Tethered Coaxial Marine Turbine Torque Cancellation Analysis

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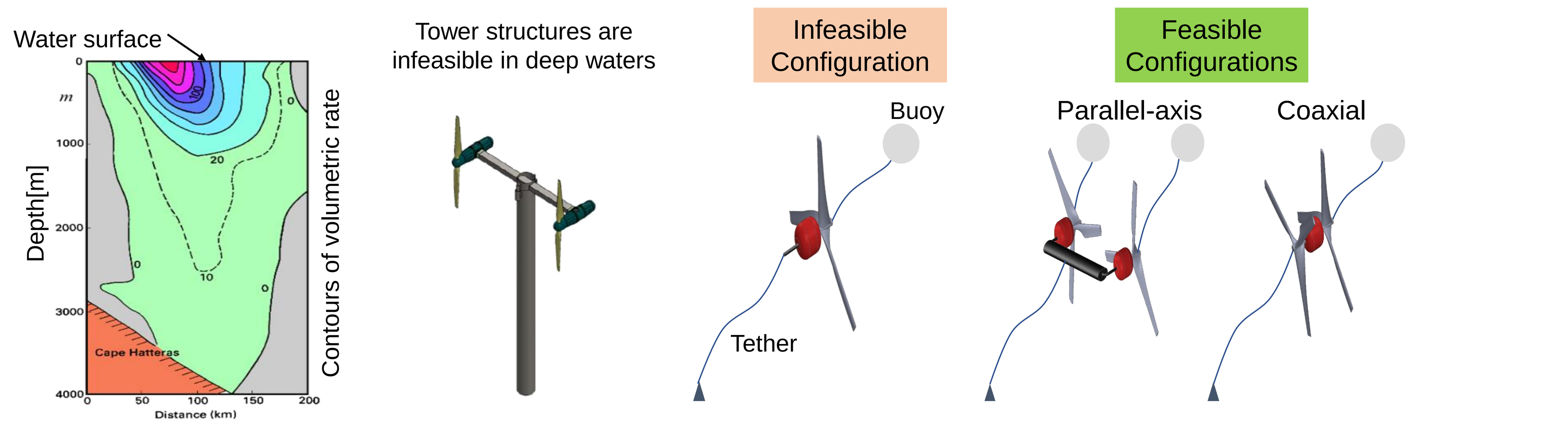
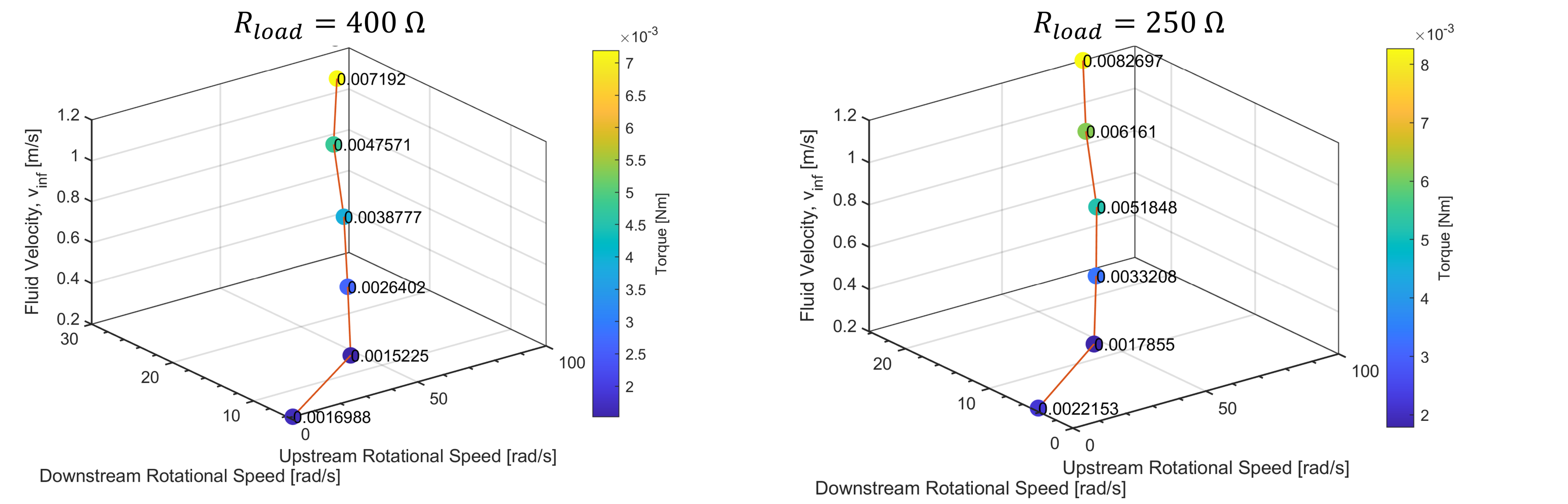
Project motivation – feasible way to extract energy from ocean currents

The Gulf Stream has high velocity fluid close to the coast of North Carolina. The greatest available energy is near the ocean surface when the floor depth is approximately 3000m, making a rigid tower infeasible. This makes a tethered system the more viable option. However, with only 1 rotor this would lead to tether tangling from unbalanced torque. The two most obvious configurations of 2 rotors to balance the torque is either coaxial or parallel. Our group previously showed that the coaxial configuration is simpler to deploy with less structural considerations.

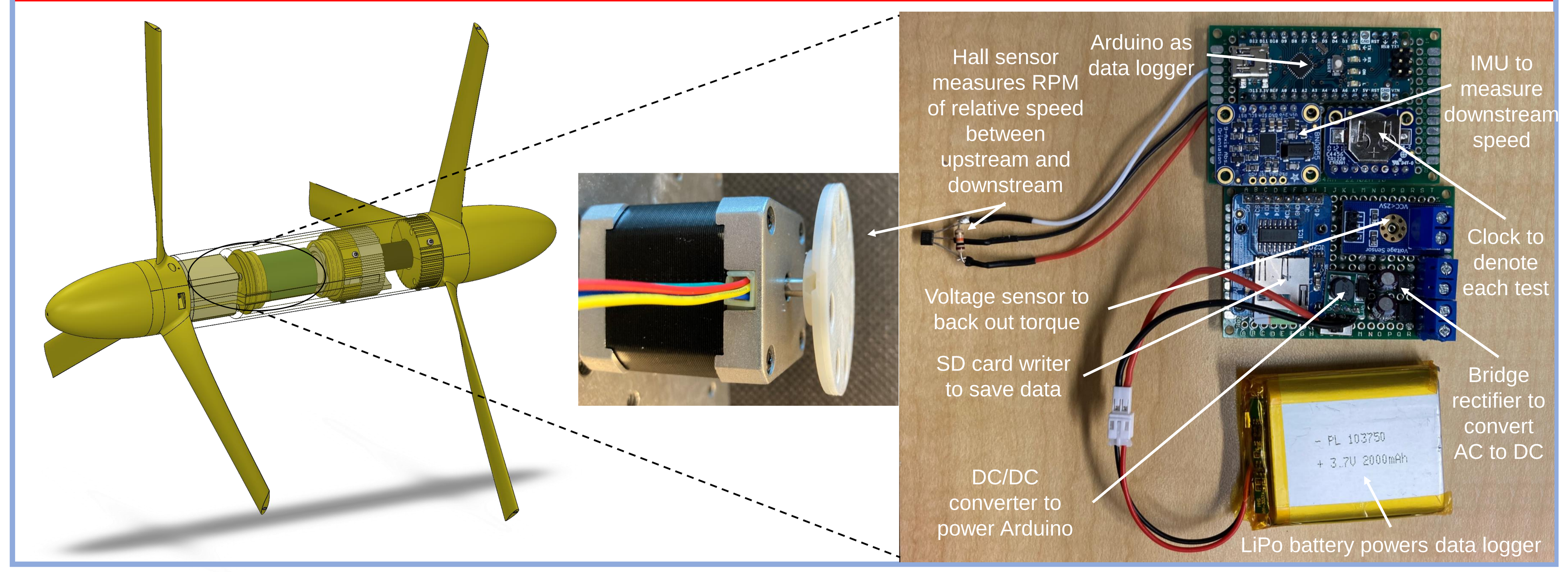


Theoretical results show trends of output when load resistance is held constant



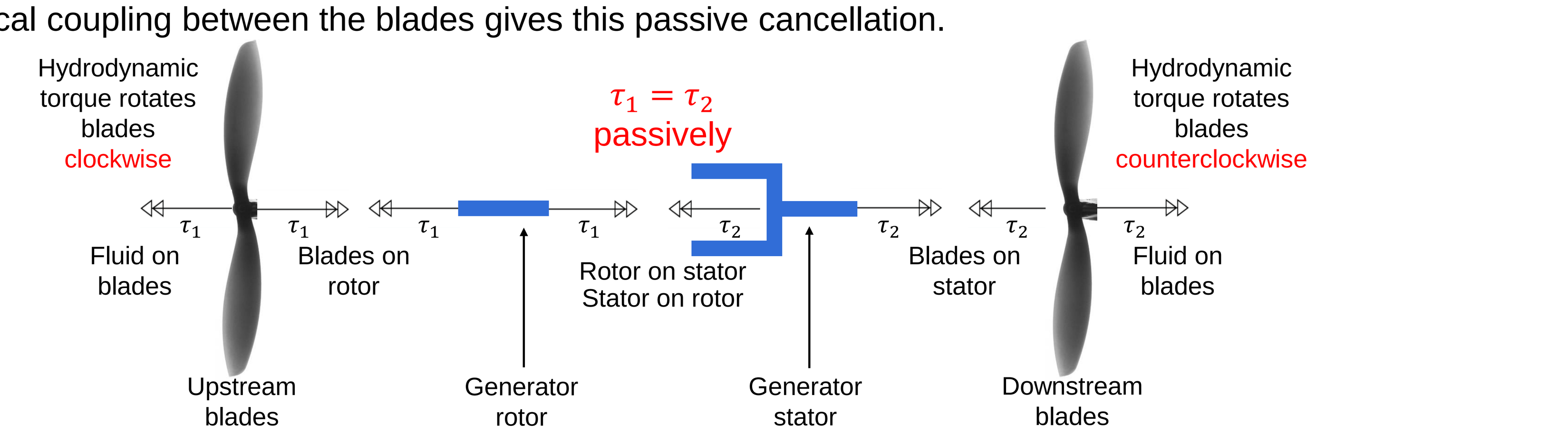
These show the 4D data of upstream speed, downstream speed, and torque for a range of fluid velocities while holding the resistive load constant. Decreasing the load resistance increases the torque and very slightly decreases the upstream and downstream speeds.

Instrumentation of prototype used to measure torque, upstream speed, and downstream speed

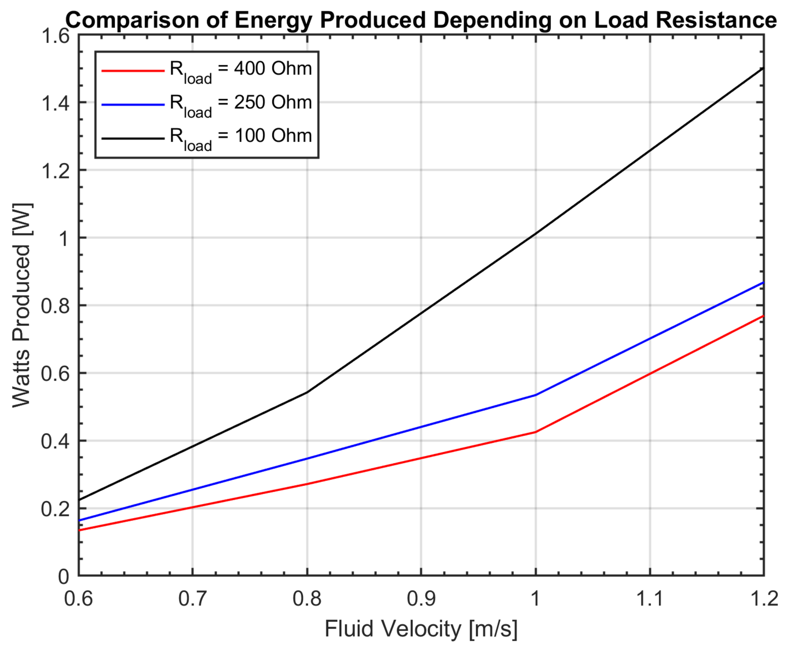


Coaxial turbine can utilize counter rotating direct drive generator to passively cancel torque

In order to avoid tether tangling, the torque must be cancelled by the two sets of blades. It is preferrable to design the system such that this is accomplished passively rather than actively due to the increase costs and design time. One way this can be accomplished is by fixing the upstream blades to the rotor of the generator and the downstream blades to the stator of the generator. Since there must be equal and opposite reactions between all components, the electromechanical coupling between the blades gives this passive cancellation.



Theoretical prediction of power generation shows lower resistance yields higher wattage



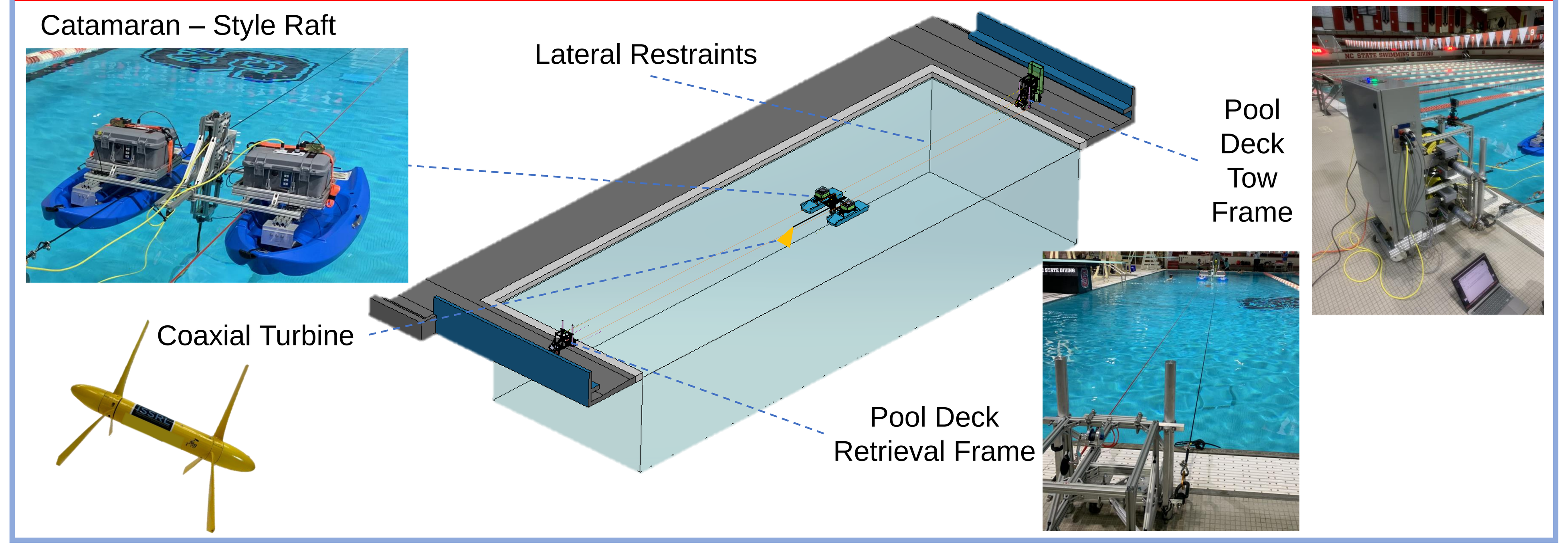
Using the properties of DC generators, the electrical power produced at the operating points solved for can be calculated. The lower load resistances can be seen to produced higher wattage than the higher loads.

$$V = iR_{load} = iR_{arm} + K_e(\omega_1 + \omega_2)$$
$$\tau = K_e i$$

K_e and R_{arm} are known parameter of the generator, therefore can solve for voltage and current using theoretical predicted operating points

$$P = VI$$

Pool tow system used to simulate fluid velocity in Gulf Stream

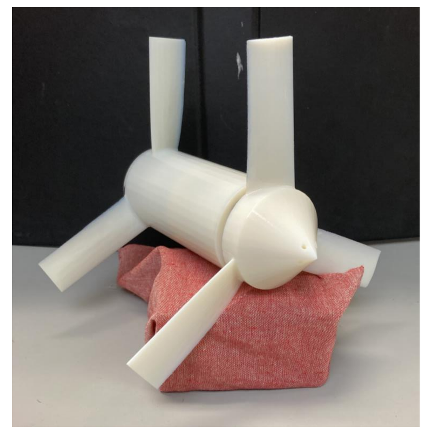


Stability analysis through prototyping and lake testing

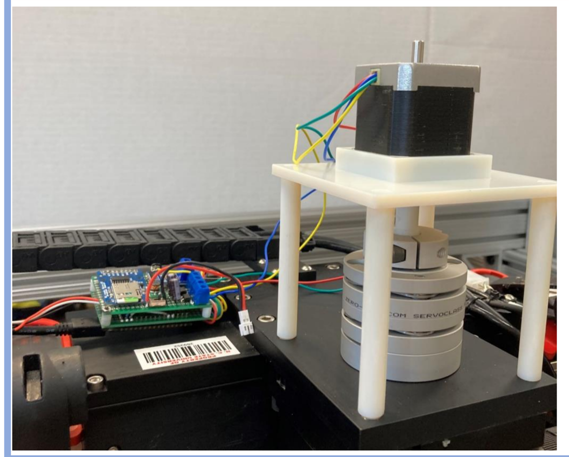
Since there are no stationary elements of the design, the stability of the counter rotating stator and rotor were empirically tested and verified.

A brushed DC motor with counter rotating blades was pulled through the lake with a ball bearing to allow for rotation and to avoid line tangling

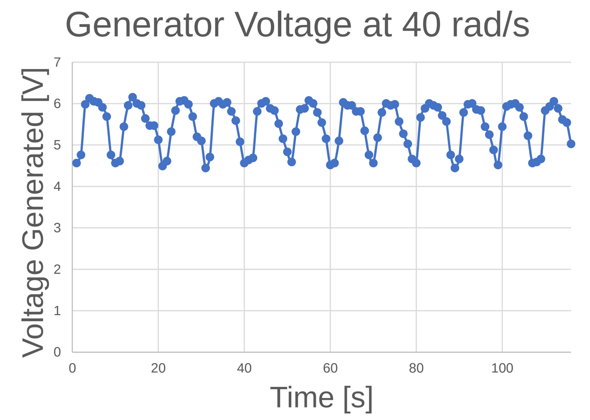
A stepper motor with a load resistance across its bridge rectified terminals is pulled through the lake to test the ability to change the equilibrium torque



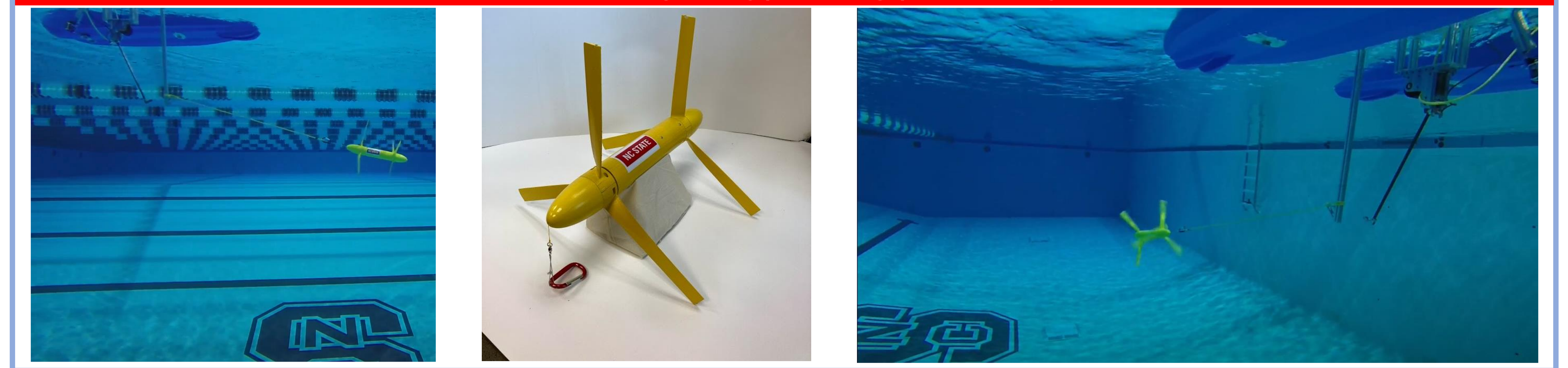
Experimental measurement of generator constants



A motor that can prescribe a constant RPM was coupled to our generator in order to characterize the generator constants. Since a bridge rectifier with smoothing capacitors is used, a repeating DC curve is generated.



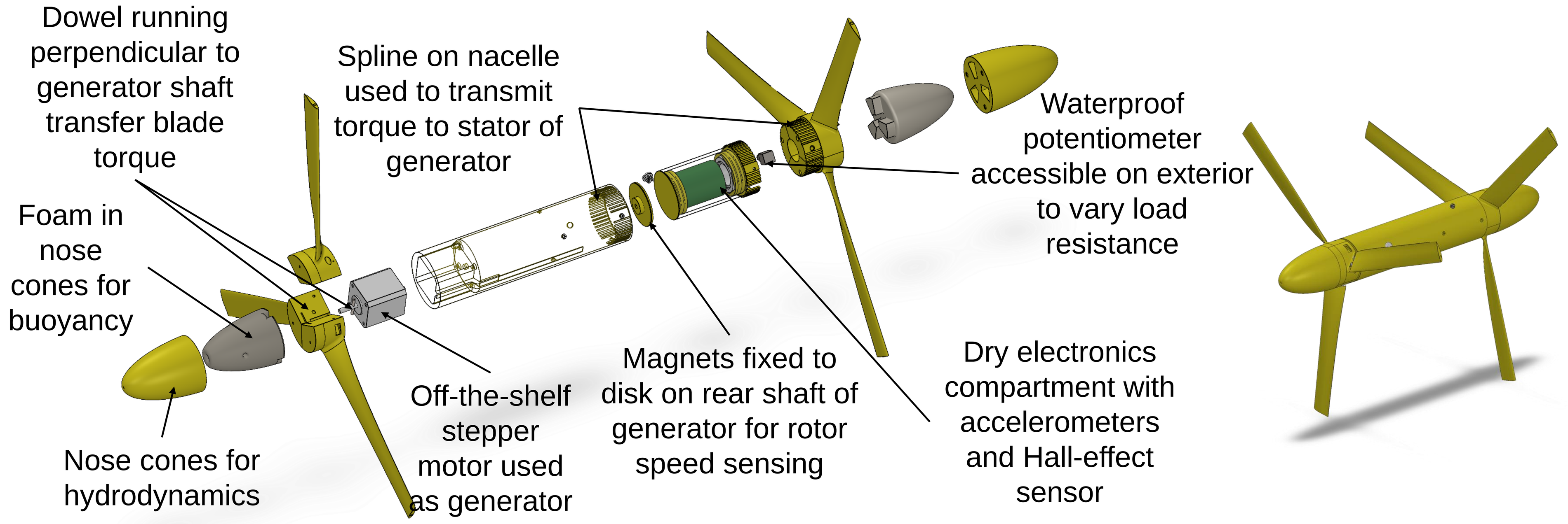
Coaxial turbine prototype using pool tow system



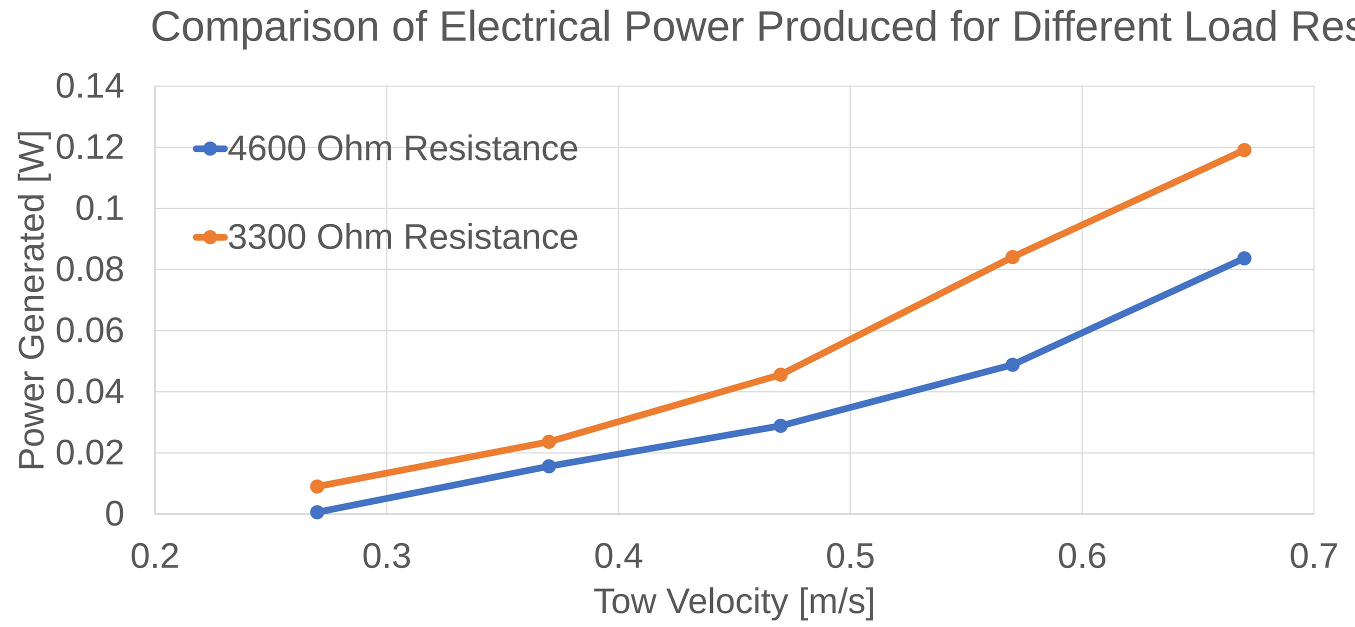
Theoretical analysis of operating points of torque, upstream speed, and downstream speed

1. For each fluid velocity, using blade element momentum theory, find valid range of upstream rotational speeds, ω_1
2. Discretize valid range of ω_1 into 100 points and find torque generated at each point
3. For each ω_1, sweep through the same range of downstream speeds, ω_2 and find its associated torque
4. Find 2 ω_2 values that give the same torque as the upstream
5. Find the load resistance that would yield this combination of torque, ω_1, and ω_2
6. Repeat for a range of fluid velocities

Experimental prototype designed to see same trends experimentally



Results of experimental campaign



Preliminary results show the same trends as the theoretical predictions. The magnitude of the power produced and the trend shape are both equivalent, as well as the hypothesis that a lower resistance will yield a high energy generation.