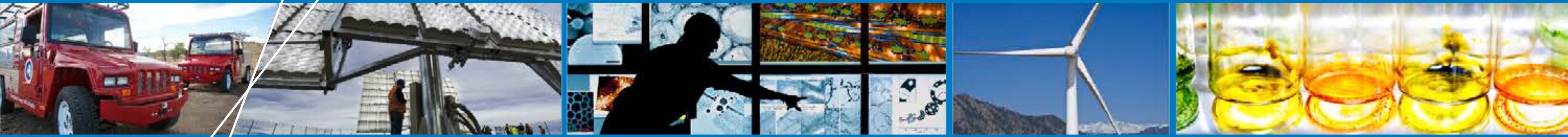
NATIONAL RENEWABLE ENERGY LABORATORY

Development and Analysis of a Swept Blade Aeroelastic Model for a Small Wind Turbine



Robert Preus, Rick Damiani, and Sang Lee
National Renewable Energy Laboratory
Scott Larwood
University of the Pacific

Small Wind Conference
June 17, 2014
Stevens Point, Wisconsin

PR-5000-62197
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.

Acknowledgments

- U.S. Department of Energy (DOE) – For Competitiveness Improvement Project (CIP) funds and computer-aided engineering (CAE) tools funds

- Scott Larwood – For implementing the original version of FAST2ADAMS in FAST6

- Reference turbine loosely based on Bergey Wind Power Excel S10.

Outline

- Quest towards optimized/advanced rotors
- CAE tools: FAST and ADAMS
- Case study
- Summary of results.

Why Advanced Rotors?

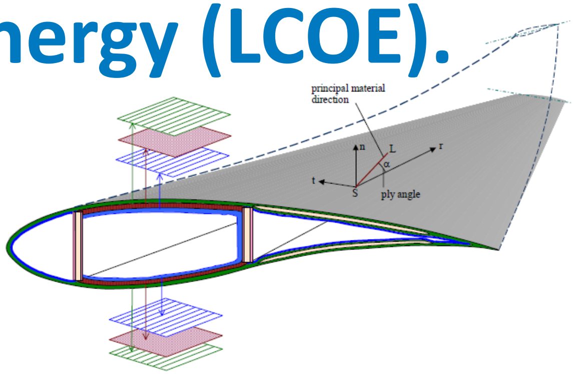
- **Reduce loads at current rotor diameter**

OR

- **Increase rotor diameter at same loading level**

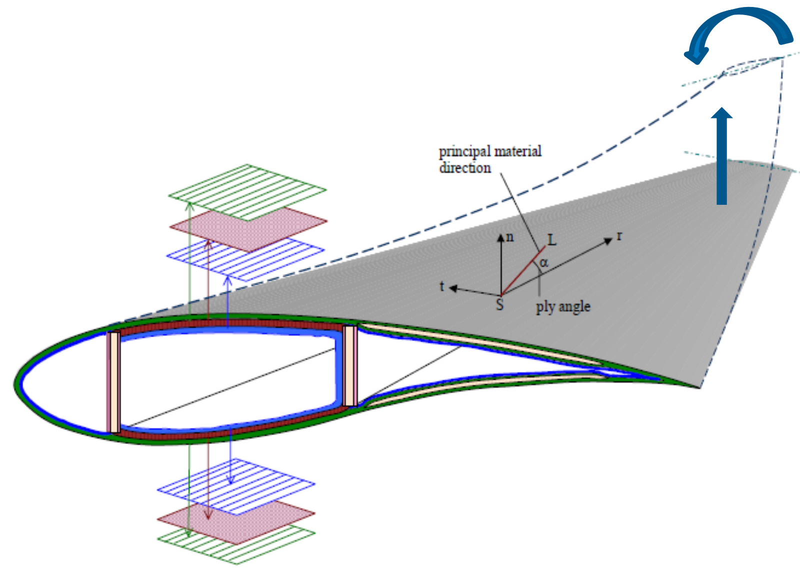
⬇

- **Reduce material**
- **Optimize utilization**
- **Reduce the levelized cost of energy (LCOE).**



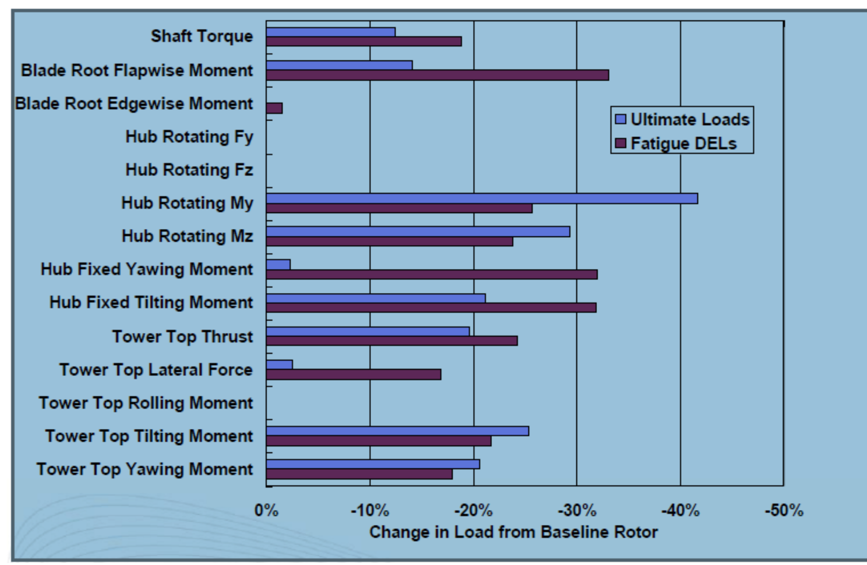
Blade Sweep→Bend-Twist Coupling

- **The lift at the tip induces pitch-feather**



Viryd CS-8 wind turbine under test at the National Wind Technology Center, *Photo by Mark Murphy, NREL 22258*

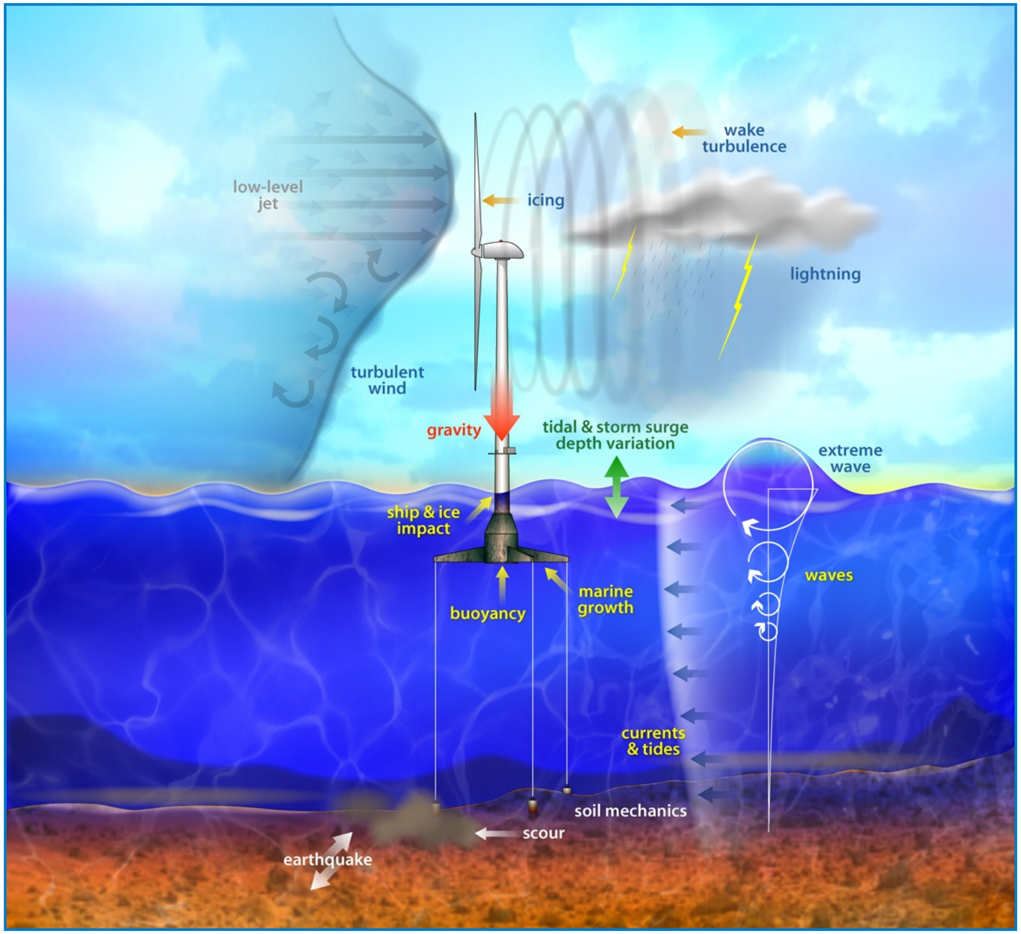
- **Load mitigation: reduce ultimate and fatigue loads**



Courtesy of Wetzel Engineering, Inc.

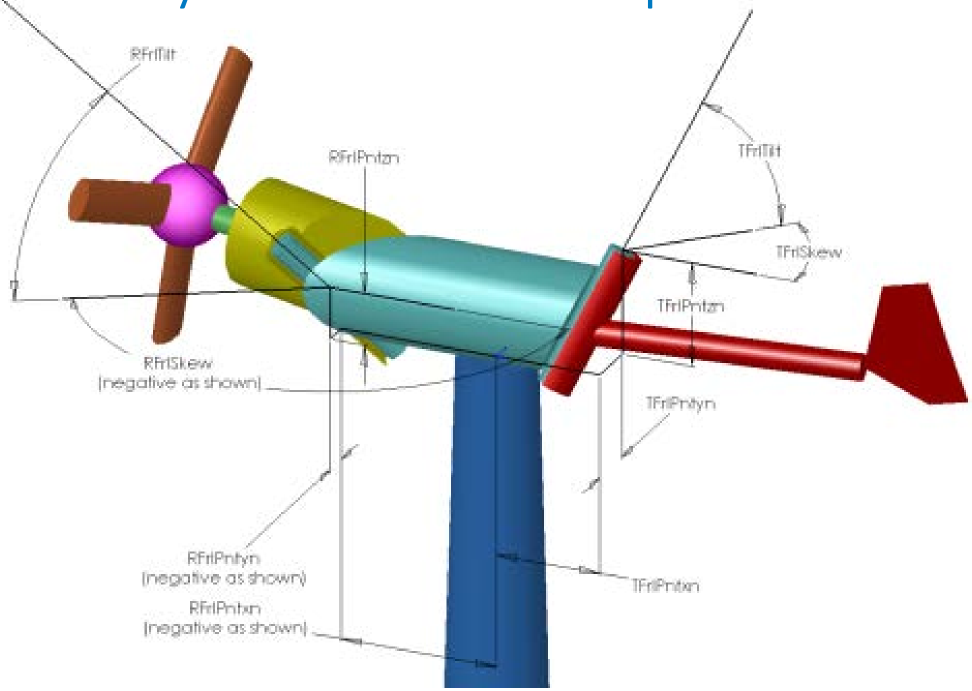
CAE Tools: FAST and ADAMS

- **FAST– Aero-Hydro-Servo-Elastic CAE Tool in Development Since 1996:**
  - Open source = FREE!
  - Capable of simulating tail and furling dynamics for small wind
  - Twenty-four degrees of freedom (DOFs) horizontal-axis wind turbine only—vertical-axis wind turbine aerodynamics captured in upcoming V8
  - Use for design to International Electrotechnical Commission load cases – certification
  - V8 will be capable of blade torsional (twist) degree of freedom
  - Can be used to prepare ADAMS input files and models.



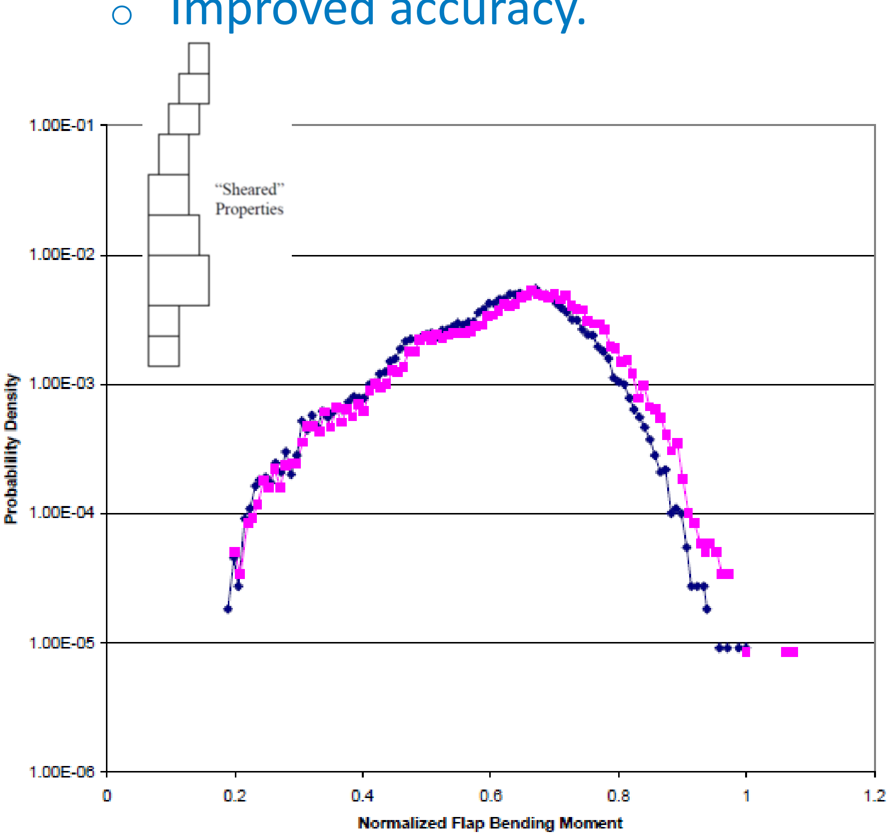
CAE Tools: FAST and ADAMS (continued)

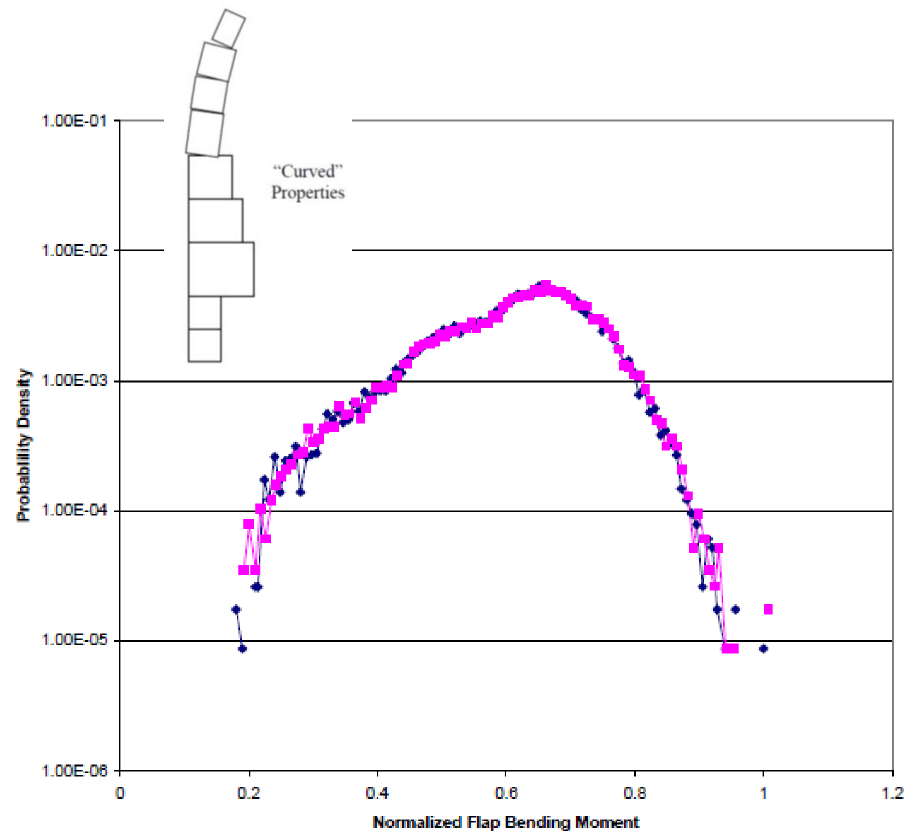
- **MSC ADAMS – Multibody Dynamics:**
    - Commercial product
    - Can be coupled to Aerodyn (FAST module) – FAST2ADAMS available for FREE
    - Can be highly customizable with user's controller library (requires a bit of programming)
    - Highly flexible – virtually any geometry you can think of
    - High fidelity – as many DOFs as the user requires.



FAST2ADAMS

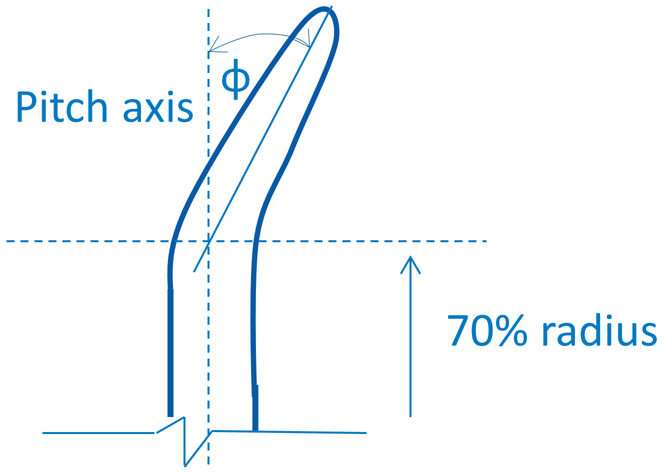
- **Original preprocessor would use the sheared approach:**
  - Leads to inaccurate representation of aerodynamic and inertial loads
- **New preprocessor follows curved properties of blade elements:**
  - Higher fidelity and physically consistent results
  - Improved accuracy.





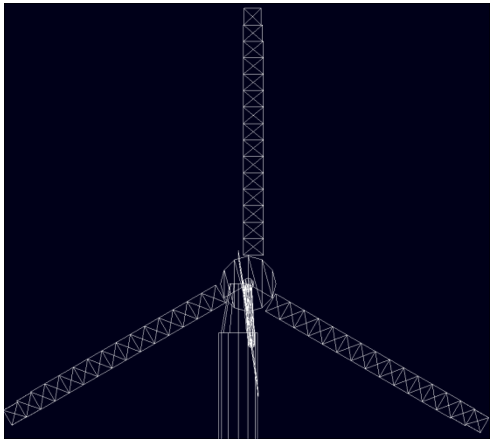
Case Study

- Started the case study from a much simpler FAST input model and created an ADAMS model of a small wind turbine
- Small wind research turbine (SWRT) baseline rendering
- Design load cases (DLCs): 1.1 from 61400-2,NTM, WS 8–16 m/s
- Five configurations: baseline and 0, 5, 10, 15, 20 deg sweep angles
- Input and output channels.

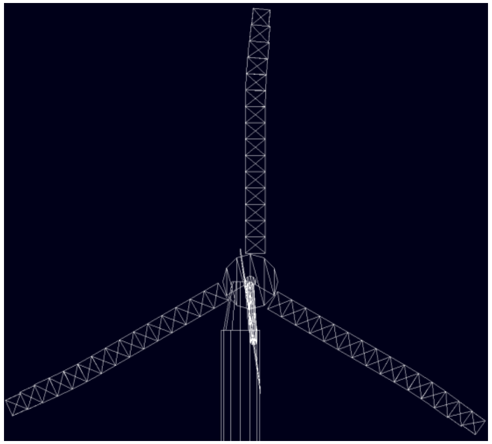


Case Studies

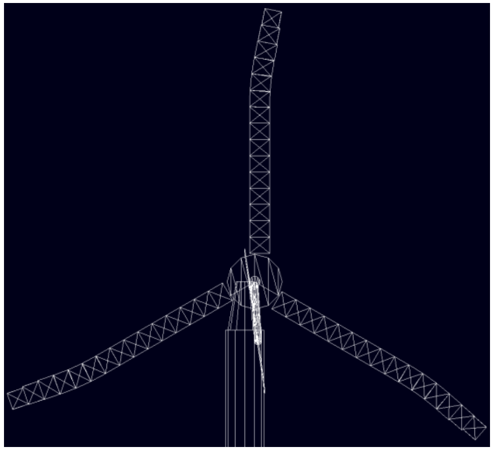
baseline



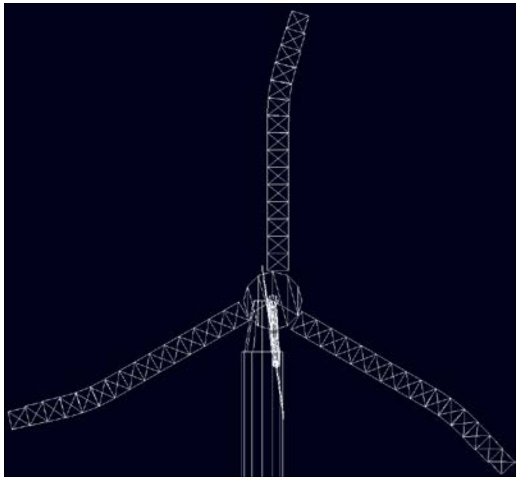
5 deg



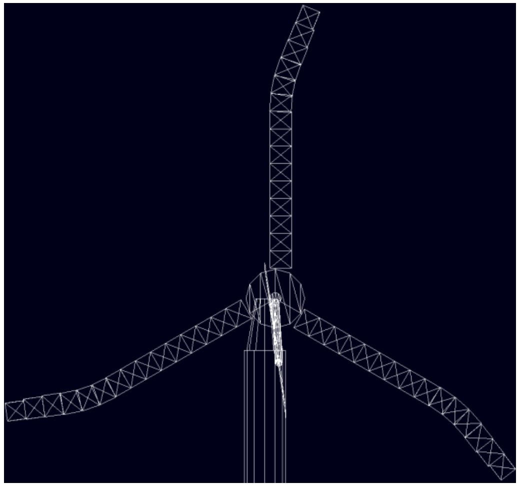
10 deg



15 deg

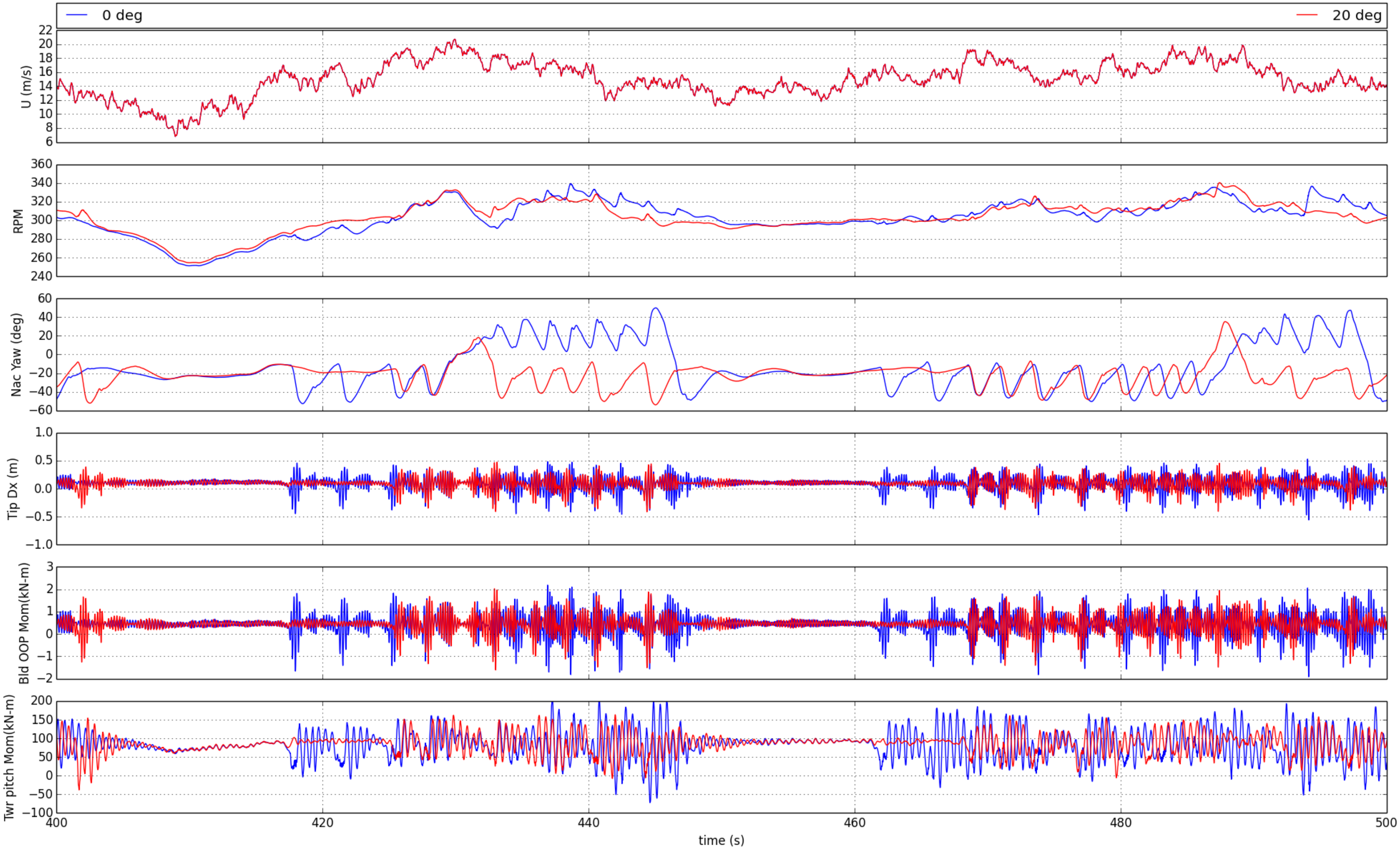


20 deg



Case Study

- Time series 0 deg and 20 deg at 14 m/s wind



Case Study

14 m/s
0 deg sweep

14 m/s
20 deg sweep

- 5.6 times slowed down

Case Study Results

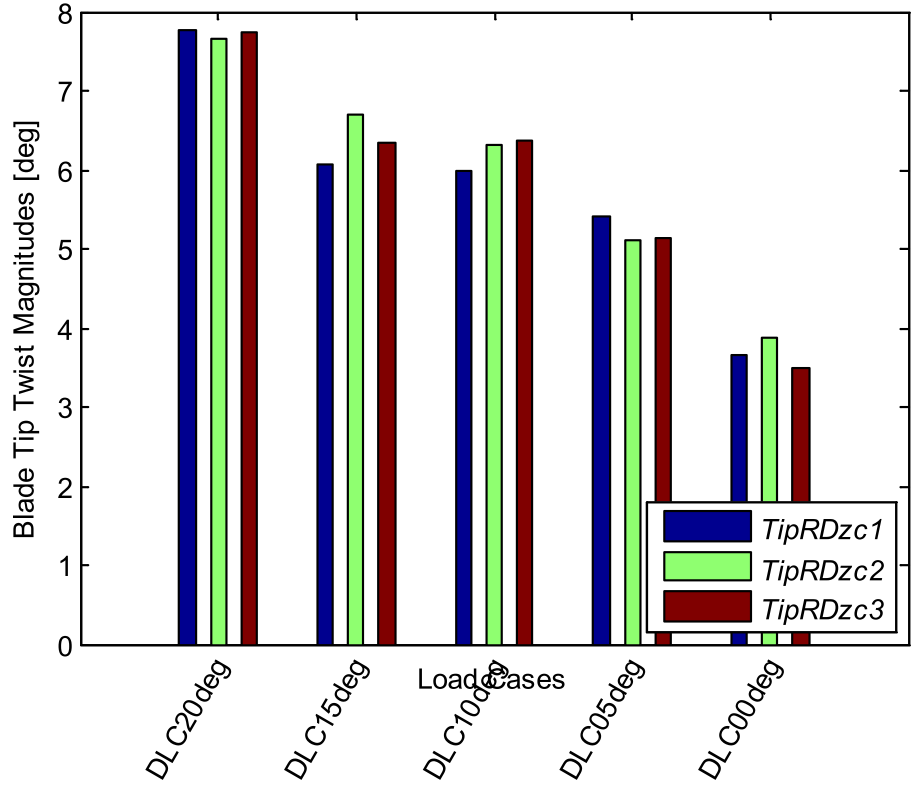
- **The mean power has not shown more than 5% variation across the various configurations**

  Note: This finding needs to be revised as the aero marker may need to be adjusted for simple blade element momentum and crossflow effects

  - Furling limits power anyways - more investigation needed
  - Stall-regulated turbine: possible power increase
- **Furling standard deviation slightly reduces with sweep.**

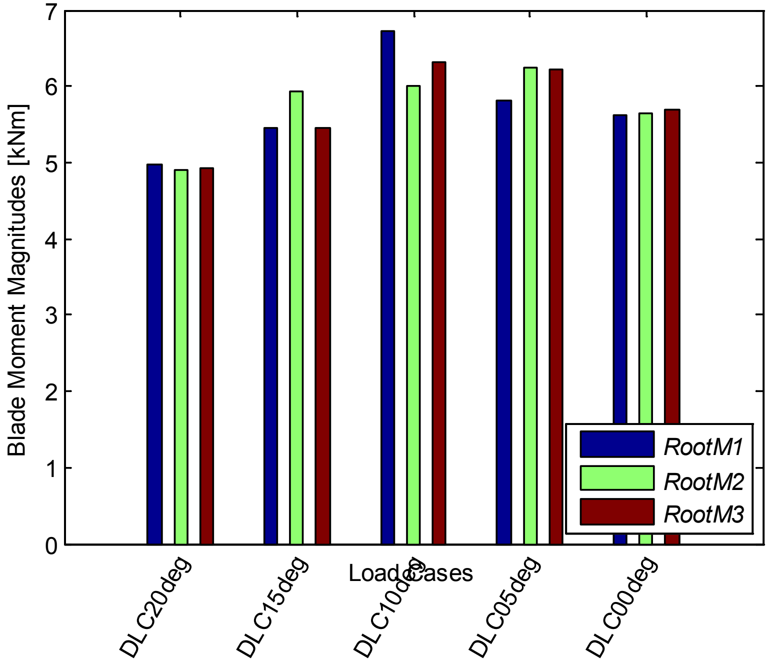
Case Study- ULS from DLC 1.1

- **Blade tip twist**



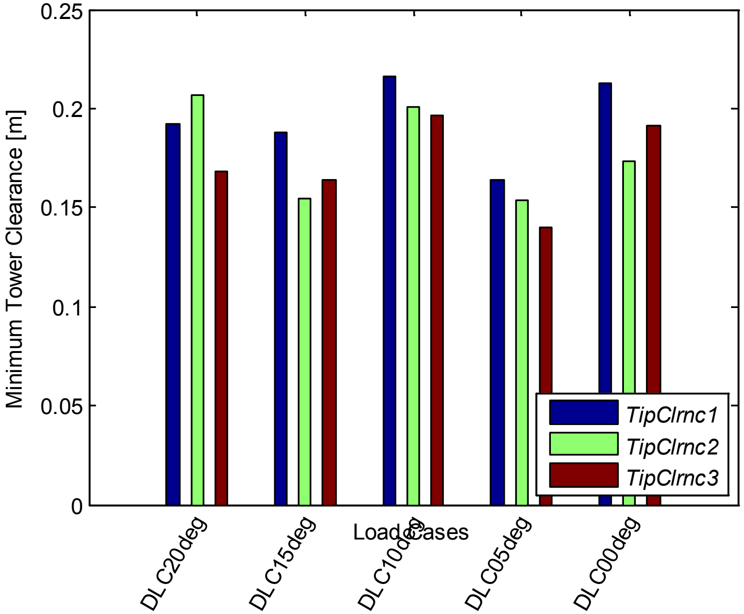
- **20 deg sweep doubles the twist at the blade tip**

Case Study- ULS from DLC 1.1



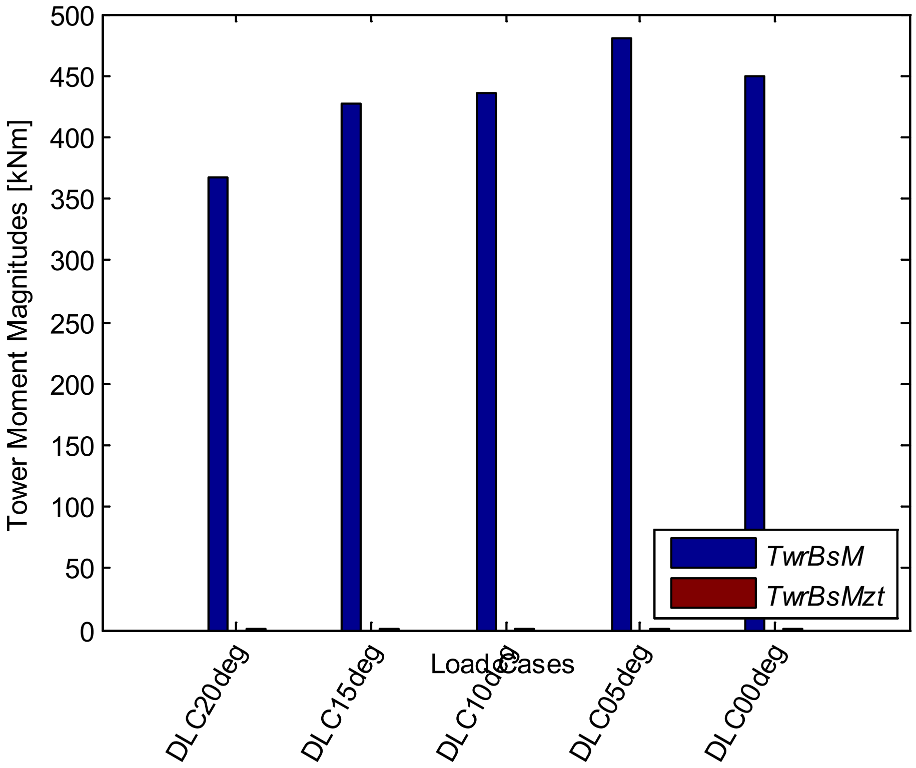
- Blade root bending moment
- 20 deg sweep mitigates UL load by some 15%
- 10 deg sweep increases UL load by some 15%.

Tower clearance almost unaffected



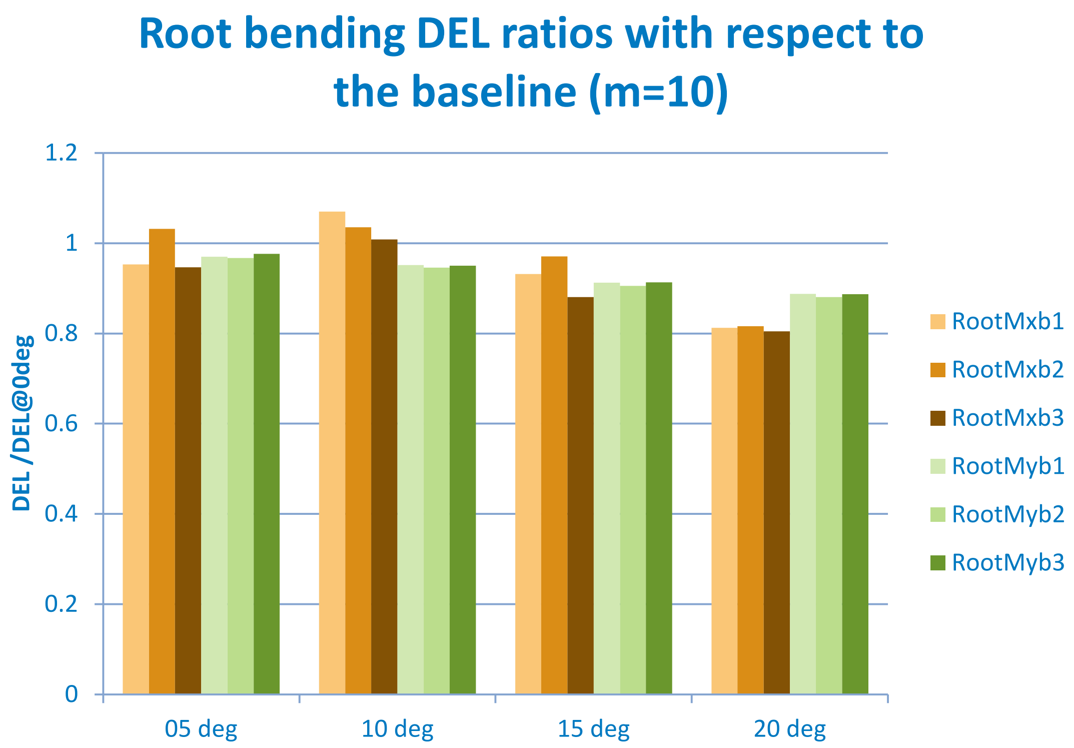
Case Study - ULS from DLC 1.1

- **Tower base bending moments**
- **Twenty degree sweep mitigates UL load by some 15%**
- **Five degree sweep increases UL load by some 10%.**



Case Study - FLS from DLC 1.1

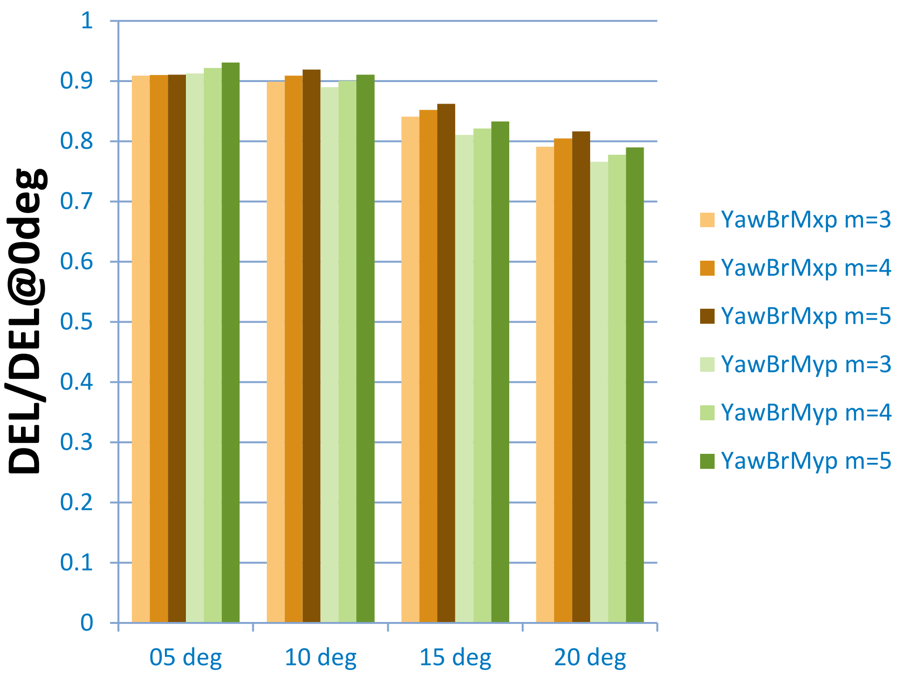
- **Blade root bending moments**
- **Twenty degree sweep mitigates damage equivalent loads (DELs) by some 15% (flap) to 20% (edge)**
- **Ten degreee sweep increases DELs by some 5% (edge).**



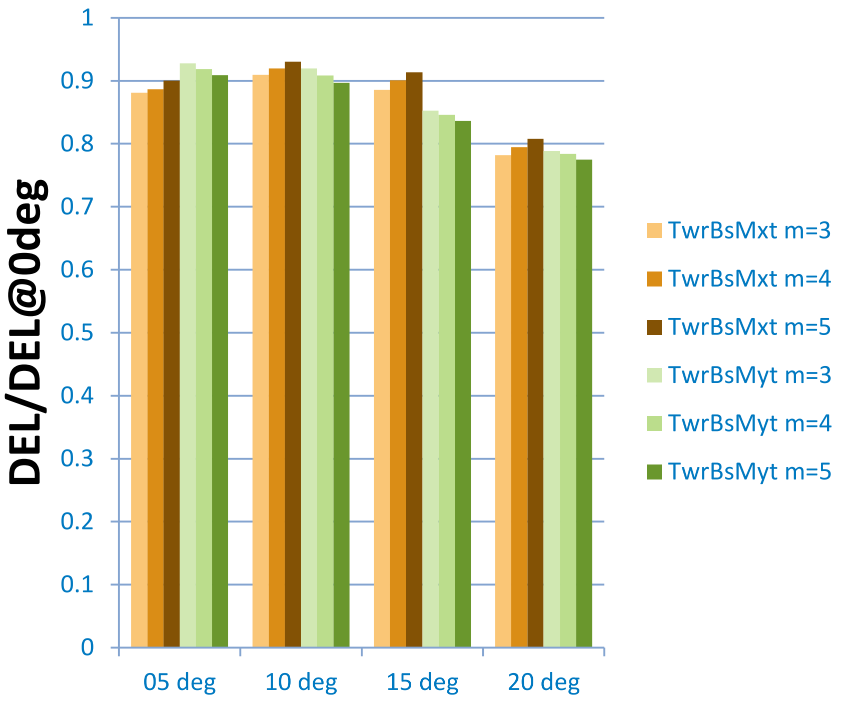
Case Study - FLS from DLC 1.1

- **Yaw-bearing bending moments DELs reduced (shaft life)**
- **Tower-base moments DELs reduced by some 20%**
- **Twenty degree sweep mitigates DELs by some 20%.**

Yaw-bearing DEL ratios with respect to the baseline



Tower-base DEL ratios with respect to the baseline



Conclusions

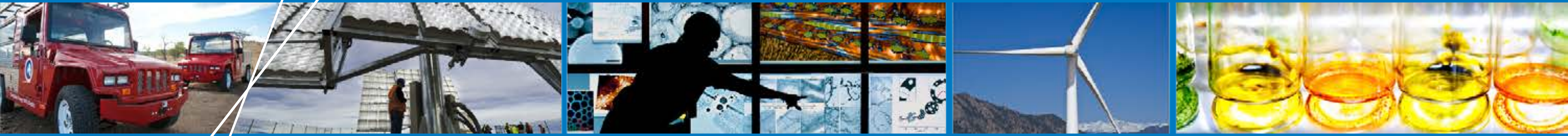
- A new ADAMS preprocessor is now available for FAST 7.02 which allows for higher fidelity representation of pre-sweep and bend of blades.

- A case study on a small wind turbine revealed the capabilities of simulating the effect of blade sweep using FAST2ADAMS
  - Results show promising effects in terms of load mitigation:
    - ULS decrease by 15% at 20 deg sweep (likely 10%–15%)
    - DELs decrease by 20% at 20 deg sweep (likely 15%–20%)
    - Little effect on power production (same rotor area)→ to be revised with new aeromarkers, possibly eliminating furling.

  - Use sweep to grow the rotors or thin the blades and reduce costs, but use caution in selecting amount of sweep, as some angles may create nonlinear effects on the dynamics of the machine and increase loads.

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

For More Information



Rick.Damiani@nrel.gov