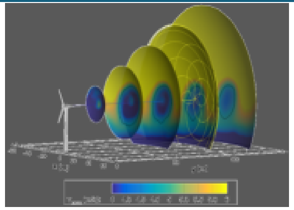
SAND2021-11807C

Sandia National Laboratories

Low Specific Power Machines: Opportunities and Challenges



PRESENTED BY

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Motivation

Substantial reductions in the cost of wind energy have come from large increases in rotor size

Performance: Larger rotors capture substantially more energy both through a greater swept area and accessing increased wind speeds at higher altitude

Grid Integration: Larger rotors also enable higher capacity factor wind plants, yielding less variability in power production

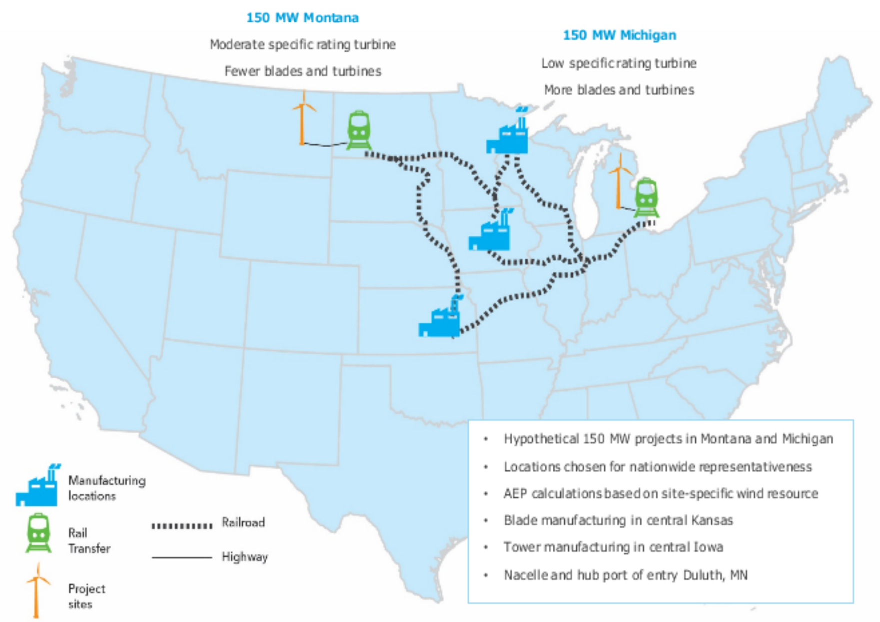
Deployment: Limited high wind resource sites remain, further deployment depends on developing lower wind resource sites

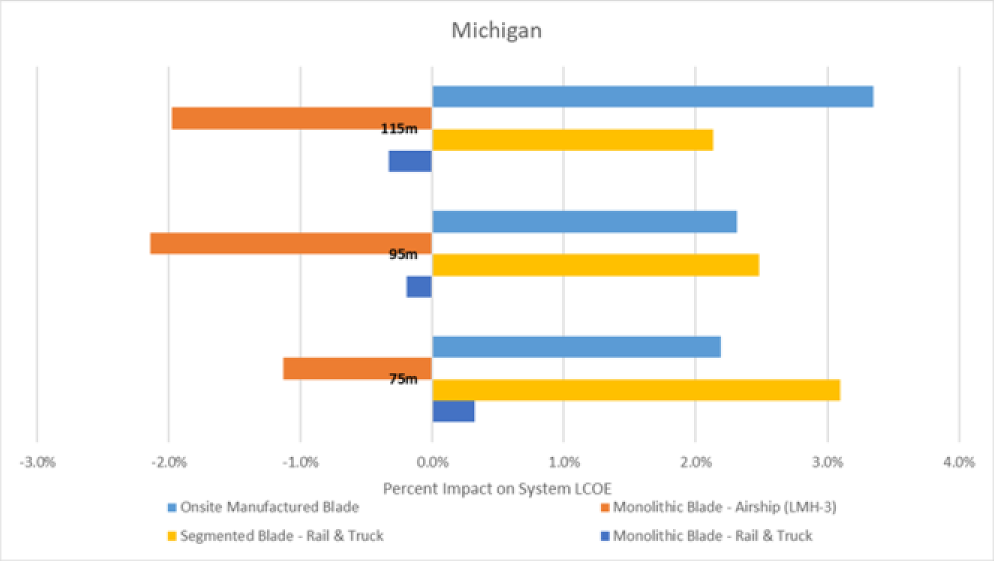
Transportation

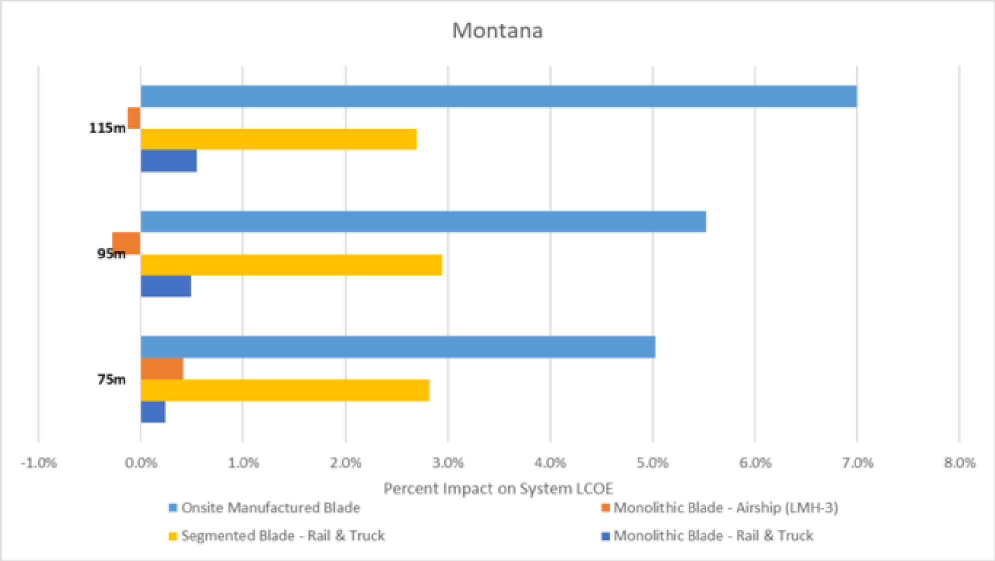
Both max-chord (4.75m) and length (~80m) constrained for transportation, and approaching root constraint

Pre-bend limited to 4m, creating tip clearance problems

Solutions are being implemented, but at a cost







Cost of transportation for different blade lengths and different logistics technology in US

Large Deflections

Conventional blades are constrained by tip deflection

Pitch rates can be prohibitive for blades > 100m; this can cause excessive design loads/deflections

Blade under high deflection during structural testing

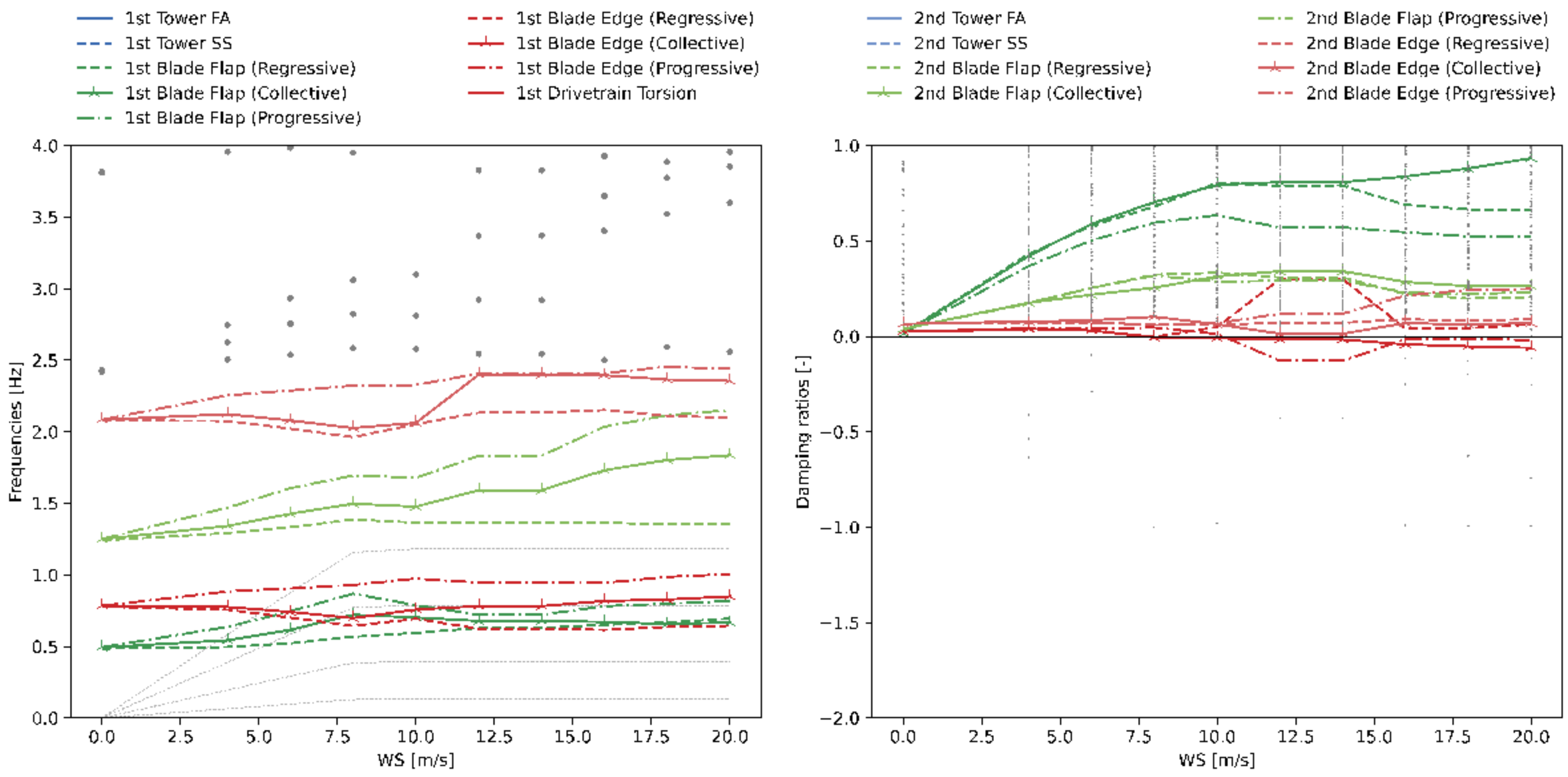
Aeroelastic Stability

Large blades are being designed and built with relatively unvalidated codes for aeroelastic stability.

Codes exist (HAWC, FAST) but have not been validated with highly flexible designs

Non-classical instabilities have been observed in edgewise direction as weight and flexibility trade off

Likely sensitive to blade deflection coupling



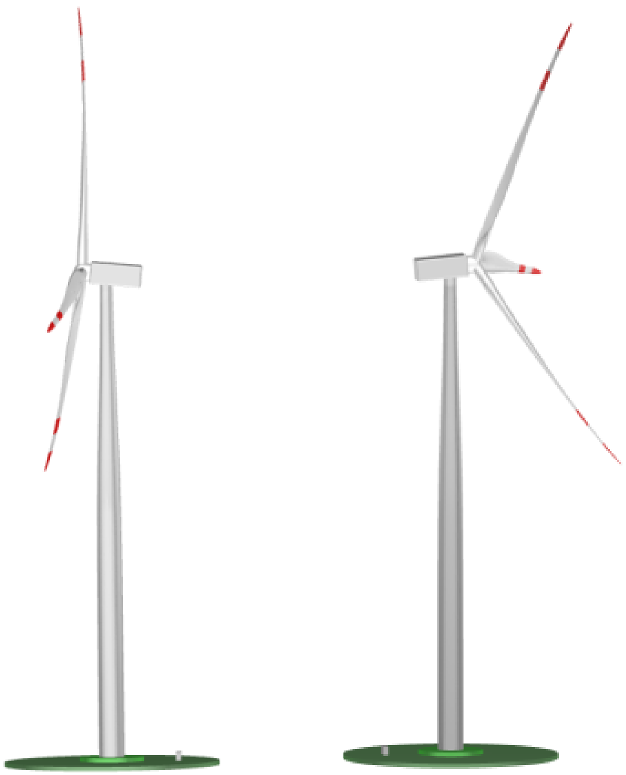
Frequency and damping of highly flexible BAR blade

Downwind Rotors

Downwind machines offer the potential to enable large flexible rotors

Challenges:

- Tower shadow can cause an increase in fatigue loading on the blades, advanced control strategies and active aerodynamic devices may decrease the LCOE
- Noise from the tower shadow is not full characterized
- Benefits of up-tilt can be explored
- Represents a large change for OEMs, so some de-risking is necessary



Upwind and downwind rotors

Distributed Aerodynamic Controls

Large rotors are limited by pitch rate which produces high strains and deflections in extreme winds

Active aerodynamics can quickly alter lift

Reduction of both fatigue and extreme loads

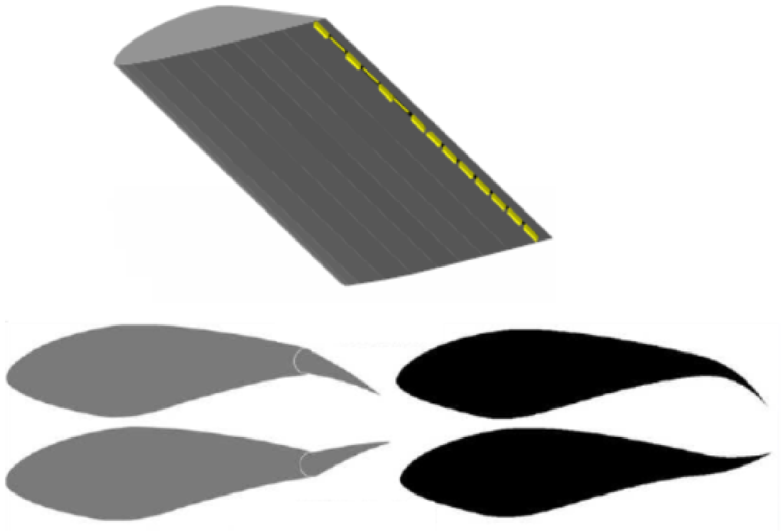
Faster actuation than pitch control

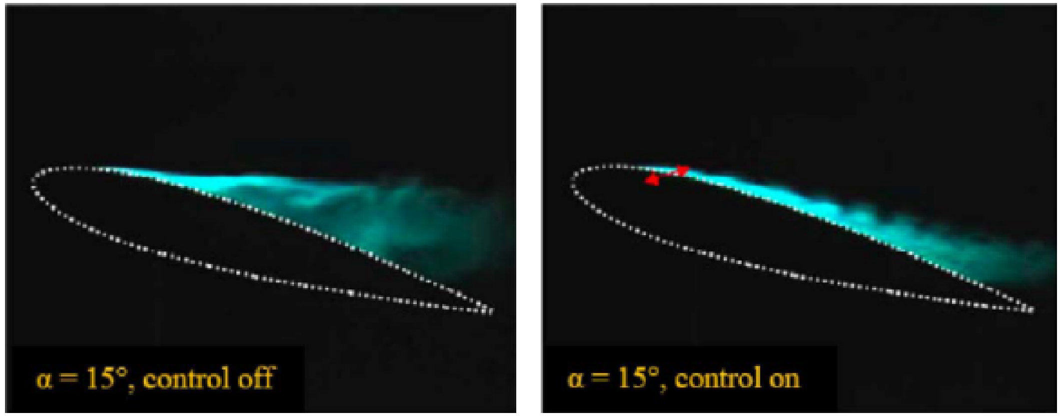
May allow for reduced pitch system requirements and duty cycle

Possible solution for flutter issues on future long flexible blades

Challenges:

- Controls Integration
- Aeroacoustics
- Reliability impact of additional sensors
- Integration into manufacturing process
- Effect of unsteady aerodynamics from actuation





Trailing edge tabs and flaps, top, and synthetic jets, bottom (UC-Davis, 2008)

Carbon Fiber

Significant increase in strength and stiffness, but at added cost

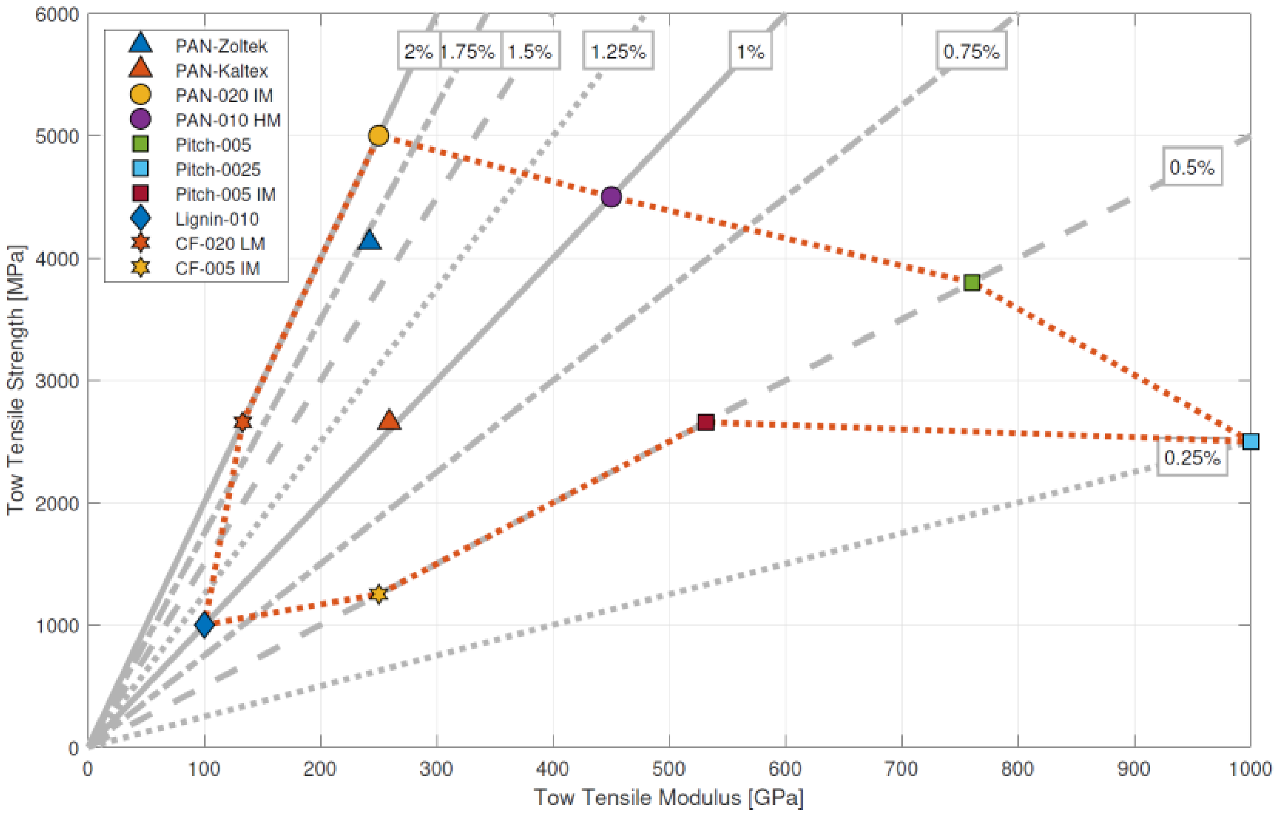
Recent innovation: Textile carbon fiber materials are processed in a heavy tow size

3MW and 10MW designs were analyzed

22% increase in cost-specific tensile strength

100% increase in cost-specific modulus

Challenges:
- Cost
- Manufacturing
- Lightning



Carbon fiber catalog tow properties representing a wide range of available commercial materials

Material	UTS(MPa)/ ($/kg)	%	UCS(MPa)/ ($/kg)	%	E(GPa)/ ($/kg)	%
Industry Baseline	147.6	100	-100.3	100	9.6	100
Heavy-Tow (full-utilization)	180.0	122	-156.9	156	19.2	200
Heavy-Tow (current)	137.0	93	-119.4	119	14.6	152
Fiberglass infusion	437.9	297	-311.7	311	20.8	217

Cost-specific strength and stiffness of heavy tow carbon fiber

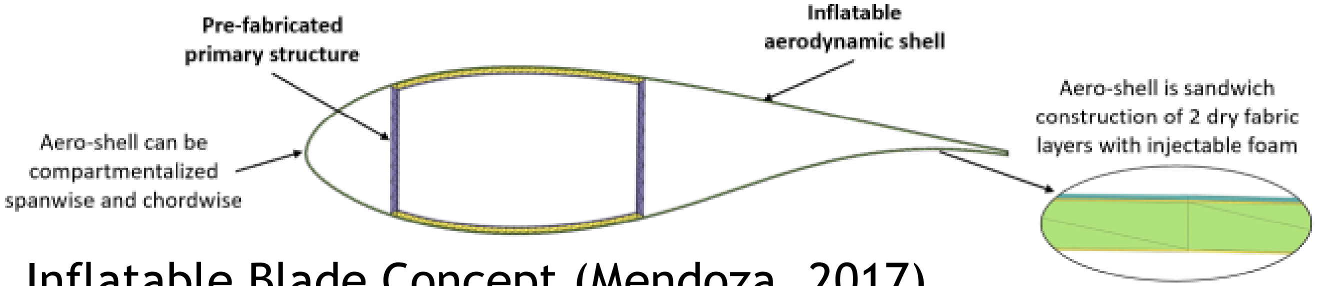
Advanced Concepts

On-Site Assembly: Moving all or part of the blade manufacturing process to site would drastically reduce transportation costs for future large blades

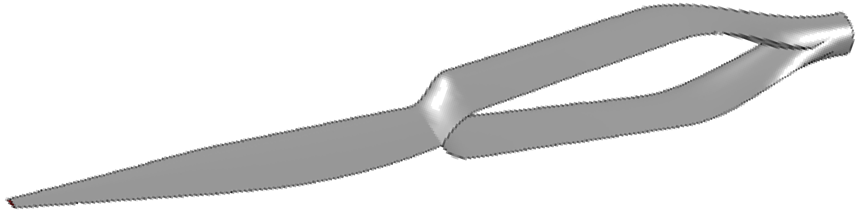
Inflatable Blade: Part of the blade is “inflated” on site for final manufacturing step. Reduces blade width for transportation

Multi-Element Blade: Uses two or more blade elements inboard to increase flap stiffness and reduce chord length. May allow for multi-piece blade with smaller, faster-acting, outboard pitch system

On-Site Manufacturing (TPI Composites, 2003)



Inflatable Blade Concept (Mendoza, 2017)



Bi-Wing Concept (Chu, 2017)

Validation Needs

Highly Flexible Blades (HFB)

Aerodynamics
- Out of plane aerodynamics
- Unsteady aerodynamics
- Wake behavior for high deflections
- High Reynolds number airfoil estimation

Structures
- Large deformations
- Dynamic torsional flexibility
- Structural dynamic validation
- Fatigue performance of subscale components
- Off-axis fiber, and bend-twist coupling
- Failure criteria (PUCK, LaRC)

Aeroelasticity
- Frequency and stability analysis
- Flutter and Vortex Induced Vibration

Validation Needs

Distributed Aero Controls
- 3D aerodynamic and wake response
- Unsteady aerodynamics
- Aeroelastic impacts
- Impact on blade structure
- Manufacturing & reliability

Downwind
- Aeroacoustics and low frequency noise
- Fatigue impacts from tower shadow
- Unsteady aerodynamics from tower shadow
- Aerodynamics of highly tilted rotors
- Control strategies for shutdowns

Thank you