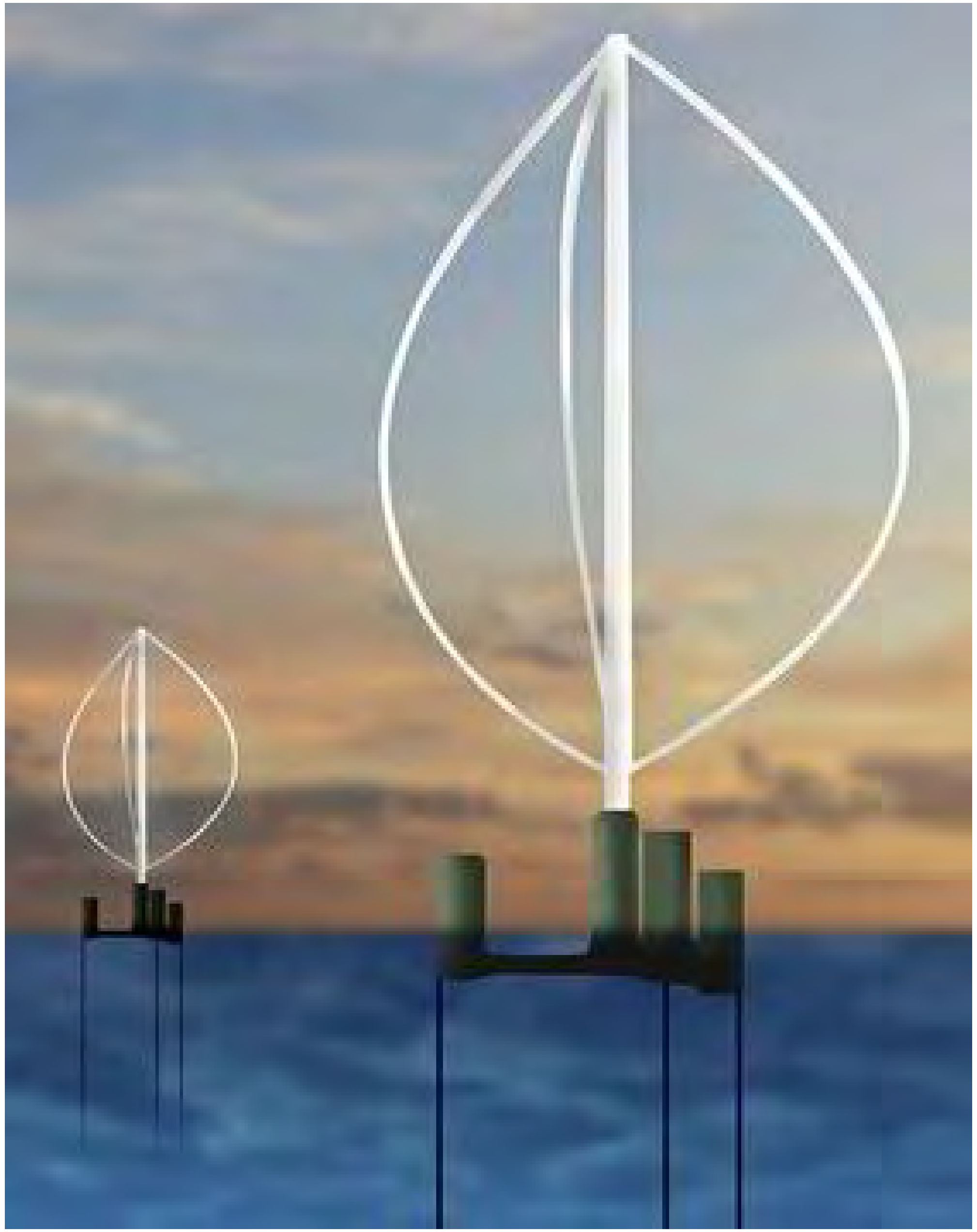
Exploring and Exploiting System-level Design Synergies for Floating Vertical Axis Wind Systems

D. Todd Griffith, PhD

University of Texas at Dallas, Mechanical Engineering

6th Wind Energy Systems Engineering Workshop

August 30, 2022 Boulder, CO, USA



A Low-cost Floating Offshore Vertical Axis Wind System

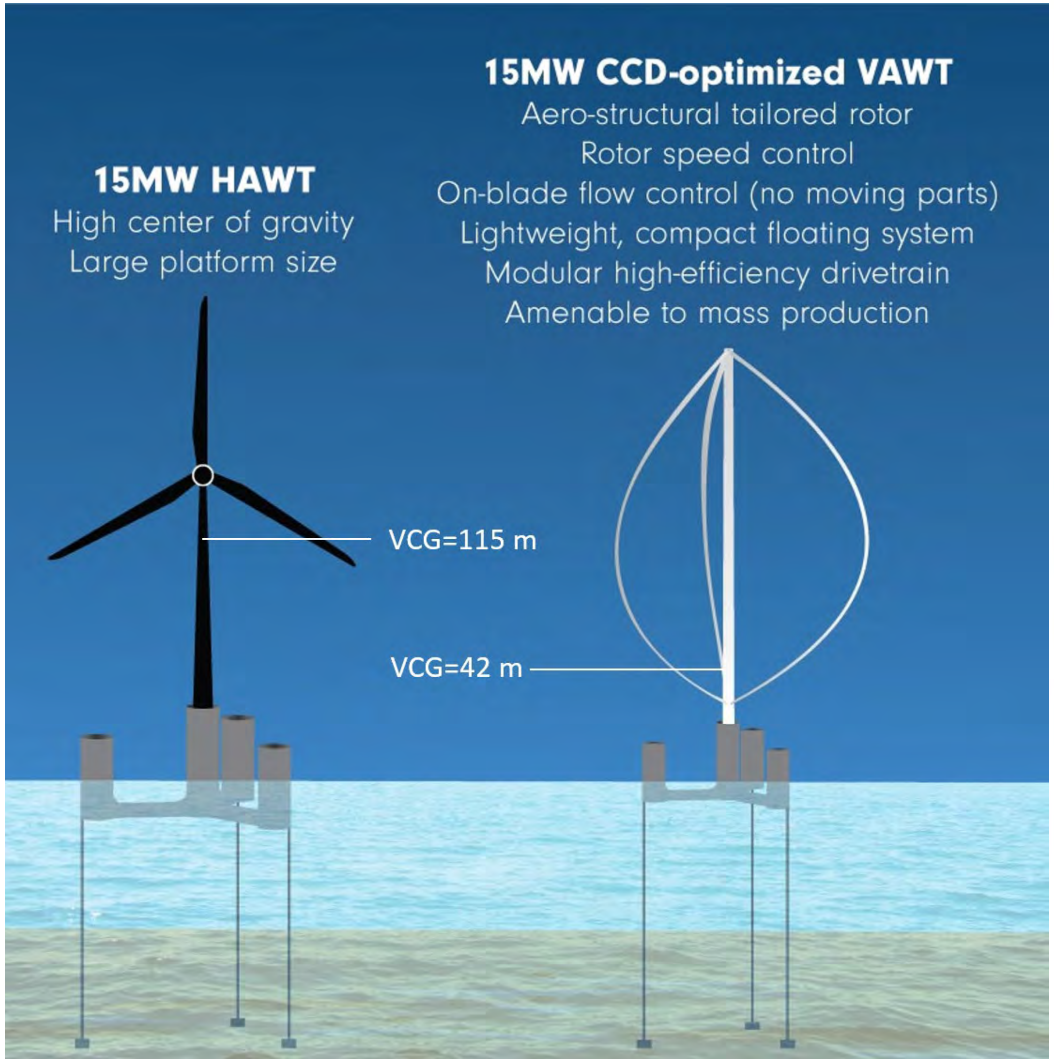
Todd Griffith, UT-Dallas

Key elements of the FloatVAWT Project

- **Inherent VAWT advantages + CCD = Market ($)**
- Main R&D thrust is a system solution using (mostly) low-risk elements optimized with CCD
- **Motivation:**
  - Deep-water offshore is a huge market opportunity.
  - New floating technologies are needed.
  - Opportunity to improve VAWT reliability with new design approach and new technologies.

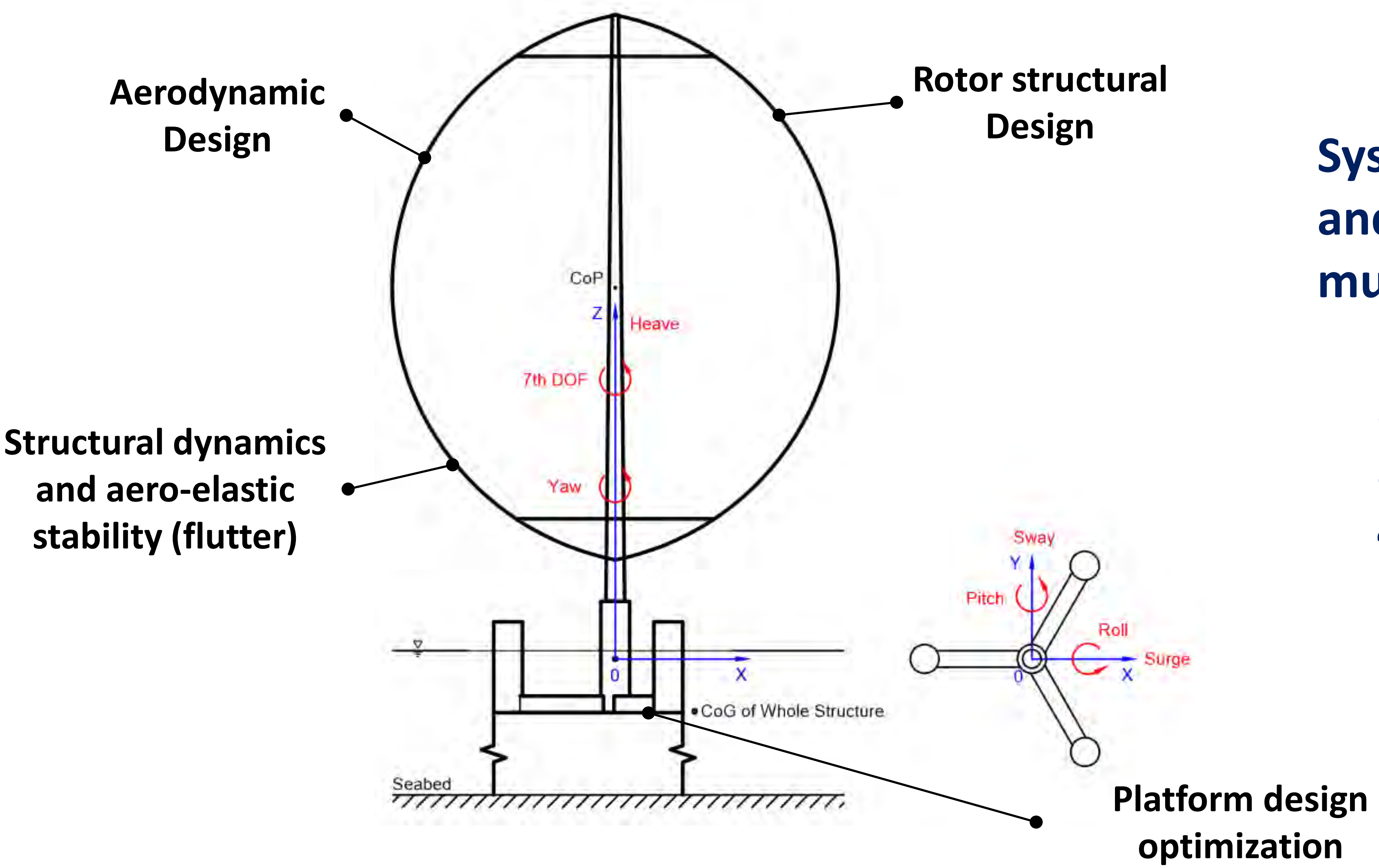
Team members

- **UT-Dallas:** rotor design, system modeling, controls, CCD
- **VL Offshore:** floating system design
- **Arctura:** active flow control, wind tunnel
- **XFlow Energy:** wind tunnel, rotor fabrication for wave tank
- **UIUC:** CCD (control co-design)



UT DALLAS The University of Texas at Dallas · VL Offshore Engineering Solutions · ARCTURA · XFLOW ENERGY · ILLINOIS · arpa·e CHANGING WHAT'S POSSIBLE

R&D Focus Areas



System-level integration and optimization of multiple disciplines:

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

1. Aero-Structural Design Optimization

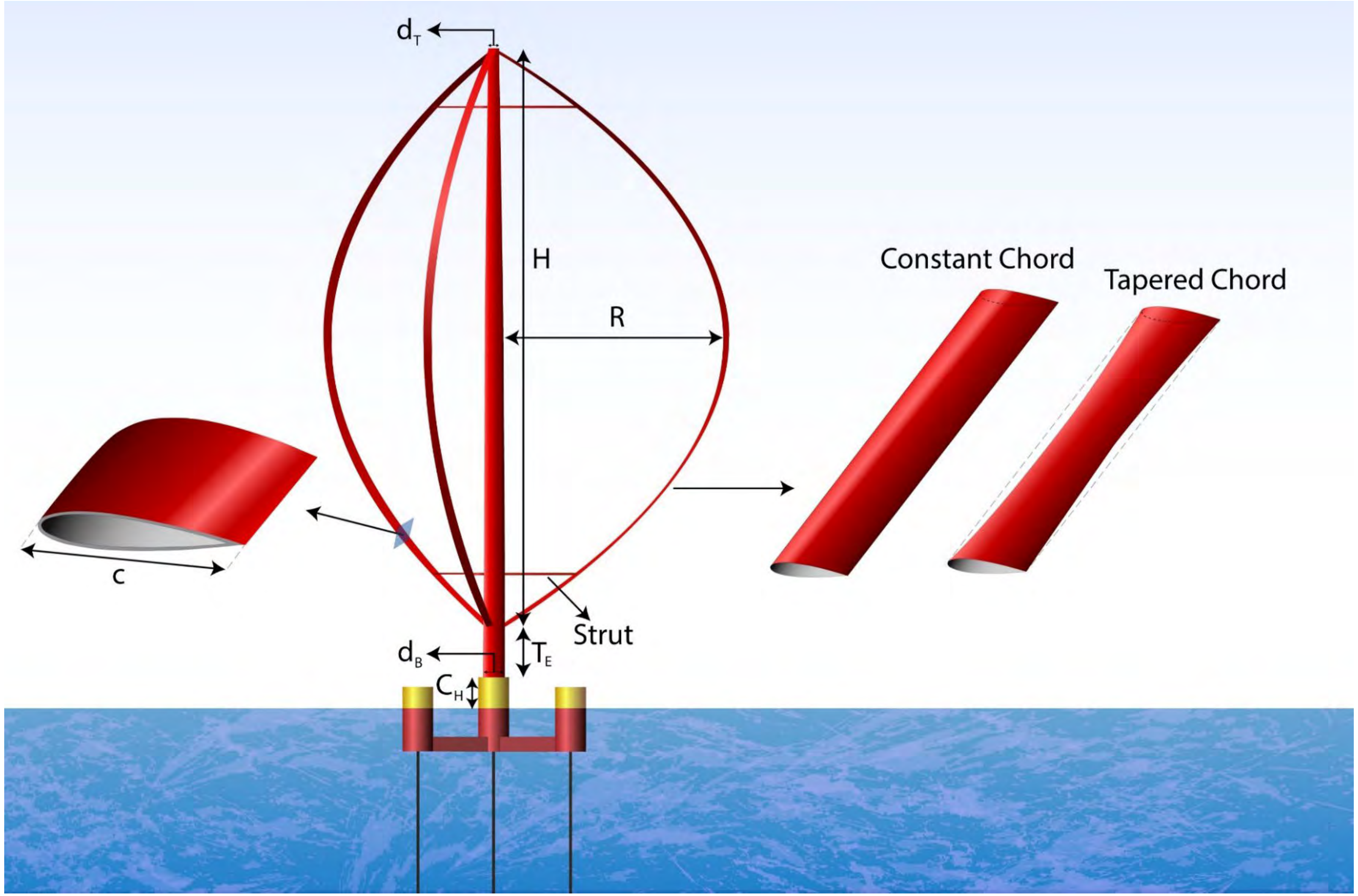
Questions:

What is the optimal solidity of the rotor?

To maximize energy capture?

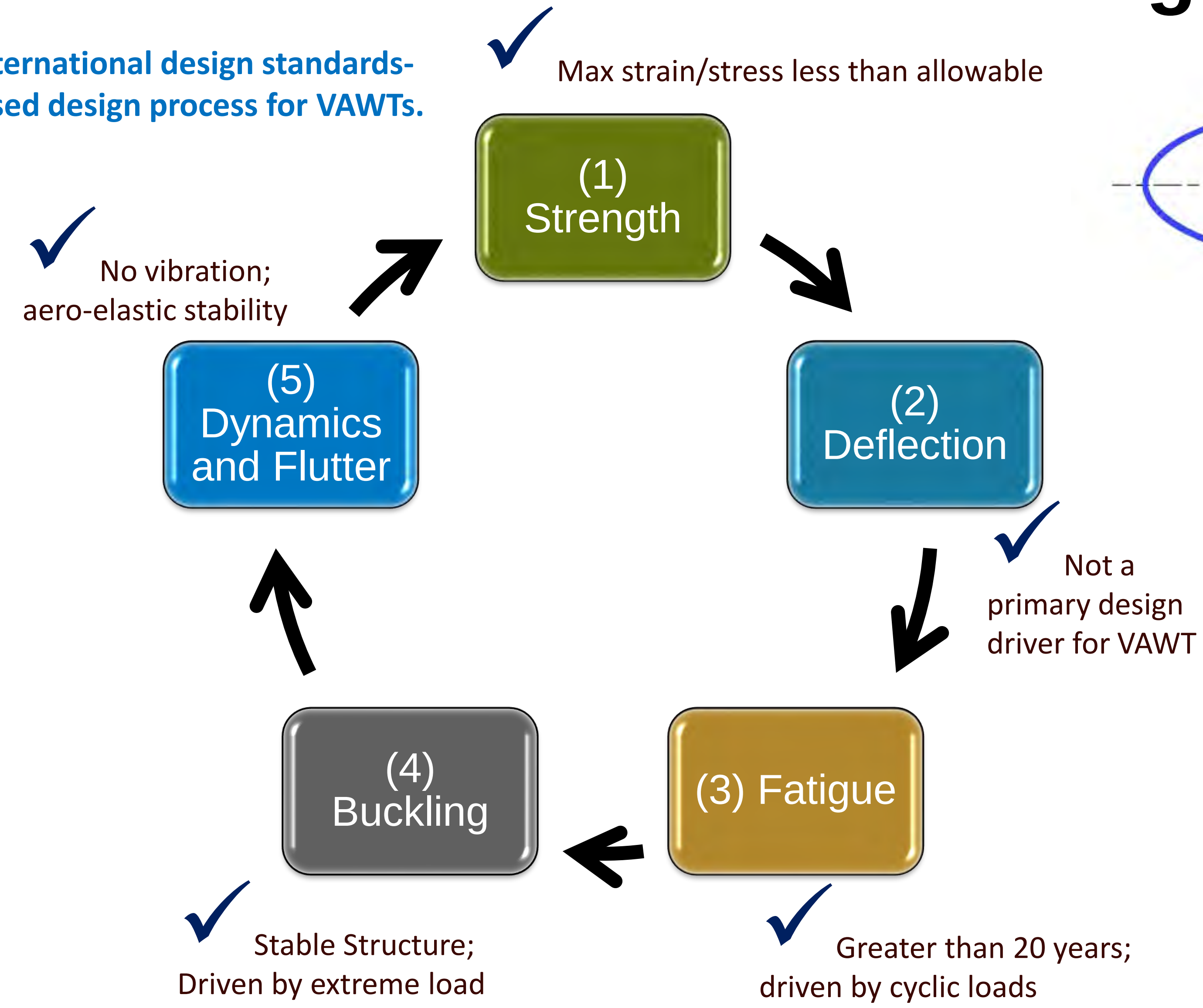
To minimize rotor mass?

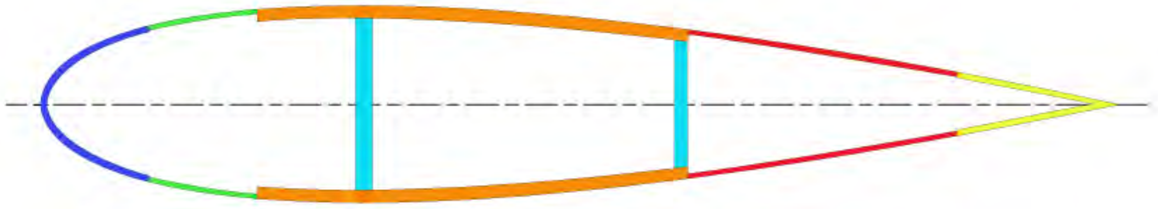
To minimize cost of electricity?



Rotor Structural Design Loop: VAWT

International design standards-based design process for VAWTs.



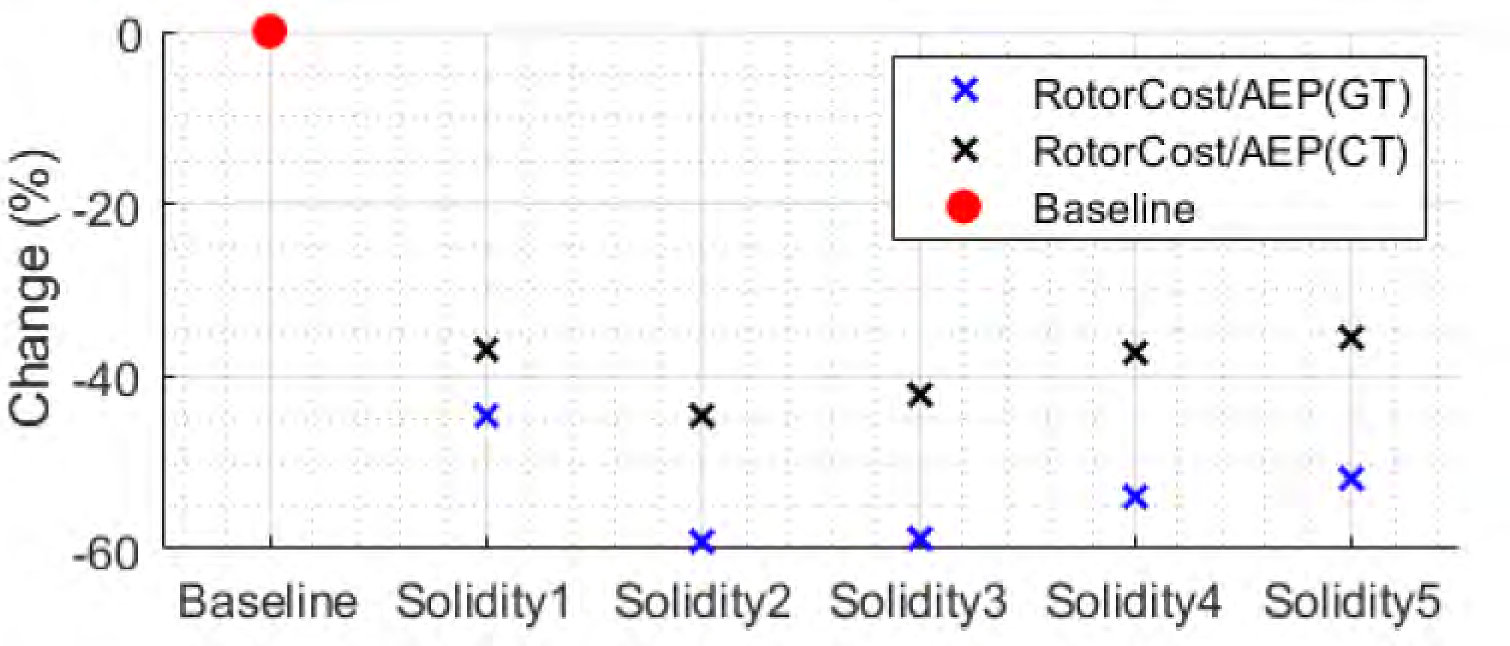


Design limits and requirements:

1. Strength: max strain check
2. Deflection: top tower deflection check
3. Fatigue: at least 20 years life
4. Buckling: No buckling for tower and blades.
5. Dynamics and Flutter: structural dynamics resonance check (Campbell diagram) and flutter analysis performed

Aero-structural Solidity Results

- **Rotor cost over AEP is used as a cost metric for comparison**



2. Aero-elastic Stability for Floating VAWTs

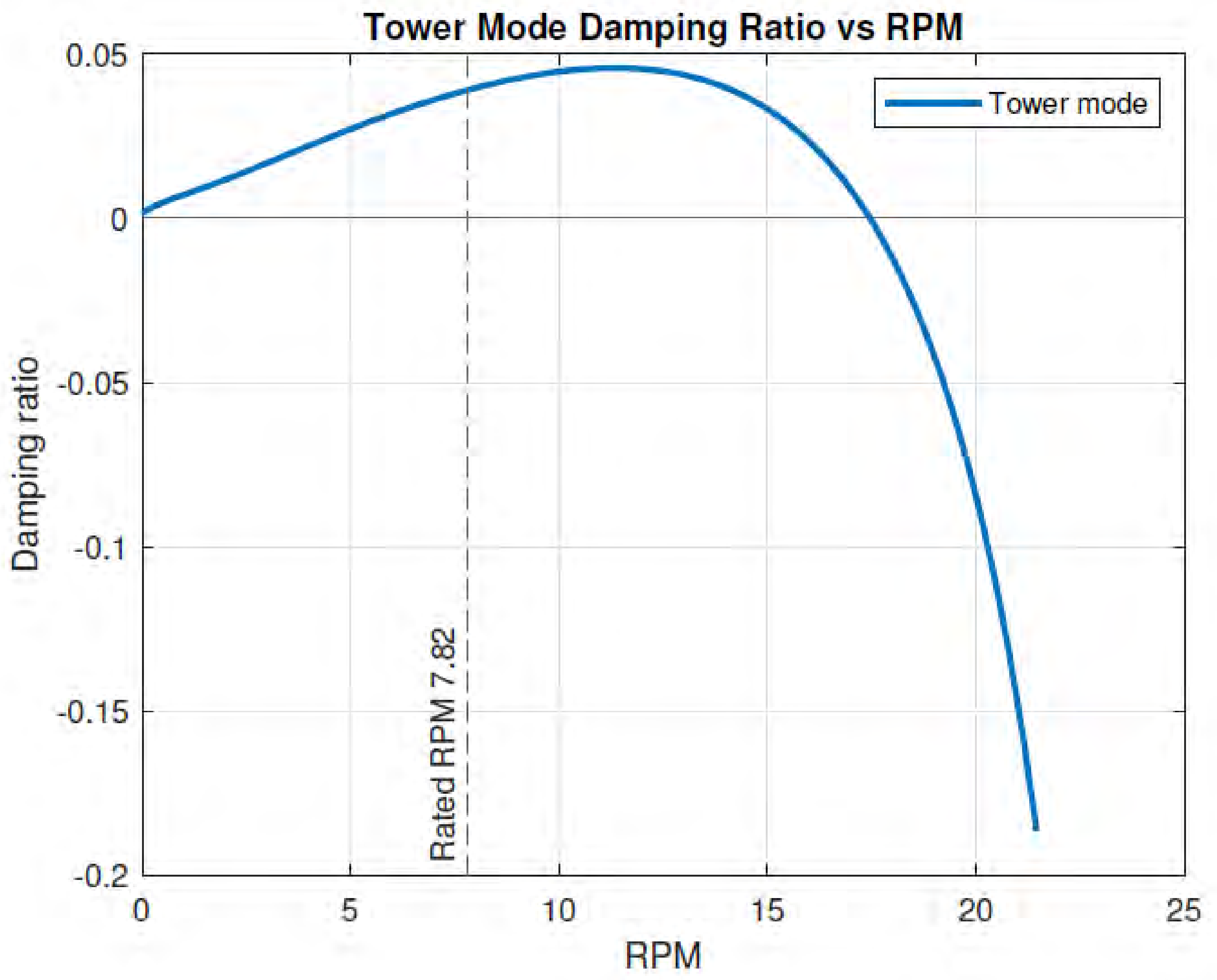
Questions:

What are the characteristic flutter modes for VAWTs?

What is the impact of rotor design parameters (tower height, chord, etc.) on flutter speed?

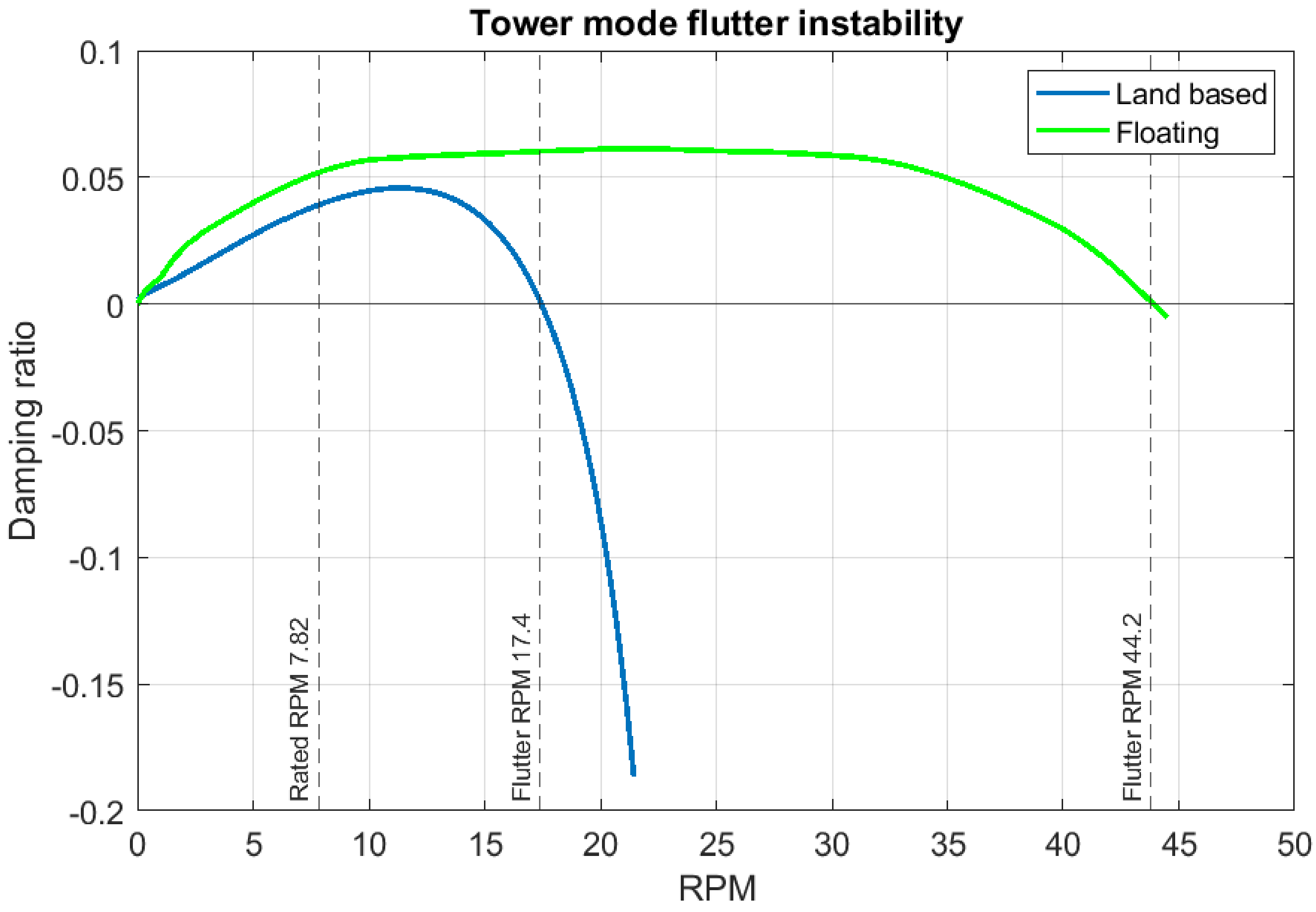
What is the impact of floating system on flutter speeds?

Are the rigid body modes stable?



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.

VAWT Flutter: Floating system has beneficial effect

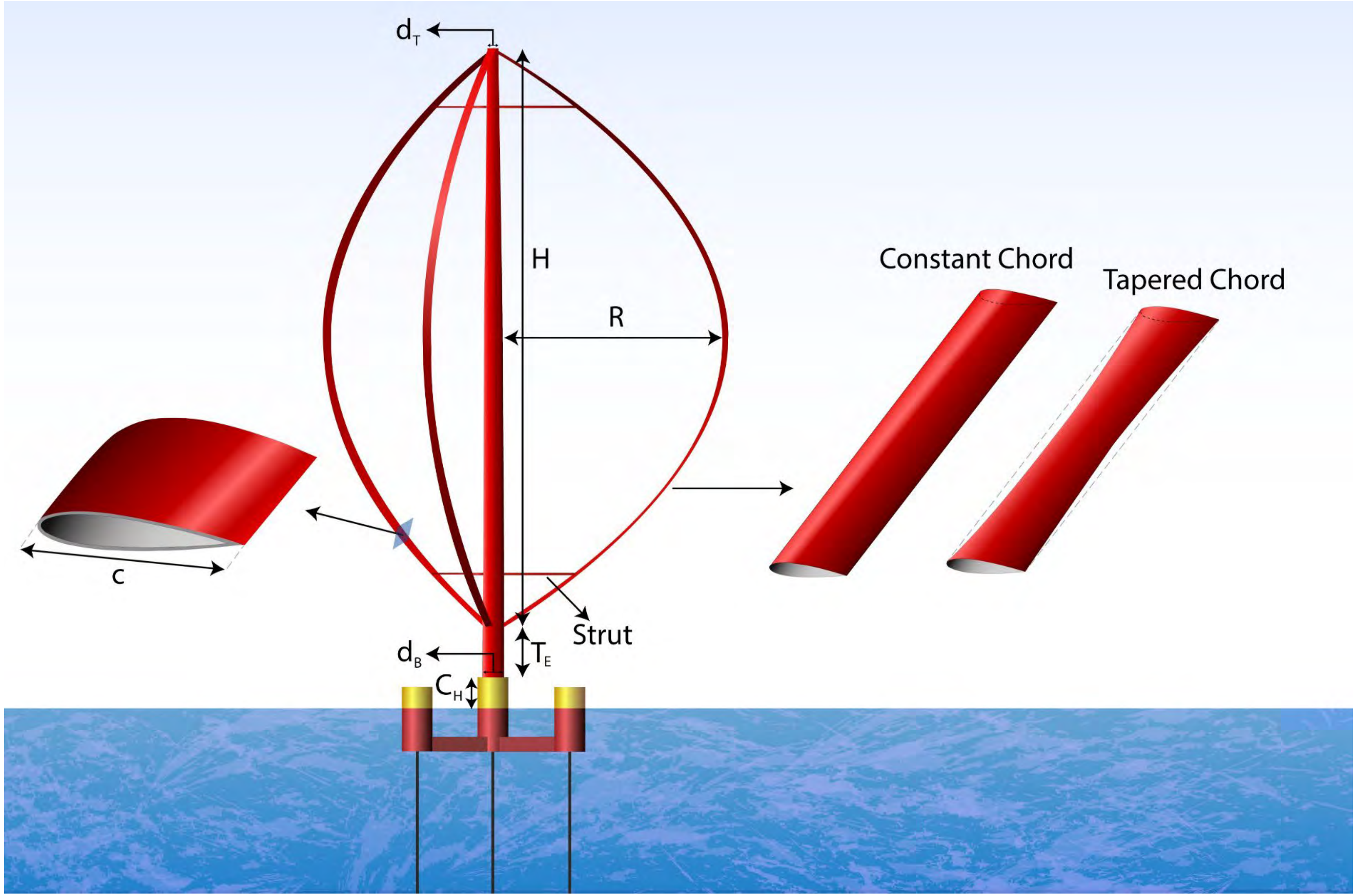


Floating system impact:

1. Flutter speed increased 154% compared to land-based VAWT.
2. Tower mode frequency increased 49%-68% compared to the land-based VAWT.

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.

3. Solidity + VAWT RPM Control



Questions:

What is the optimal configuration of the rotor for a floating VAWT?

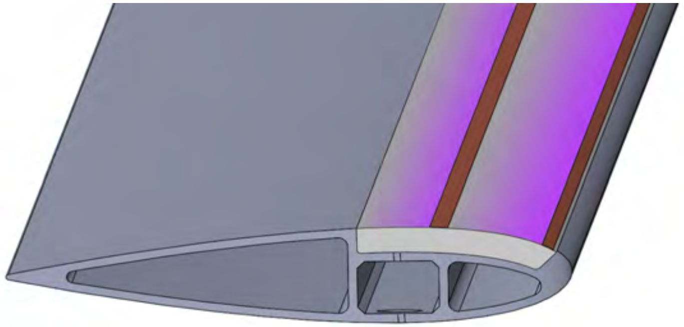
What is the impact of combining solidity design with intracycle RPM control?

4. Wind tunnel evaluation 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

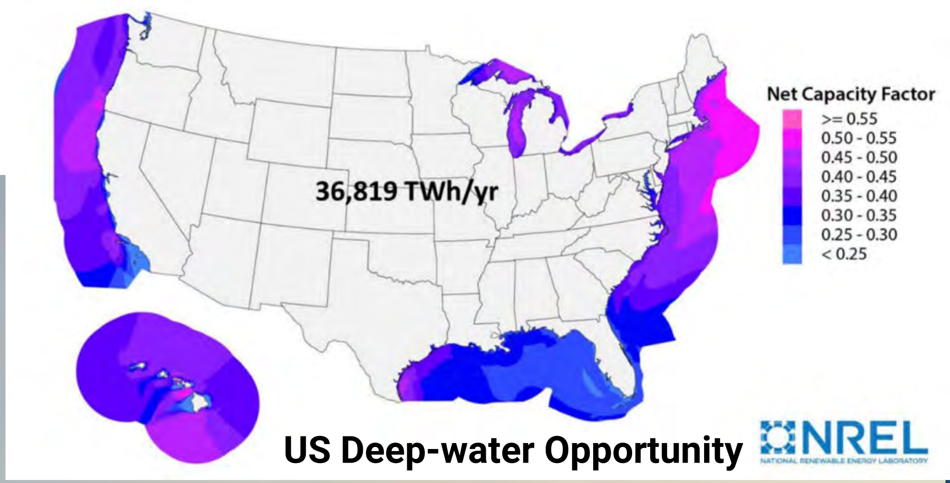
Photo in Wind Tunnel with Plasma Actuation

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.

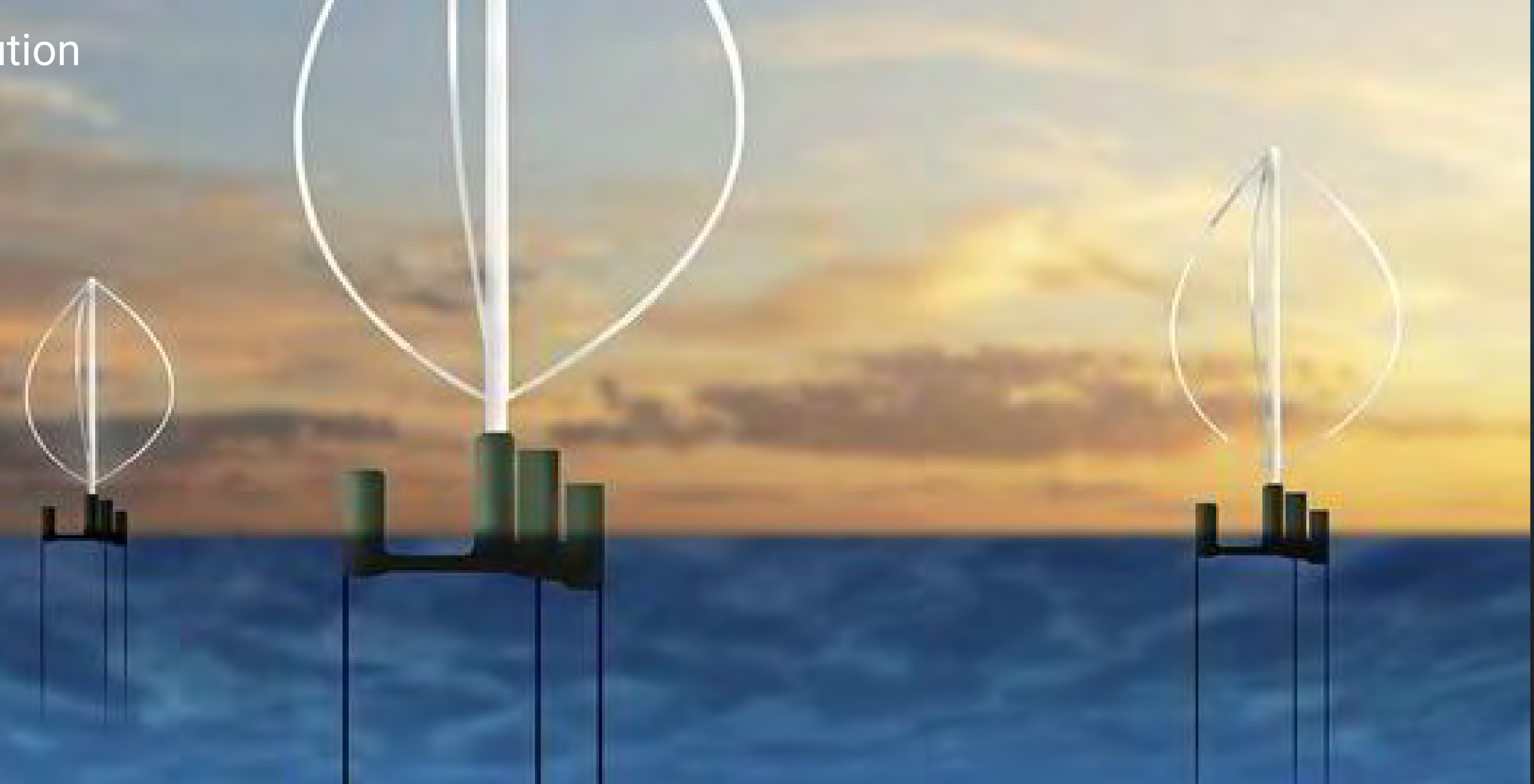
Concluding remarks

- Why floating VAWTs?
- Design synergies / interactions examined:
  1. Aerodynamics
  2. Structural / Structural Dynamics
  3. Hydrodynamics
  4. Controls (plasma control and intra-cycle RPM control)
- Good opportunity for CCD with floating VAWTs
  - H-CCD (hierarchical control co-design) developed for system-level optimization of aero, structure, hydro and control elements

Future Look



- Development plans with industry/components suppliers:
  - Composites
  - Hull fabrication
  - Installation & Execution



Please contact:
Todd Griffith
tgriffith@utdallas.edu
Website:
labs.utdallas.edu/Griffith

References

VAWT Aerodynamic Design

- Sakib, M.S. and Griffith, D.T., "Parked and operating load analysis in the aerodynamic design of multi-megawatt-scale floating vertical-axis wind turbines," Wind Energy Science, 7 (2), 677-696, https://doi.org/10.5194/wes-7-677-2022, 2022.

VAWT Structural Dynamics and Flutter Analysis

- 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.

VAWT Floating System Modeling

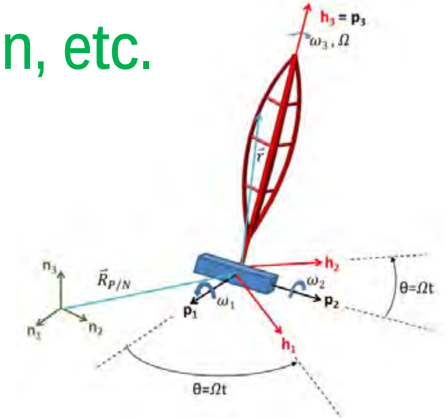
- Gao, J., Griffith, D.T., Sakib, M.S., and Boo, S.Y., "A Semi-coupled Aero-servo-hydro Numerical Model for Floating Vertical Axis Wind Turbines Operating on TLPs," Renewable Energy, September 2021, https://doi.org/10.1016/j.renene.2021.09.076.

VAWT System Design Studies and Cost Analysis

- Griffith, D.T., Barone, M., Paquette, J., Owens, B., Bull, D., Simao-Ferriera, C., Goupee, A., and Fowler, M., "Design Studies for Deep-Water Floating Offshore Vertical Axis Wind Turbines," Sandia National Laboratories Technical Report, SAND2018-7002, doi:10.2172/1459118.
- Ennis, B. and Griffith, D.T., "System Levelized Cost of Energy Analysis for Floating Offshore Vertical-Axis Wind Turbines," Sandia National Laboratories Technical Report, SAND2018-9131, doi:10.2172/1466530.

The quest for larger rotors continues at UT-Dallas........

New design concepts, sub-scale demonstration, flutter mitigation, segmentation, etc.



Thank You
D.T. Griffith
tgriffith@utdallas.edu

labs.utdallas.edu/griffith