Swept Blade Aero-Elastic Model for a Small Wind Turbine

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Outline

• Background on optimized/advanced rotors
• Numerical modeling tools
• Case study
• Summary of results
Need for Advanced Rotors

• Sweep introduces bend/twist coupling that can reduce loads at fixed rotor diameter size

OR

• Increase rotor diameter at same loading level

  • Reduce material
  • Optimize utilization

• Reduce the levelized cost of energy (LCOE)
• **MSC ADAMS – Multibody Dynamics:**
  - Commercial product
  - Can be coupled to Aerodym (FAST module) –
  - FAST has a translator to convert FAST input to ADAMS input
  - Highly customizable with user’s controller library (requires a bit of programming)
  - Highly flexible – virtually any horizontal axis wind turbines
  - High fidelity – as many degrees of freedom 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

- FAST input model of a small wind turbine converted to ADAMS model using FAST2ADAMS
- NREL Small Wind Research Turbine (SWRT) baseline
- Design load cases (DLCs): 1.1 from IEC 61400-2
  - Normal Turbulence Model
  - Wind Speed = 8–16 m/s
- Five configurations: baseline and 0, 5, 10, 15, and 20 degree sweep angles
- Study blade and tower moments
  - Maximum blade and tower loads (max in 10 minutes)
  - Blade tip clearance
  - Damage equivalent loads (fatigue) – blades and tower

Diagram:
- Pitch axis
- 70% radius
Blade configurations

baseline

5 deg

10 deg

15 deg

20 deg
Bending Moments

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

U: streamwise velocity  Nac Yaw: Nacelle Yaw
Bld OOP: blade root out-of-plane bending moment  Twr Pitch Mom: tower pitch moment
Power and Furling

• The mean power has not shown more than 5% variation across the numerous configurations

  Note: This finding needs to be revised as the aerodynamic model does not include cross-flow effects

• Furling impact on same order or greater than sweep impact

• Furling standard deviation slightly reduces with sweep
Maximum Blade Twist Angle from DLC 1.1

- Blade-tip twist

- 20 deg sweep doubles the twist at the blade tip
Maximum blade load and Tower Clearance Statistics from DLC 1.1

- Blade root bending moment
- 20 deg sweep mitigates maximum blade moment by ~15%
- 10 deg sweep increases maximum blade moment by ~15%

Tower clearance almost unaffected
Maximum tower Load from DLC 1.1

- Tower-base bending moments
- Twenty degree sweep mitigates max tower moment by ~15%
- Five degree sweep increases maximum tower moment by ~10%
Fatigue Load Statistics from DLC 1.1

- Blade root bending moments
- Twenty degree sweep mitigates damage equivalent loads (DELs) by ~15% (flap) to 20% (edge)
- Ten degree sweep increases DELs by ~5% (edge)
Case Study – Fatigue Load Statistics from DLC 1.1

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

**Yaw-bearing DEL ratios with respect to the baseline**

**Tower-base DEL ratios with respect to the baseline**
Conclusions

- Preliminary study – further investigation needed
- A new FAST2ADAMS preprocessor is now available for FAST 7.02 that allows for higher fidelity representation of presweep and bend of blades
- A case study on a small wind turbine revealed the capabilities of simulating the effect of blade sweep using ADAMS
  - Results show promising effects in terms of load mitigation:
    - Max. loads 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 improved aerodynamic modeling and possibly eliminating furling
  - Use sweep to reduce costs by
    - growing the rotor size and/or
    - thinning the blade structure
  - Use caution in selecting amount of sweep, as some angles may create nonlinear effects on the dynamics of the machine and increase loads