Active Control Devices for Wind Turbine Blades

2006 Sandia Blade Workshop

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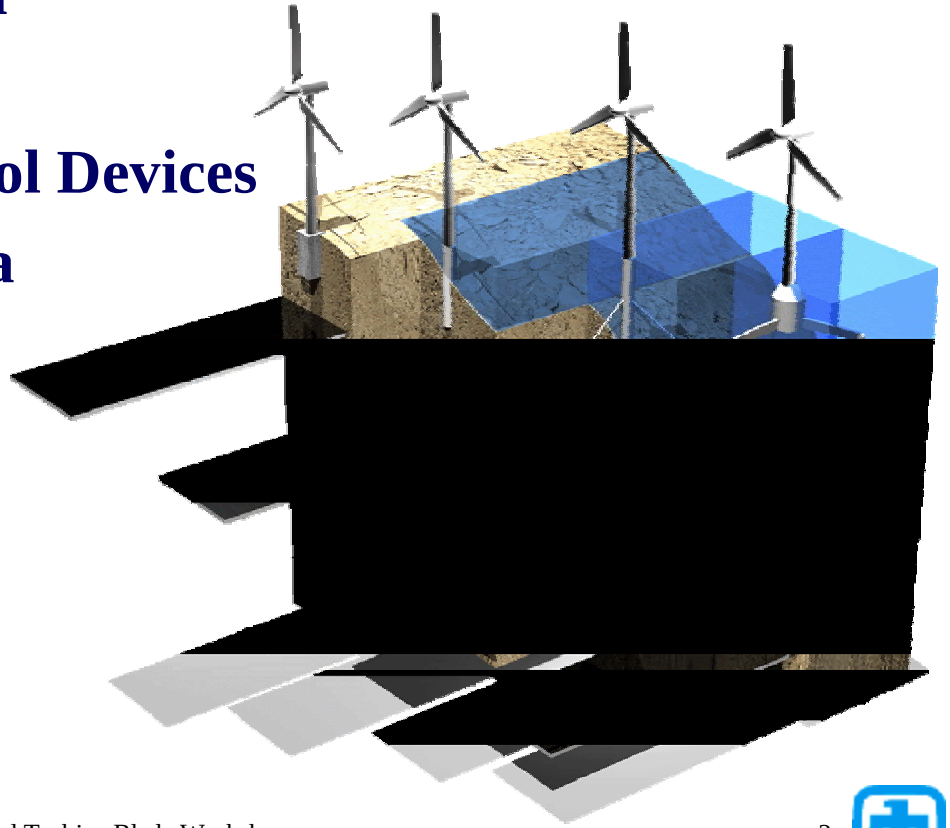
- Problem Statement and Goal
- Active Control Background
- Understanding Active Control Devices
- Wind Turbine Blade Criteria
- Potential Offshore Benefits
- Microtab Example
- Modeling
- Future Work
- Conclusion



Problem Statement & Goal

As Wind Turbines Blades Continue to get Larger and Heavier, Can the Rotor Weight be Reduced by Adding Active Devices?

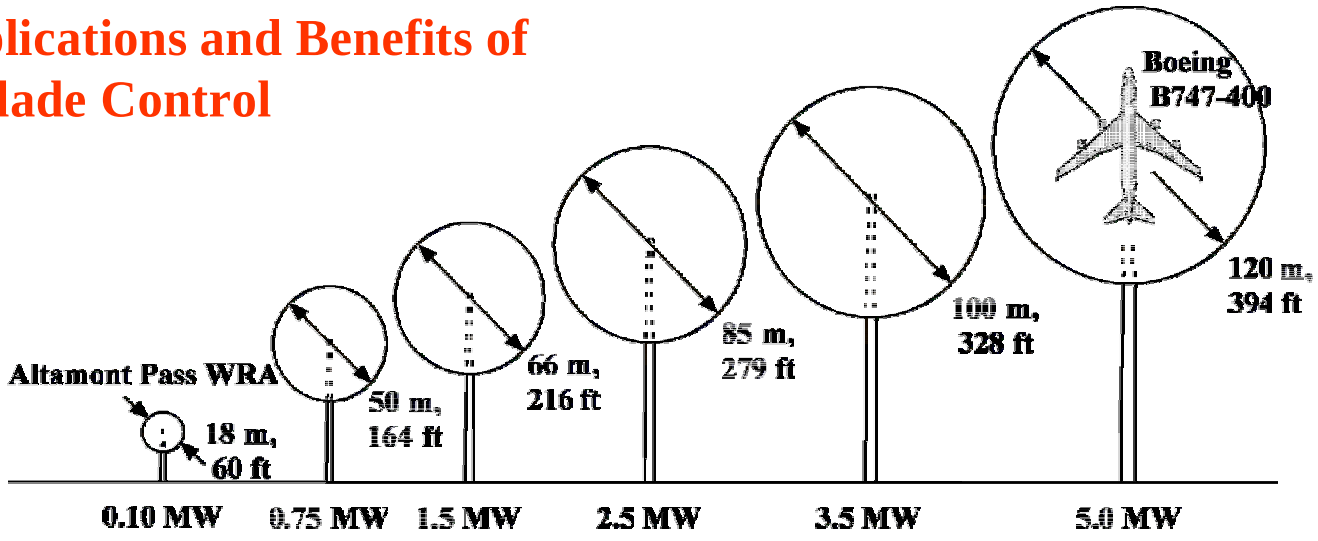
Can Active Control be Used to Reduce Fatigue Loads?

Can Energy Capture in Low Wind Conditions be Improved?

Can Offshore O&M Cost be Reduced?

Research Goal:

Understand the Implications and Benefits of Embedded Active Blade Control



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Active Flow/Load Control

- **Blade Load Variations Due to Wind Gusts, Direction Changes, and Large Scale Turbulence**
- **Active Load Control on Blade/Turbine can be Achieved by Modifying:**
  - **Blade incidence angle (pitch)**
  - **Flow velocity (modification in RPM)**

  } **Current Technology - VSVP**
  Variable Speed Variable Pitch

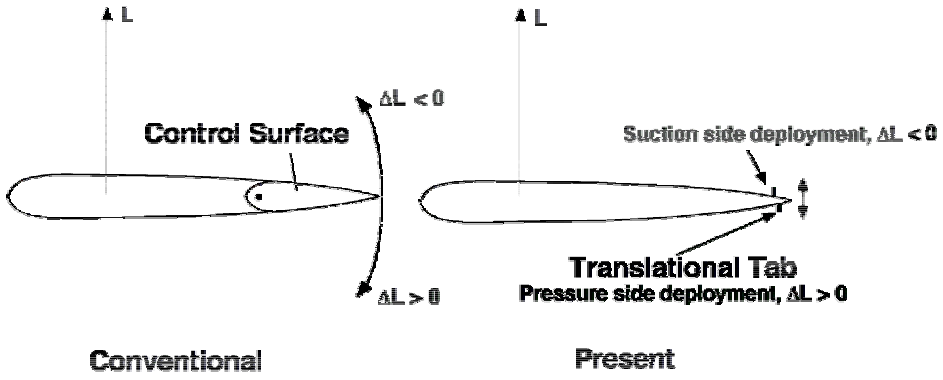
  - **Blade length**
  - **Blade aerodynamic characteristics through:**
    - **Changes in section shape (aileron, smart materials, microtab)**
    - **Surface blowing/suction**
    - **Other flow control techniques (VG's, surface heating, plasma)**

Active Flow/Load Control

- **Active Load Control:**
  - **May remove fundamental design constraints for large benefits**
  - **May allow for lighter more slender blades designs**
  - **Could potentially be used in conjunction with VSVP control, to alleviate high frequency loads**

These Large Benefits are Feasible if Active Control Technology is Considered from the Beginning

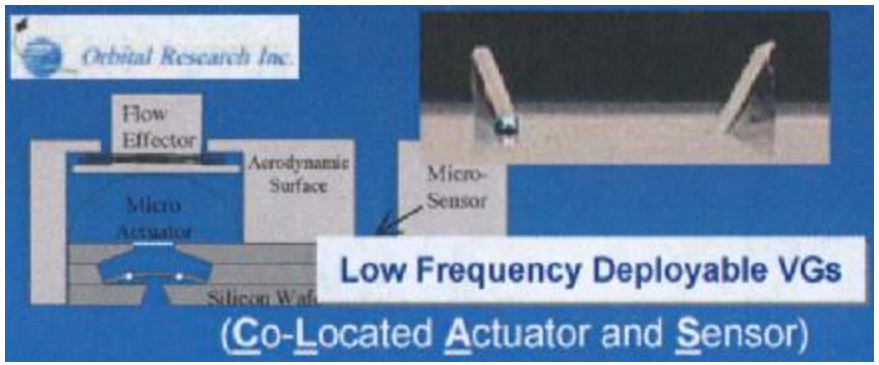
Examples of Active Flow/Load Control



Microtab Concepts

Courtesy: NREL

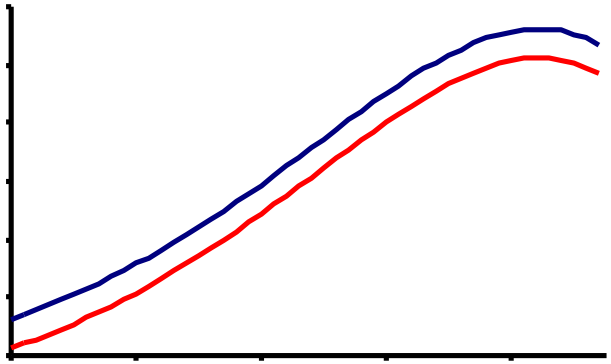
Active Aileron on a Zond 750 Blade



Active Vortex Generators

Adaptive Airfoils

Aerodynamic Effect of Active Control



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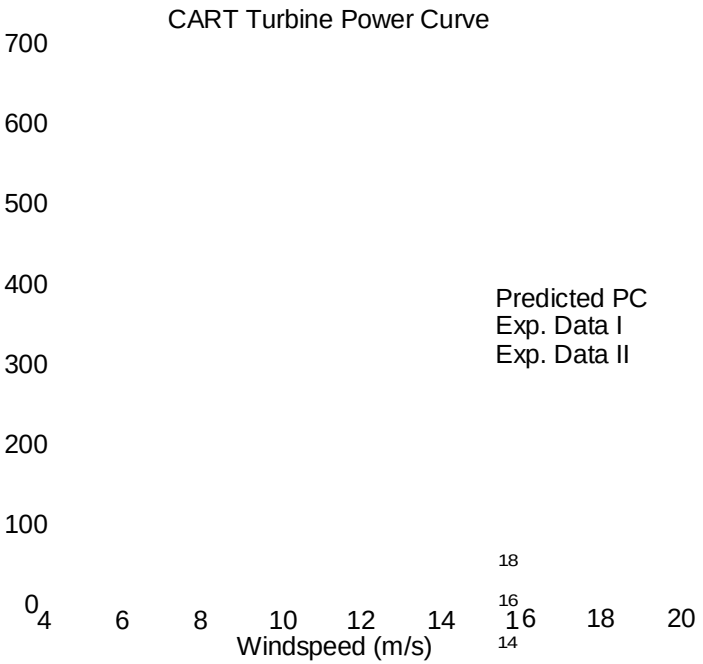
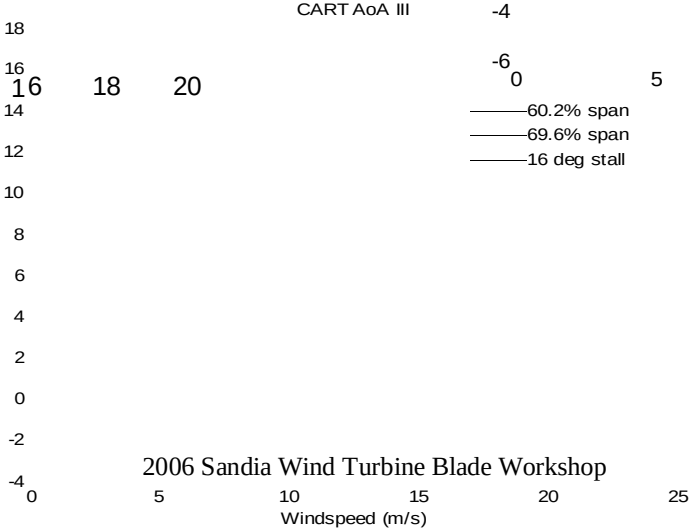
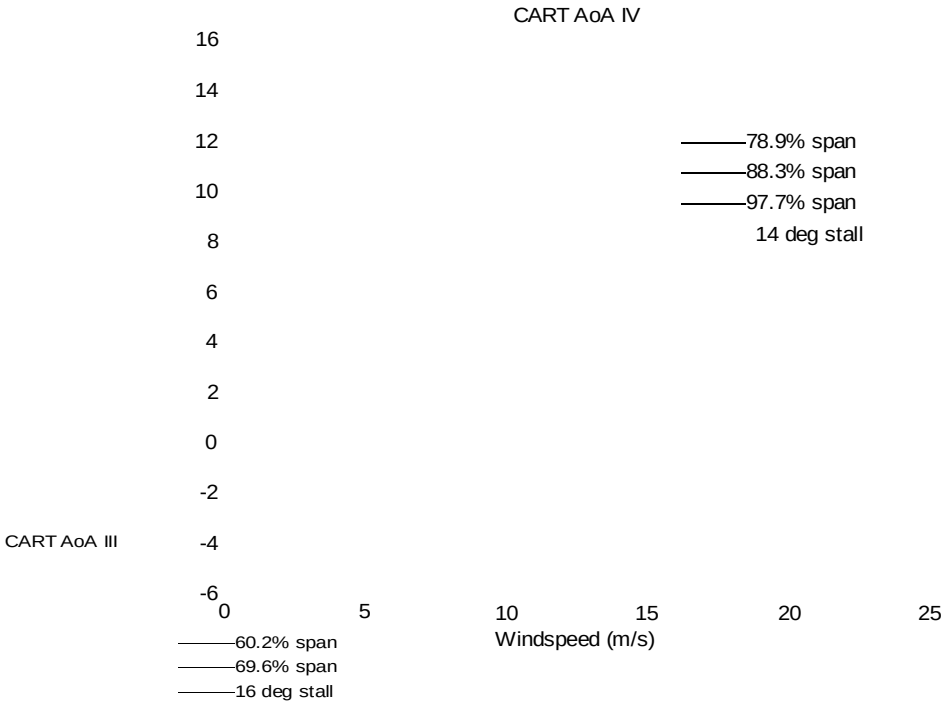
Plasma
Active VG's
Surface Blowing/Suction
Surface Heating
Synthetic Jets

Flaps
Ailerons
Spoilers
Microtabs
Airfoil Morphing

Sectional AoA –vs- Wind Speed







Data for NREL CART Turbine

Switch to Variable Pitch

Ranking Criteria for Active Devices

Factors to Consider

Cost
- **Materials**
- **Repair or replace**
- **Manufacturing**
- **Installation**

Life Expectancy of the Device

Weight

Actuation

Sub-Factors

Complexity

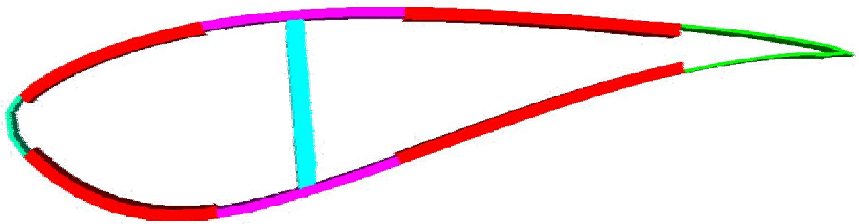
Manufacturability

Maintainability

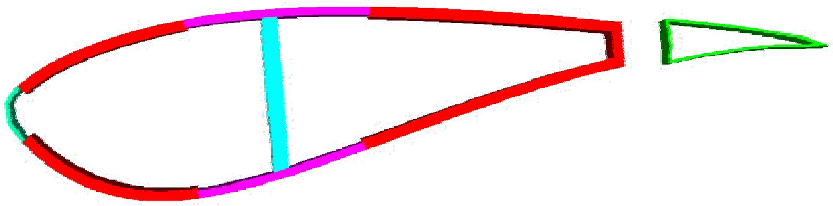
Noise

Environmental Effects (Ice & Dust)

Performance



Traditional Design

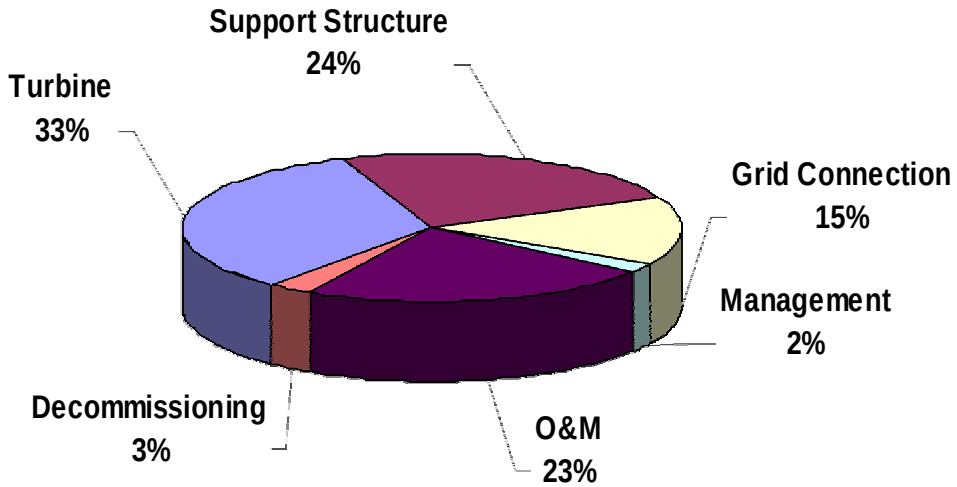


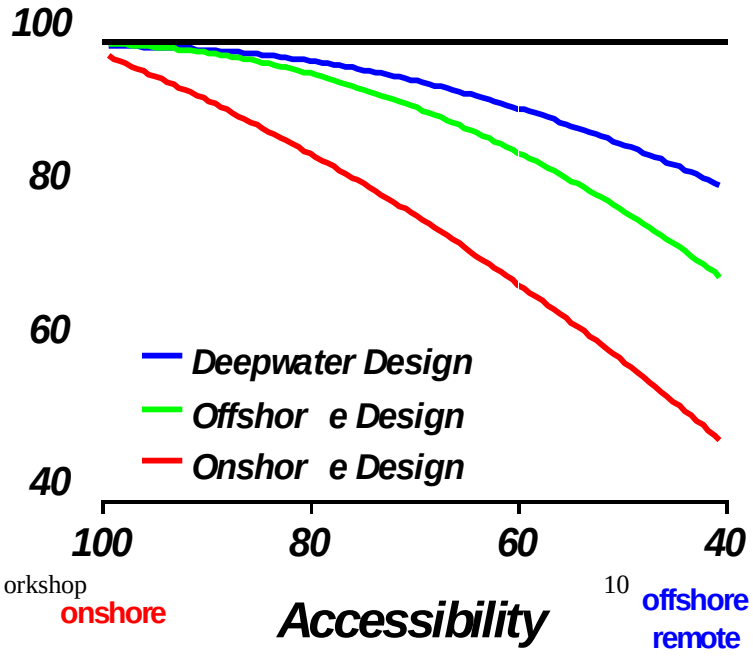
Potential Future Design

Active Control for Offshore

Can Offshore O&M Cost be Reduced?

- Active devices could be used to lower the fatigue loads
- Potentially less noise constraints
- Coupled with smart bi-modal control algorithms, could allow for less frequent visits





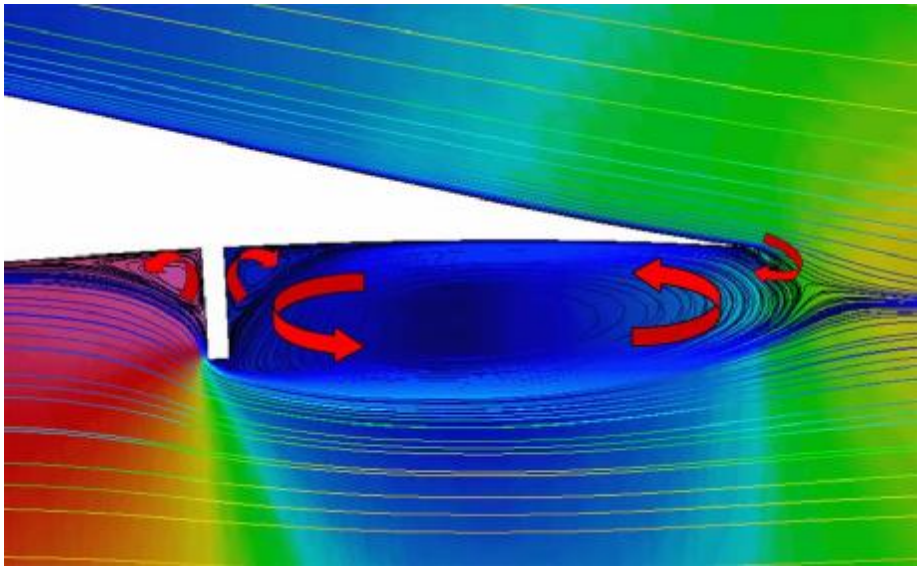
Navy Patent on Active Control

U.S. Patent 6,769,863

Dynamically Reconfigurable Wind Turbine Blade Assembly

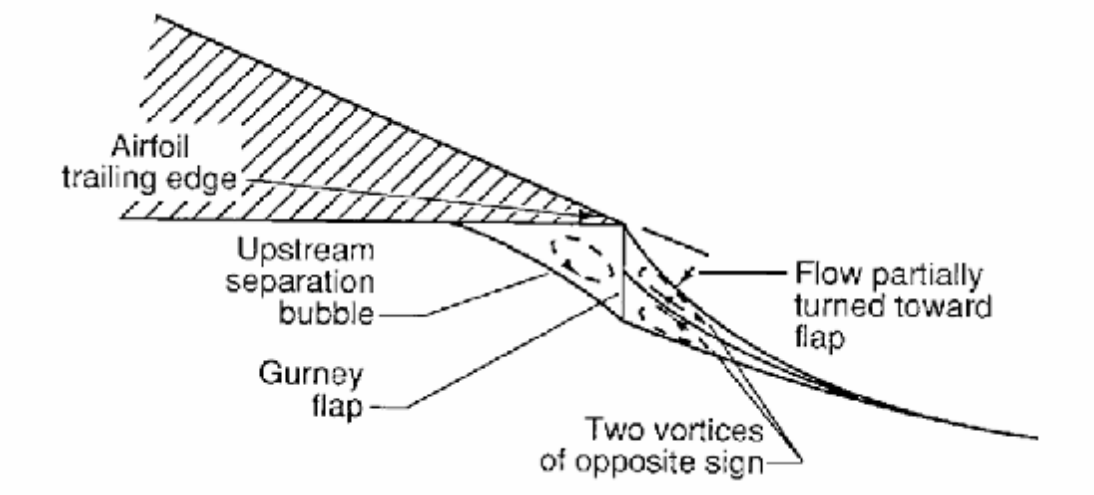
Objectives:

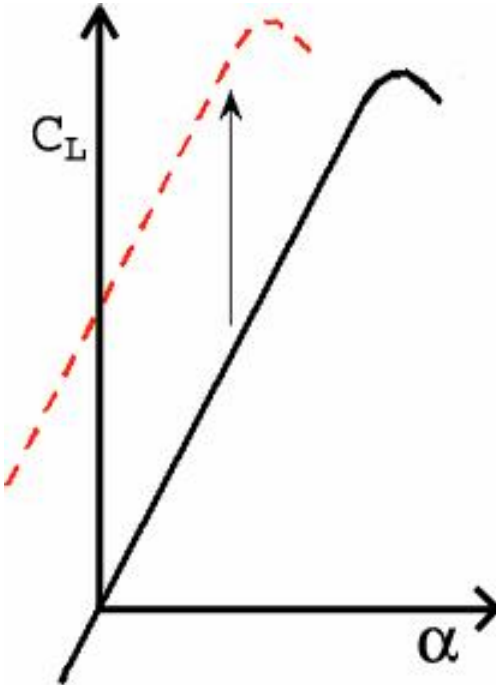
- Twist blade to increase energy efficiency in low winds and reduce loads in high winds
- Control dynamics to compensate for shear and yaw errors
- Allow machine to start up in lower wind speeds



Gurney Flap (Passive)

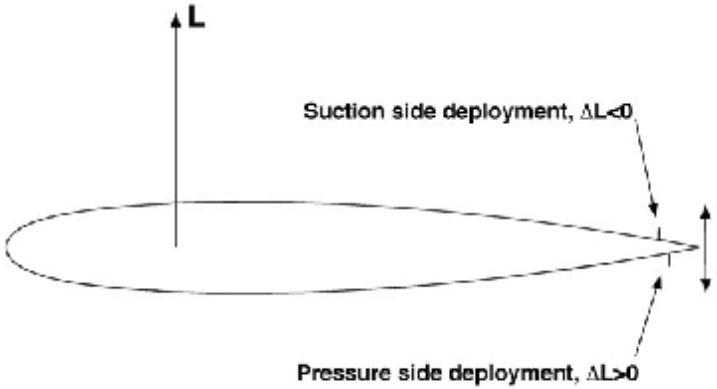
- **Gurney Flap (Liebeck, 1978)**
  - **Significant increases in C_L**
  - **Relatively small increases in C_D**
  - **Properly sized Gurney flaps D increases in L/D**

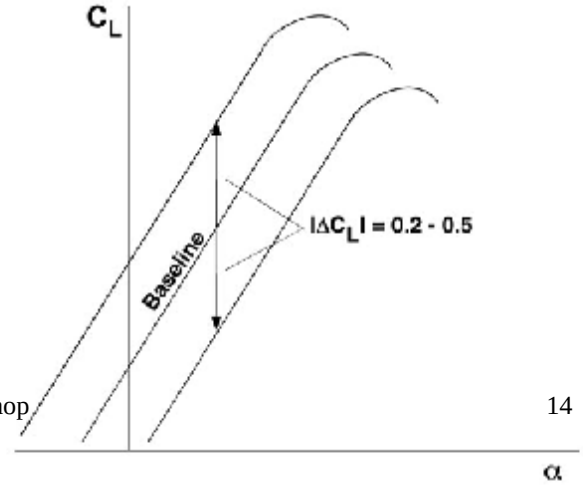




Microtab Concept

- **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)**





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Microtab Concept

Small, Simple, Fast Response

Retractable and Controllable

Lightweight, Inexpensive

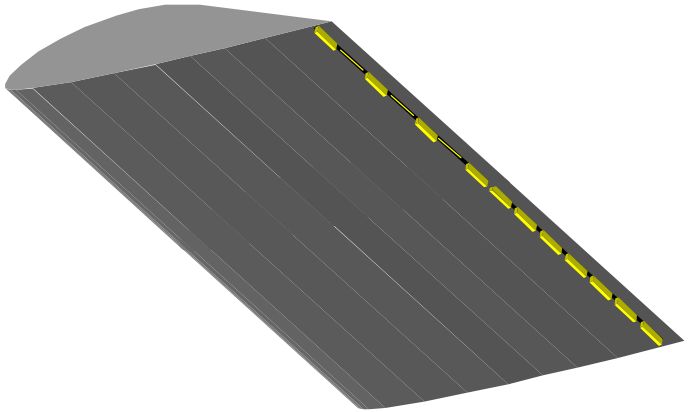
Two-Position "ON-OFF" Actuation

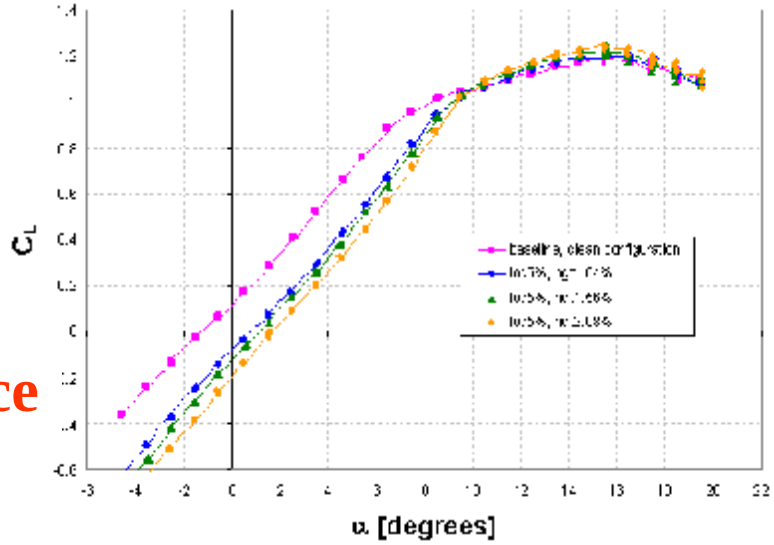
Low Power Consumption

No Hinge Moments

Expansion Possibilities (scalability)

Do Not Require Significant Changes to Conventional Lifting Surface Design (i.e., manufacturing or materials)





Tabs Deployed on the Upper Surface

Full System Modeling - Background

Wind Turbine Model

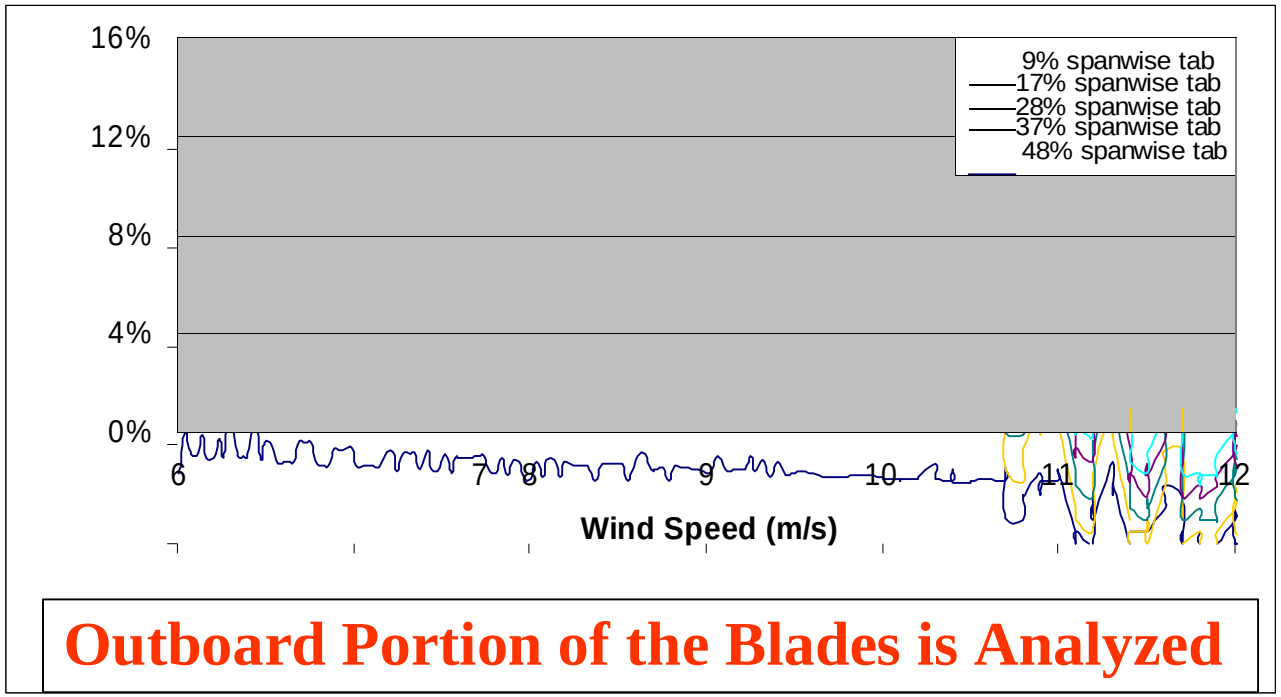
- **Micon 65 Stall Regulated**
- **3-bladed upwind**
- **Model results have been verified with field data**

Dynamic Simulation Tools

- **FAST (Fatigue, Aerodynamics, Structures, and Turbulence)**
  - **Modal representation**
  - **Limited degrees of freedom**
  - **Used as a preprocessor to ADAMS**
- **ADAMS (Automatic Dynamic Analysis of Mechanical Systems)**
  - **Commercial multi body dynamic simulation software**
  - **Virtually unlimited degrees of freedom**

Micon 65 – ADAMS Model

Percent Reduction in Flapwise Bending Moments



Outboard Portion of the Blades is Analyzed

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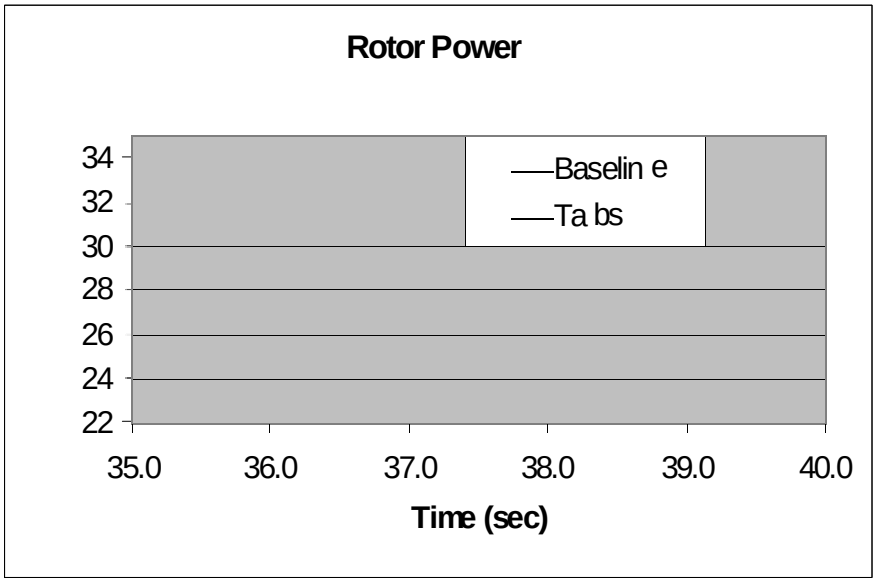
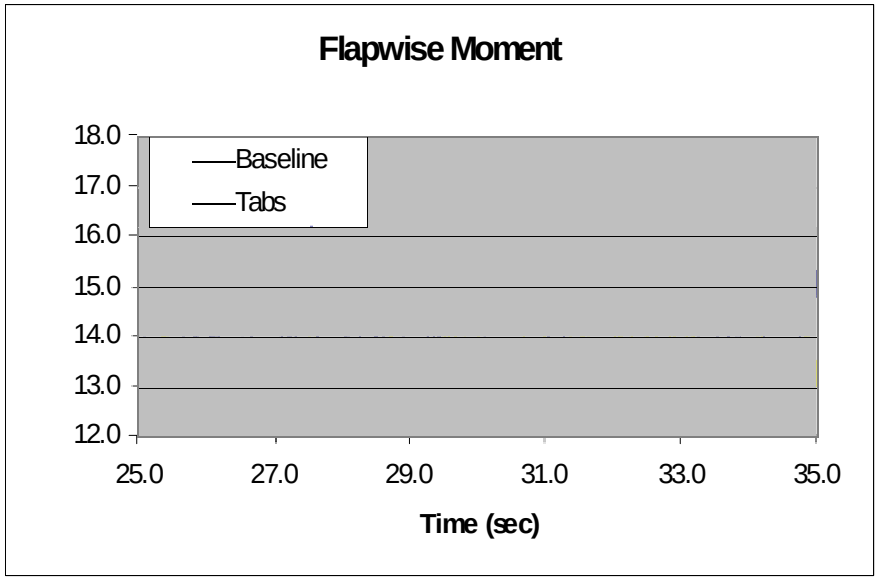
Dynamic Effect of Microtabs
(no control)

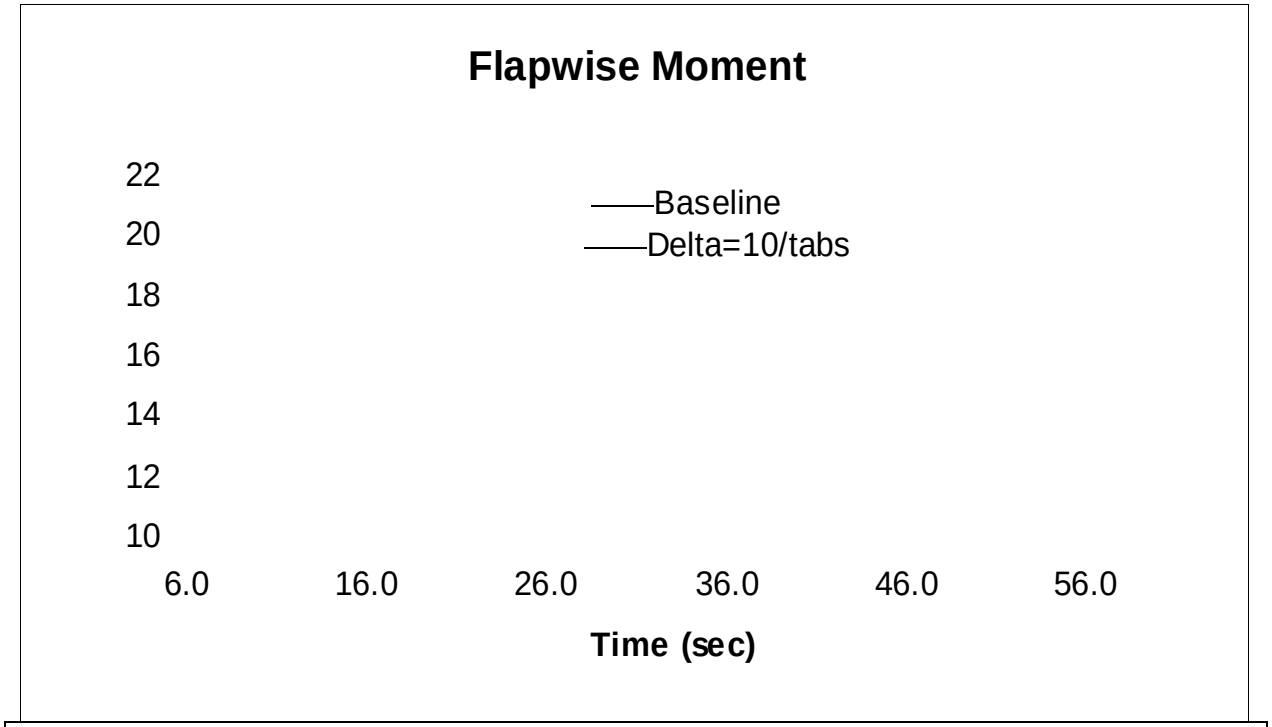
10-12% Difference





Microtabs Deployed for the Entire Simulation

Controlled Microtab Results



Microtabs Response Using Simple Controller

Sensor Research

Focus on Cost Effective Sensors (for lab and field environments)

- **Strain sensors**
- **Embedded composite pressure sensors for airflow measurements**
- **Fiber optic sensors**
- **Piezo-ceramic**
- **Displacement and proximity (blade tip deflection)**

Sensor Networks

- **Control inputs**
- **Damage detection and health monitoring**

Embedded Sensors

- **Composite structures**
- **Exploring possibilities of collaborating with SNL MEMS facility**
- **Exploring potential benefit of PZT's with NASA**

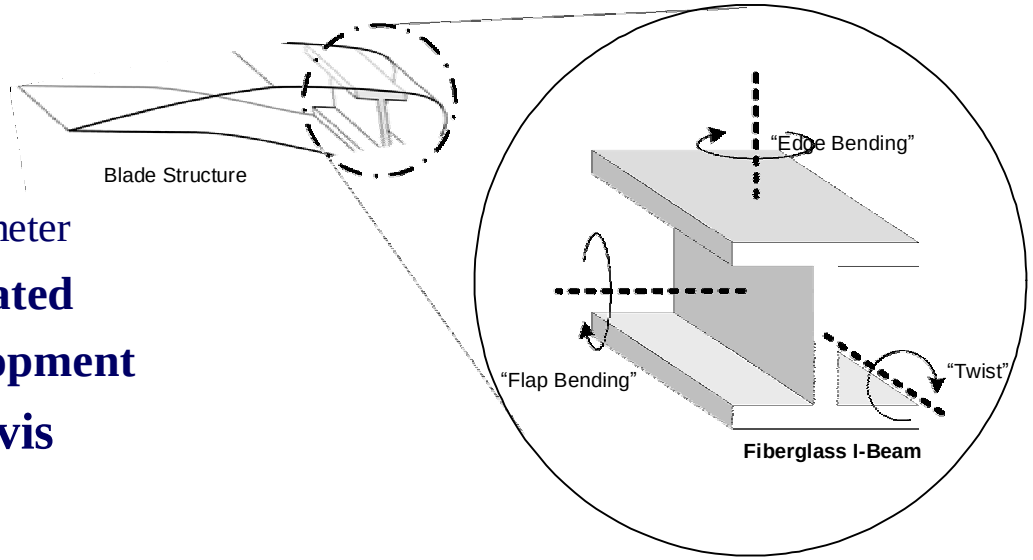
Redundant Sensors are Needed to Reduce Offshore O&M Cost

Fiber Optics (FO) Research

<u>Goal:</u> Develop New Fiber Optic Interrogating Method to Reduce System Cost

- **Use FO's to measure flap and edge bending, as well as twist**
- **Relies on using**
  - **tunable filter and**
  - **superluminescent diode**
  - - Eliminates costly interferometer
- **Temperature compensated**
- **Currently under development**

Partnership with UCDavis



Future Work

Continue to Analyze other Potential Devices (flaps, spoilers, etc.)

Model Devices on a VSVP Machine (in progress)

Develop a MATLAB Simulink Controller for Active Devices

Develop and Analyze Active Control Microtab Airfoil Model for Wind Tunnel Testing

Analyze Active Control Devices for Increase Energy Capture

Publish Document Outlining Potential Devices

Conclusion

Potential Advantages of Active Control have been Investigated

Active Devices may Provide Substantial Benefit for Future Wind Turbine Designs both Onshore and Offshore

Microtab Analysis has been Quantified both Computationally and Experimentally (wind tunnel)

Potential Microtab Benefits have been Demonstrated on a Full System Model

Yo GW, I Got Your Back!!