# A Vision for Future Wind Turbine Rotor Systems: Rotor Concepts, New Technologies, and Digitization

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UTD Center for Wind Energy

Sandia Blade Workshop

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# Offshore Wind

**Biden Administration:** 30GW by 2030 (est. powering of 10 million homes)

## Opportunities

- Proximity to population centers
- Consistent / better winds
- Vast resource
- Scale-up opportunity

## Challenges

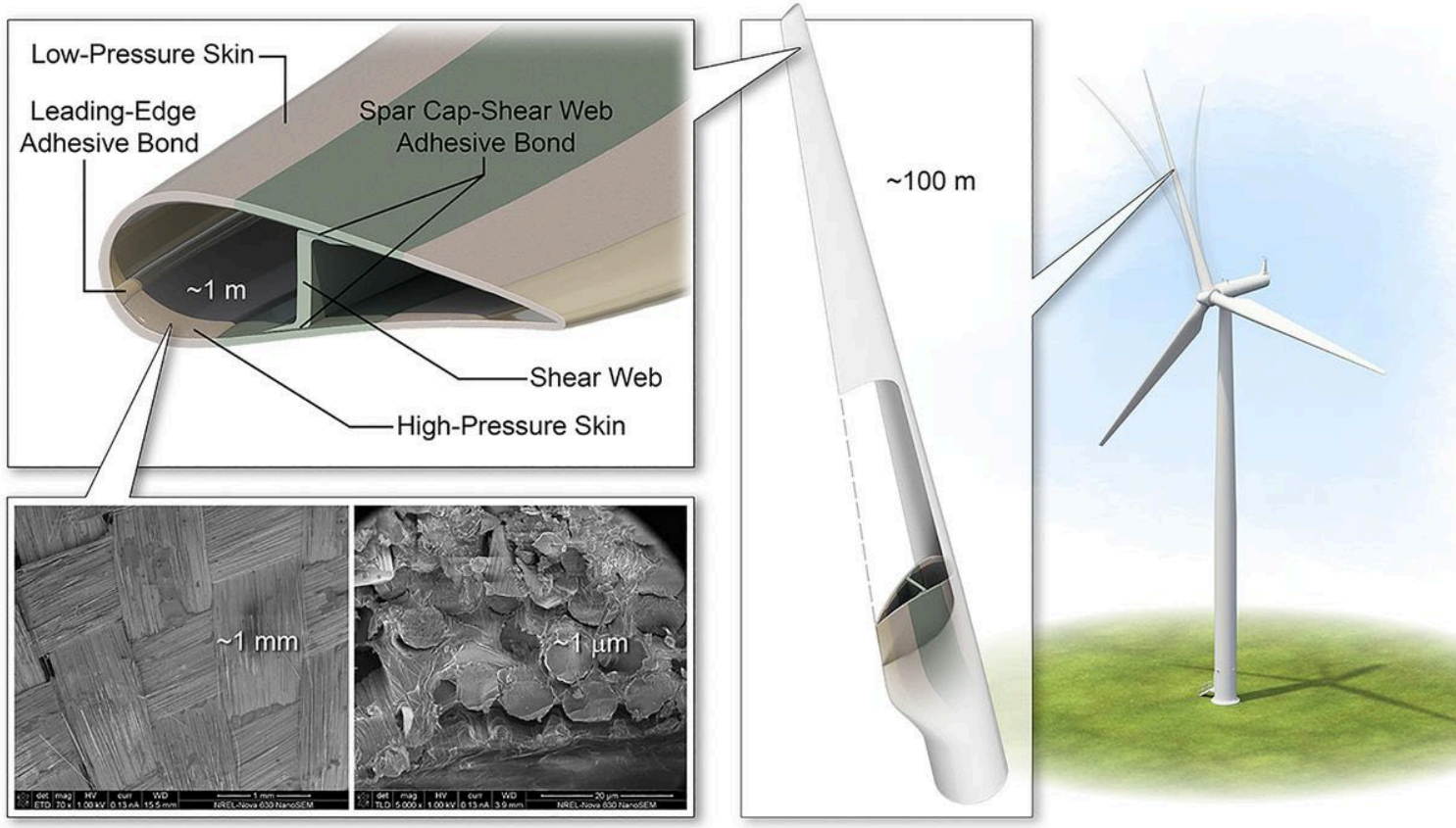
- Higher LCOE
- Higher BOS costs
- Accessibility, Harsh environment
- Inexperience, Immaturity

# Grand Challenges in the Science of Wind Energy

**First grand challenge:**
**Improved understanding of the wind resource and flow in the region of the atmosphere where wind power plants operate**

**Second grand challenge:**
**Addressing the structural and system dynamics of the largest rotating machines in the world**

**Third grand challenge:**
**Designing and operating wind power plants to support and foster grid reliability and resiliency**



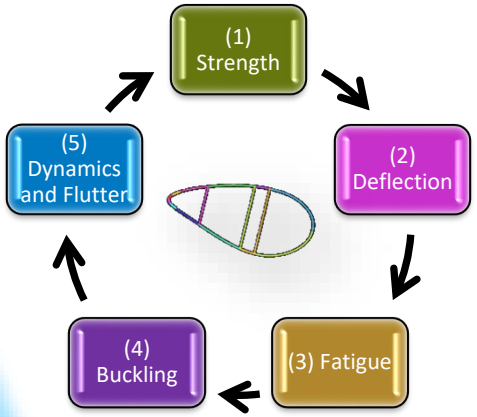

Material Blade Turbine

**"Grand challenges in the science of wind energy," Veers, et al, Science, 10 Oct 2019, Vol 366, Issue 6464, DOI: 10.1126/science.aau2027.**

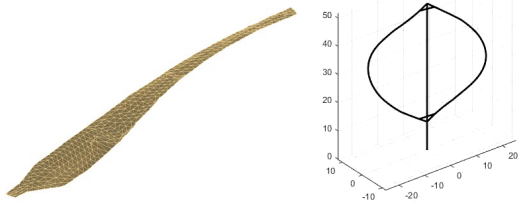
# Quest for larger rotors at UT-Dallas

## Turbine Concepts + New Rotor Technology Innovations = Future Rotor Systems

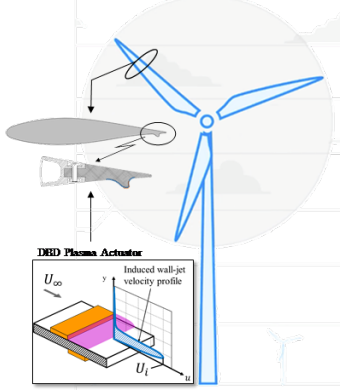
### Blade Design




### Structural Dynamics



### Active Load Control




### Digital Twins

### Blade Segmentation

### Prototypes

# Active Aerodynamic Load Control for Wind Turbines

**Project Summary**

**Title:** Active Aerodynamic Load Control for Wind Turbines

**Partners:** Aquanis (lead), **UT-Dallas**, TPI Composites, Inc., Sandia National Laboratories

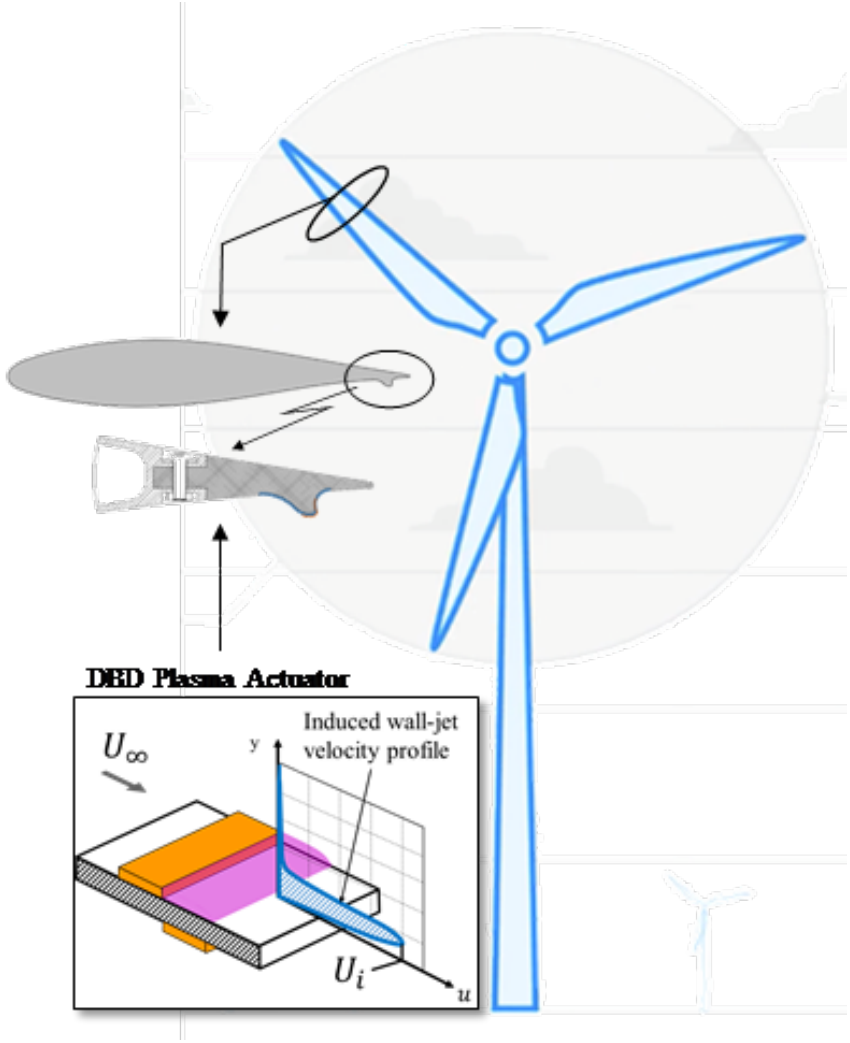
**Funding:** DOE/ARPA-E (OPEN 2018 Program)

## Research Description

**Motivation:** Reduce loads on turbines to enable larger wind turbines and reduce the cost of energy.

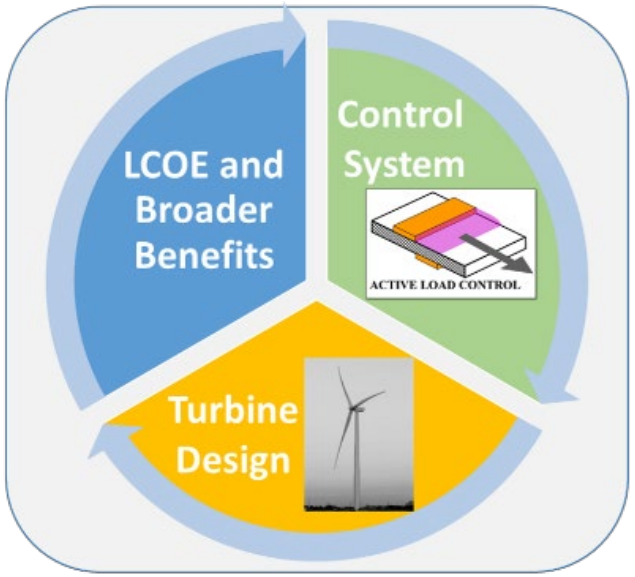
**Objectives:**

- Develop advanced controls to reduce aerodynamic loads for next generation large, smart turbines.
- New design solutions to reduce LCOE.
- Demonstrate at wind tunnel and field scale.

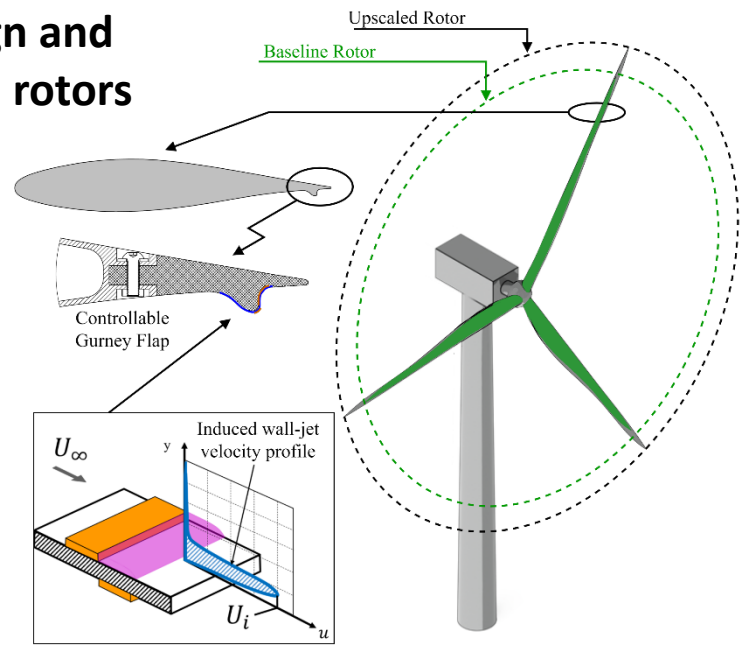


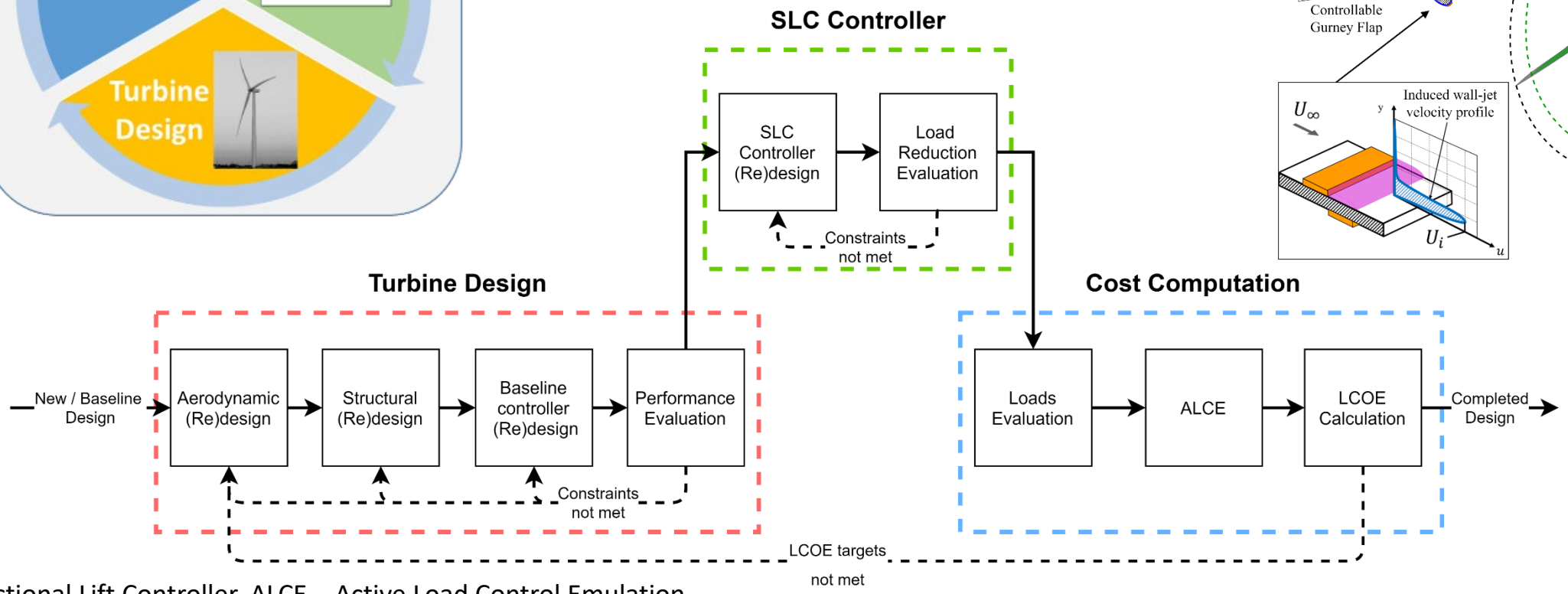

Griffith DT, Fine NE, Cooney JA, Rotea MA, Iungo GV. Active Aerodynamic Load Control for Improved Wind Turbine Design. *J Phys: Conf Ser*. 2020;1618:052079. doi:10.1088/1742-6596/1618/5/052079

# Sequential Iterative Design Methodology




**Recent focus on re-design and cost analysis for upscaled rotors**



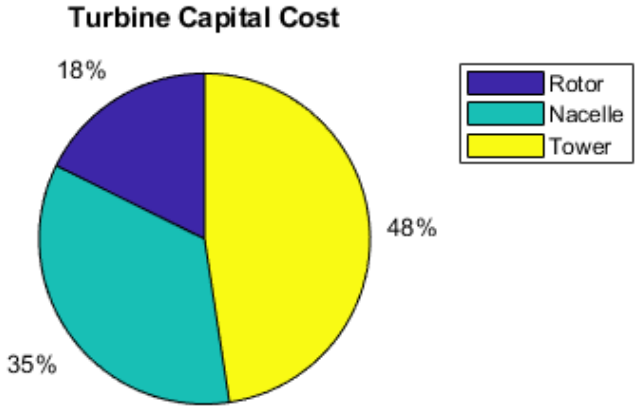

SLC – Sectional Lift Controller, ALCE – Active Load Control Emulation

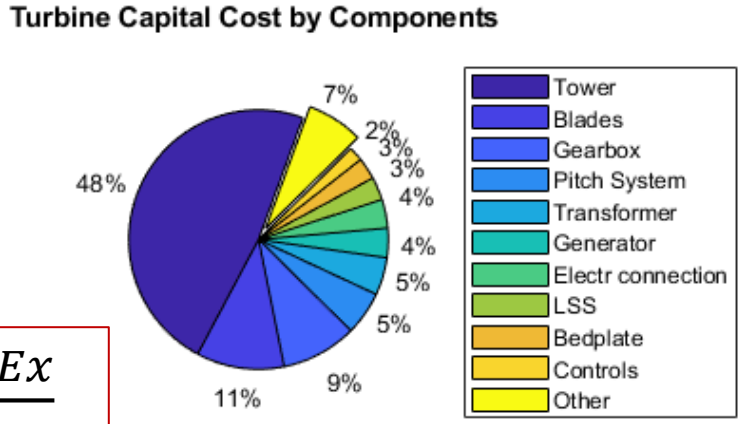
Chetan, M., Sakib, M.S., Griffith, D.T., Gupta, A., and Rotea, M.A., "Design of a 3.4MW Wind Turbine with Integrated Plasma Actuator-based Load Control" Wind Energy, September 2021, DOI: 10.1002/we.2684.

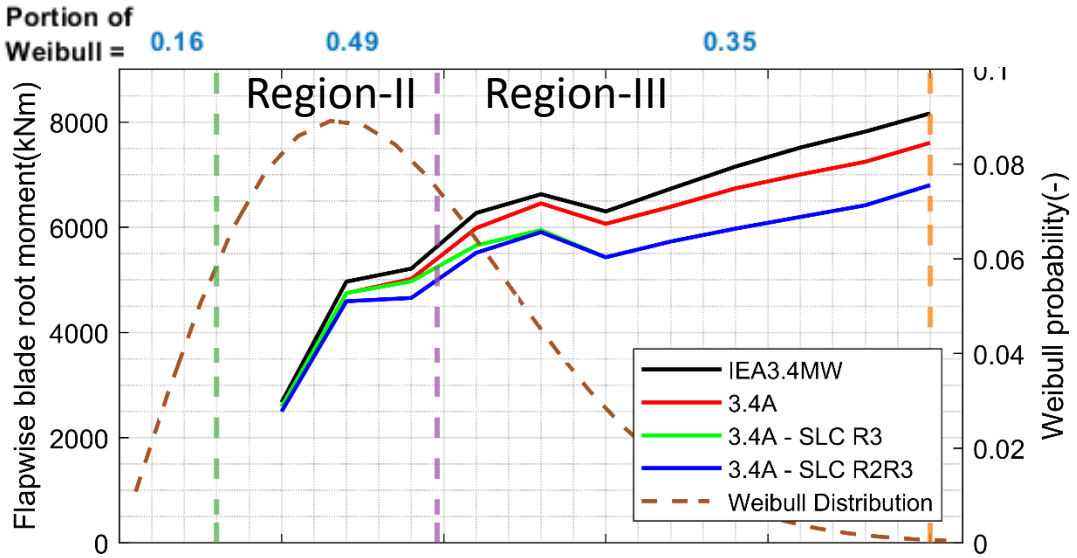
# Active Load Control: Reduces Blade and Non-blade Component Loads

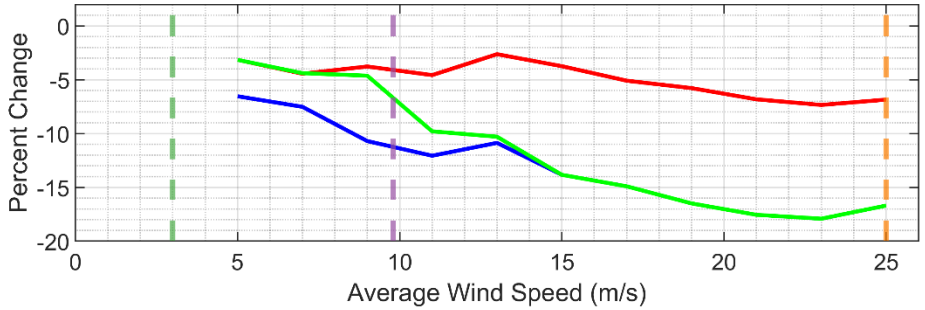
- The CapEx breakdown for the IEA 3.4MW RWT.
- Tower, blades, gearbox, and pitch system are 74% of turbine CapEx.
- Active Load Control provides load reduction in all these major components: blades, tower, gearbox, pitch systems, etc.

$$LCOE = \frac{(CapEx \times FCR) + OpEx}{AEP_{net}}$$




Extending SLC to Region-II (over Region-III only operation) resulted in a further 34% decrease in DELs.

Chetan, M., Sakib, M.S., Griffith, D.T., Gupta, A., and Rotea, M.A., "Design of a 3.4MW Wind Turbine with Integrated Plasma Actuator-based Load Control" Wind Energy, September 2021, DOI: 10.1002/we.2684.

# Wind Turbine Digital Twins for Decision Support

## Project Summary

**Title:** "Decision Support Using FAST Aero-elastic Models of Operating Wind Turbines"

**Funding:** NSF/WindSTAR IUCRC

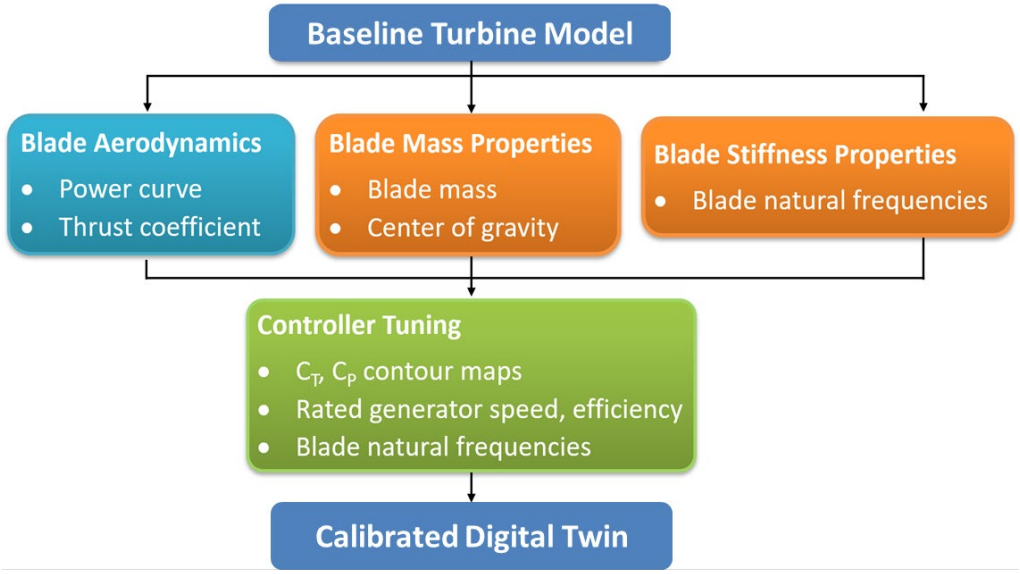
**Motivation:** Support decision-making of windfarm owner/operators in managing existing fleets of operating turbines.

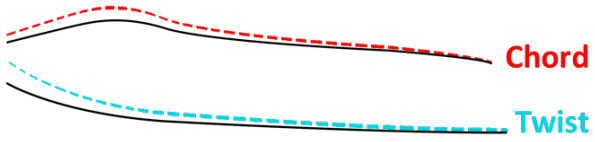
**Research Goal:** Ability to create accurate models of existing turbines from limited available data (e.g.; overcome data sharing limitations).

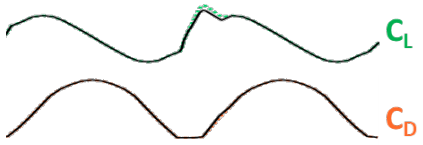
**Use Cases:** Life extension studies, trouble-shooting, assess integrity of repair, performance upgrades, etc.

## Key Results

- Methodology based on limited data to capture torque and thrust loads was developed.
- Digital Twin model used to demonstrate "decision support".

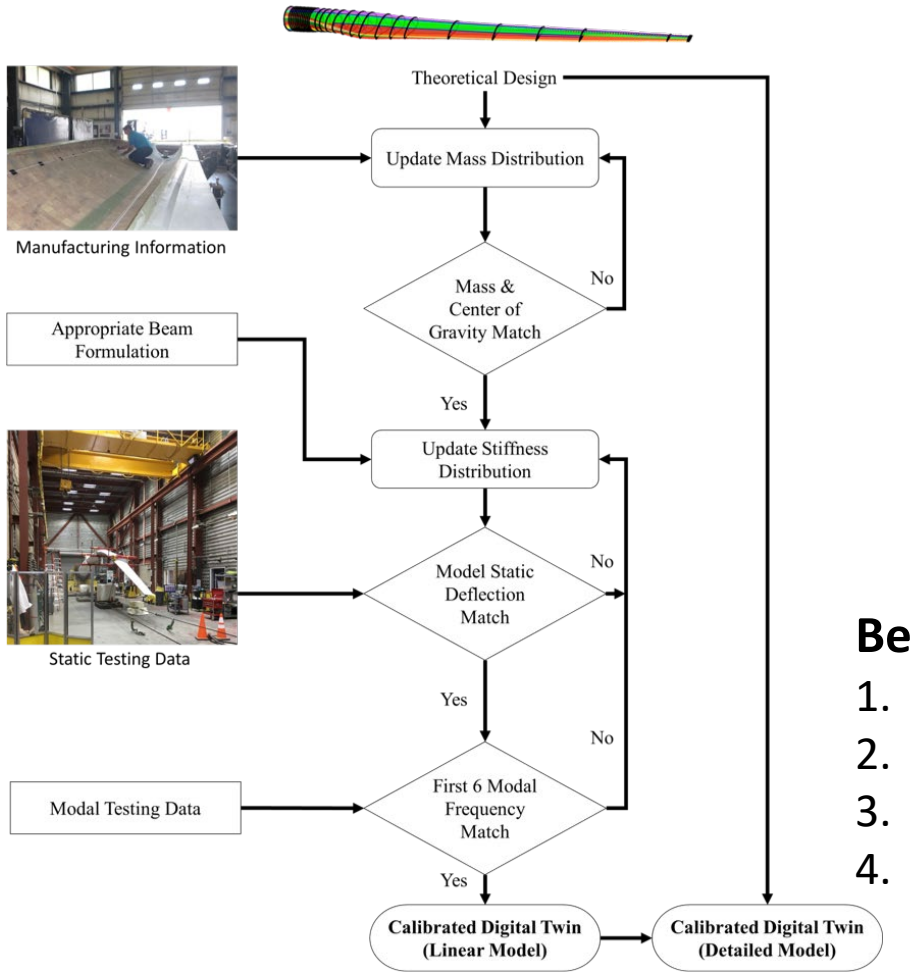


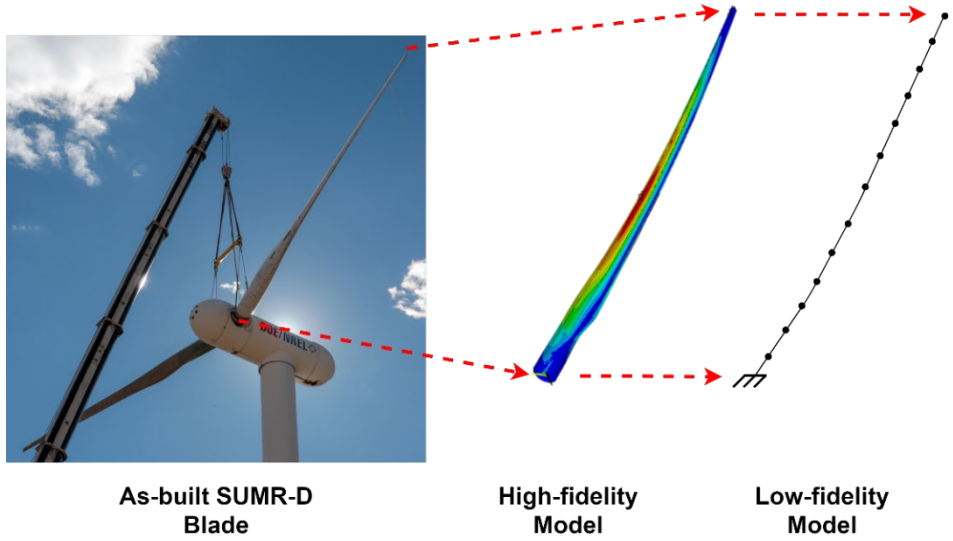



# Multi-fidelity Digital Twin Model

Method follows blade from *design*, to *manufacturing*, to *lab testing*, to *field operation*.




**<u>Multi-fidelity Digital Twin Structural Model:</u>** High-fidelity composite layup model and low-fidelity beam model (FAST model)

**Benefits of multi-fidelity digital twin:**

1. Ensure safety requirements confirmed using high-fidelity twin model
2. Accurate blade "twin" model provided for controller design/implementation
3. Higher-fidelity component model for life-extension evaluation
4. Can implement for major components (blade, drivetrain, tower, pitch sys) to follow a component from design through operation and end of life.



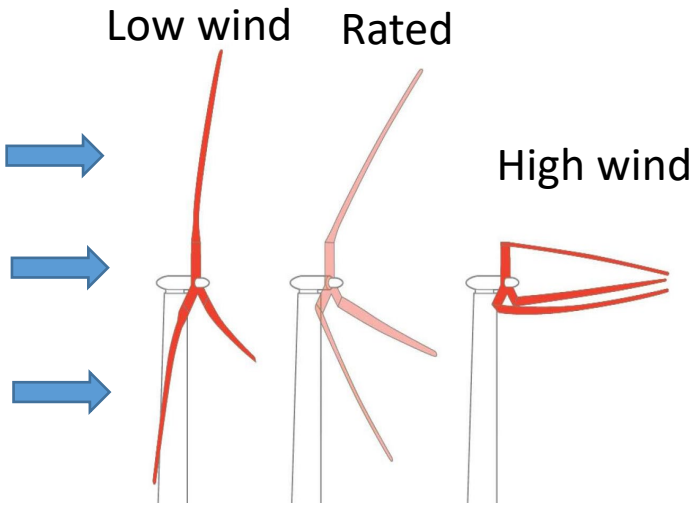
Chetan, M., Yao, S., and Griffith, D.T., "Multi-fidelity Digital Twin Structural Model for a Sub-scale Downwind Wind Turbine Rotor Blade," Wind Energy, February 2021, doi: 10.1002/we.2636.

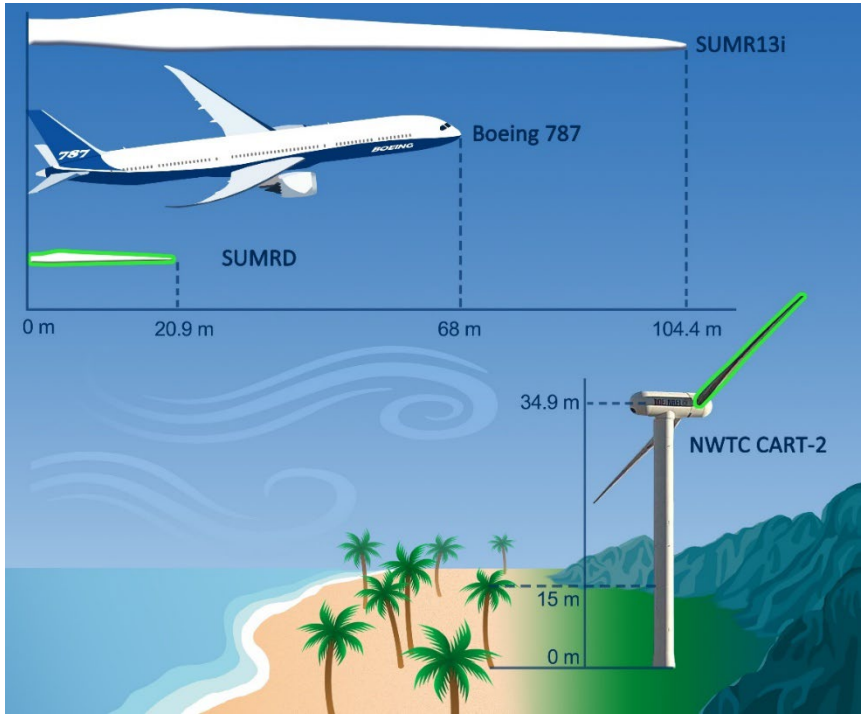
# Segmented Ultralight Morphing Rotors (SUMR) Project

**Project Summary**

**Title:** 50MW Segmented Ultralight Morphing Rotor (SUMR)

**Partners:** UVA (lead), **UT-Dallas**, CUB, UIUC, NREL



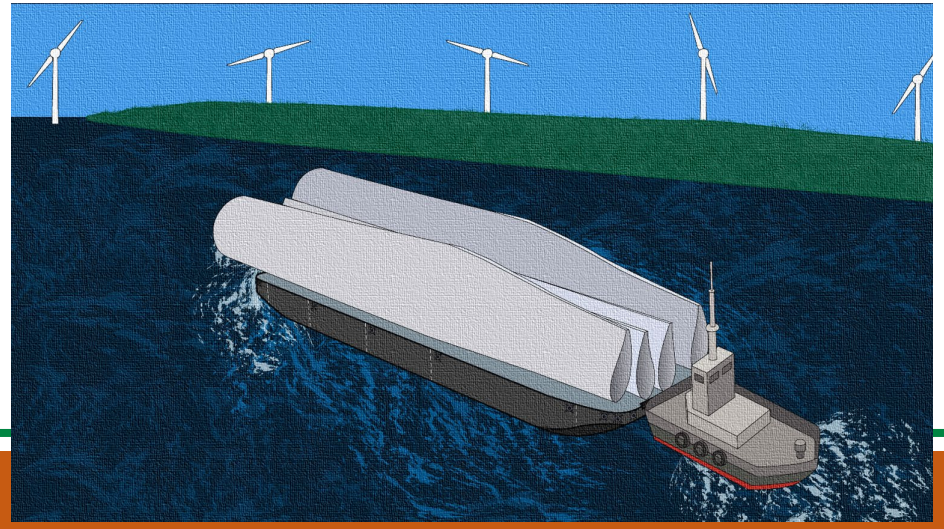




**Research Description**

**Summary:** Downwind rotors with load alignment (aerodynamic, gravitational, and centrifugal) to enable lightweight extreme-scale turbines (e.g., 13-50 MW).

**Key Rotor Design Results**

1. SUMR13i rotor achieved 25% mass reduction.
2. A 1/5$^{th}$ scale demonstrator (SUMR-D) was successfully designed, fabricated, and field tested.
3. Structural design for a 250-meter blade for 50MW rotor.



Project website: https://sumrwind.com/

# Structural Design of SUMR-D:

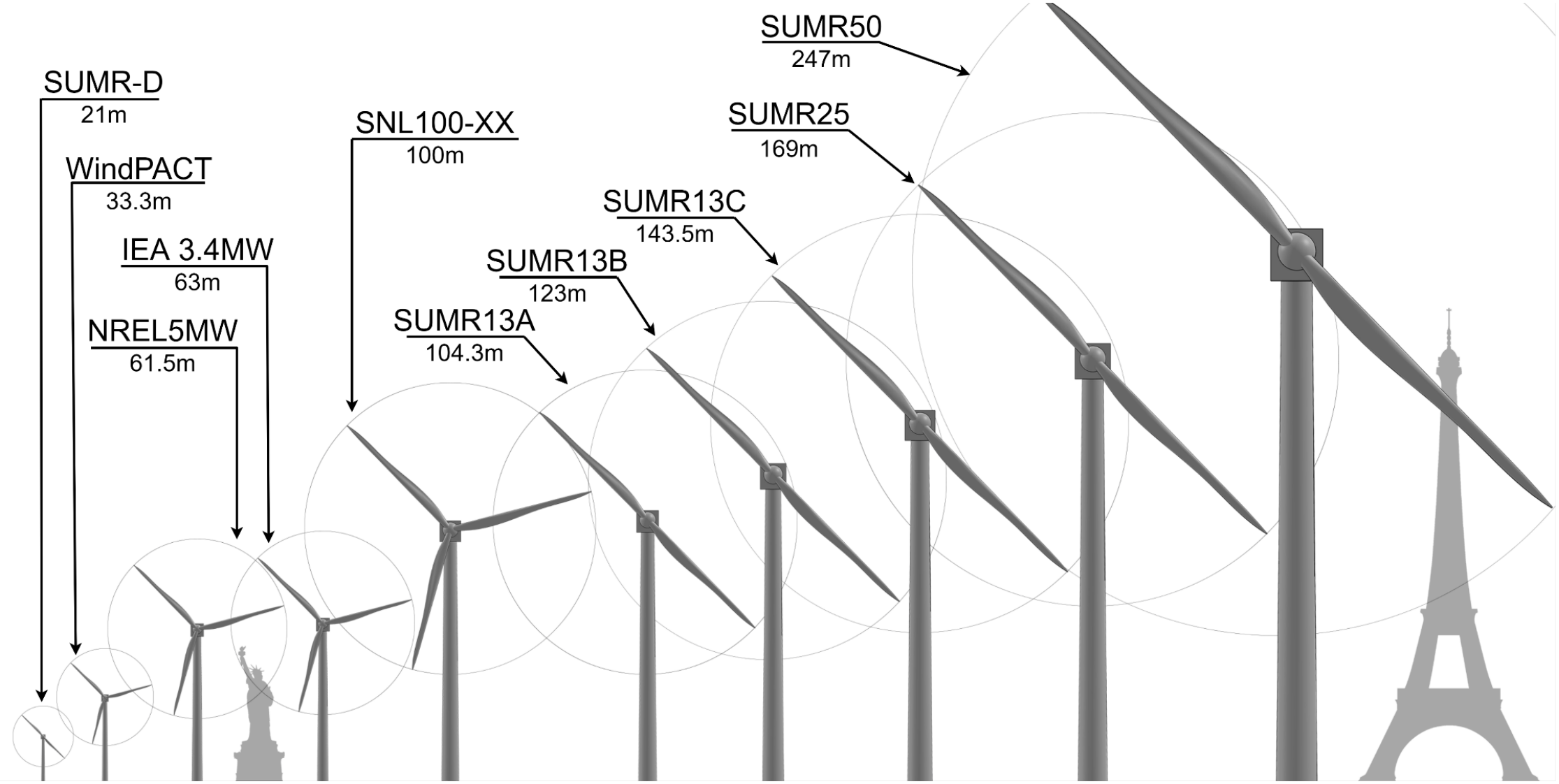
## GAS scaling and structural safety requirements met to successfully test a scaled 13.2MW downwind rotor

1. GAS = gravo-aeroelastic scaling used to mimic aero and gravitational loads, and dynamics of the full-scale 13.2 MW rotor
2. Site requirements also dictate design for safe operation (max strains, deflection, buckling, etc) in extreme events

| | GAS Target | Design | As Built |
|---|---|---|---|
| Blade mass [kg] | 351 | 827 | 995 |
| Center of gravity [m] | - | 4.6 | 4.94 |
| 1st flapwise frequency at rated [Hz] | 1.53 | 1.5 | 1.22 |
| Nondimensional flapwise frequency [-] | 4.18 | 4.10 | 3.33 |
| Tip deflection [m] | 1.42 | 1.39 | 1.18 |
| Nondimensional tip deflection [-] | 0.068 | 0.067 | 0.056 |

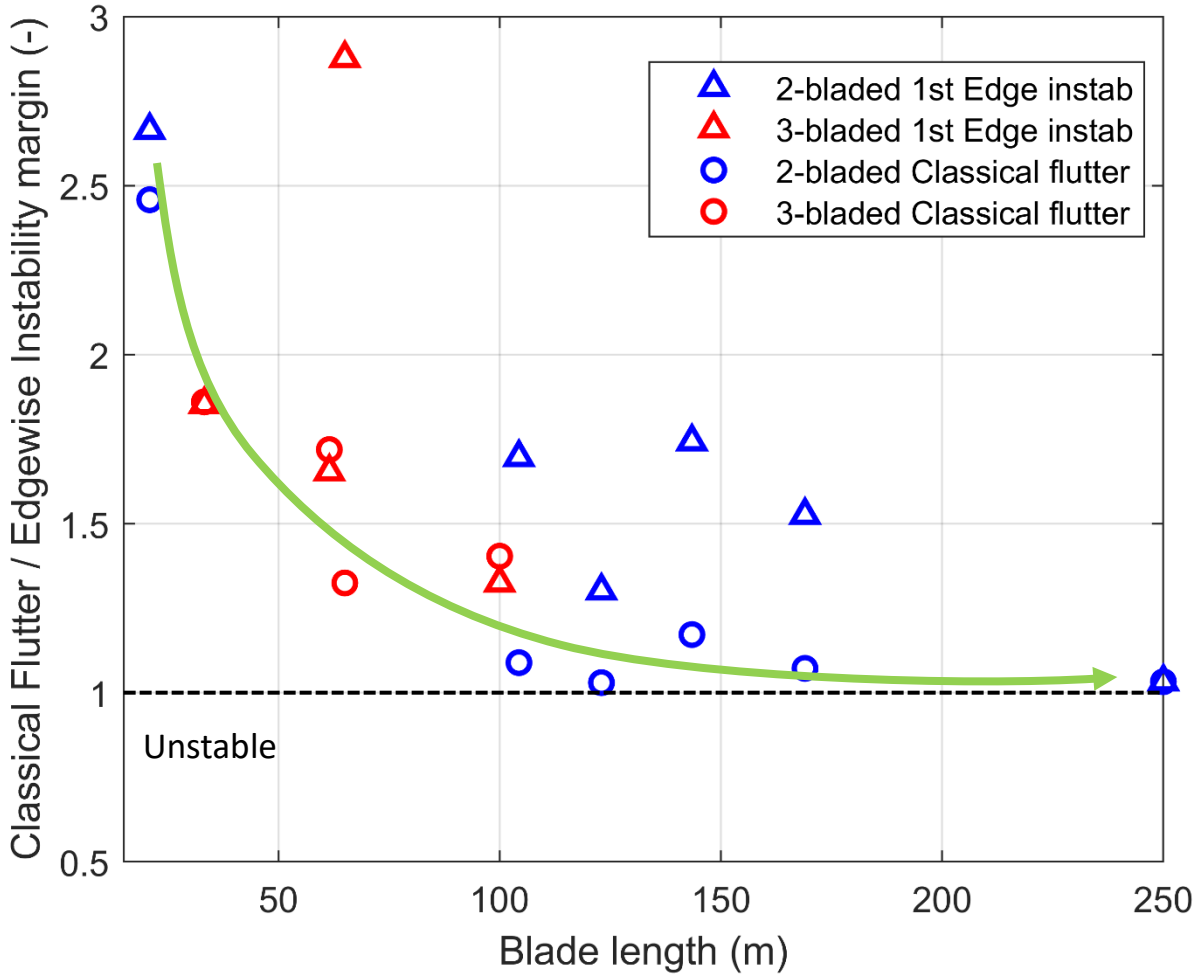
Yao, S., Griffith, D.T., Chetan, M., Bay, C., Damiani, R., Kaminski, M., and Loth, E., “A gravo-aeroelastically scaled wind turbine rotor at field-prototype scale with strict structural requirements,” Renewable Energy, 2020.

# Aero-elastic stability analysis: 2-bladed and 3-bladed




Chetan, M., Yao, S., and Griffith, D. T.: Flutter Behavior of Highly Flexible Two- and Three-bladed Wind Turbine Rotors, Wind Energ. Sci. Discuss., https://doi.org/10.5194/wes-2021-132, August 2022.

# Aero-elastic stability analysis: 2-bladed and 3-bladed

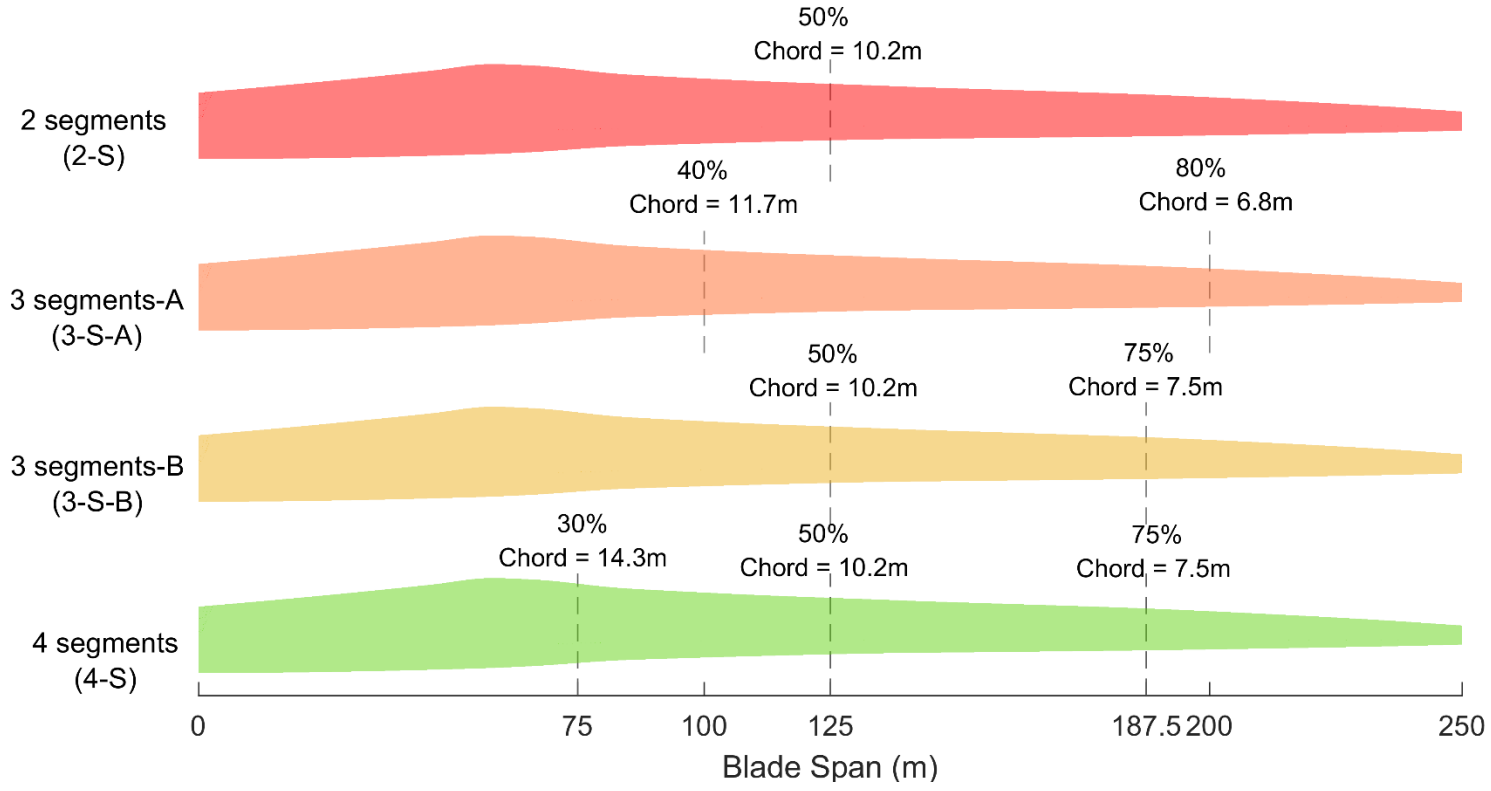


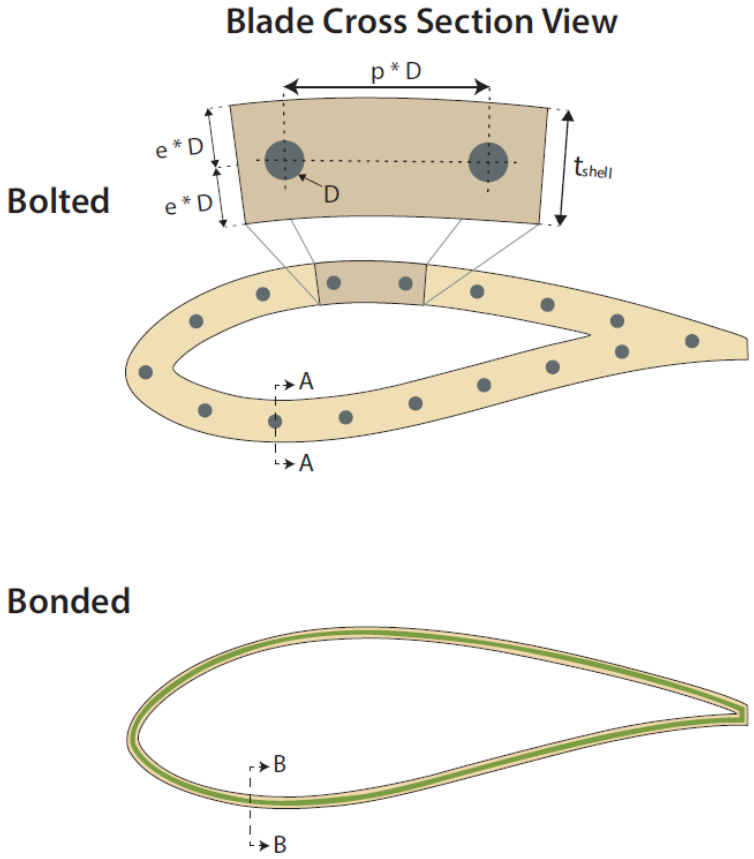

**Key Take-aways:**

1. For 3-bladed turbines, first instability is primarily **edgewise vibration**.
2. For 2-bladed designs, **classical coupled mode flutter occurs first (at lower RPM)**.
3. We can observe **asymptotic** nature for both two- and three-bladed designs.
4. Structural modification (re-design) showed to be viable to increase flutter speed without mass penalty.

Chetan, M., Yao, S., and Griffith, D. T.: Flutter Behavior of Highly Flexible Two- and Three-bladed Wind Turbine Rotors, Wind Energ. Sci. Discuss., https://doi.org/10.5194/wes-2021-132, August 2022.

# Segmented 250m Blade Design (50MW) and Cost Analysis



# Project: “A Low-cost Floating Offshore Vertical Axis Wind System”

**Inherent VAWT advantages + Control co-design = Market ($)**

UT DALLAS The University of Texas at Dallas

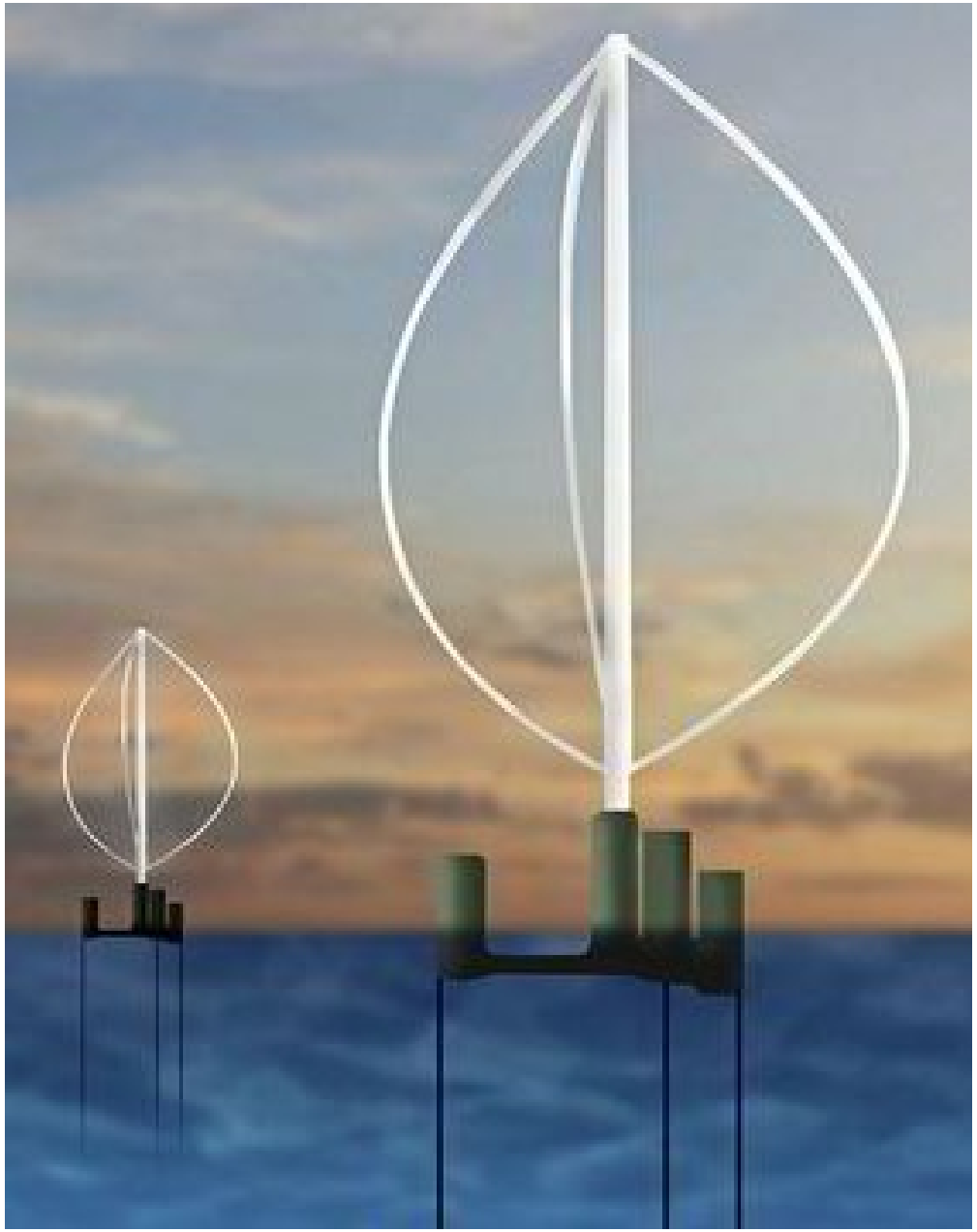
VL Offshore Engineering Solutions

ARCTURA

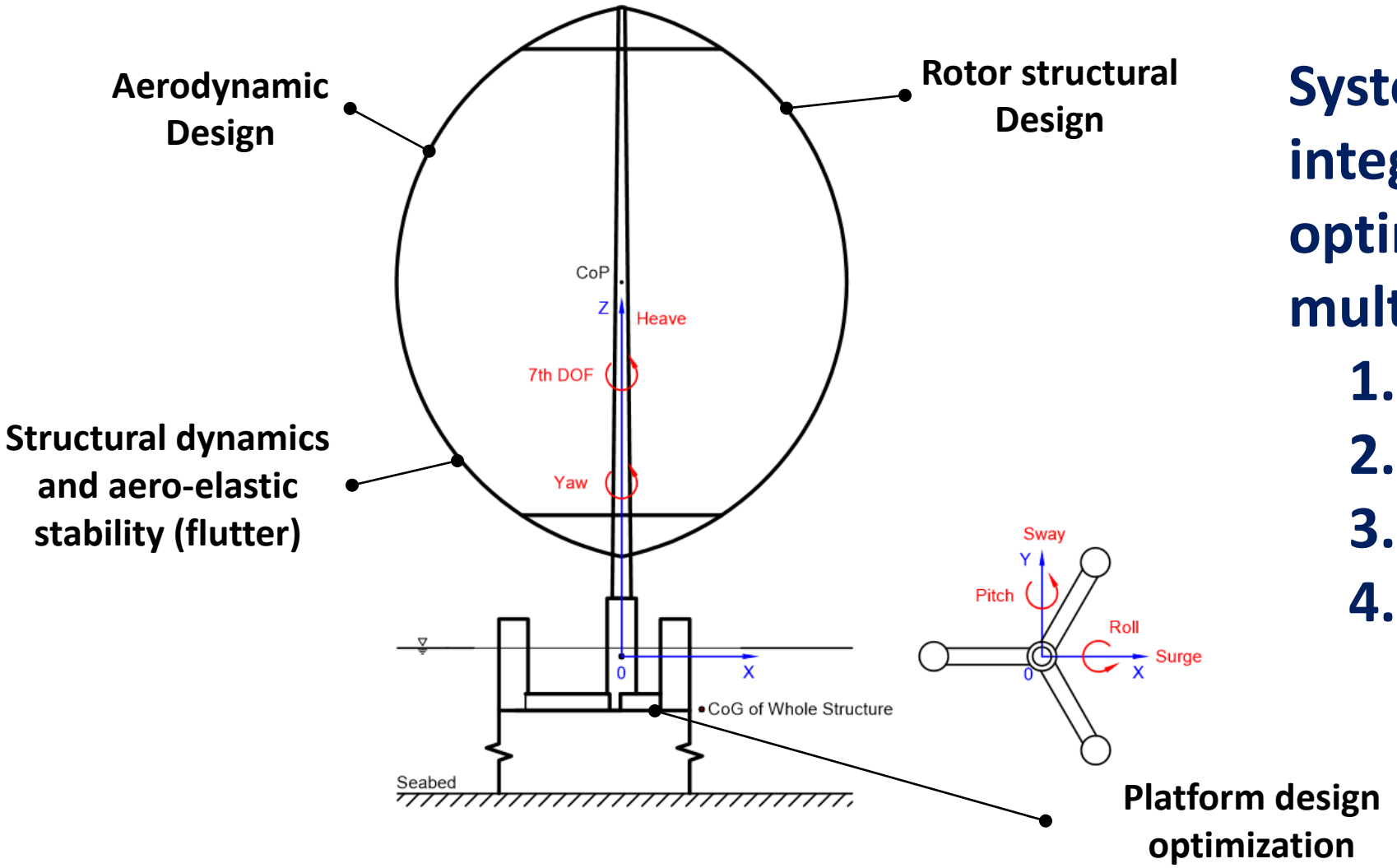
XFLOW ENERGY

ILLINOIS

ARPA-E ATLANTIS Program



# R&D Focus Areas




**System-level integration and optimization of multiple disciplines:**

1. Aerodynamics
2. Structural
3. Hydrodynamics
4. Control system

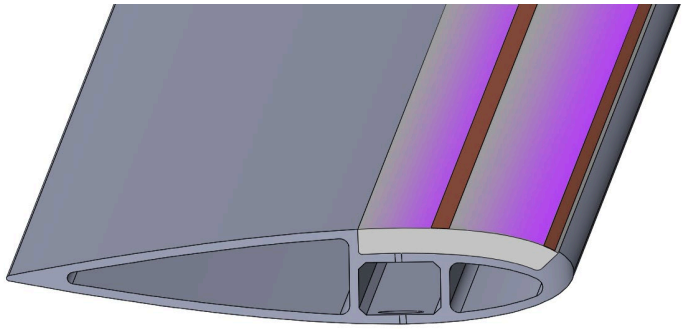
# Wind tunnel demonstration of two control methods

**Experimental Test Bed Designed and Tested**

Demonstration of new control elements

Data gathering to inform full-scale

- **Intra-cycle RPM Control**
- **Plasma Actuation**



**Plasma Actuators**

**Photo in Wind Tunnel with Plasma Actuation**

Jafari, M., Sakib, M.S., Griffith, D.T., Brownstein, I., Strom, B., and Cooney, J., "Wind Tunnel Experiment to Study Aerodynamics and Control of H-Rotor Vertical Axis Wind Turbine," Journal of Physics: Conference Series 2265 (2), 022084.

# Thank You

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## Thanks to our Sponsors.

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NSF National Science Foundation

WindSTAR
Wind-Energy Science, Technology, and Research
Industry/University Cooperative Research Center

IFE Institute for Energy Technology

# References


1. Chetan, M., Yao, S., and Griffith, D.T., “Flutter Behavior of Highly Flexible Blades for Two- and Three-bladed Wind Turbines,” Wind Energ. Sci. Discuss., https://doi.org/10.5194/wes-2021-132, August 2022.
2. Jafari, M., Sakib, M.S., Griffith, D.T., Brownstein, I., Strom, B., and Cooney, J., “Wind Tunnel Experiment to Study Aerodynamics and Control of H-Rotor Vertical Axis Wind Turbine,” Journal of Physics: Conference Series 2265 (2), 022084.
3. Ahsan, F., Griffith, D.T., and Gao, J., “Modal dynamics and flutter analysis of floating offshore vertical axis wind turbines,” Renewable Energy, December 2021, https://doi.org/10.1016/j.renene.2021.12.041.
4. Escalera Mendoza, A.S., Yao, S., Chetan, M., and Griffith, D.T., “Design and Analysis of a Segmented Blade for a 50 MW Wind Turbine Rotor,” Wind Engineering, January 2022.
5. Yao, S., Griffith, D.T., Chetan, M., Bay, C., Damiani, R., Kaminski, M., and Loth, E., “A gravo-aeroelastically scaled wind turbine rotor at field-prototype scale with strict structural requirements,” Renewable Energy, 2020.
6. Griffith DT, Fine NE, Cooney JA, Rotea MA, Iungo GV. Active Aerodynamic Load Control for Improved Wind Turbine Design. *J Phys: Conf Ser*. 2020;1618:052079. doi:10.1088/1742-6596/1618/5/052079.
7. Chetan, M., Sakib, M.S., Griffith, D.T., Gupta, A., and Rotea, M.A., “Design of a 3.4MW Wind Turbine with Integrated Plasma Actuator-based Load Control” Wind Energy, September 2021, DOI: 10.1002/we.2684.
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9. Yao, S., Chetan, M., Griffith, D.T., Escalera Mendoza, A.S., Selig, M., Martin, D., Kianbakht, S., Johnson, K., and Loth, E., “Aero-Structural Design and Optimization of 50 MW Wind Turbine with over 250-meter Blades,” Wind Engineering, July 2021, https://doi.org/10.1177/0309524X211027355.