Optimized Active Aerodynamic Blade Control for Load Alleviation on Large Wind Turbines

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Problem Statement and Goal

- **With Wind Turbines Blades Getting Larger and Heavier, Can the Rotor Weight be Reduced by Adding Active Devices?**
- **Can Active Control be Used to Reduce Fatigue Loads?**
- **Can Energy Capture in Low Wind Conditions be Improved?**

Initial Research Goal:

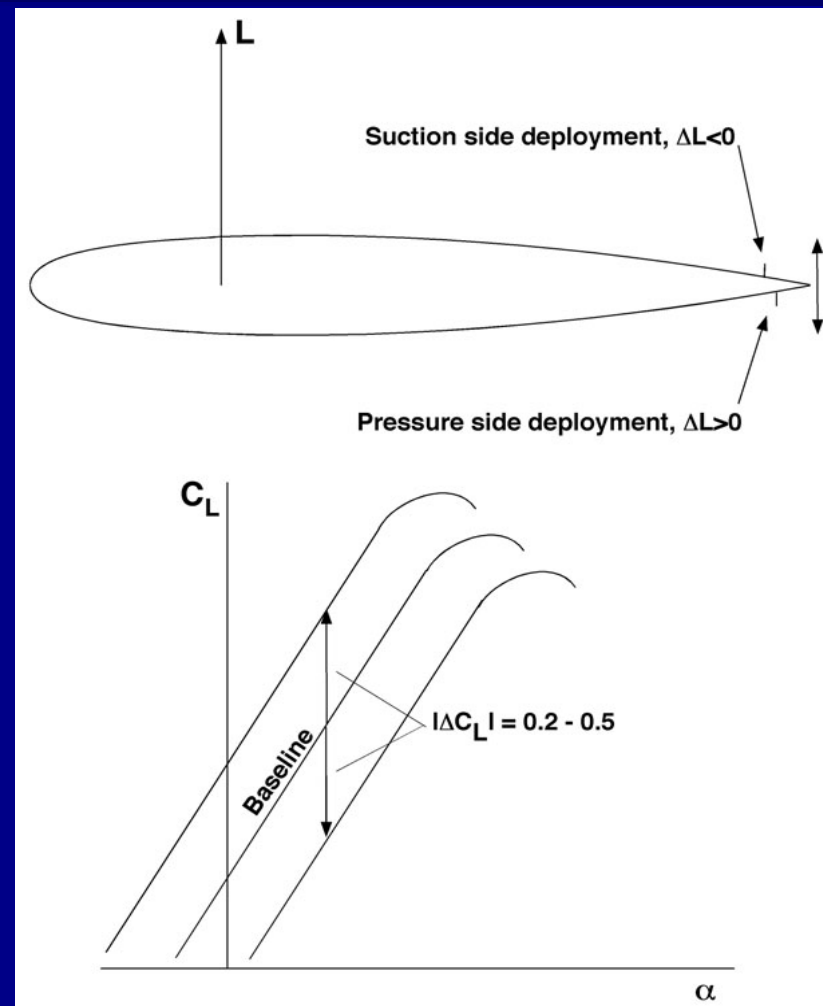
Understand the Implications and Benefits: Embedded Active Blade Control: Alleviate High Frequency Dynamics

Research Objectives

- Define the active aero control problem (critical path /drivers, analysis/simulation scenario, performance index: maximize energy capture, minimize root moment, other)
- Proof-of-concept (i.e., microtab control to reduce fatigue loads/cycling)
- Preliminary Technical Approach:
  - Optimization for tab on/off sequencing
  - Conventional feedback control for reducing load/fatigue in turbulent case
  - Dynamic stall flutter problem analysis w/ nonlinear power flow limit cycle control proof-of-concept

Microtab Concept Background

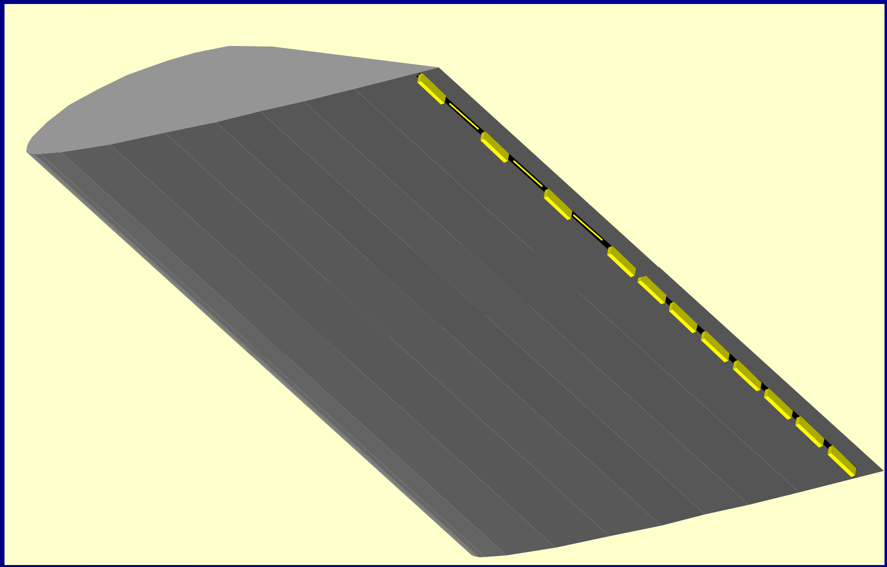
- Evolutionary Development of Gurney flap
- Tab Near Trailing Edge Deploys Normal to Surface
- Deployment Height on the Order of the Boundary Layer Thickness
- Effectively Changes Sectional Camber and Modifies Trailing Edge Flow Development (so-called Kutta condition)



Collaboration: Case van Dam at UC Davis

Microtab Concept

- Small, Simple, Fast Response
- Retractable and Controllable
- Lightweight, Inexpensive
- Two-Position "ON-OFF" Actuation (option)
- Low Power Consumption
- No Hinge Moments
- Expansion Possibilities (scalability)
- Do Not Require Significant Changes to Conventional Lifting Surface Design (i.e., manufacturing or materials)



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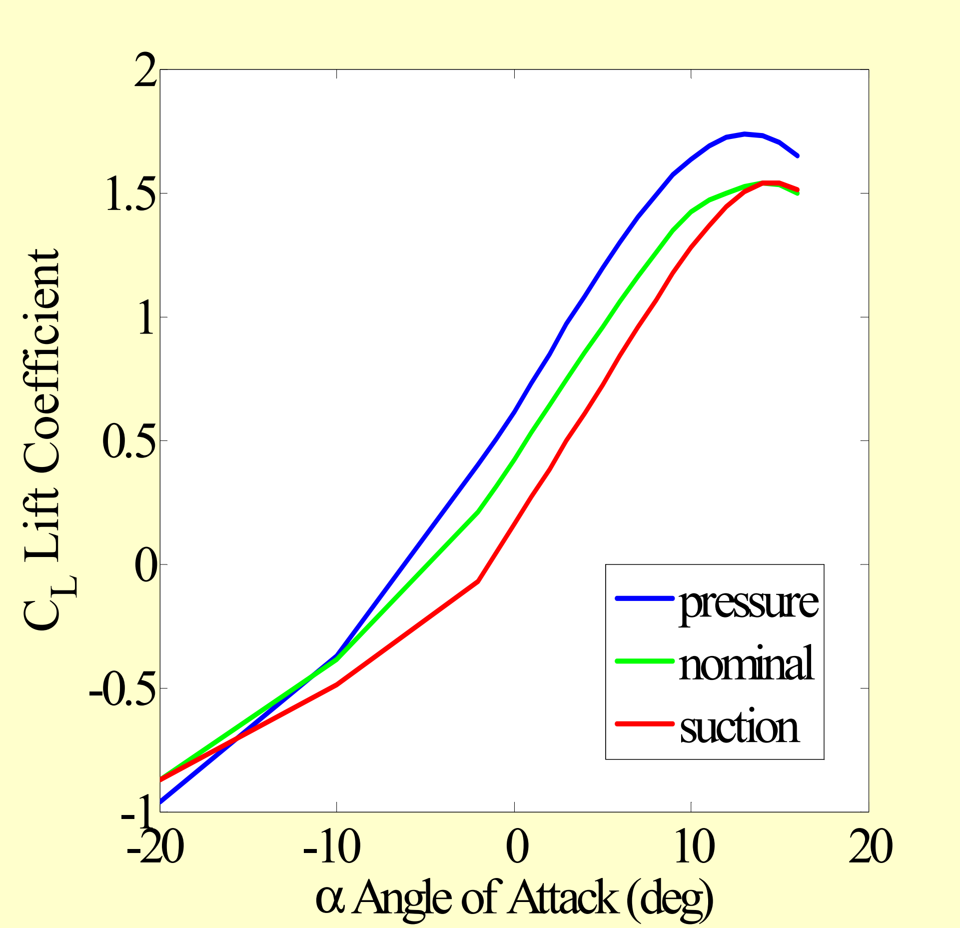
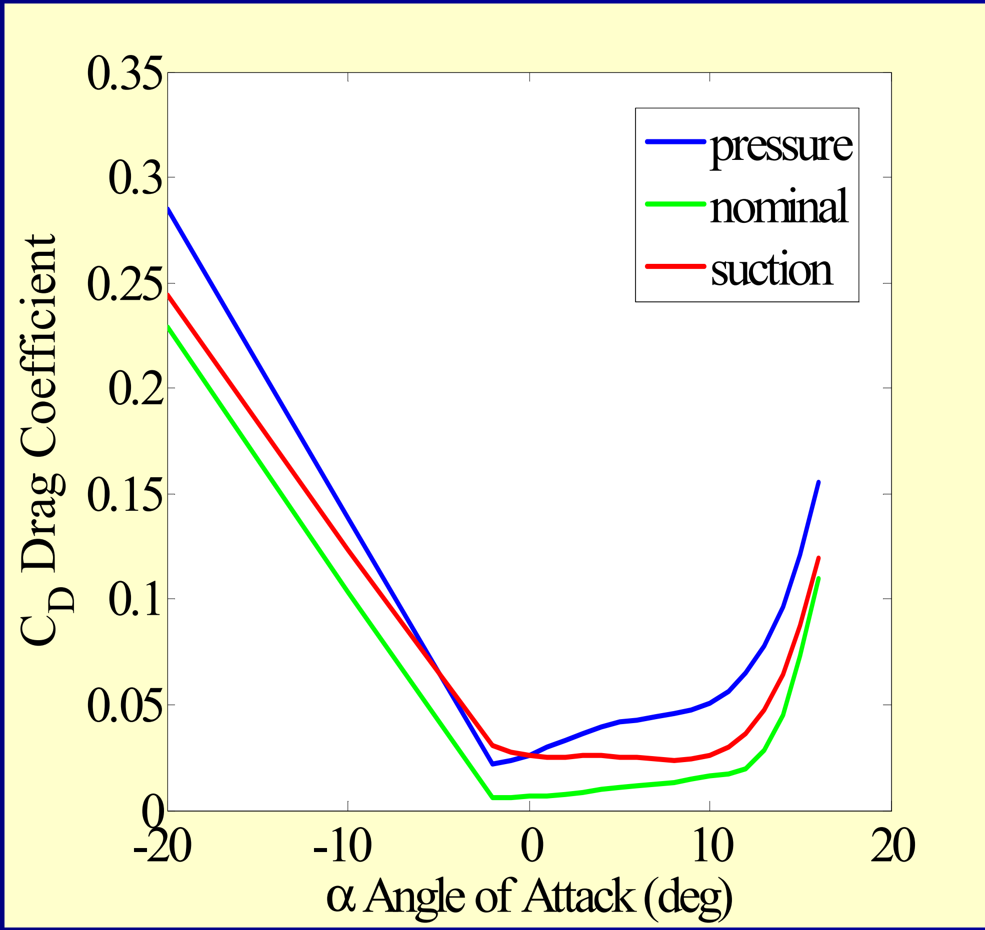
Case van Dam
UC Davis

MicroTab Profiles AeroDyn Inputs



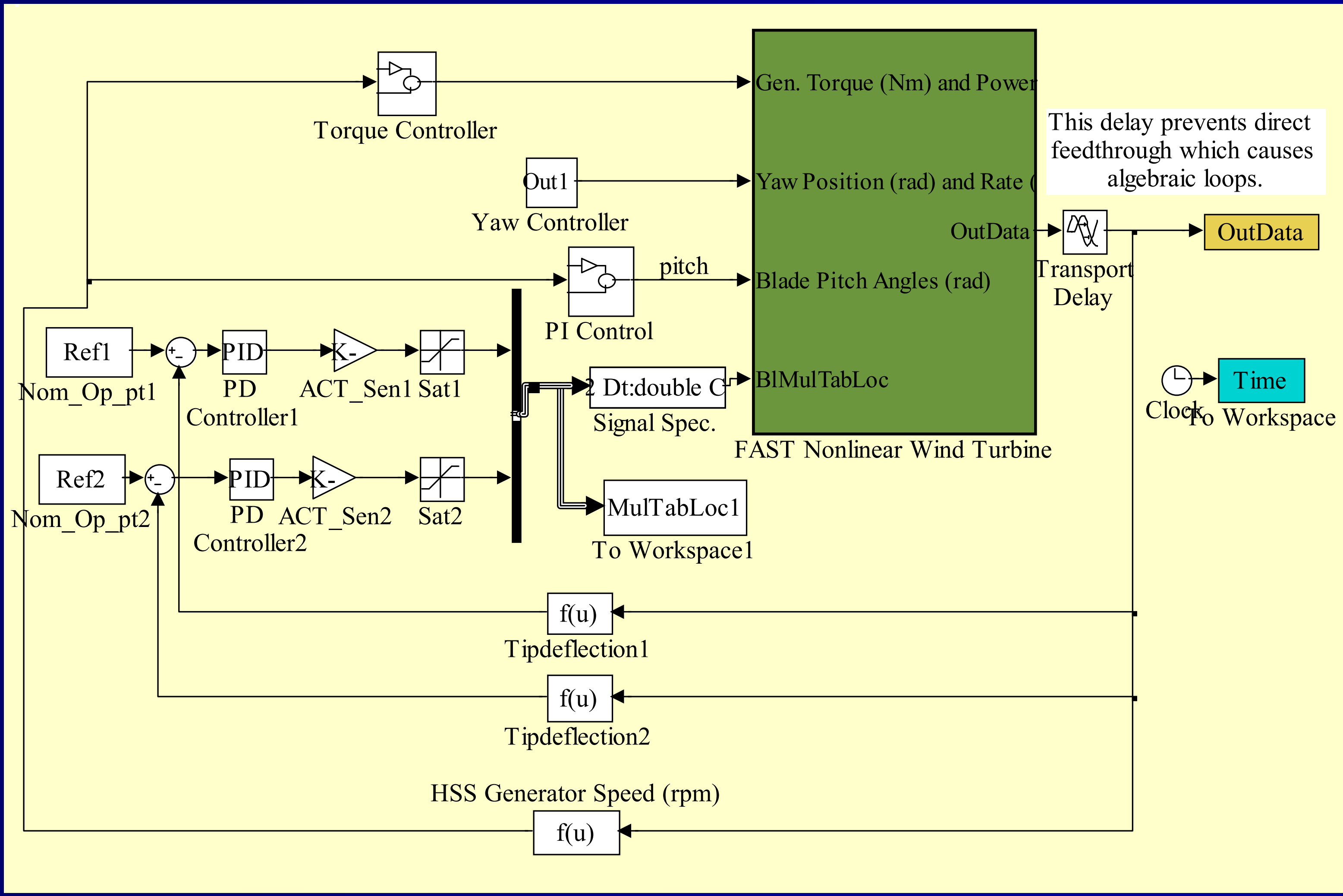


Modified Control System Design

- **Hybrid Controller:** Proportional-Integral (PI) Blade Pitch Control with Proportional-Derivative (PD) Microtab Control for above rated wind speed conditions, Region III
- **Microtab PD Control:** Uses tip deflection feedback and nominal reference tip deflection as set point
- **Optimize** controller gains based on Performance Index for constant power output while minimize cyclic loads (root flapwise bending moment) in Region III

System Modeling and Analysis Augmented w/ Microtab Control

Dynamic Simulation Environment: FAST (Fatigue, Aero-dynamics, Structures, and Turbulence) run within Matlab/ Simulink



CART Model Investigated

Controls Advanced Research Turbine (CART): utilized as simulation testbed with 600kW rated power @ 42 RPM

Turbulence: Loading/Vibrational Energy Impact on Rotor Blades [1]

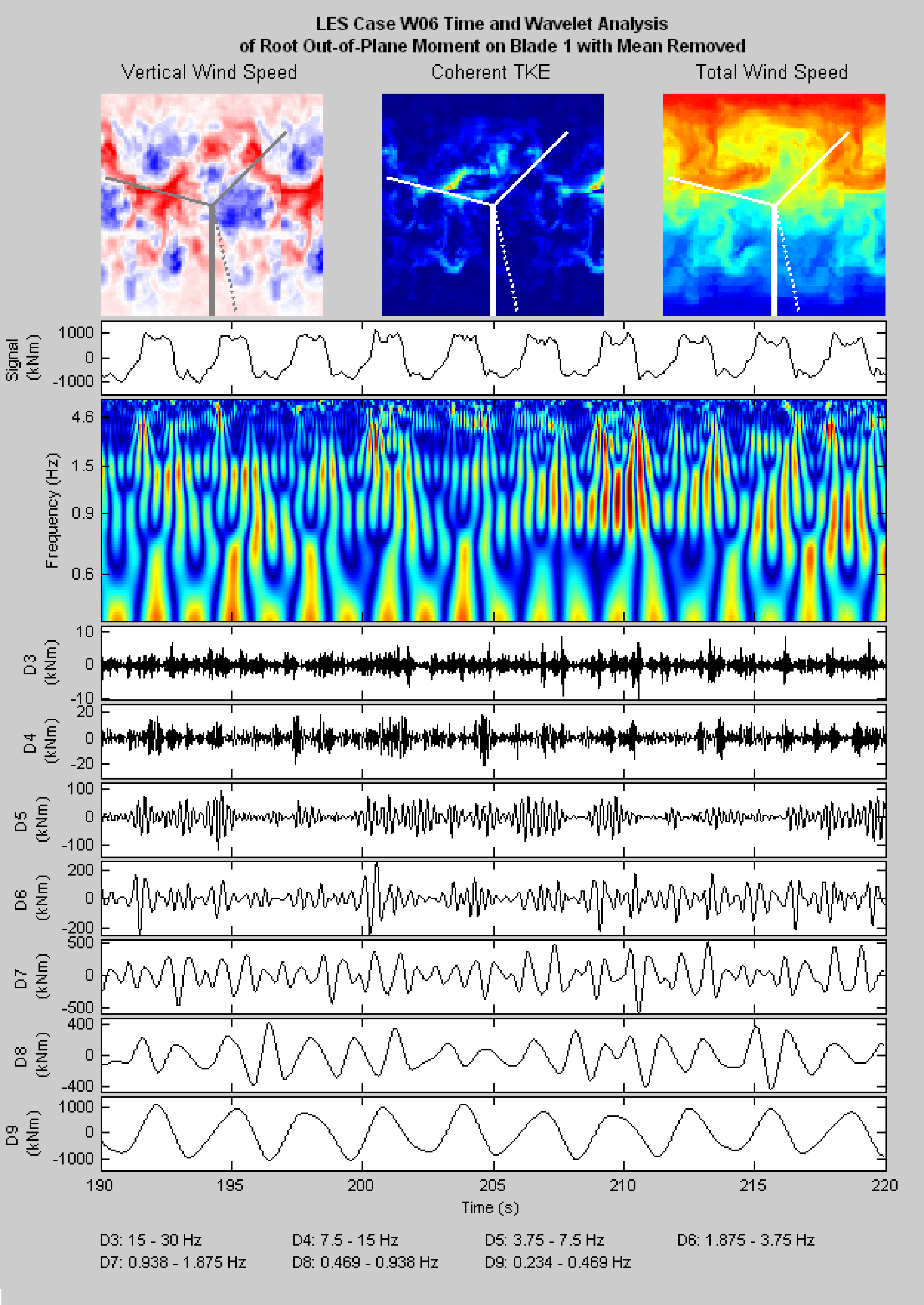
WindPACT Virtual Turbine Calculated Static System Frequencies [2]

Wavelet Detail Band	Frequency Range (Hz)	Vibrational Modes Characteristics
D9	0.234 – 0.469	1-P, Tower bending
D8	0.469-0.938	2-P
D7	0.938-1.875	Blade 1st bending
D6	1.875 – 3.75	Blade 2nd bending
D5	3.75 – 7.5	Blade, blade/tower
D4	7.5 – 15	Blade, blade/tower
D3	15 – 30	Blade, blade/tower

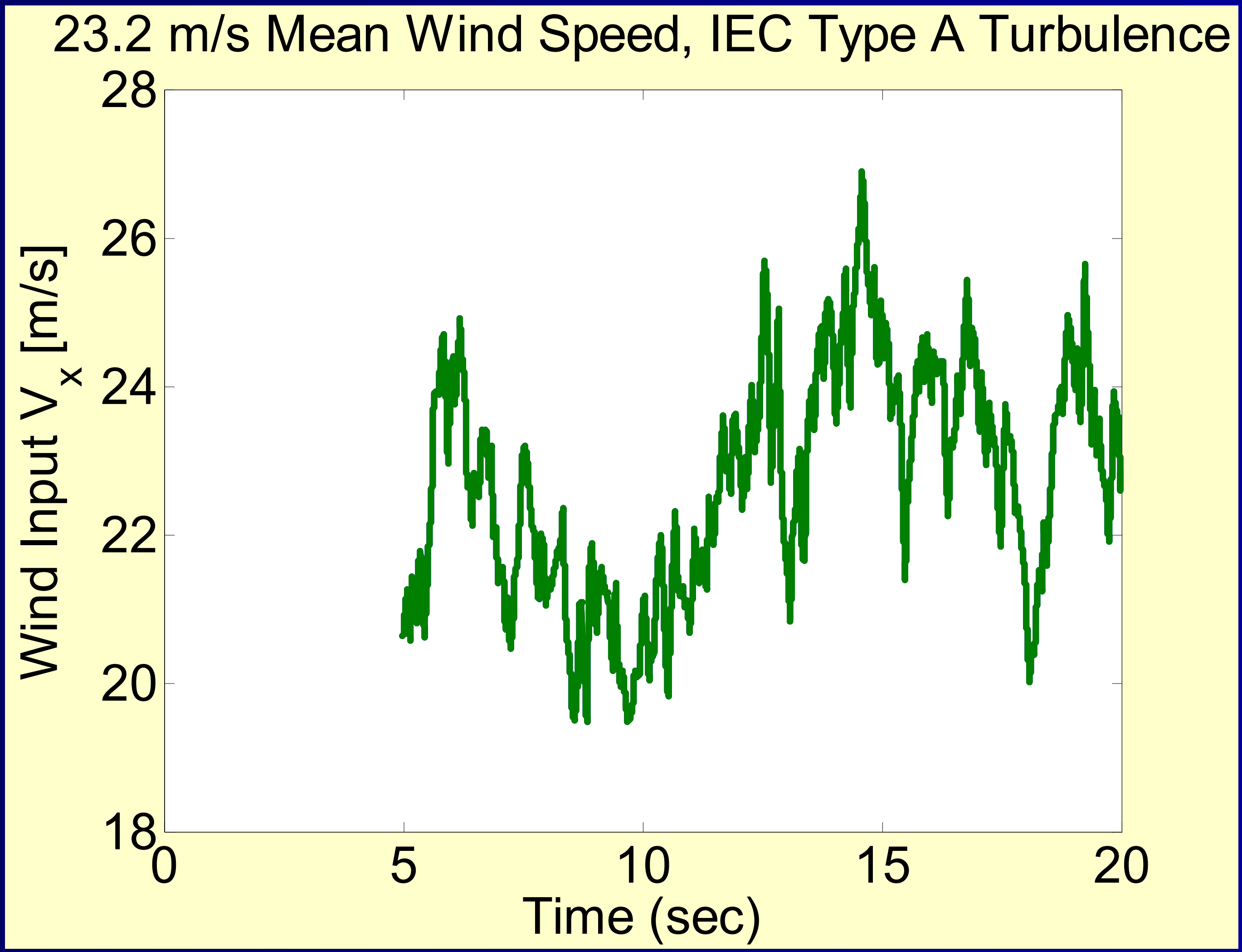
[1] N.D. Kelley, et. al., The Impact of Coherent Turbulence on Wind Turbine Aeroelastic Response and Its Simulation, WindPower 2005 Conf., NREL/CP-500-38074, August 2005
[2] Jonkman, J.; Cotrell, J. (2003). *Demonstration of the Ability of RCAS to Model Wind Turbines*. National Renewable Energy Laboratory. Golden, CO. NREL/TP-500-34632. 59 pp

Turbulent Intensity [1]

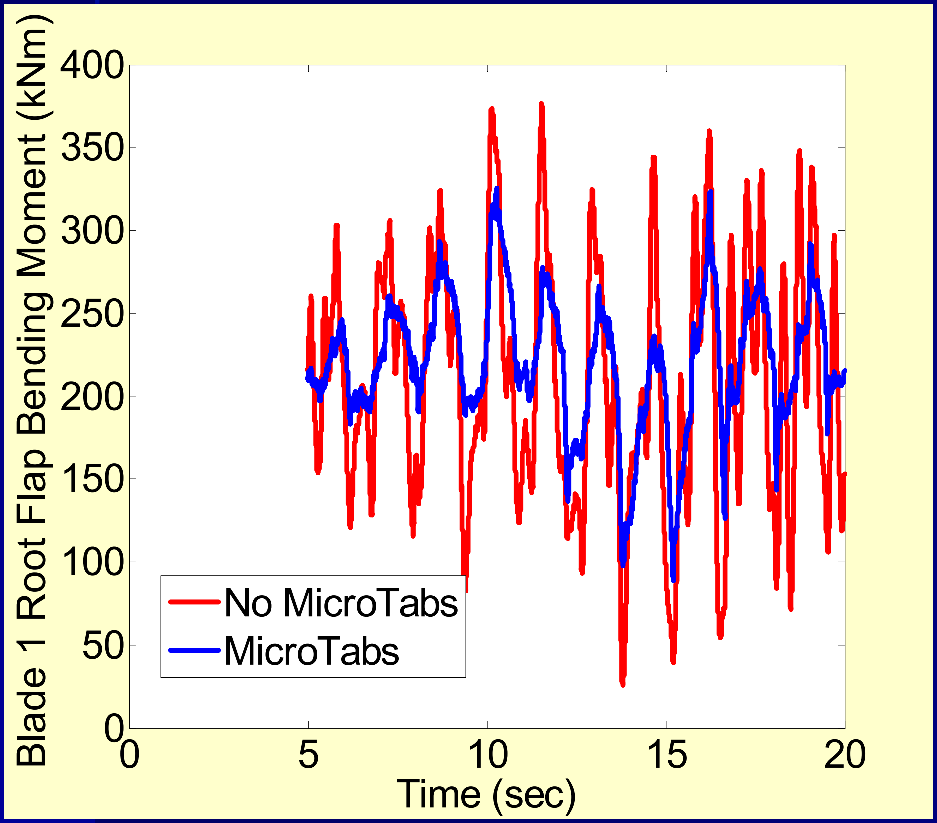
- Derived from model: virtual variable-speed 1.5-MW, 3-bladed upwind turbine: 85-m hub height, 70.5-m rotor DIA. Examine time-varying turbulence/loading response
- Root Flapwise Bending Loads, Band D6-D7
- Time-frequency spectral decomposition of root flapwise load encountering coherent turbulent structure
- Red color signifies occurrence: highest level of dynamic stress energy - dark blue least
- While peak amplitudes of load time histories in Bands D6 - D7 decreases, number of stress reversals increase as rotor passes through coherent turbulent structures
- Due to nature of load application and existence small values of structural damping – potential significant transient storage of vibrational energy that must be dissipated
- Potential modal dynamic amplification may exist, could contribute to lower than designed component service lifetimes
- **Microtabs good candidate to reduce high frequency dynamics and fatigue loads**

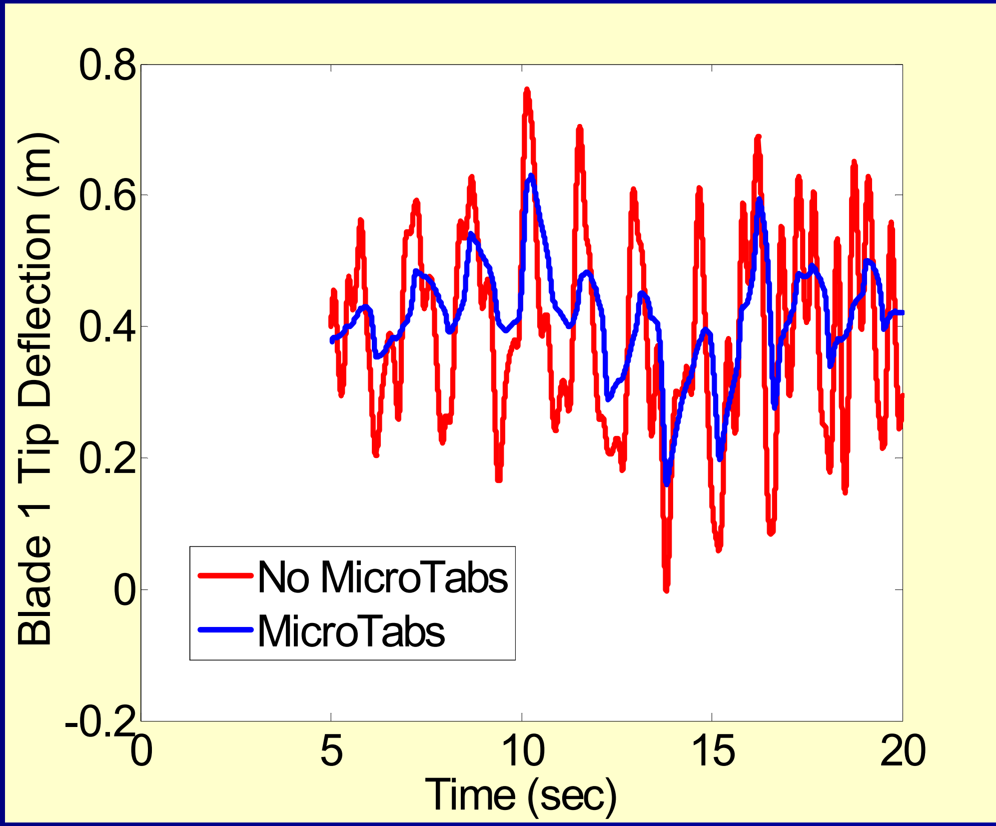


Turbulent Wind Input (Specific Case Explored)



Time Domain - FAST/Simulink Simulation Results





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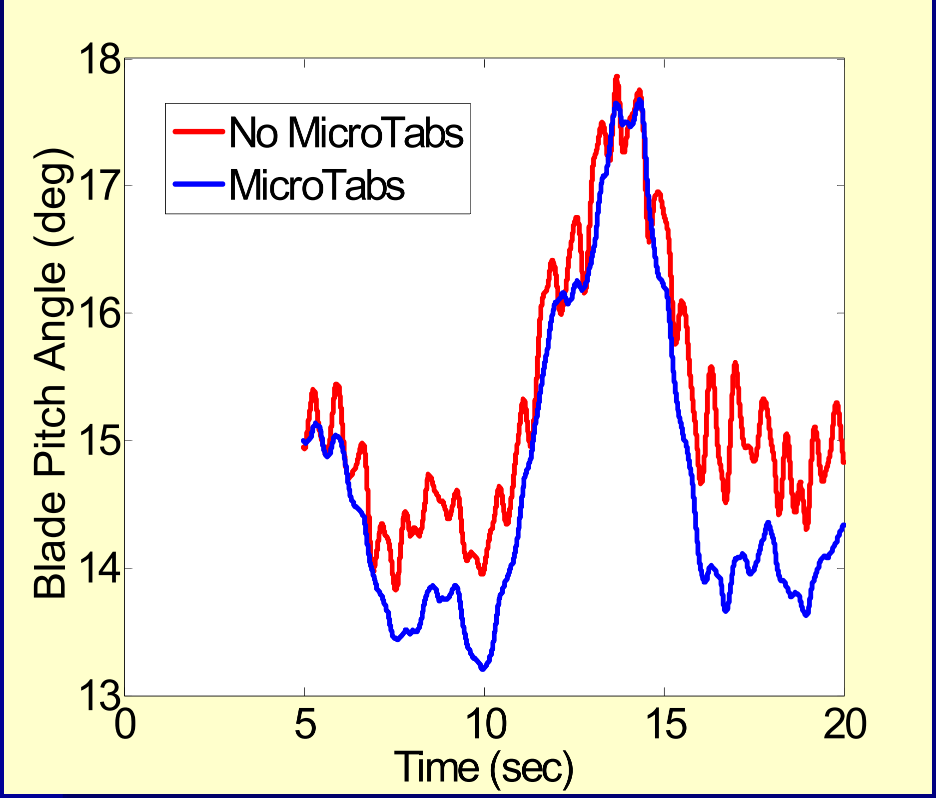

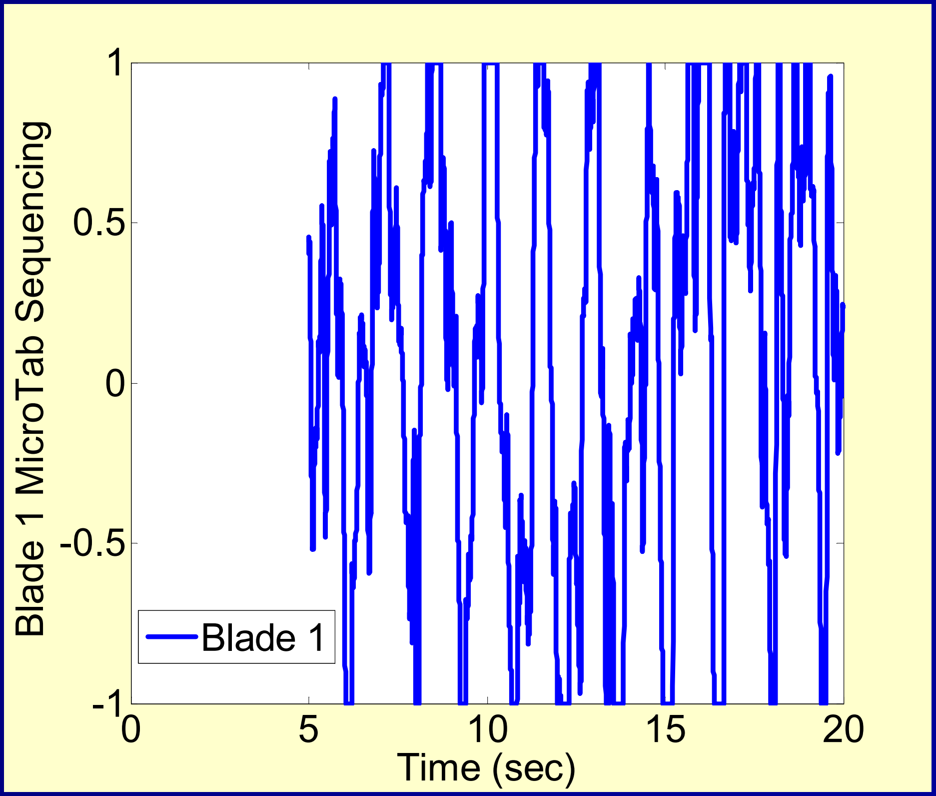

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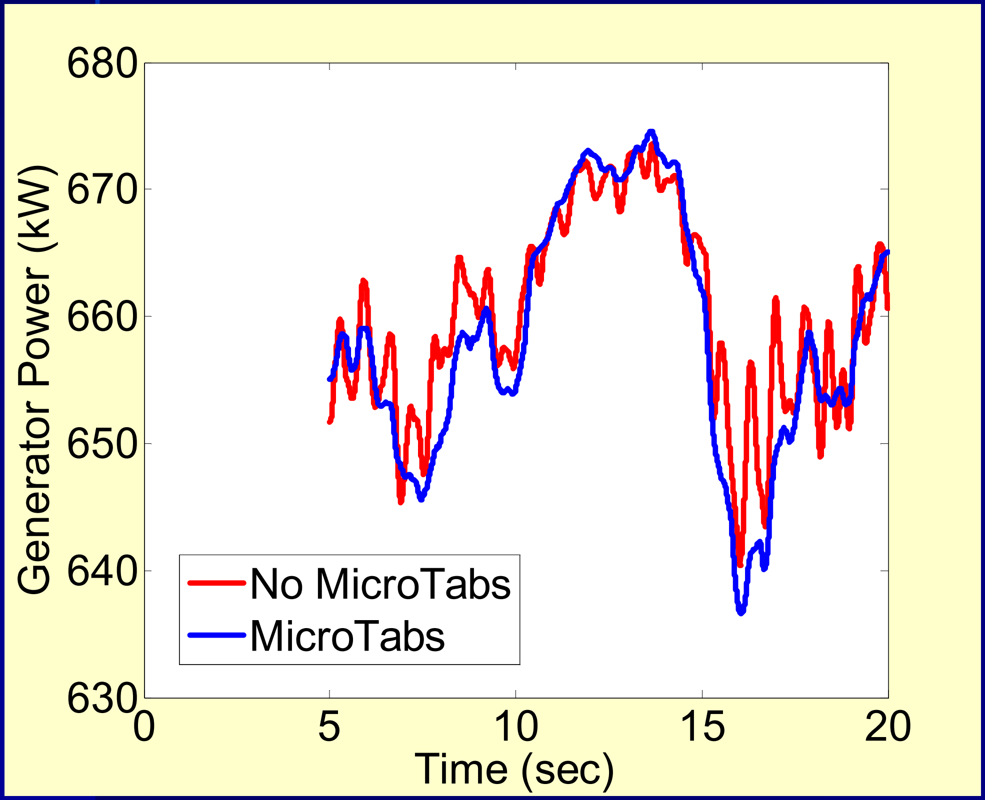

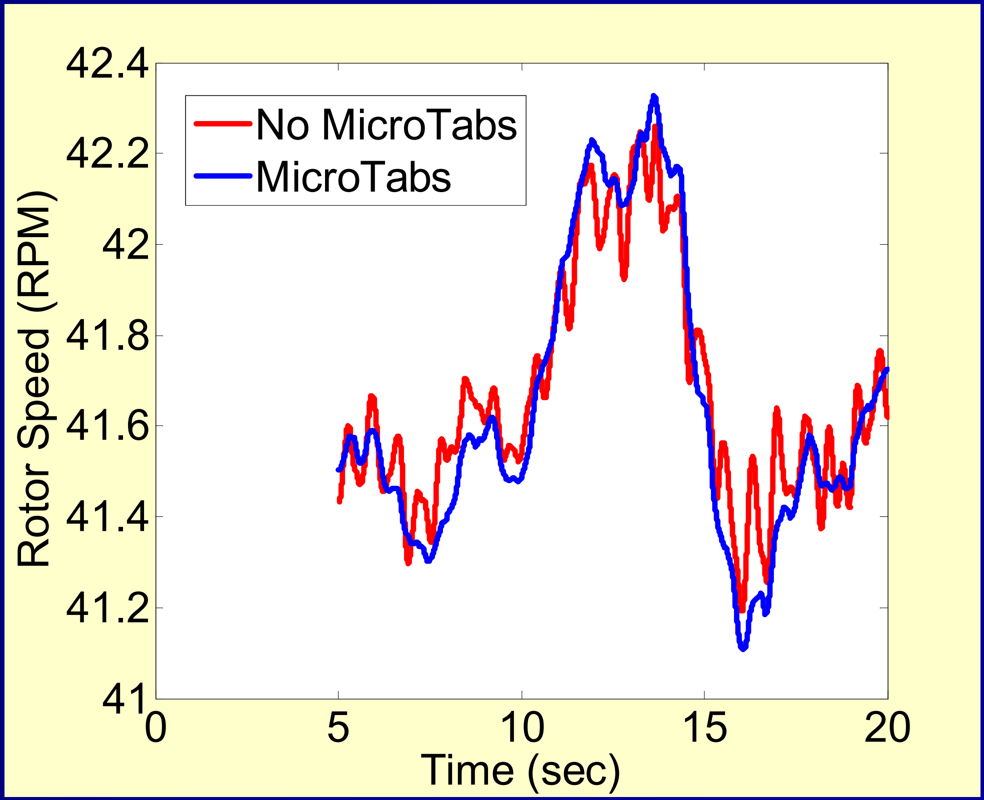

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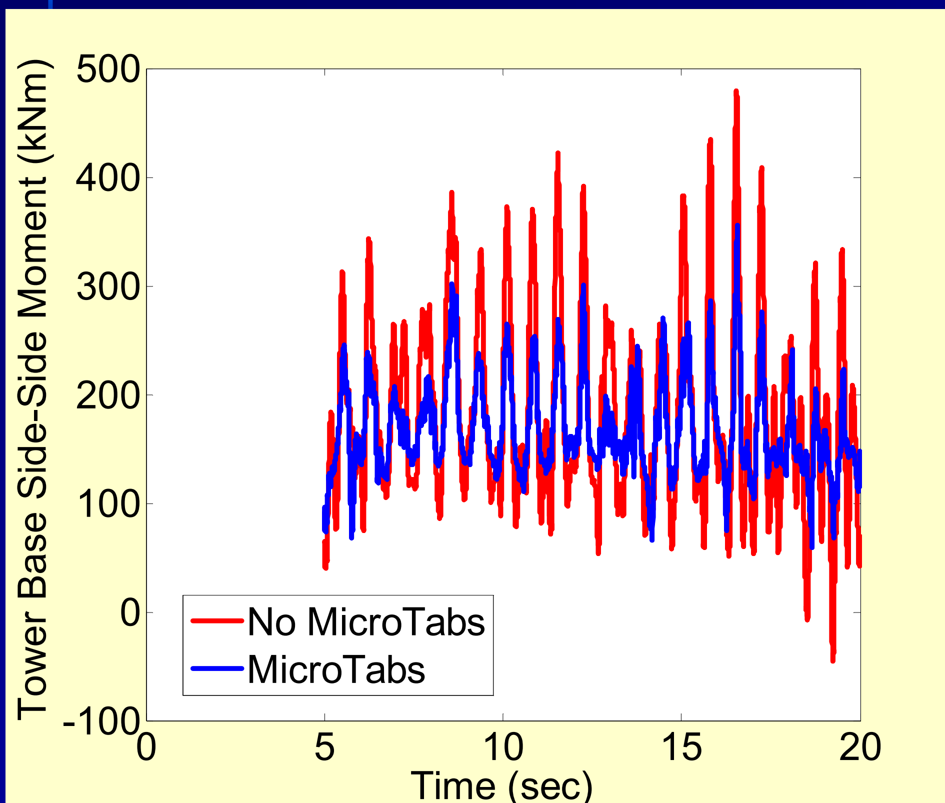
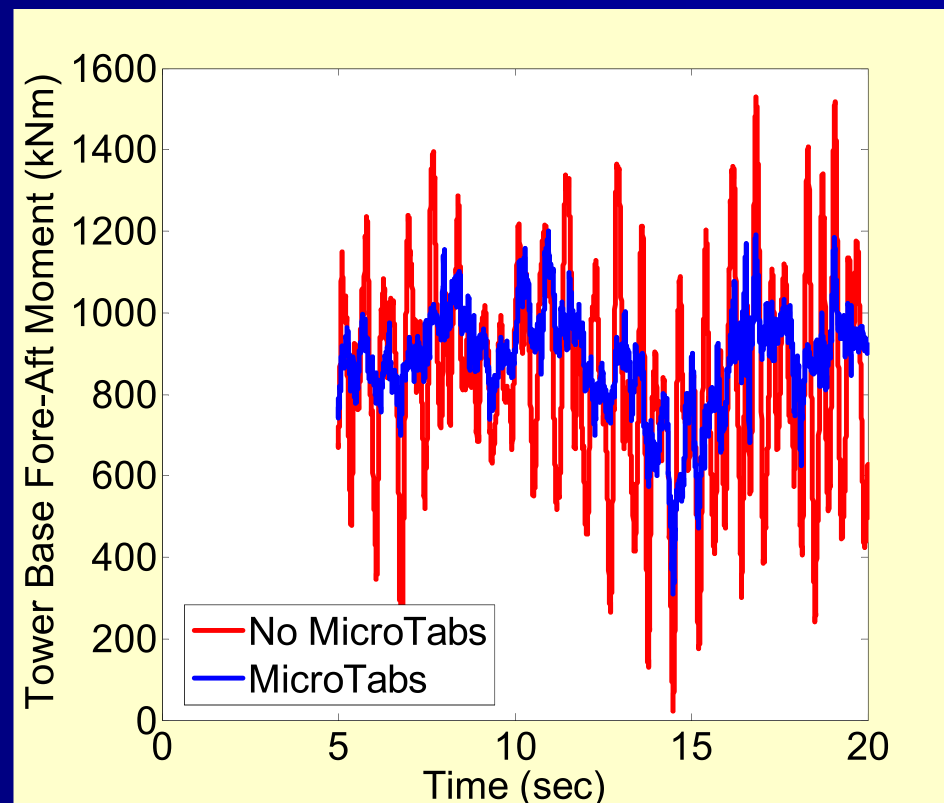
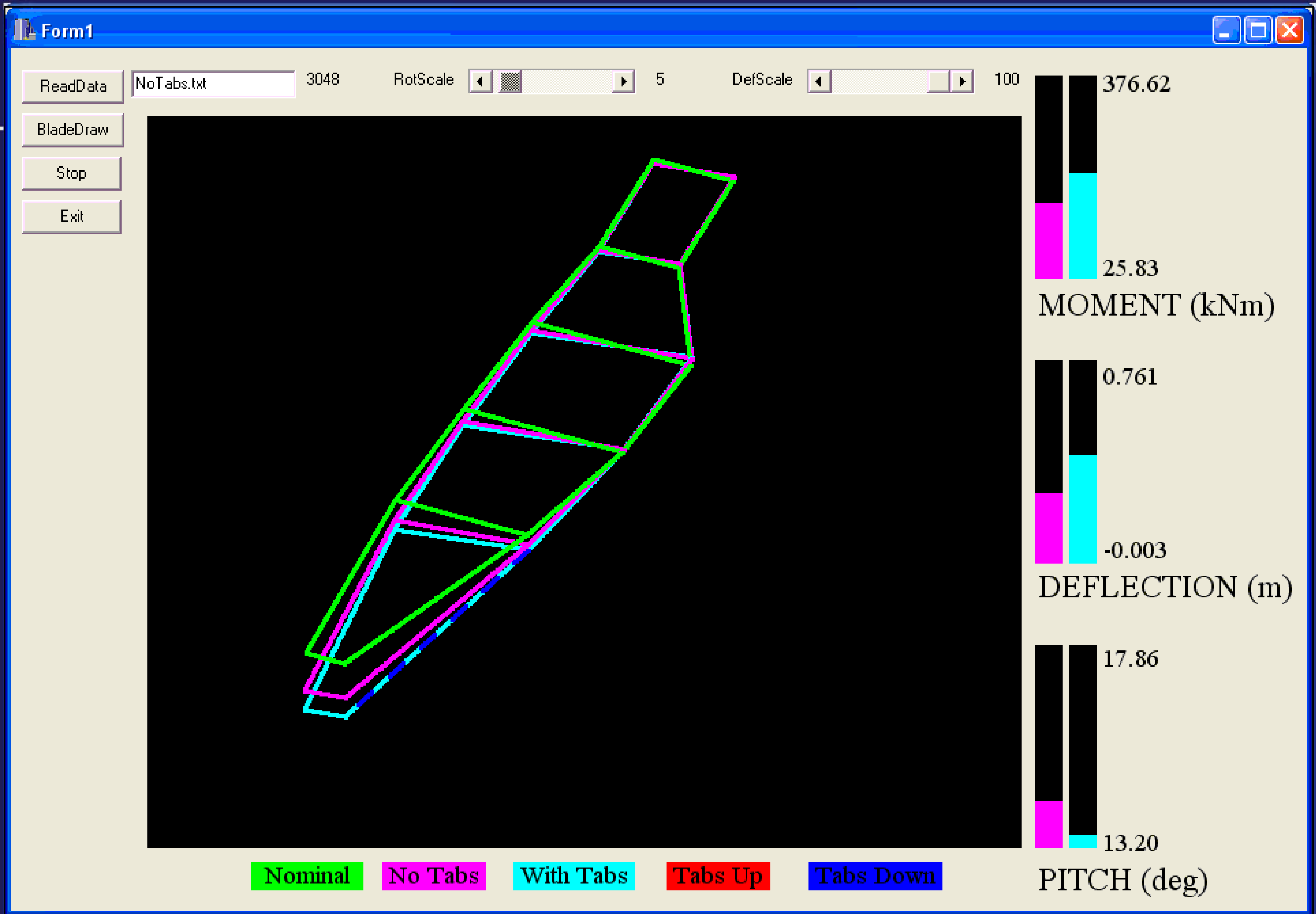




Visualization: MicroTab Control

(Click on image below to play video)



Observations - Summary

- Potential Benefits to Designer:
  - Increase Effective Rotor Size
  - Extend Potential Life Expectancy and Reliability
  - Ultimately Reduce Cost-Of-Energy of Future Large Wind Turbine Machines
- Active Aero Devices may Provide Substantial Benefit for Future Wind Turbine Designs

Future Control Design: Reduce Load/Fatigue: Increase Energy Capture

- Lightweight adaptive blade design with embedded sensors and actuators utilizing integrated hybrid pitch/distributed flap control system
- Combined blade pitch/flap control system: reduced loading above rated speed (may increase energy capture below rated speed)
- Nonlinear flutter control system based on nonlinear power flow design: identifies stability boundary, improved performance by promoting lightweight/high strength blade design
- Smart structures technology to be investigated to facilitate implementation of smart blade concept