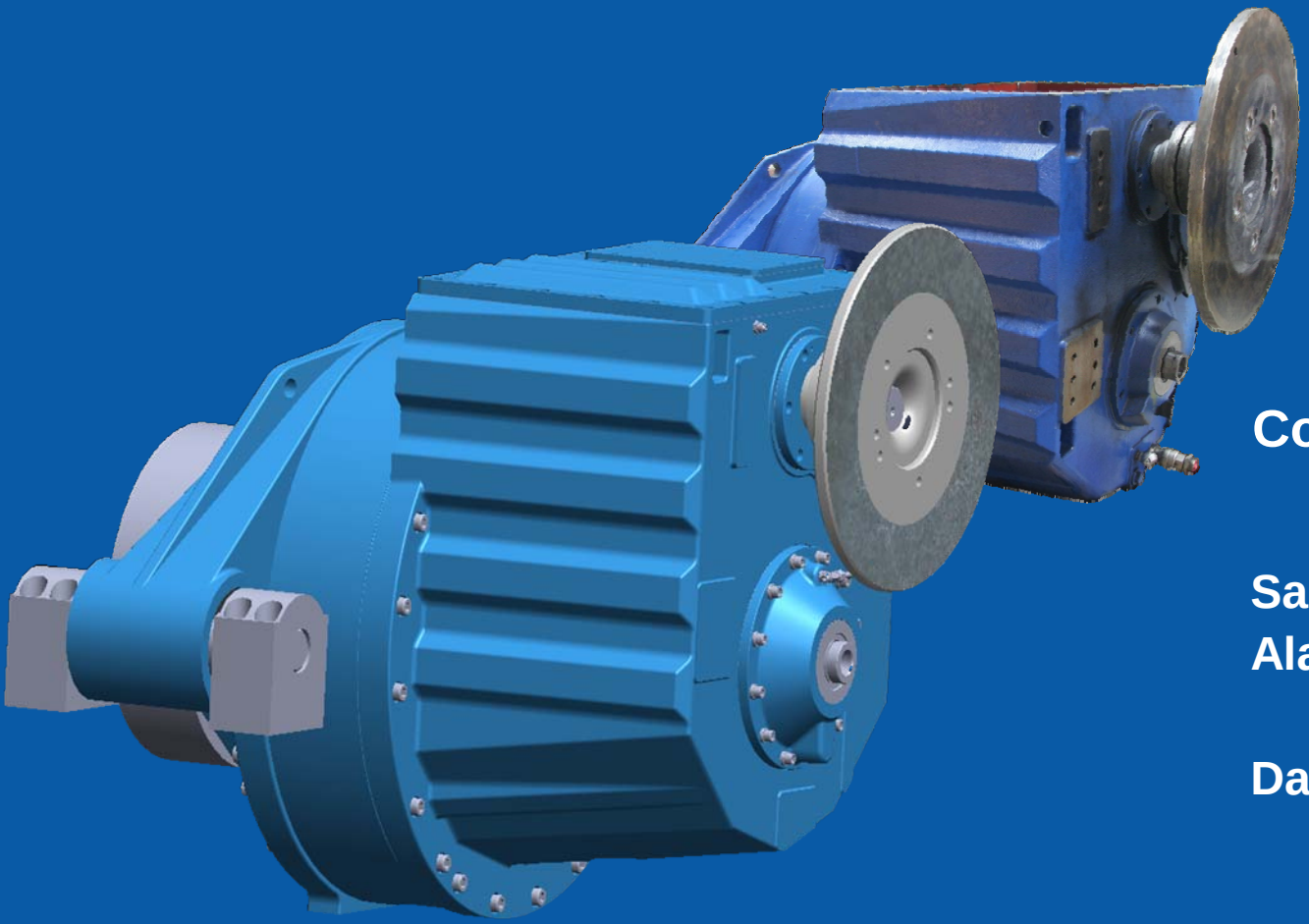
National Renewable Energy Laboratory
Innovation for Our Energy Future

Vision for Advanced Wind Plant Health Monitoring: Beyond Gearboxes



Condition Monitoring Workshop

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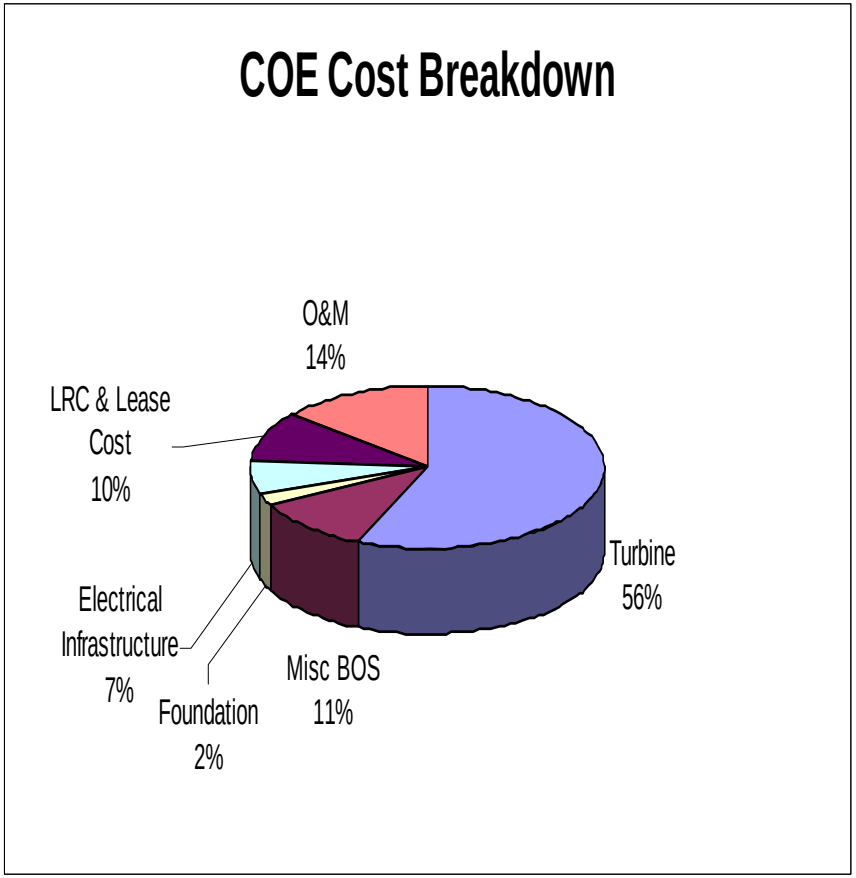
NREL is a national laboratory of the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy operated by the Alliance for Sustainable Energy, LLC

Why are We Here?

- Understand current CM practices
- Reduce cost of O&M
- Optimize wind plant operation for site specific lowest COE
- Anticipate maintenance
- Automate data interpretation and detection of abnormal operation
- Expand the concept and exploitation of predictive maintenance management
- Increase fidelity of knowledge base
- Close the loop on the design process.



(Note: O&M assumes before tax)

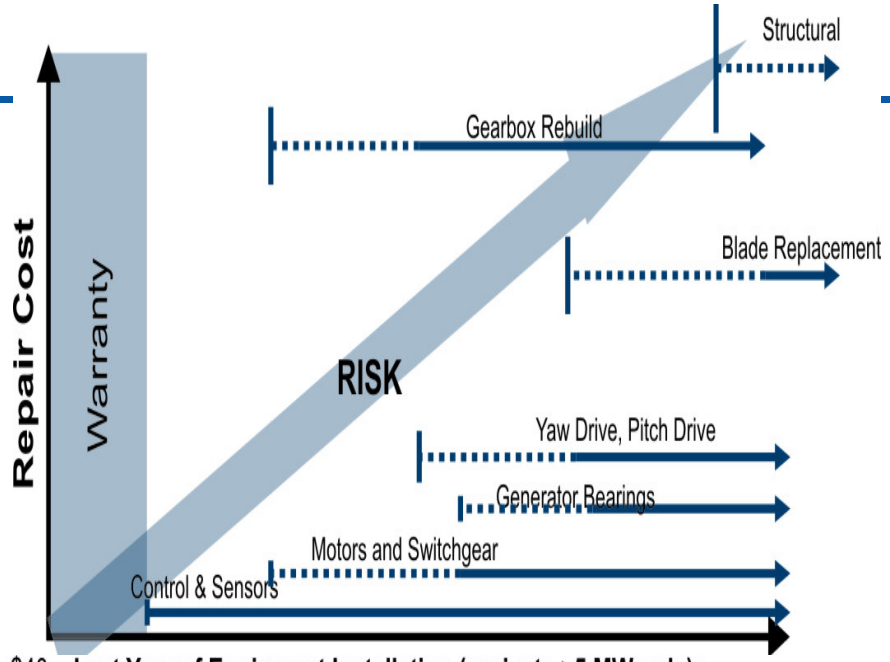
Managing Risk

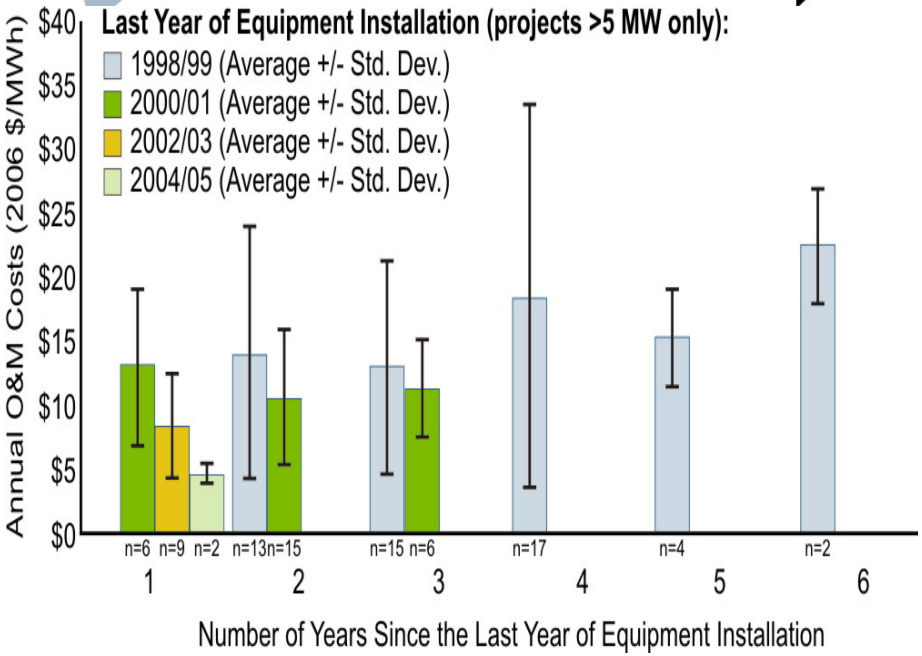
<u>Age Matters</u>

- Risk of failure cumulative
- Major components most costly
- Gearbox major offender
- Blades next most costly
- Other electrical most frequent but easiest to repair

<u>SHM Can Help Manage Risk</u>

- Gearbox condition monitoring
  - Damage detection maturing
  - Feature extraction immature
  - Prognostics very immature
- Blade monitoring?





Current Practice

- Scheduled maintenance based on estimates of actual maintenance needs (instead of actual need)
- Huge volume of SCADA data, potentially useful but difficult to interpret
- Unscheduled events require reactive (inefficient) responses (“rip, read and react” to fault reports)
- Maintenance is performed usually after damage is already done

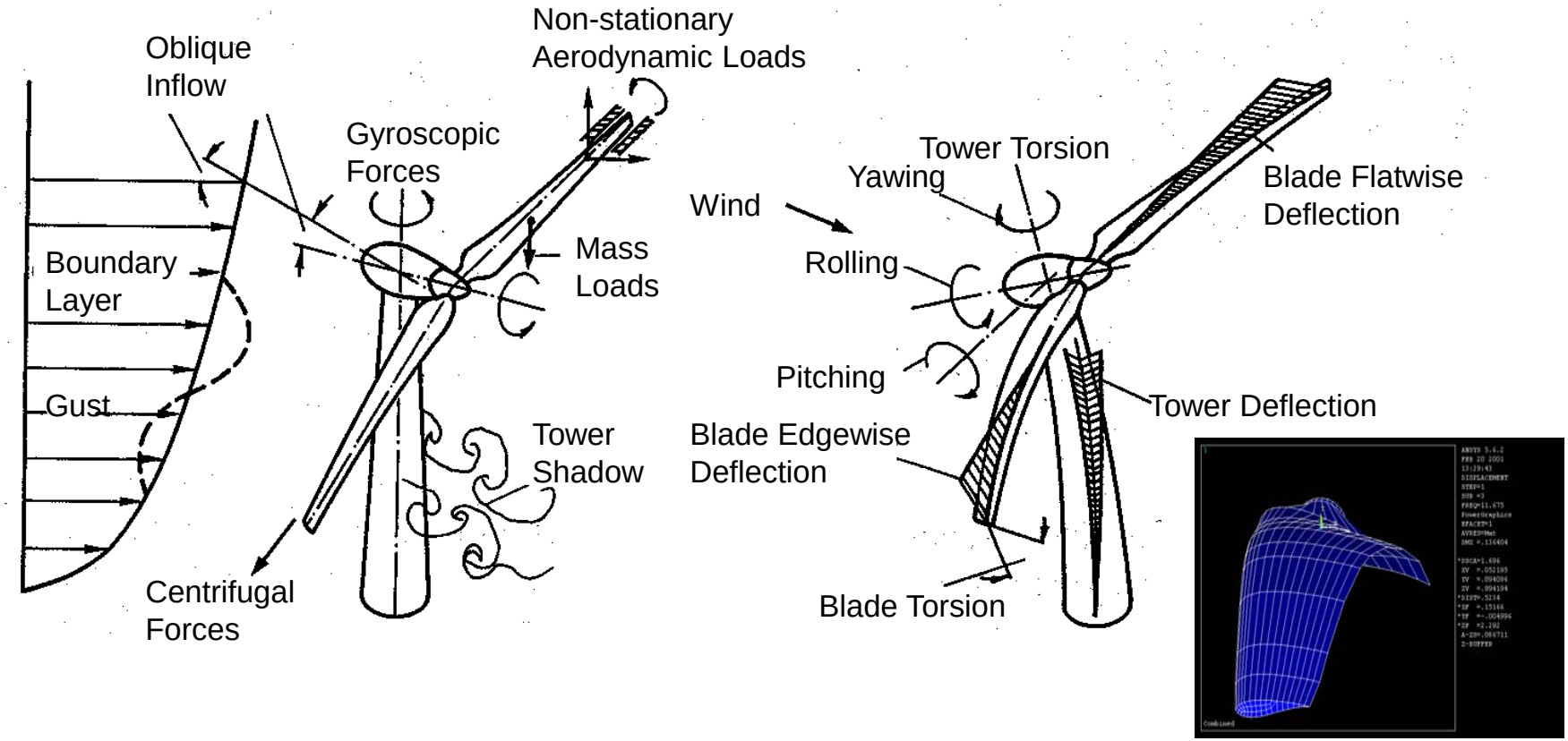
An Asset Managers Dream……

Wouldn’t it be nice if we knew:

- what caused poor performance on certain machines
- when the turbines were experiencing damage rate operating conditions and why
- exactly when components were going to fail and why
- How to improved design weaknesses at each retrofit cycle

Understanding the Operating Environment

- Isolating Sources of Loads Can be Difficult
- Aeroelastic Models Can Help

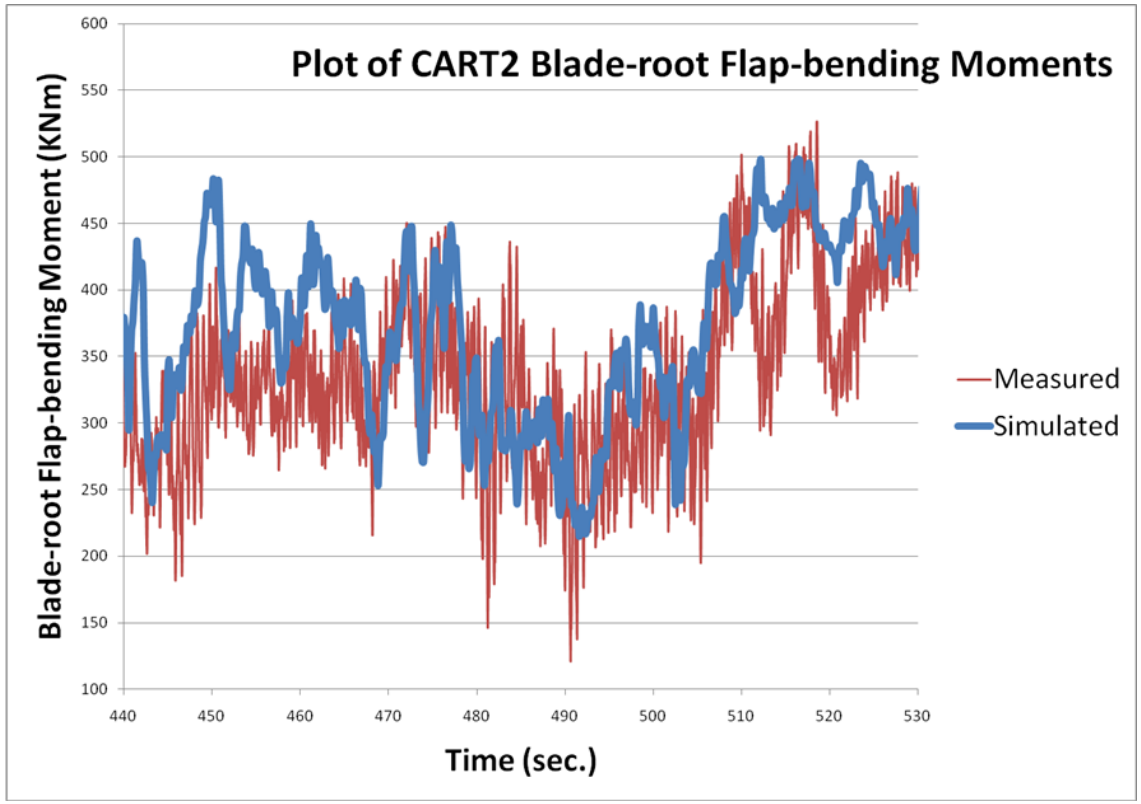


- **Blade vibrations interact with aerodynamic forces = aeroelasticity**
- **Mode shapes and natural frequencies critical**

Dynamics Modeling and Controls

- Can we correlate inflow/atmospheric conditions with high load operating conditions?
- Can we use turbine sensors feeding dynamic models to establish a more complete picture of the machine operating state?
- Can we apply modern control theory to avoid high load operating conditions?

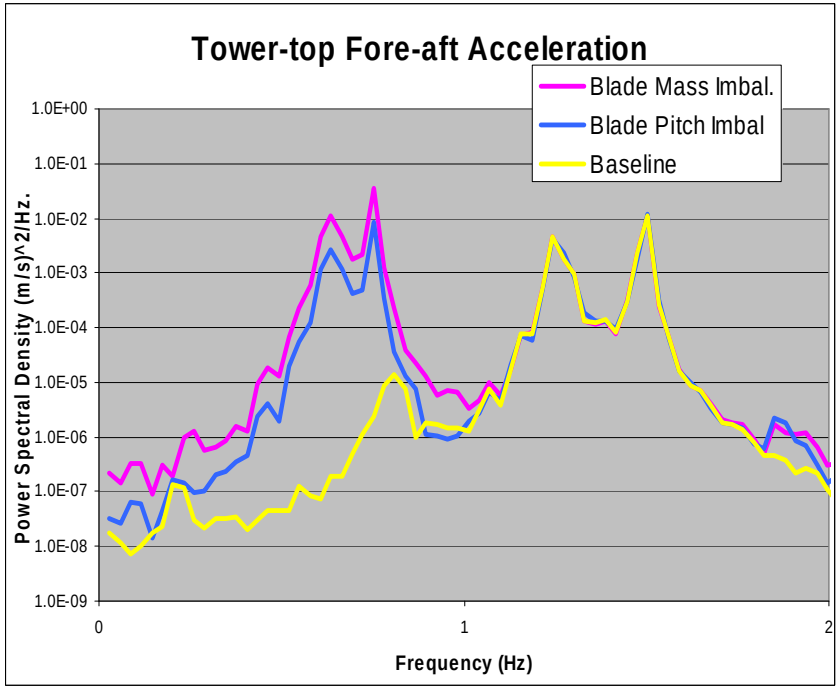
Example: FAST simulation (with only wind input) compared to measured blade load

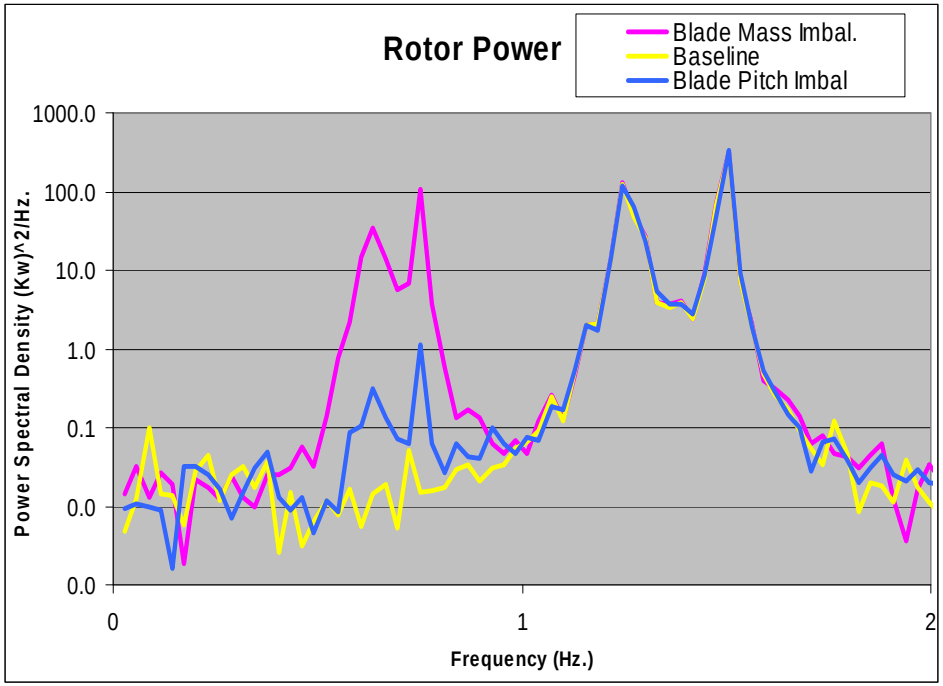


Detecting Rotor Imbalance

- Rotor imbalances can be aerodynamic or mass
- They can cause
  - Performance losses
  - Increased loads and vibration
- Detection is not straight forward
  - Both cause vibration
  - One is symmetrical (side to side motion)
  - The other causes yaw oscillations
- Model assisted detection strategies can help isolate and quantify the problem

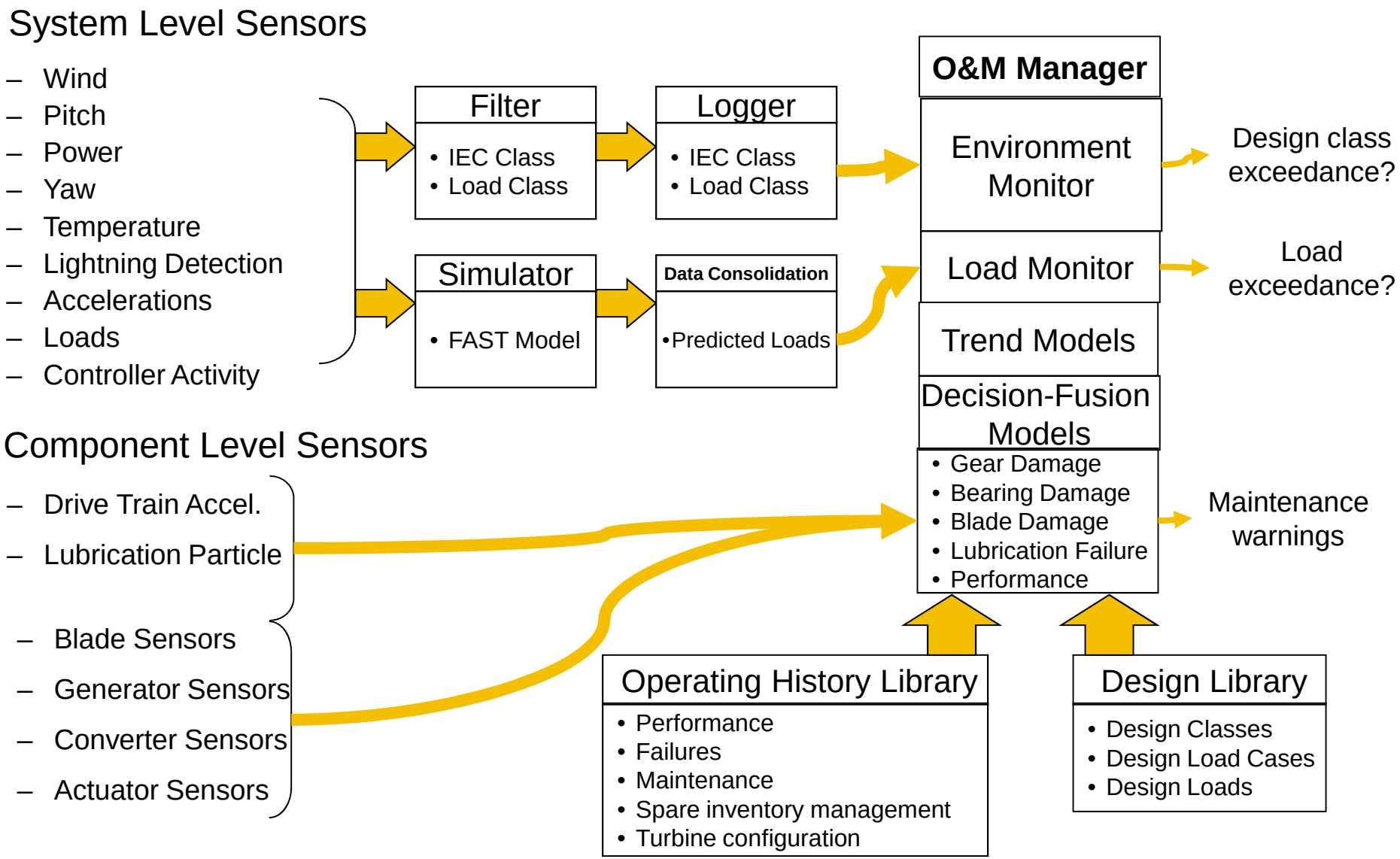
Rotor imbalance example





- 0.4% mass imbalance
- ½ degree pitch imbalance

Possible Integrated O&M Manager System



Unique Opportunities

Bad news:

- Hundreds of machines in each plant

Good news:

- Hundreds of machines in each plant
- robust failure statistics
- Automated detection techniques can identify damaging behavior
- Opportunities to correlate high load operating conditions with environmental conditions
- Model assisted load estimation can be a fatigue damage meter.

Thank You

“The future ain’t what it used to be.” - Yogi Berra