TOWARDS DISRUPTIVE LCOE: EMPIRICAL VALIDATION OF A SURFACE-PIERCING, VERTICAL-AXIS, VARIABLE-PITCH, MARINE HYDRO-KINETIC TURBINE

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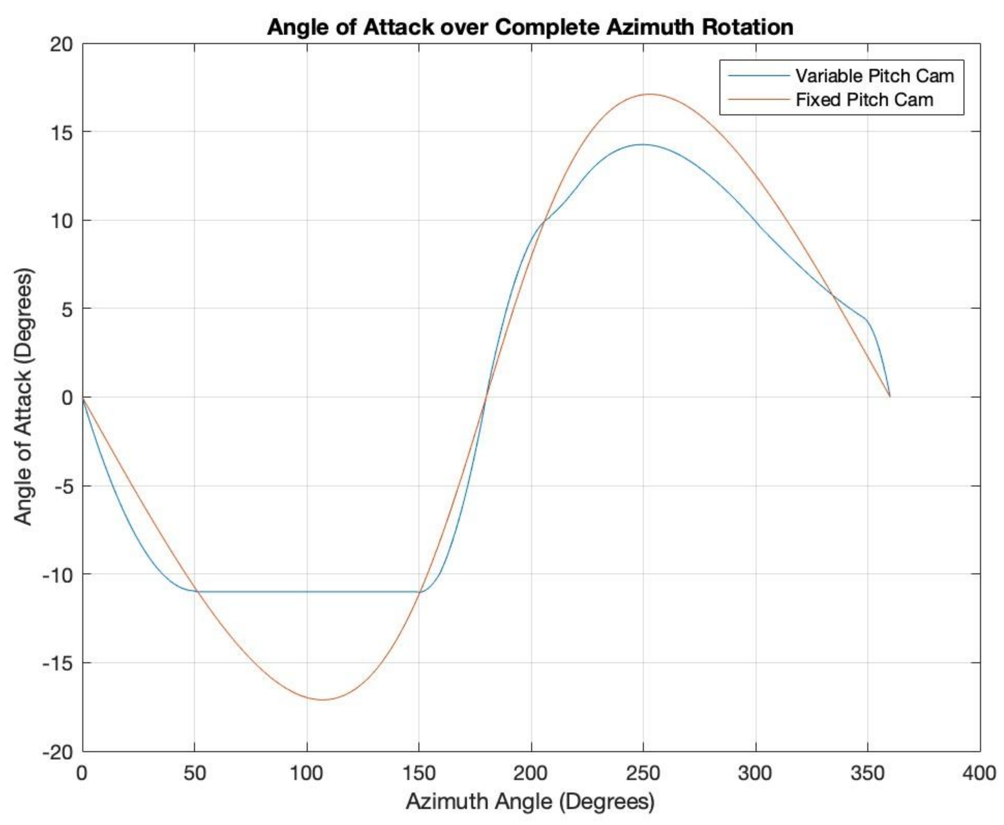
Introduction

The objective of this project is the testing of a novel surface-piercing, vertical-axis, vertically-actuated, variable-pitch (VP) marine hydro-kinetic (MHK) power generation approach in partnership with Adaptide. Vertical actuation of a surface-piercing, vertical-axis turbine may enable renewable power generation from aggressive tidal and/or river resources which would destroy most or possibly all existing MHK devices. Additional benefits include proactive debris or fauna avoidance and significant reduction or elimination of the need for site characterization prior to deployment; the resultant system may enable a disruptive reduction of the levelized cost of energy (LCOE). A novel VP turbine design was developed from a fixed pitch (FP) Adaptide prototype which demonstrated that a 20% power coefficient (Cp) was achievable with a rudimentary design at reduced scale. The VP design operates at increased scale as compared to the FP design and utilizes an inexpensive mechanical pitching system. Low-cost benefits were maintained while increasing max Cp potential as compared to the FP design. Empirical validation shows comparable Cp with a FP law to the FP system and increased Cp with a conservative pitching law.

Angle of Attack Comparison

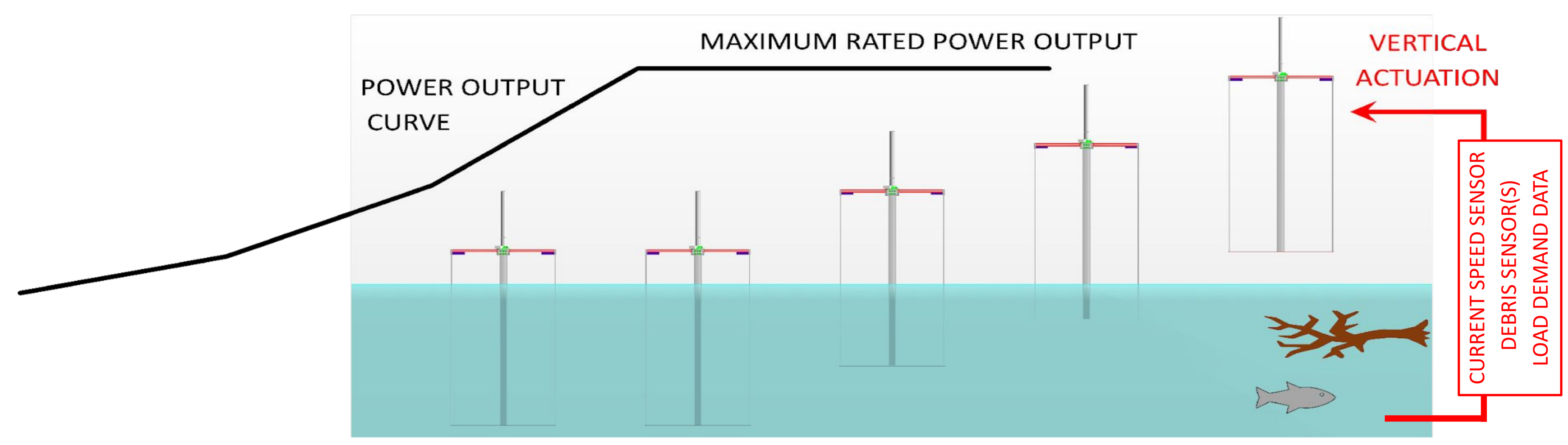


*Assuming uniform freestream velocity and no reduction in velocity across the turbine

Discussion

- Testing was conducted at Joseph Sayer's Reservoir in Bald Eagle State Park, PA
- Flowmeter was positioned ~2.5 turbine diameters upstream of the device
- Brake system provided torque output
- Tachometer provided angular velocity
- FP cam produced similar Cp to the previous reduced scale FP tests
- FP cam did not self-start
- VP cam self-started at ~0.5m/s (with lighter retard springs)
- The bow wave volume increased with scale
- Ventilation was not observed as with previous tests
- Structural drag losses were reduced from the FP architecture to the VP architecture
- Structural improvements were made between FP cam and VP cam testing to reduce vibration in the system
- FP cam test - Tachometer readings were unsteady due to poor instrumentation and misalignment of shaft bearings
- Torque output fluctuated per the expected torque curve
- VP cam test - Torque and angular velocity unsteadiness were reduced
- The pitching law was guided by a literature review and sought to optimize angle of attack (AoA) on the upstream stroke and minimize drag losses on the downstream stroke. This approach is also well suited to asymmetric foil profiles.
- Power output was increased from FP cam test to VP cam test

Disruptive LCOE: A New Approach



ADVANTAGES:

SURVIVAL:
The Adaptide turbine is automatically removed from the water when sensed current speed exceeds a prescribed maximum. This functionality enables survival of aggressive but infrequent king tide or river flood events, access to previously inaccessible energetic current resources, and known structural and electrical limits which enable optimal engineering design.

MAXIMAL ENERGY CAPTURE:
Constant maximum rated power output over a range of common current speeds is enabled through modulation of turbine operating depth, which may enable a capacity factor increase of more than 300% relative to fully-submerged, fixed-pitch devices which are commercially available today.

PROACTIVE DEBRIS AND FAUNA AVOIDANCE:
The turbine is temporarily removed from the water when debris or fauna are detected by sonar, mechanical, and/or optical sensors.

REDUCTION OR ELIMINATION OF SITE CHARACTERIZATION PRIOR TO DEPLOYMENT:
Adaptive, variable depth operation significantly reduces or eliminates the need for precise characterization of currents which may be encountered at any candidate deployment site.

NO SUBMERGED PARTS AND EASE OF MAINTENANCE:
No submerged electrical components, above-water installation and maintenance, straight turbine blades are inexpensive to manufacture and easily replaced if damaged or scoured.

SIGNIFICANCE:

The Adaptide VP capable turbine employs a novel cam and follower mechanism which minimizes parasitic power loss while maximising accuracy of the candidate pitching law . Through pitching the foils about their own axes, a target angle of attack (AOA) between the relative velocity and the foil chord line is achieved to maximize the lift coefficient and in turn the lift force generated. Multiple cams may be designed and easily installed to test candidate pitching laws.

A circular cam may also be installed to operate the turbine as a FP device; testing the turbine in this configuration will enable parasitic power losses due to the VP mechanism to be quantified. In later trials, empirical testing of various cam geometries will enable validation of candidate optimal pitching laws, which generally maximize power in the upstream arc of travel and minimize power loss on the downstream arc of travel.

Application-specific sensor apparatuses have been developed and built to improve measurement accuracy in a real-world environment. The flow meter mount enables current speed measurement at ~2.5 turbine diameters upstream of the turbine shaft. The depth gauge is outboard of the predicted turbine wake zone.

References

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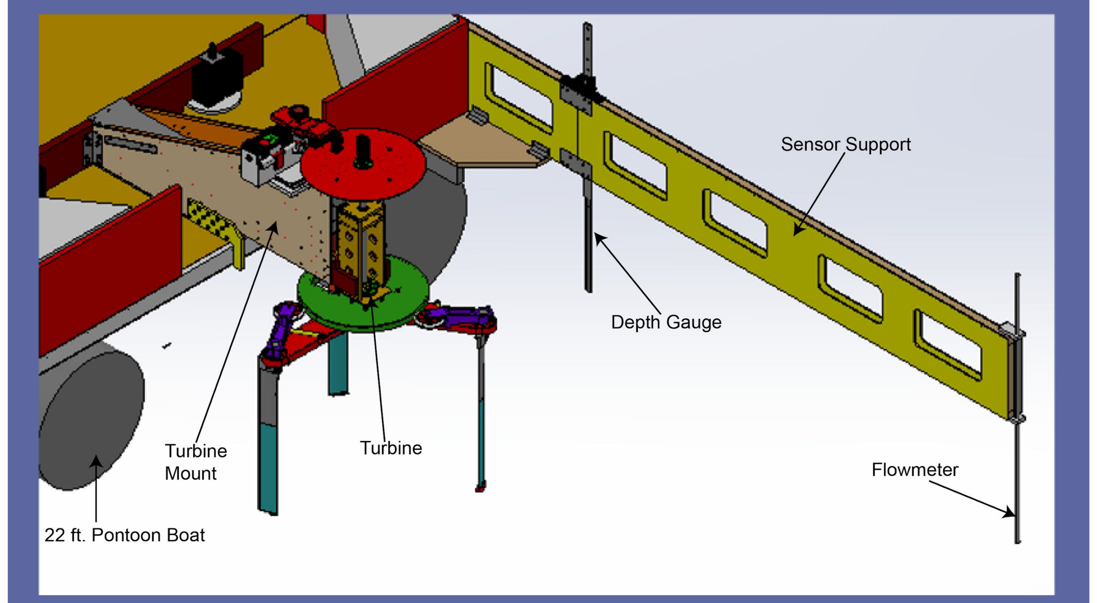
All references available upon request

Acknowledgements

Partial funding provided by the USMC and Dynovas Inc.

Thank you to Bucknell's College of Engineering, Dan Johnson, Aaron Clark, Tim Baker, Hugh Weber, Andrew Cannavo, Jose Juarez, Caiden Covell, Owen Davis, and Matthew McTammany.

Design



VP Turbine Details

Diameter = 1m (39.4 inches)

Number of Blades = 3

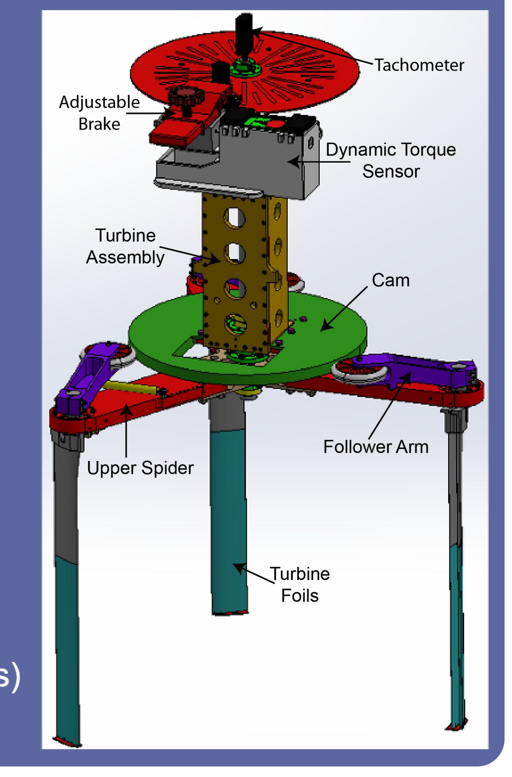
Foil Type = NACA 2412

Solidity = 0.471 $\left(\frac{chord * N_{blades}}{radius}\right)$

Solidity = 0.075 $\left(\frac{chord * N_{blades}}{circumference}\right)$

Foil Chord = 0.0785m (3.09 inches)

Max Foil Depth = 0.4318m (17 inches)



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