Performance of cross-flow turbines for varying blade materials and unsupported blade span length

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Background & Motivation

- Axial-flow vs. cross-flow turbine
- High-Deflection hydrofoil (HDF) project, ORPC, DE-FOA 1663
  - Goal: lower levelized cost of energy (LCOE)
  - How? Modify:
    - materials
    - free end length
    - blade shape
      - Straight
      - Helical

Photo credit: https://simecatlantis.com/tidal-stream/

Photo credit: https://orpc.co/press-release/

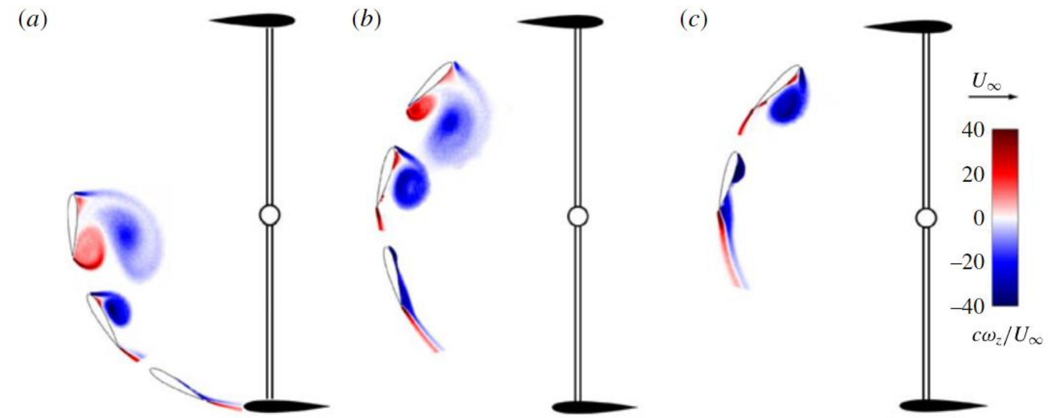


FIGURE 3. (Colour online) Phase-averaged vorticity contours and vector fields in the vicinity of a NACA0015 vertical axis wind turbine blade, for selected tip azimuthal blade positions. The $Re_c = 70\,000$ case is chosen for illustration, and $K_c = 0.15$. (a) $\lambda = 1$; (b) $\lambda = 2$; (c) $\lambda = 3$.

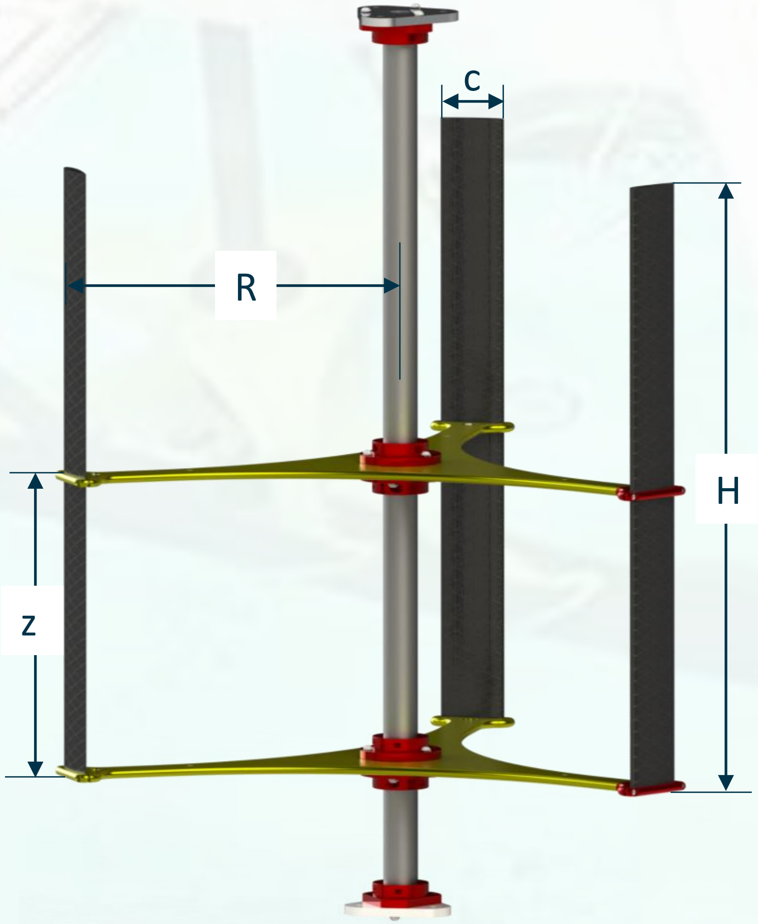
(Buchner et al. 2018, JFM)

Experimental Setup – HDF Turbine

- Vertical-axis cross-flow turbine (CFT)
  - Three NACA 0018 straight blades
  - Two support struts:
    - one fixed in position
    - one adjustable
- Constant parameters:
  - c = 0.095 m , R = 0.500 m, H = 0.900 m

Blade Material	Maximum allowable strain*	Strut Position, z/H				
		1	0.75	0.5	0.25	0.14
Carbon Fiber	0.24%	X	X	X	X	X
E-glass Fiber	0.35%	X	X	X	X	X
Hollow E-glass Fiber	0.35%	X	X	X	X	-

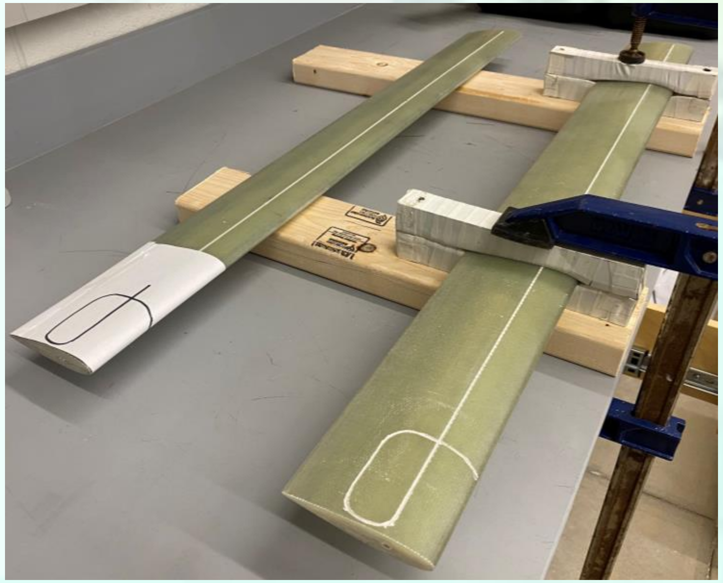
* Estimate from DNVGL-ST-0164



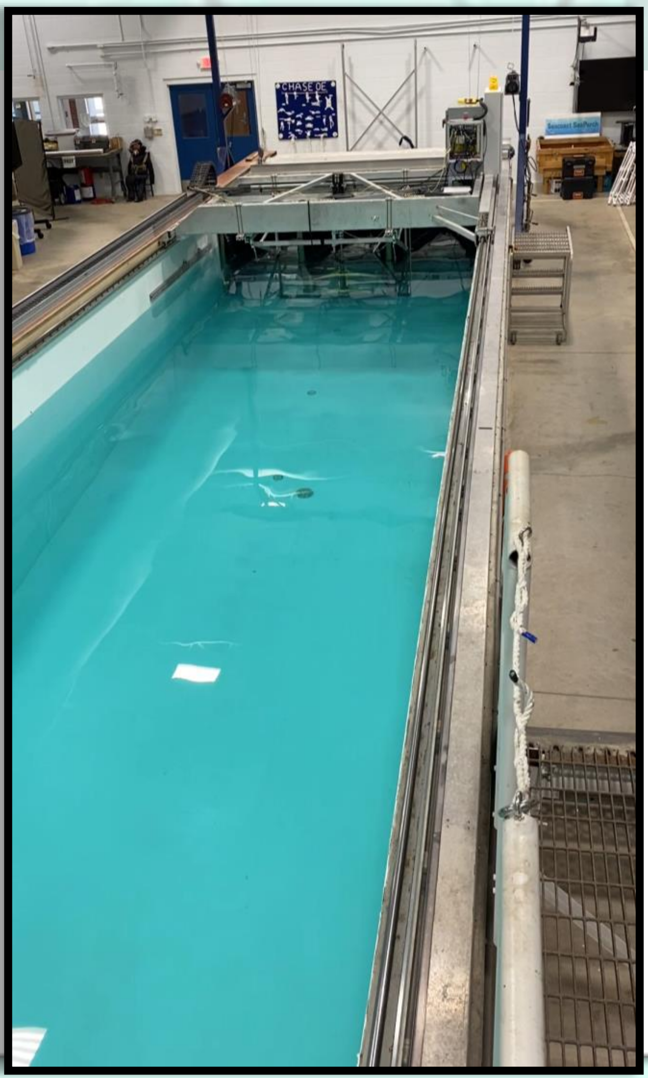
Experimental Setup – Fiber Optic Sensors

- distributed fiber optic sensor embedded in 2 out of 3 blades (front and back) - one 5m long optical fiber
- Bare fiber between blades secured to lower strut with conformable low-friction tape

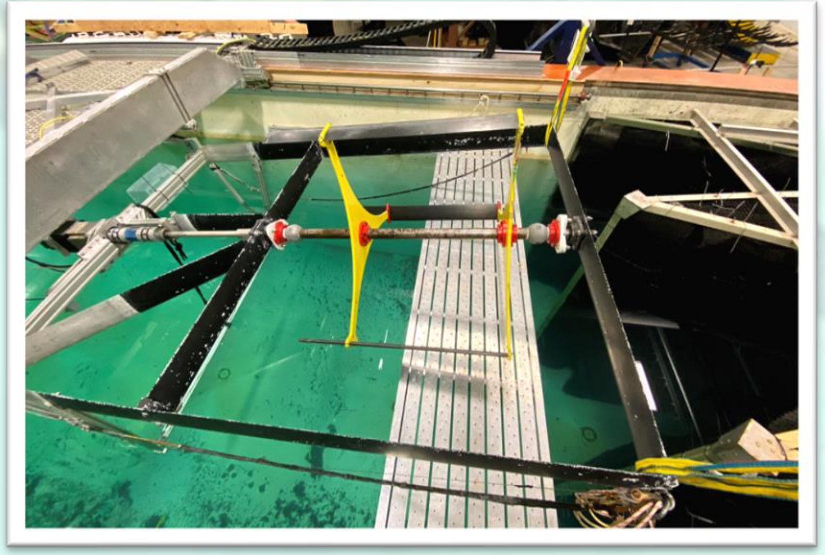
https://ati.mydigitalpublication.co.uk/articles/distributed-fiber-optic-sensing-leads-the-way-to-better-bonding-and-welding



Experimental Setup – UNH Turbine Test Bed & Tank



Renishaw LM15 linear encoder:	10 µm/pulse
Kollmorgen AKM62Q servo motor:	10^5 pulse/rev
2X Sentran ZB3-500 load cells:	+/- 0.6 N
Interface T8-200 rotary transducer:	+/- 0.5 Nm
Sentran ZB3-200 load cell:	+/- 0.2 Nm

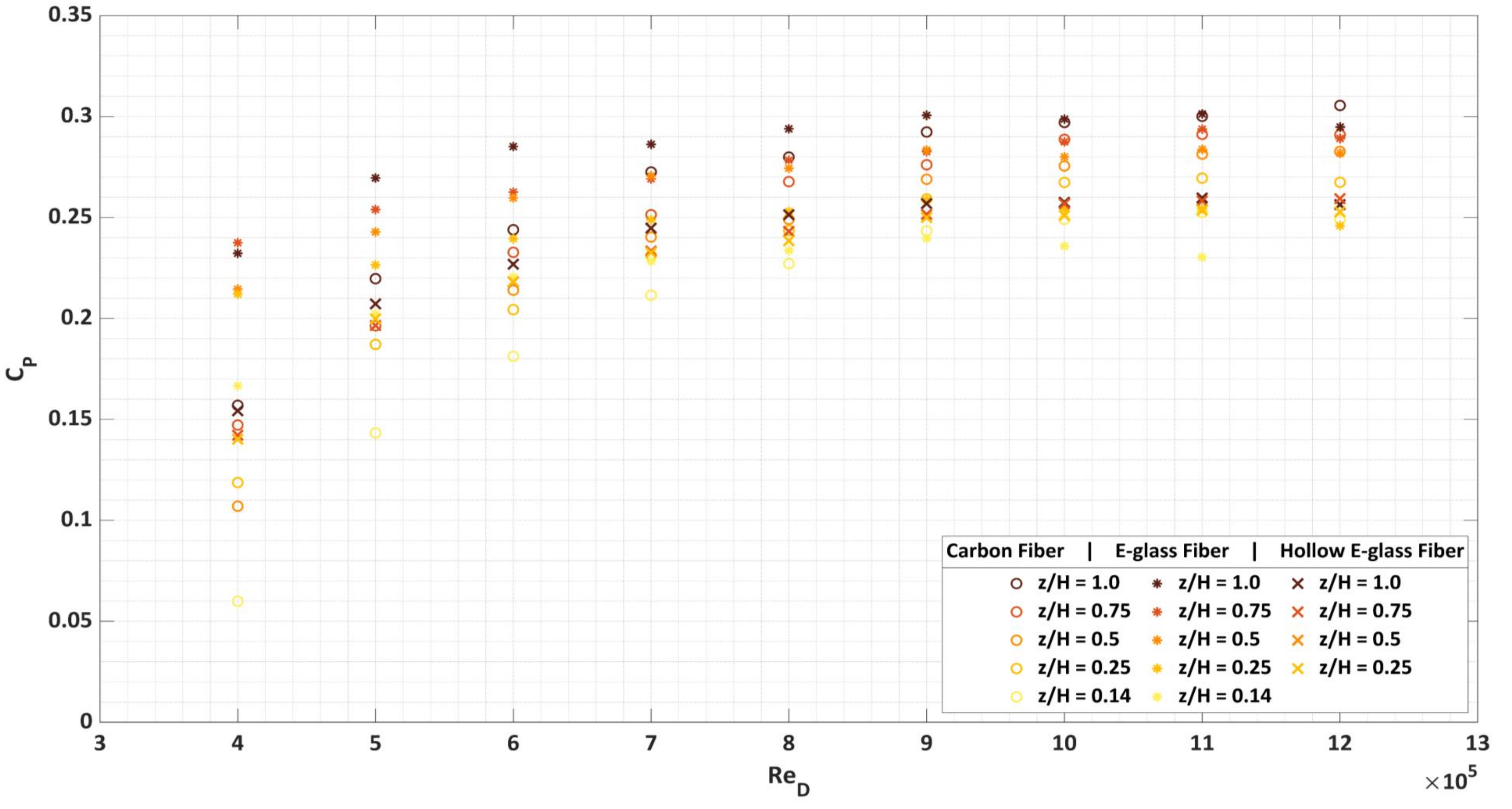


Experimental Results – Re Dependence

$$C_p = \frac{T\omega}{\frac{1}{2}\rho A U_\infty^3}$$

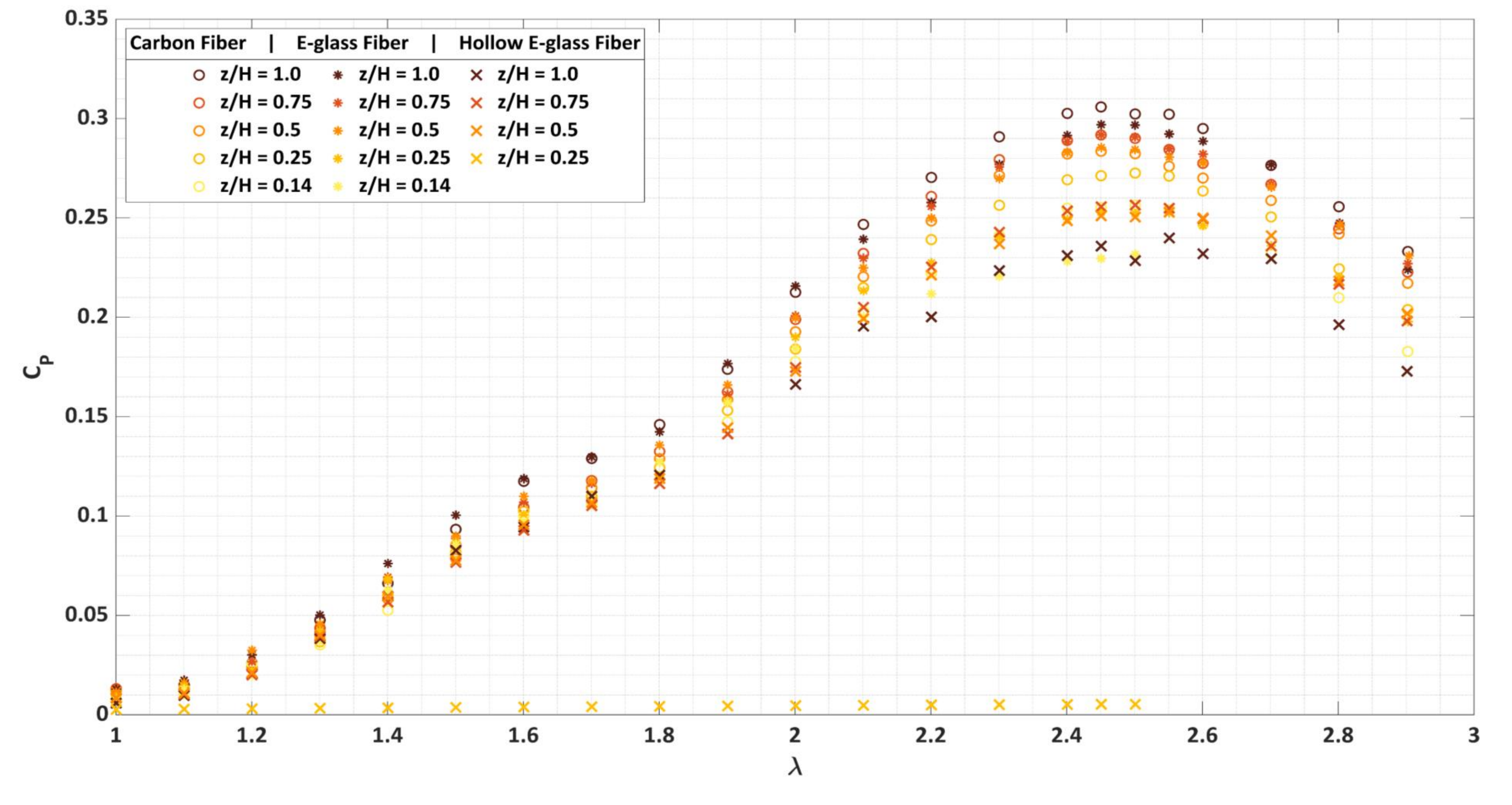
$$Re_D = \frac{U_\infty D}{\nu}$$

$$\lambda = \frac{\omega\,(D/2)}{U_\infty}$$



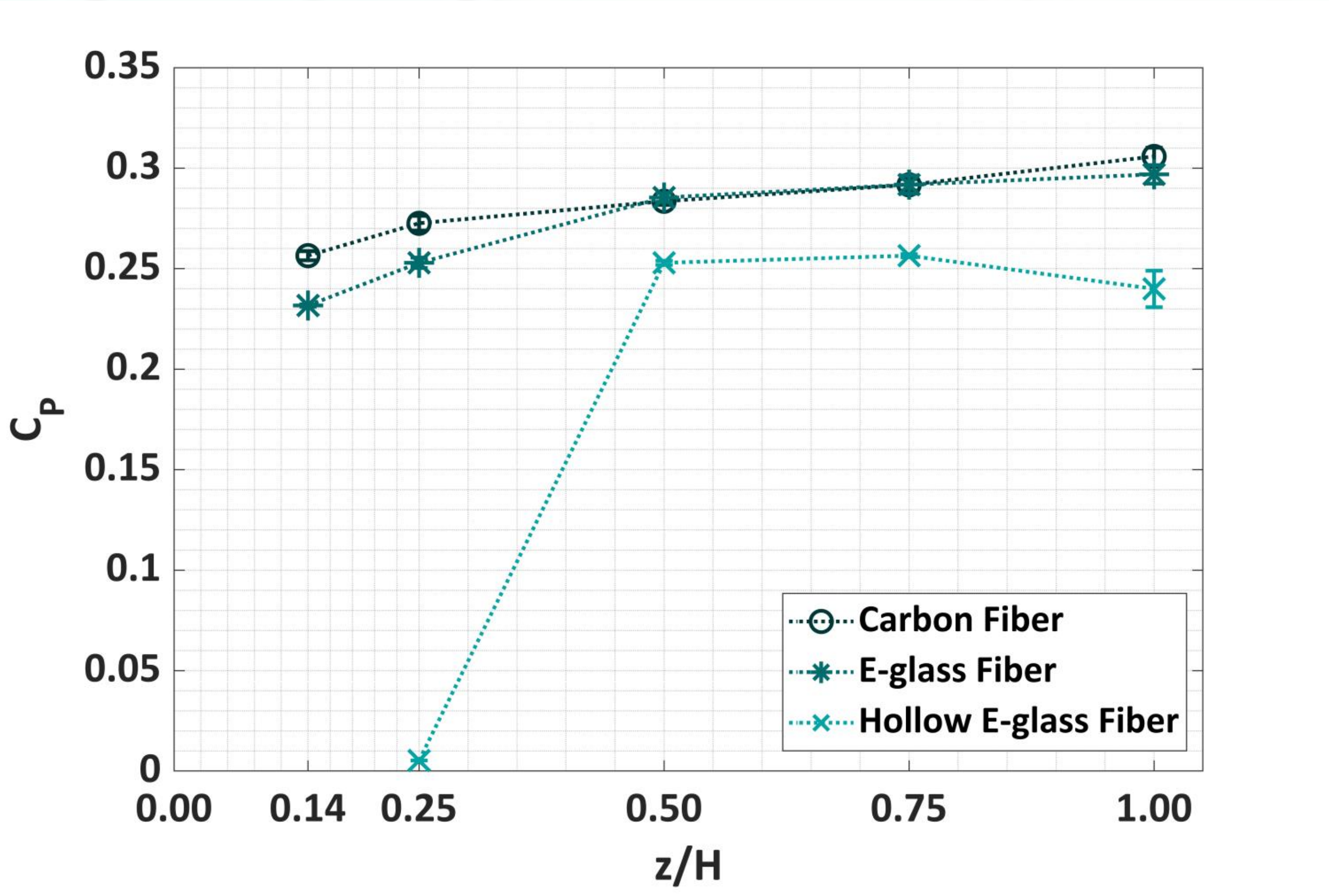
Constant λ = 2.5 and varying free end length.

Experimental Results - Performance



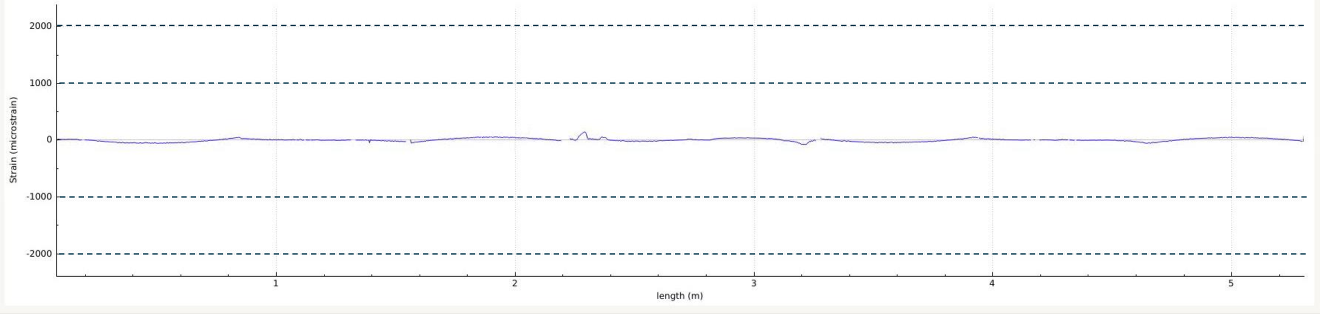
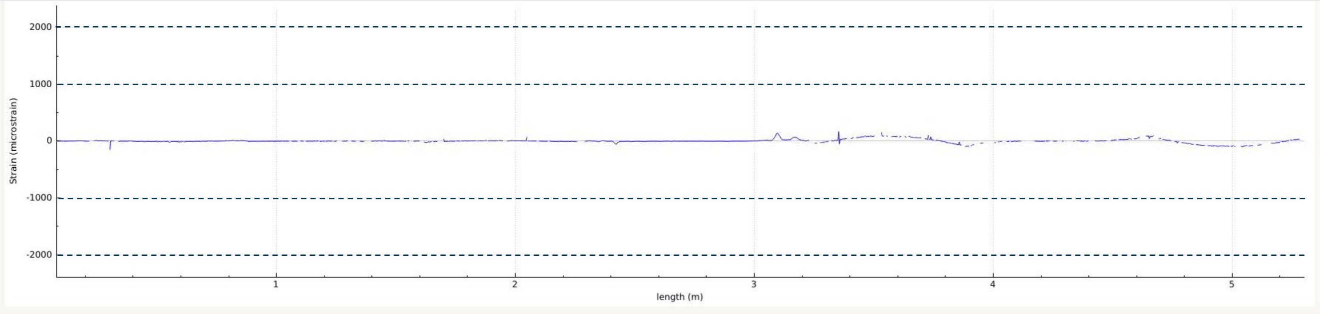
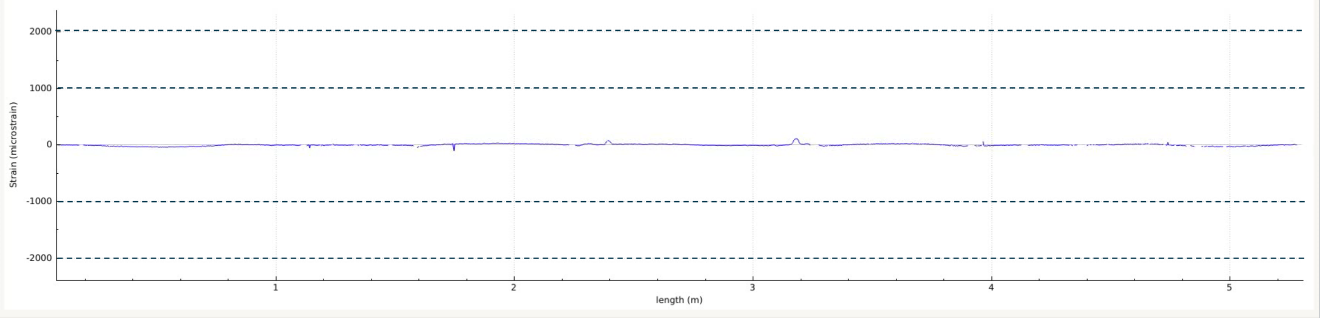
Varying unsupported blade length with U_∞ = 1.1 m/s at a range of λ for each strut position, z/H.

Experimental Results - Performance

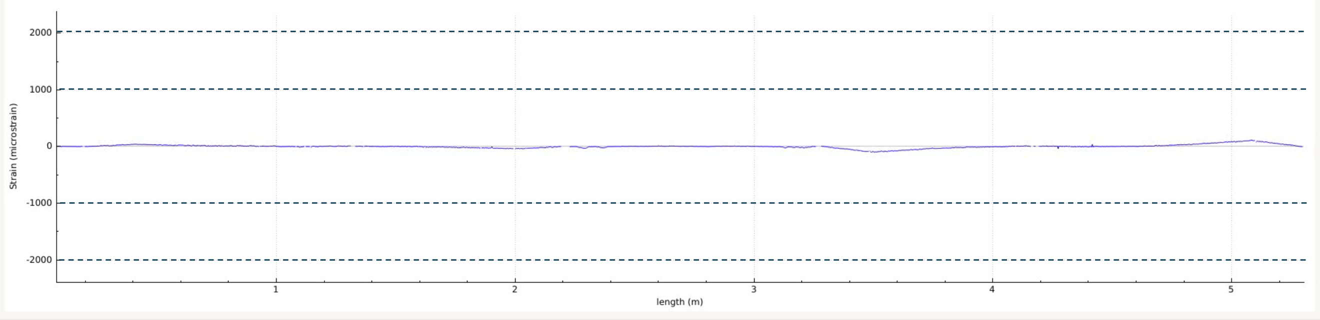
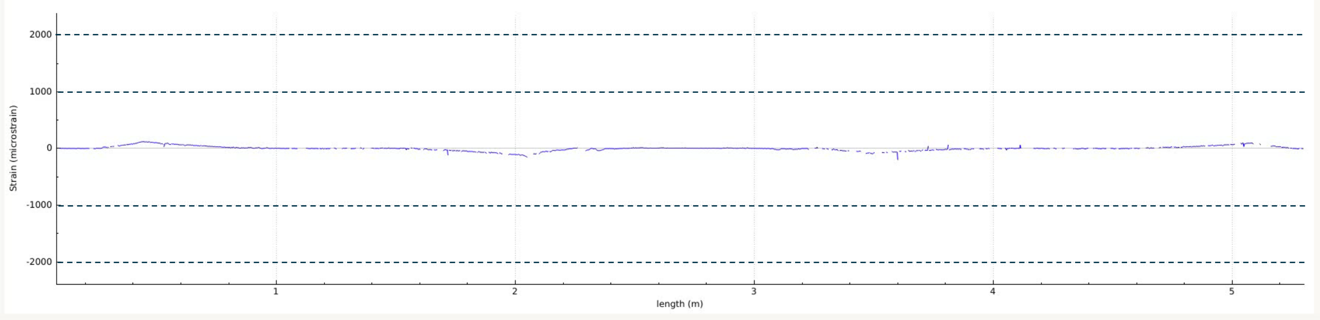
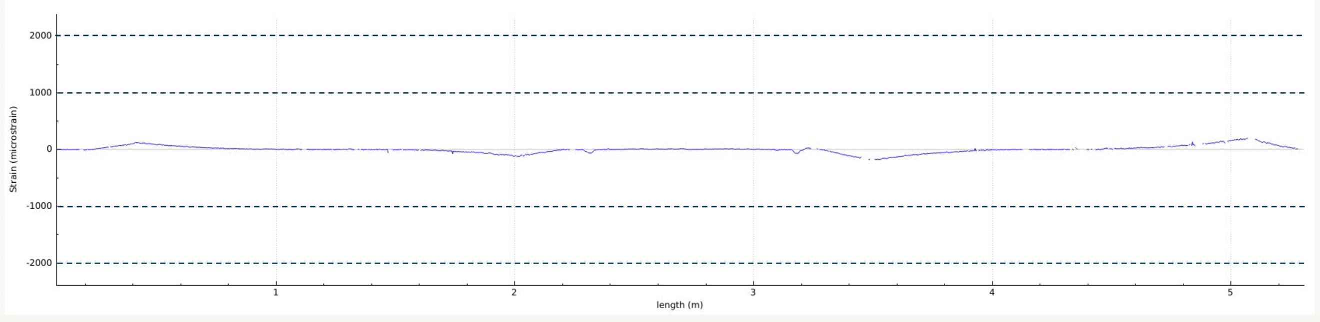


Varying unsupported blade length with U_∞ = 1.1 m/s at the maximum CP for each strut position, z/H.

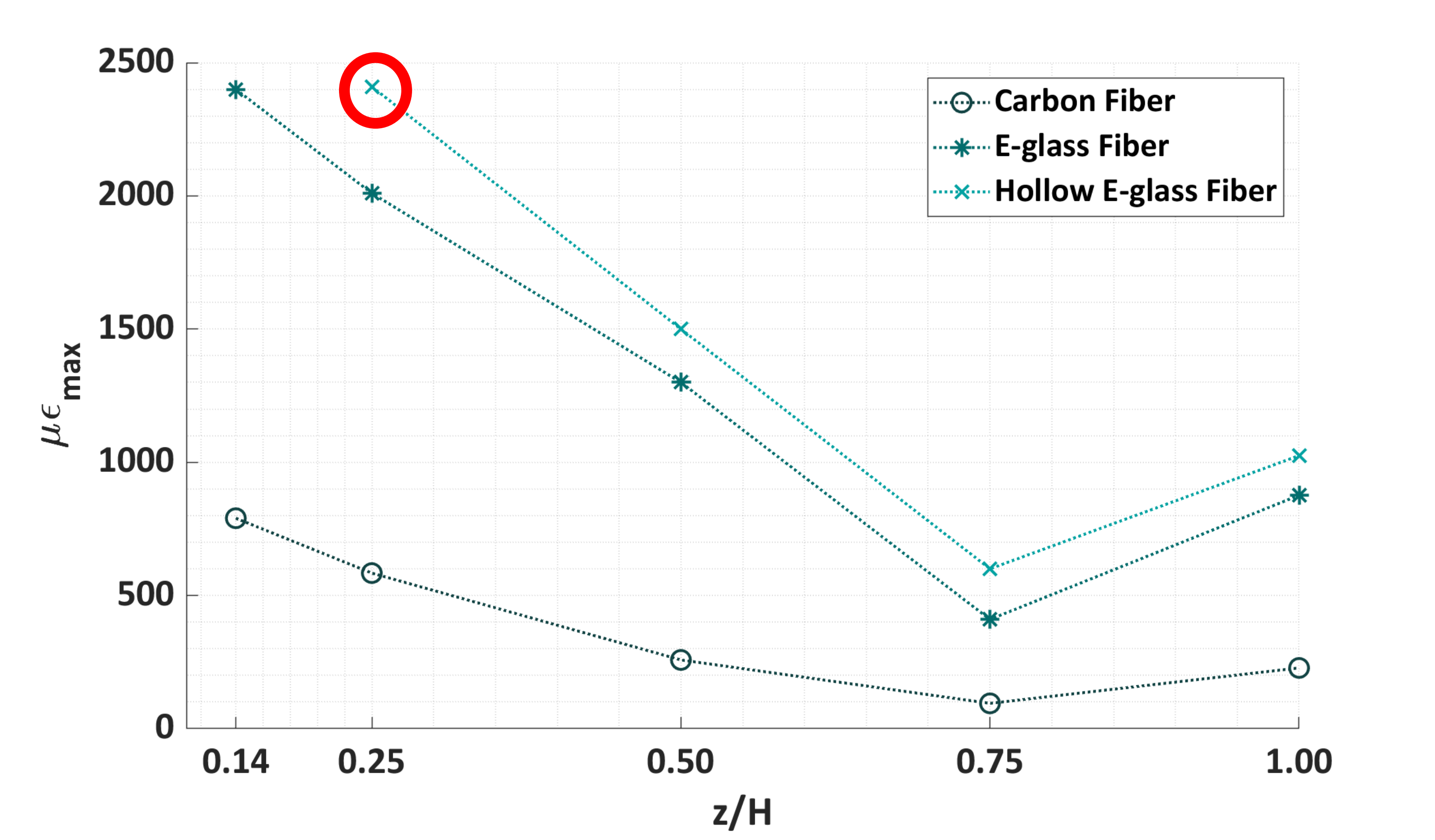
Experimental Results – Strain: λ = 2.5, U_∞= 1.1 m/s, z/H = 0.75

CARBON FIBER	
E-GLASS FIBER	
HOLLOW E-GLASS FIBER	

Experimental Results – Strain: λ = 2.5, U_∞= 1.1 m/s, z/H = 0.25

Carbon Fiber	
E-Glass Fiber	
Hollow E-glass Fiber	

Experimental Results - Strain



What does this mean for CFTs?

Can lower LCOE by:

- selecting less expensive, less rigid materials **without sacrificing performance**
- minimizing number of struts required along blade span **without sacrificing performance**

This data provides guidance on how far this can be pushed!!

- Selecting highly deflective materials will result in poor performance

- Next steps and ongoing work:
  - Further strain data analysis
  - Determination of critical point of performance between number of struts vs. highly deflective material

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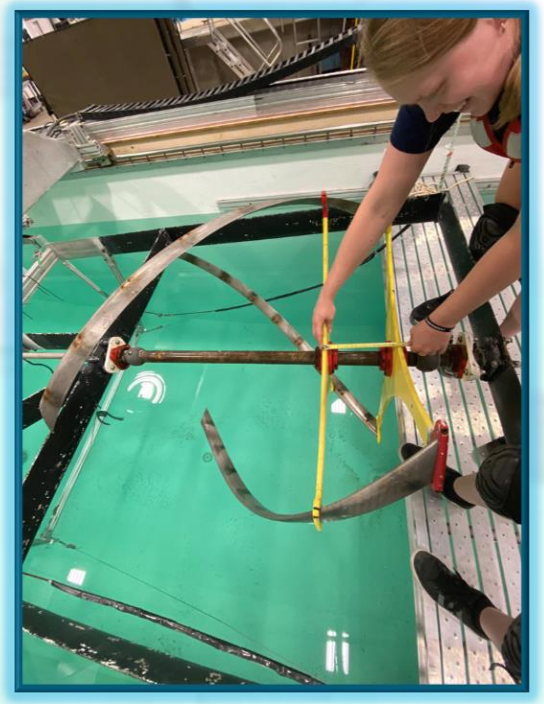

References

1. Buchner, A.J., Soria, J., Honnery, D. and Smits, A.J. (2018) Dynamic Stall in Vertical Axis Wind Turbines: Scaling and Topological Considerations. Journal of Fluid Mechanics, 841, 746-766. https://doi.org/10.1017/jfm.2018.112
2. IEC (2015). IEC TS 62600-202 – DTS Marine energy – Wave, tidal and other water current converters – Part 202: Scale testing of tidal stream energy systems.

Extra

- Performance measured by varying Reynolds numbers and tip speed ratios for each z/H
- Tow tank tests followed IEC TS 62600-202

$$\lambda = \frac{\omega\,(D/2)}{U_\infty} \qquad Re_{c,avg} \approx \frac{\lambda U_\infty c}{\nu} \qquad Re_D = \frac{U_\infty D}{\nu} \qquad C_p = \frac{T\omega}{\frac{1}{2}\rho A U_\infty^3} \qquad C_D = \frac{F_D}{\frac{1}{2}\rho A U_\infty^3}$$

Where:

λ	= tip speed ratio,	U_∞	= freestream or tow carriage velocity,	ρ	= density of water,
ω	= angular velocity of turbine rotor,	Re_D	= turbine diameter Reynolds number,	$Re_{c,avg}$	= average blade chord Reynolds number,
A	= projected area of turbine,	C_P	= power coefficient,	C_D	= thrust coefficient,
D	= turbine rotor diameter,	ν	= water kinematic viscosity,	T	= shaft torque.

Extra