor Conclusions

- Hub must be perfectly balanced independently
- Shows qualitative balance more than true quantified imbalance
- Actual balance is close to 0.5%
- Corresponds to a shake force
  2.6 % of total rotor weight at design speed

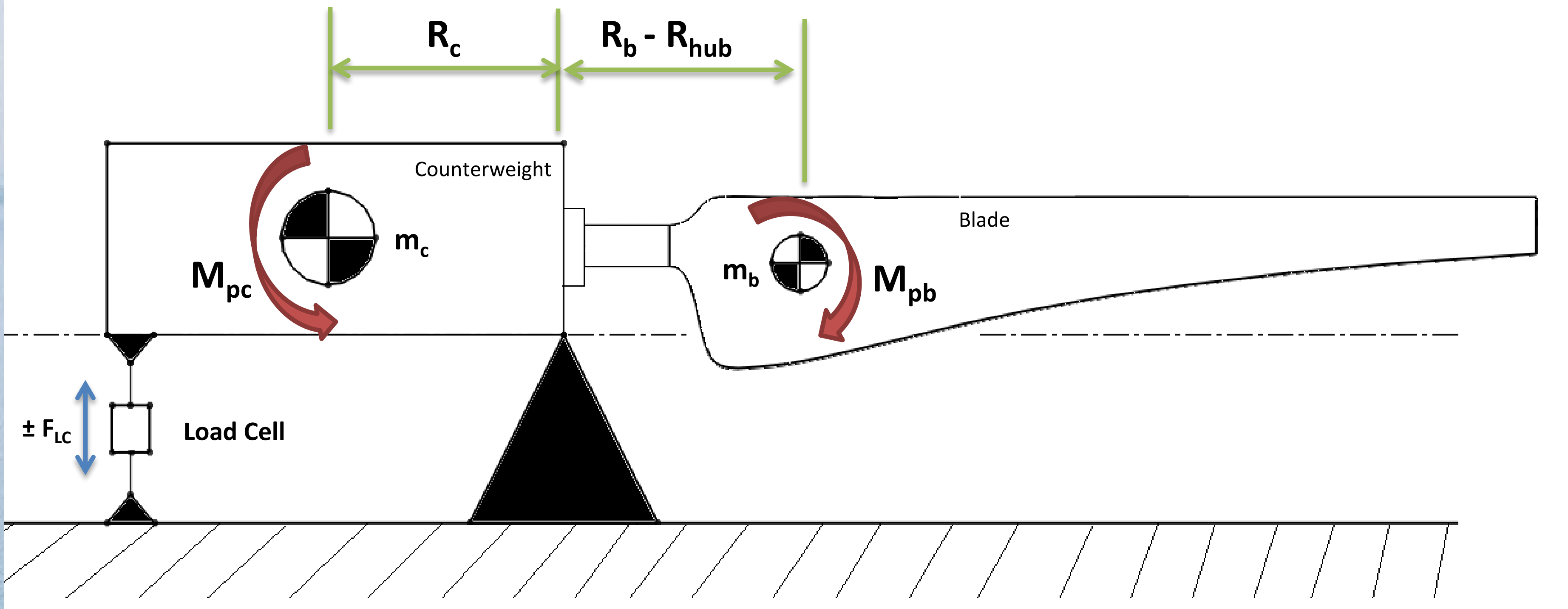
Method 2: Single Blade

- Individual blades resting on a knife edge
- Must account for not having a hub, i.e. distance from C.G. to pivot plane is R_{hub} shorter than on full rotor method





Single Blade Method



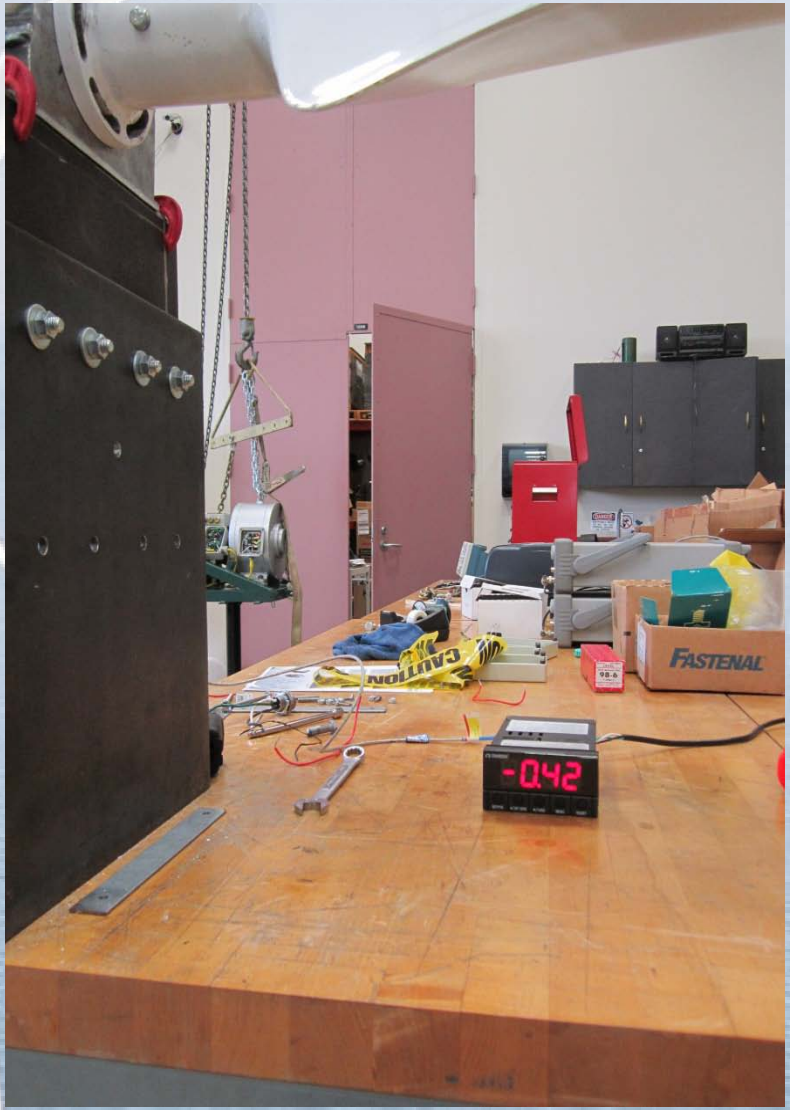
Errors and Result

- Load cell tolerance is critical
- Inaccuracy on pivot plane
  - Alignment
  - Rattle
  - Level

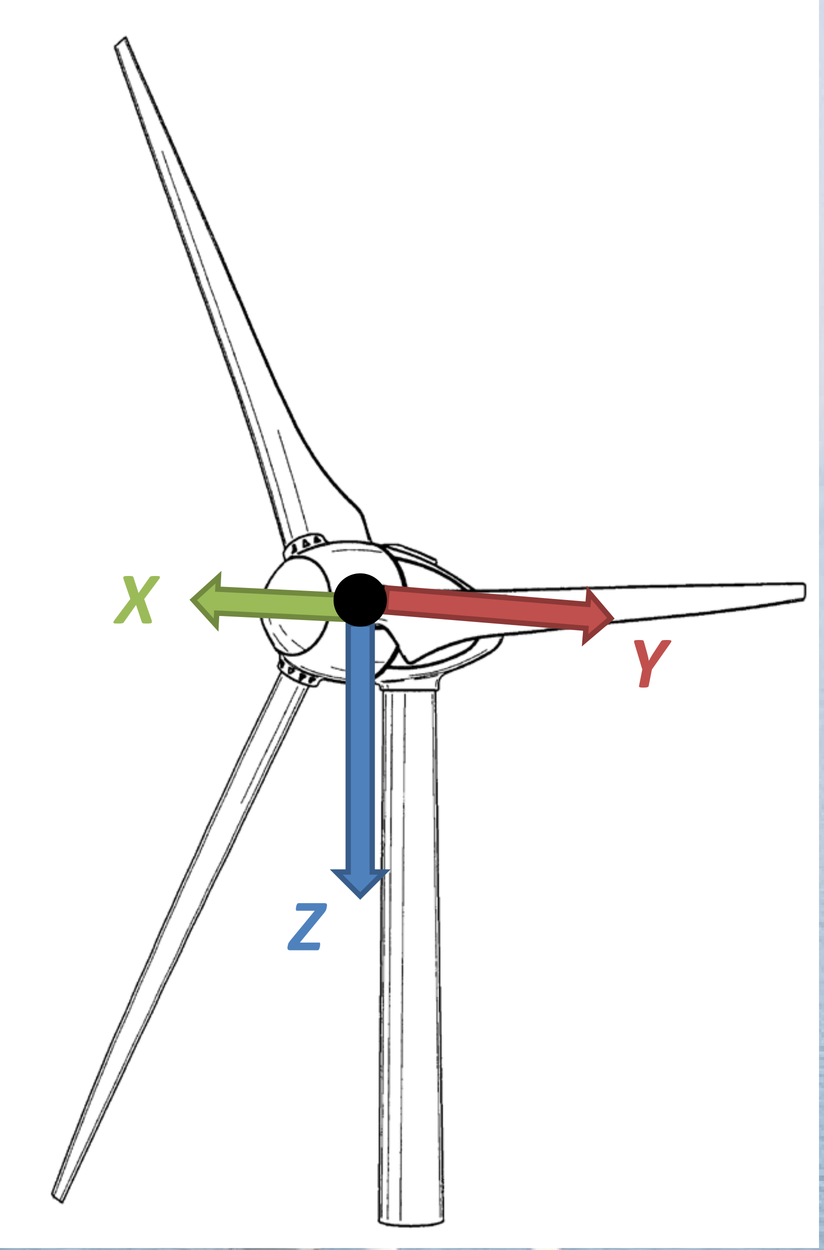
•Rotor within 1% balance

•Corresponds to a shake force 4% of total rotor weight at design speed

•With further refinement could be appropriate for utility scale



Experimental Verification



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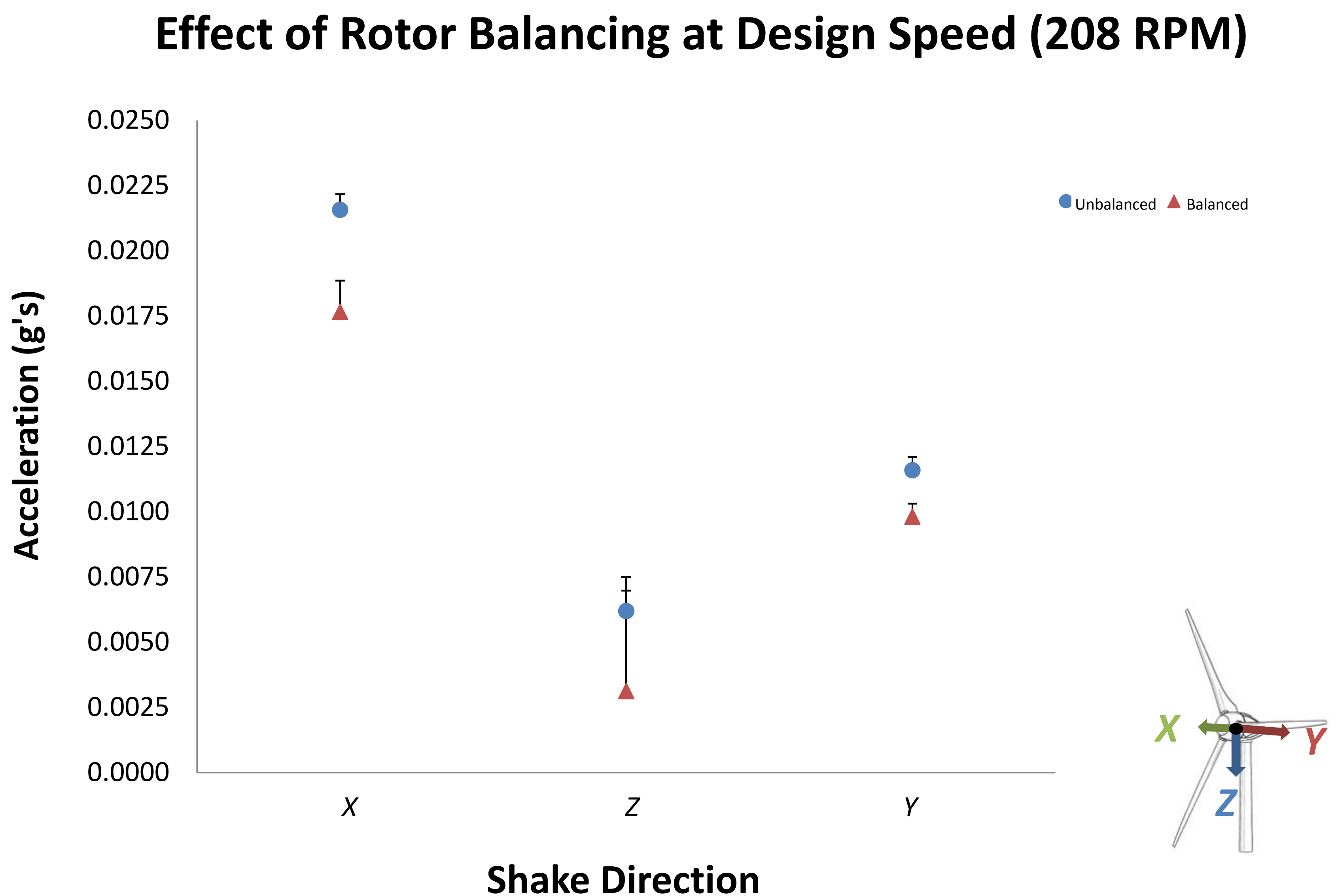

Thank Yous

- Bently Center for Engineering Innovation at Cal Poly

- California Central Coast Research Partnership (C^3RP)

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