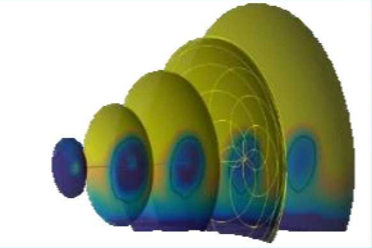
SAND2019-5680C

Big Adaptive Rotor (BAR)




PRESENTED BY

Josh Paquette
Principal Member of the Technical Staff
Wind Energy Technology Department

SAND2019-XXXXC

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Project Team

Project Overview

Objectives

- Investigate value of low specific power turbines
- Evaluate all innovative rotor technologies
- Understand logistics challenges for large on-shore blades
- Design 5MW turbine with 206m rotor with 60% capacity factor in Class III, low wind speed site
- Identify enabling technology for the next generation of high capacity factor wind turbine rotors

Impact:

- Enable high capacity factor wind rotors to maintain grid resilience in high renewable penetration future
- Open up large areas of the U.S. for potential wind development
- Reduce all-inclusive LCOE for wind
- Push turbine innovations towards commercialization

Project Tasks

Task 1: Trends, Impacts, and Value Analysis (NREL/LBNL)

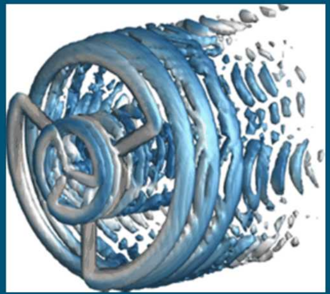
Task 2: Concept Screening (NREL/SNL)

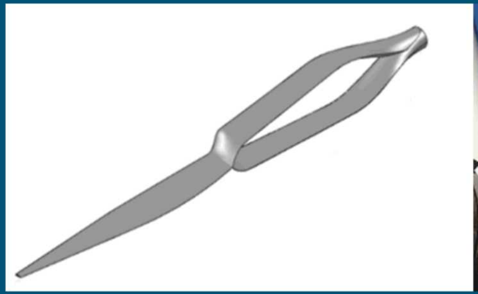
Task 3: Logistics Challenges (LBNL)

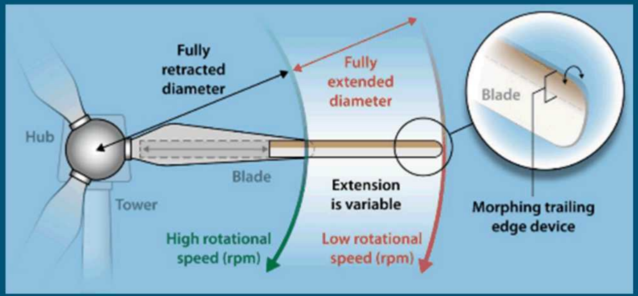
Task 4: Detailed LCOE Analysis (NREL/SNL)

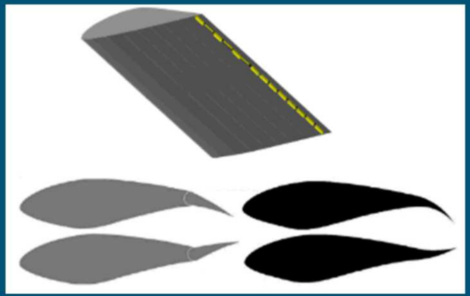
Task 5: Wind-Optimized Carbon Fiber (SNL/ORNL)

Concepts

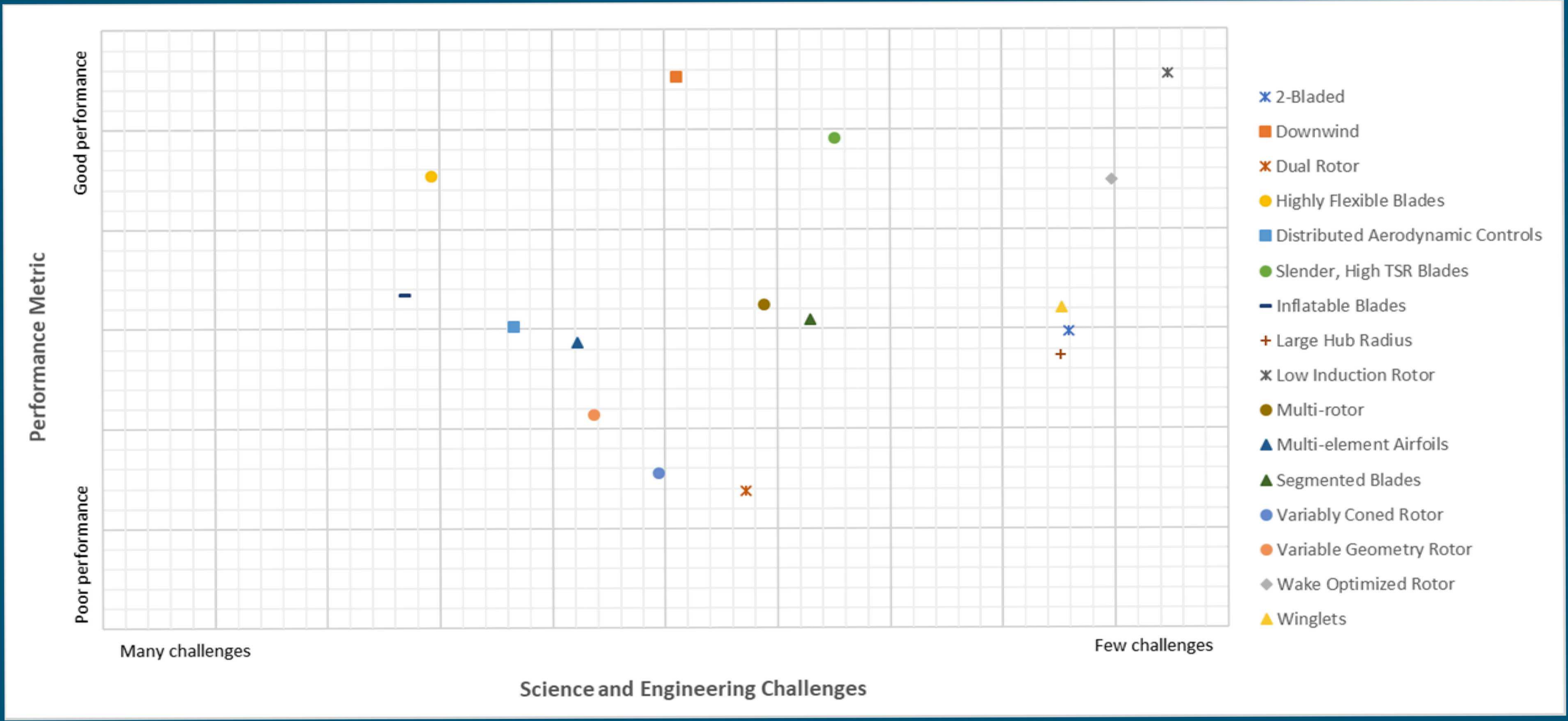





Fully retracted diameter
Fully extended diameter
Blade
Hub
Blade
Tower
Extension is variable
Morphing trailing edge device
High rotational speed (rpm)
Low rotational speed (rpm)



Down-Select Results



Baseline Blades

5MW-206m turbine with conventional technology
- Glass spar
- No root/cord limitations

Variants
- Carbon spar
- Spanwise joint
- Chord and root limitations

Challenges
- Transportation constraints and costs for onshore rotors
- Stiffness constraints for large blades
- Blade/hub connections, pitch bearings and actuators, overall turbine capital cost go up substantially with weight
- LCOE increases due to heavy conventional blades

Parameter	BAR00
Wind Class	IIIA
Rated Power	5.0 MW
Specific Power	150 W/m^2
Tip Speed Ratio	9.0-11.0
Rotor	3B upwind
DT & Gen.	DFIG
Rotor Diameter	206 m
Tower Height	140 m
Rotor cone angle	4 deg
Nacelle uptilt angle	6 deg
Max prebend	3 m
Max pitch rate	2 deg/s

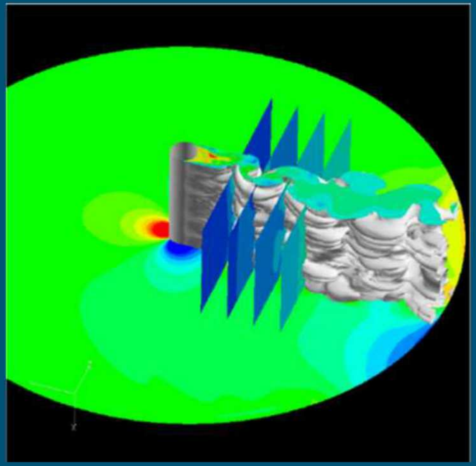
Downwind Rotor

Benefits

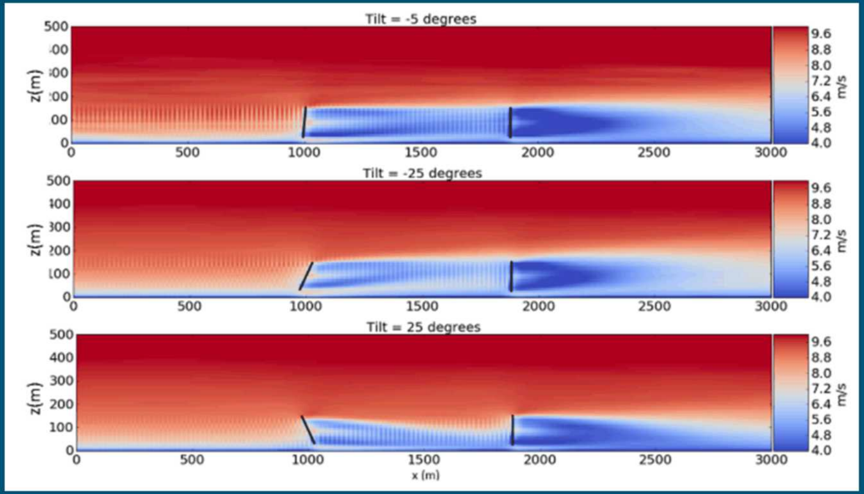
- Increased tower clearance, resulting in lower blade mass and cost
- Recent work (Bortolotti et al. 2018) found 7% and 3% savings in blade mass and cost respectively for a 10 MW rotor converted to downwind
- Increased possibility to uptilt the rotor and redirect the wake
- Possible slight benefits in AEP thanks to nacelle blockage and in presence of upflow (hills, ridges)
- Simplified yaw system, and placement of anemometer

Challenges

- Aerodynamics of tilted rotors
- Aeroacoustics of tower-blade interaction
- Tower shadow load impacts
- Control strategies to mitigate blade motion during e-stops
- Tilt control and optimization



CFD simulations modeling the wake behind a WT tower



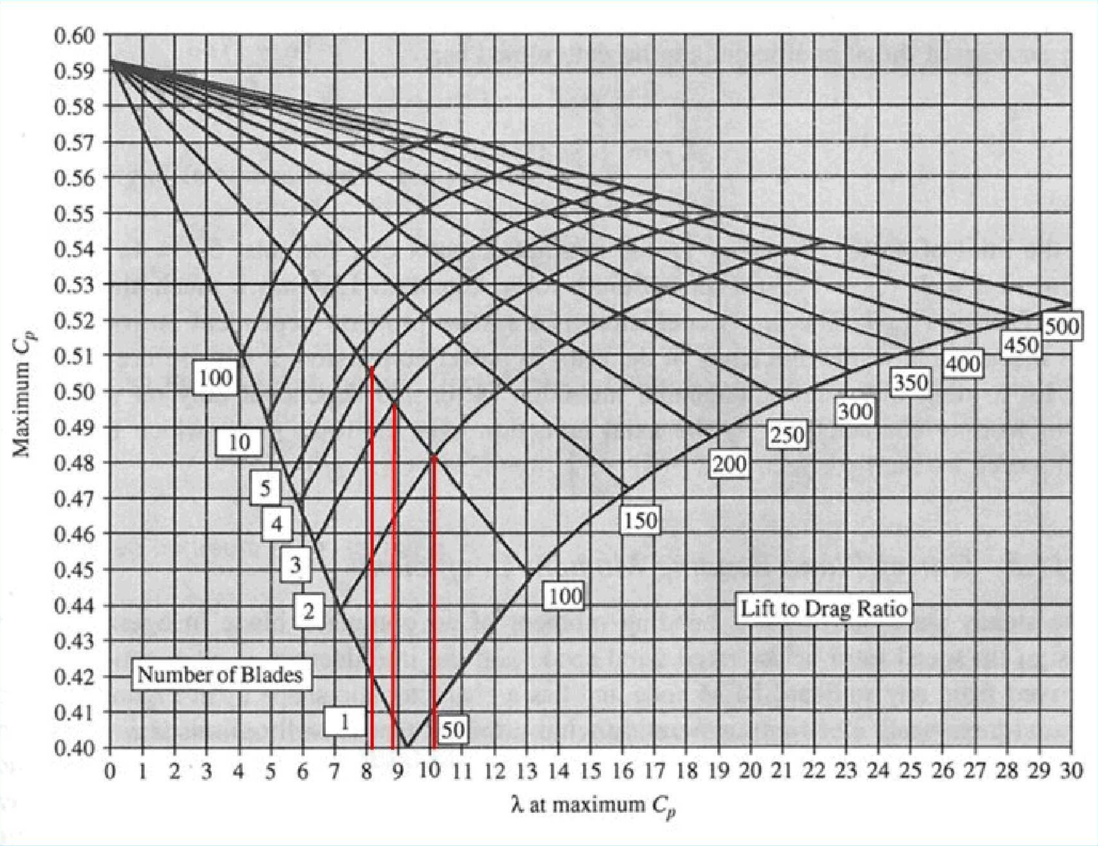
Wake steering by rotor tilting

4/5-Bladed Rotor

Benefits
- Better performance at lower tip speed ratio (TSR)
- Lower loading per blade allows for lighter blades, reducing gravitational loading of long blades
- Smaller chord lengths ease transportation concerns
- Lower noise
- Potential for through-hub piece to lessen pitch system issues (4-bladed)

Challenges
- Standard aeroelastic methods should be applicable, but little validation
- Aeroelastic stability due to flexible blades
- Increased rotor cost by ~33%, total system cost 3-6%
- Determine maximum flexibility of blades before tower clearance issues
- Understand complicated system dynamics associated with blade number
- Determine lower TSR impacts on gearbox torque loading

Circulation/induction is proportional to:
chord x *velocity* x *n-blades*



Maximum efficiency for different number of blades as a function of tip speed ratio (Jameson, 2011)

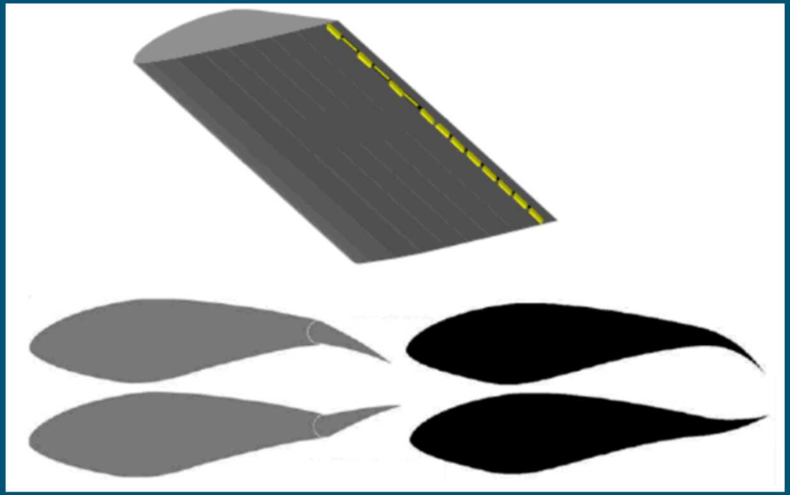
Distributed Aerodynamic Controls (Active Aero)

Benefits

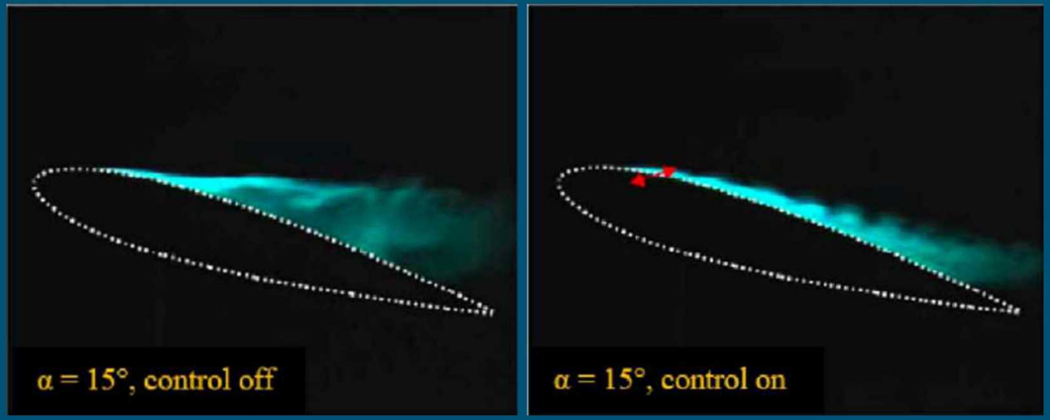
- Reduction of both fatigue and extreme loads
- Faster actuation than pitch control
- May allow for reduced pitch system requirements and duty cycle
- Potential to allow for longer blades while maintaining loads envelope
- Possible solution for flutter issues on future long flexible blades
- Novel sensors enable wind turbine/plant control opportunities

Challenges

- Integration with aeroelastic and controls toolsets
- Failure modes and impacts cost
- Device selection based on noise
- Flaps impact on structural design
- Reliability impact of additional sensors
- Integration into manufacturing process
- Effect of unsteady aerodynamics from actuation
- Best modes and materials for actuation



Trailing Edge Devices: Microtabs, Flaps, Morphing Trialing Edge (UC-Davis)



Effect of Synthetic Jets on Flow Attachment (UC-Davis)

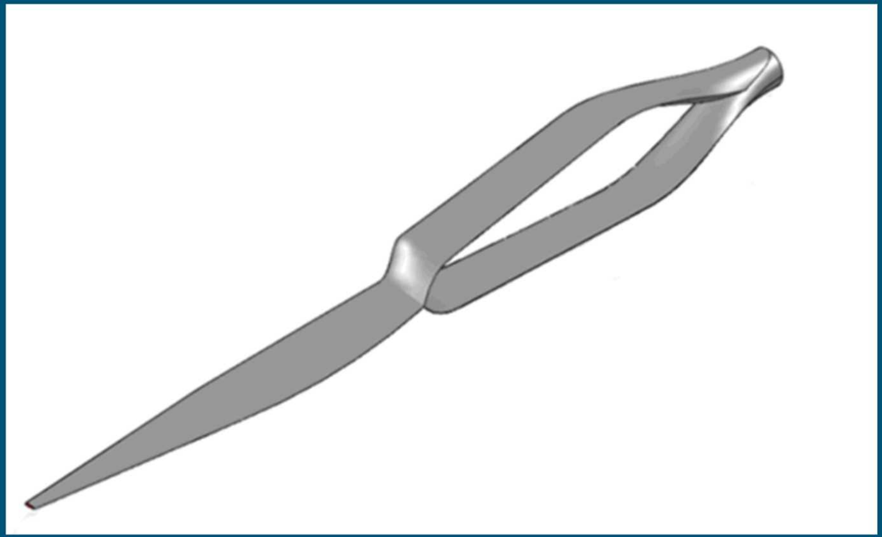
Multi-Element Airfoils

Benefits

- More aerodynamically efficient, and less flow separation for inboard section of blade [1]
- Lower blade loads due to reduced unsteady aerodynamic effects
- Lower weight; LCOE impacts
- Cut-in and rated power at lower wind speeds
- Lends itself to modular blade design; reduces transport logistics

Challenges

- Determine reliability impacts
- Updates to models for blade aerodynamic design and loads analysis
- Determine noise of multi-element surfaces
- Characterize joint if used
- Optimization of thin airfoils
- Determine torsion and shear properties
- Determine wake impacts
- Characterize manufacturing challenges with struts, flaps, slats, and segments
- Determine impacts on blade mass



Bi-Wing Blade (UCLA)

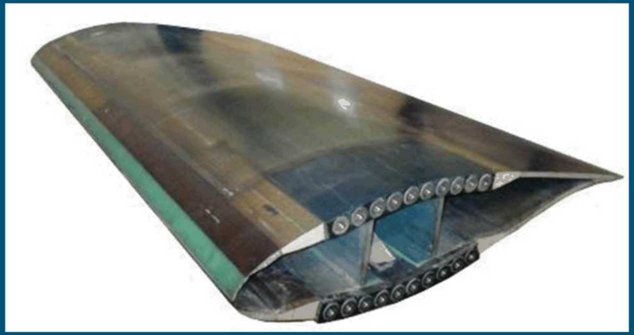
Segmented Blades

Benefits

- Segmented blades can utilize established low-cost transportation methods

Challenges of addressed

- Determine cost compared to other transport solutions
- Determine costs associated with bolted joints and high mass
- Determine cost penalty, onsite assembly process risk of adhesive joints
- Determine structural reliability for very large rotors
- Determine onsite assembly procedures for consistency and rotor balancing



Bolted joint (Nabrawind)

Modular blade (GE, formerly Blade Dynamics)

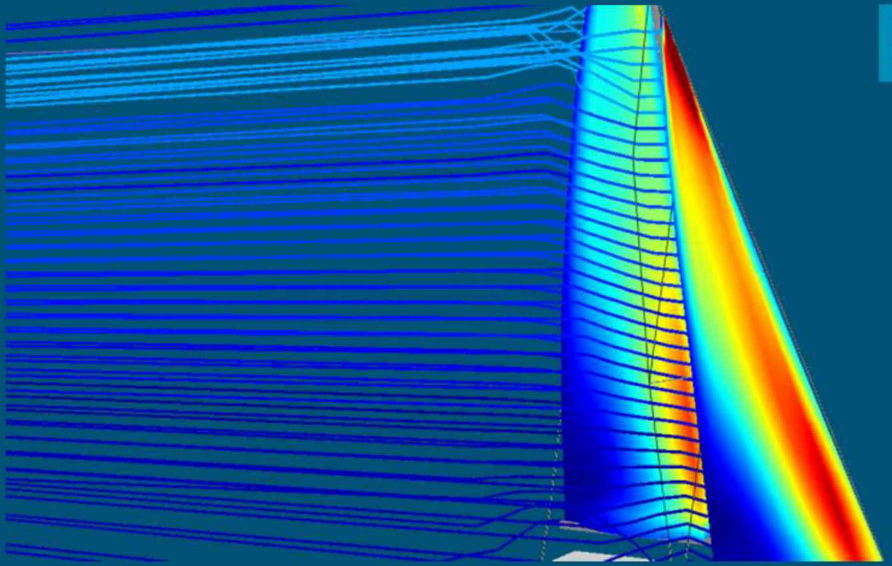
Inflatable and Sail Blades

Benefits

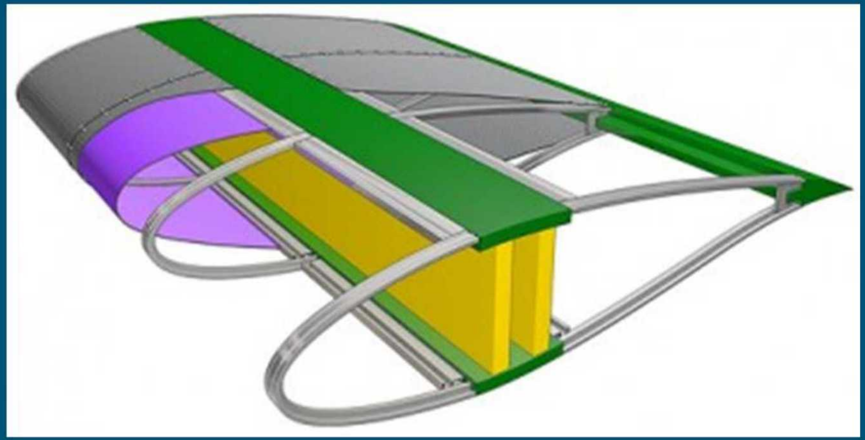
- Enables on-site manufacturing; avoids transportation constraints
- Outboard pitching may reduce constraints on pitch system design (bearing/actuators)
- Separating structural and aerodynamic design allows overall design to be lighter
- May be able to exploit advanced design and manufacturing (e.g. 3-D printing) to foam material
- Lighter blades
- Ease of manufacture
- Ease of repair - fabric more simple to replace than fiberglass
- Easier to transport

Challenges

- Unsteady aero effect for potential small changes in airfoil shape over time
- Aeroelastic effects
- Materials research for skin and foam
- Connection between inflatable airfoils and load carrying structure
- Potential challenges with mid-span pitching
- Reliability of UV and puncture risk of skin material
- Determine skin materials and properties
- Characterize unsteadiness/flutter
- Fabric material may be expensive

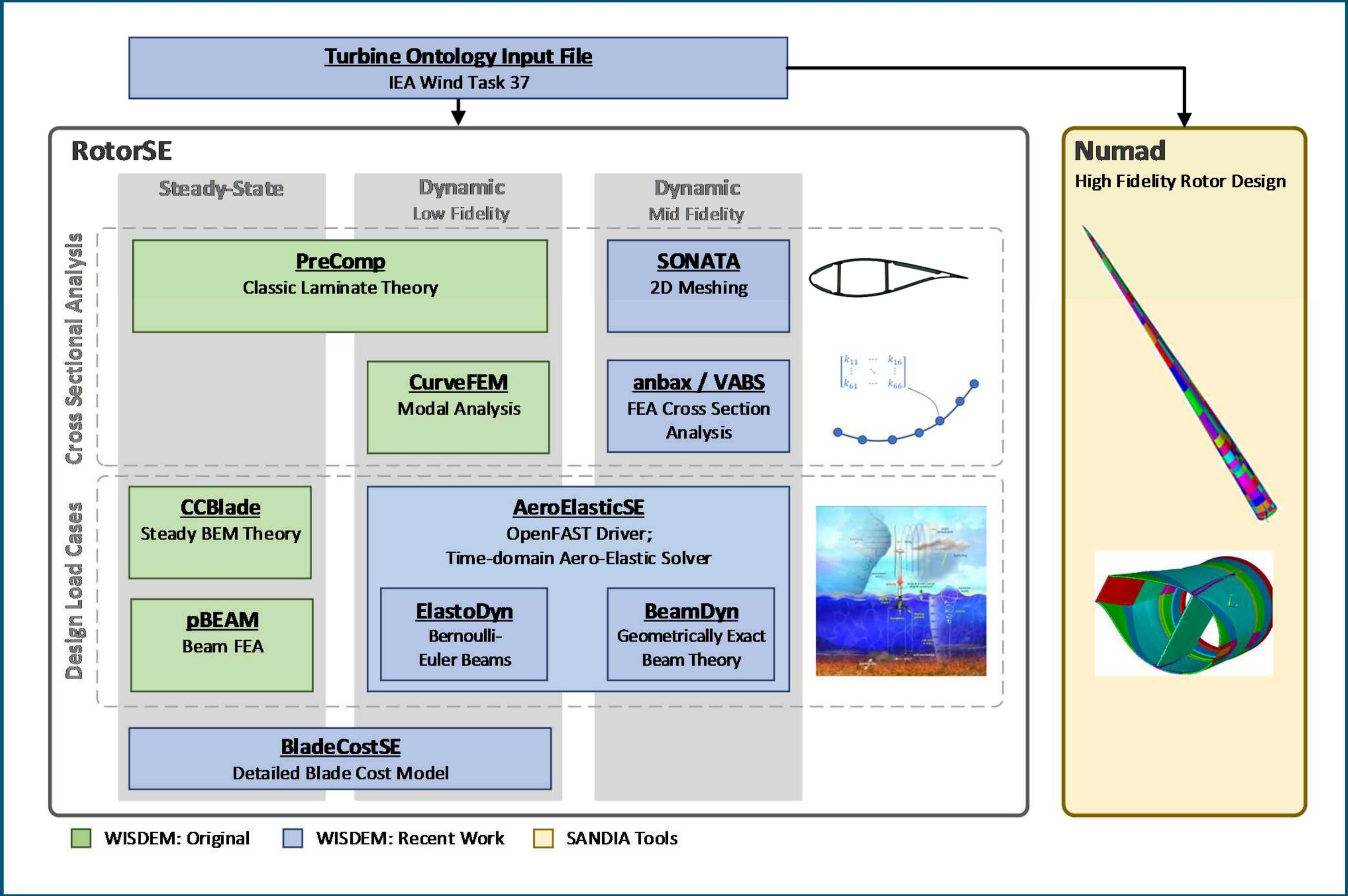


Pressure contours on ACT Sail concept, currently being applied to wind turbine blade design (ACT)

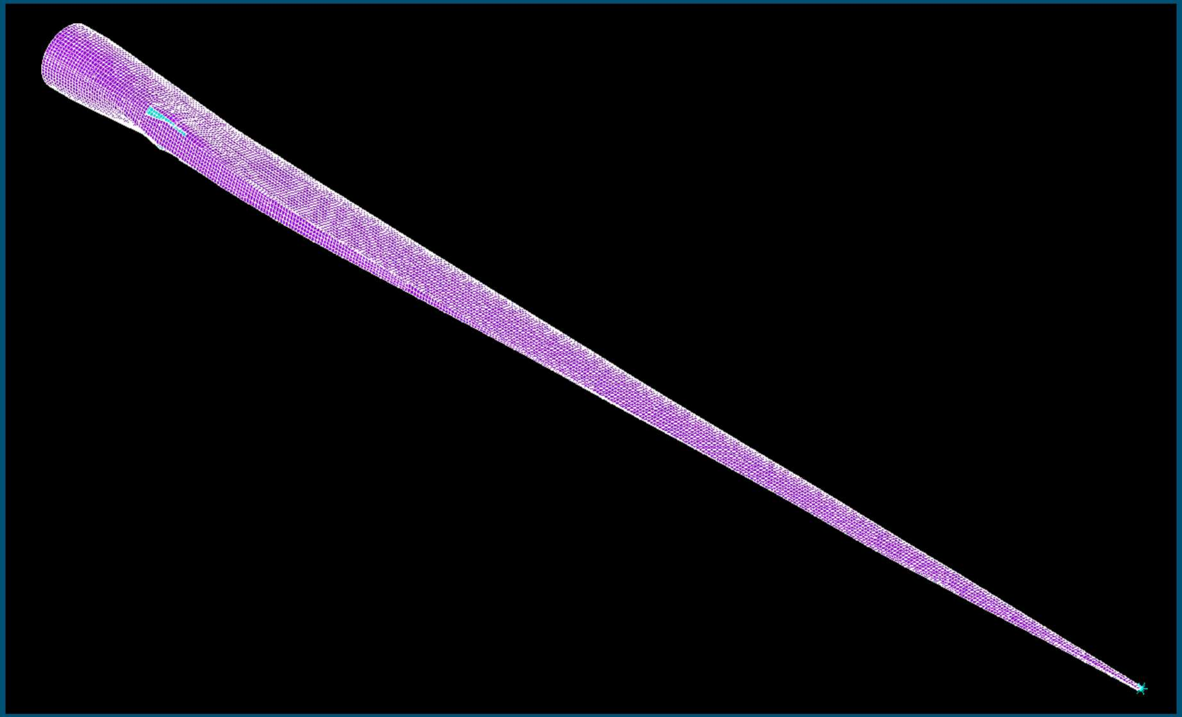


GE Tensioned fabric blade concept (GE)

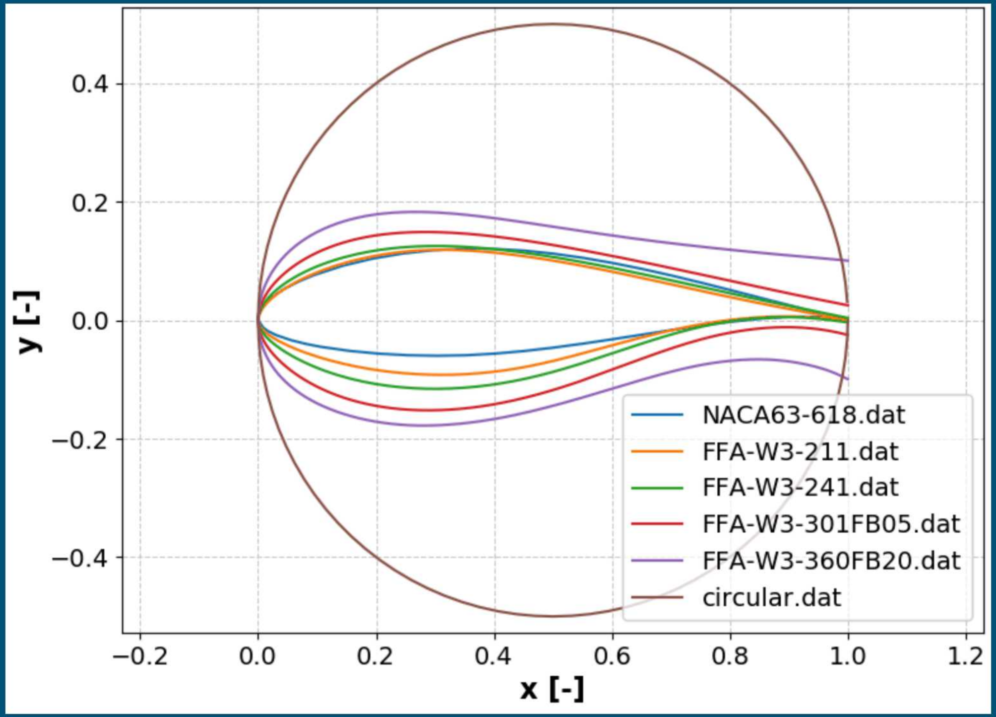
Design Process



Initial Model



BAR Baseline FEA Model



BAR Airfoils

Model Development/Improvements

Downwind
- Acoustics
- Tower Shadow

Highly Flexible Blades
- Flutter
- Pitch System Dynamics
- Complex Aerodynamics

Distributed Aerodynamic Controls
- Active Aero Controls and Aerodynamics

Mutli-Element Airfoils
- Beam Representations
- FEA Models

4/5 Blades
- Allowance of >3 blades

Next Steps

FY19 (end of September 2019)

- Complete baseline modeling
- Final check of challenges and limitations of baselines
- Complete modeling improvements and upgrades

FY20

- Complete analysis of BAR technologies as necessary
- Controller co-design
- Evaluate impacts of feed-forward controls