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USDOE's Marine & Hydrokinetic Turbine System Test Bed for Model Verification & Validation

Water Power Technologies Office

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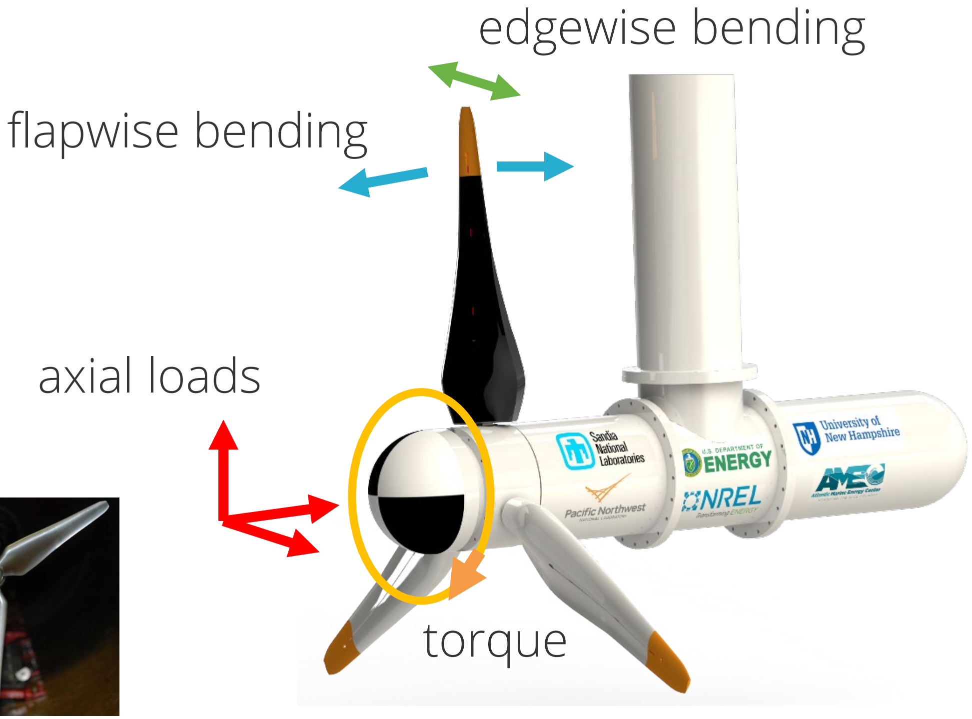
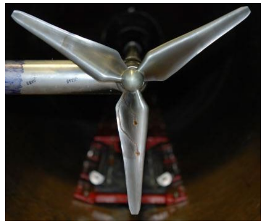
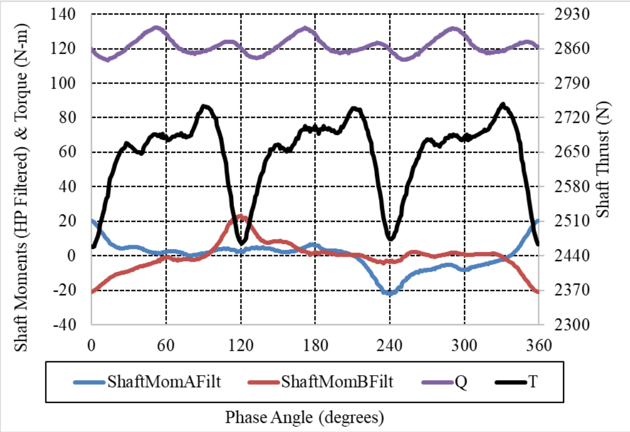
Motivation

Tidal turbines subject to wide range of load conditions (steady, cyclic, stochastic, resonant) in marine environment

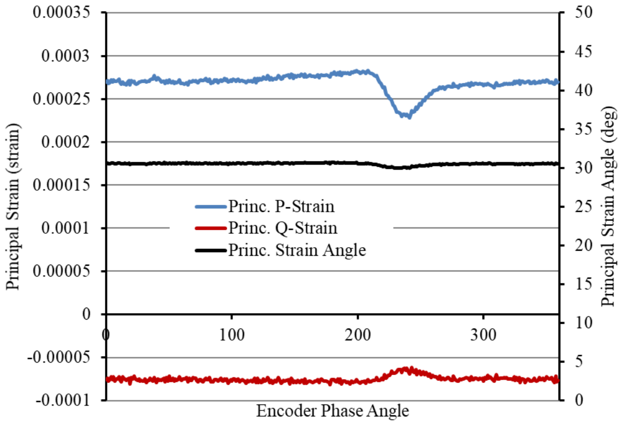
Publicly available data on flow-structure interactions limited mainly to controlled environment scale-model testing, e.g., Fontaine et al. 2020







Unsteady shaft loads plotted versus phase angle



Unsteady principal strains at midspan

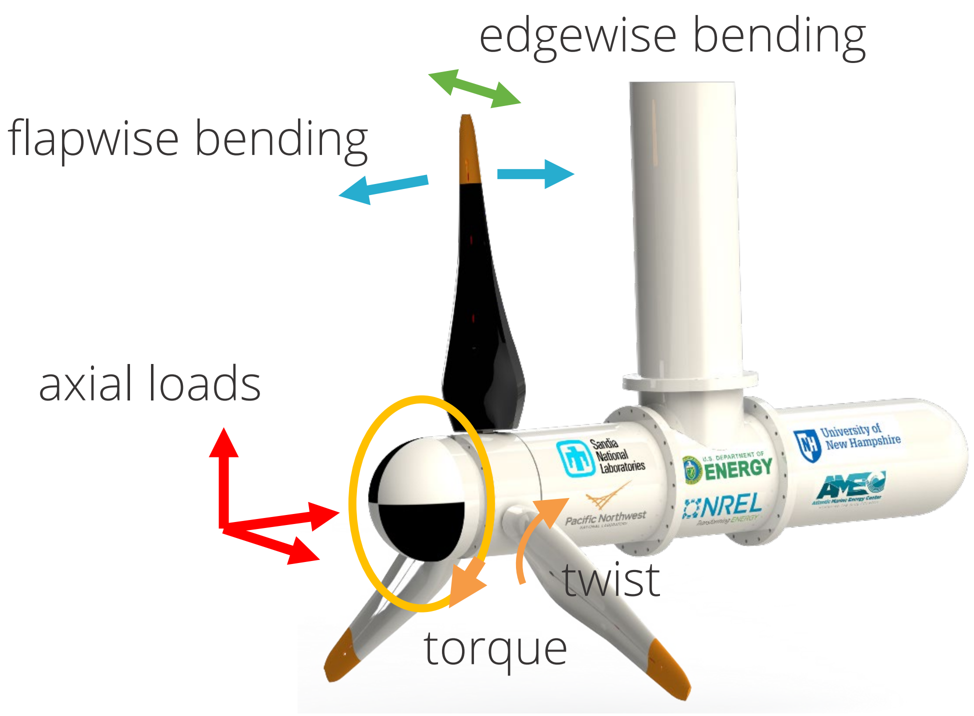
Fontaine et al. 2020. 'Performance and wake flow characterization of a 1:8.7-scale reference USDOE MHKF1 hydrokinetic turbine to establish a verification and validation test database, Renewable Energy, 159: 451-67. https://doi.org/10.1016/j.renene.2020.05.166

Goal, Study Objectives

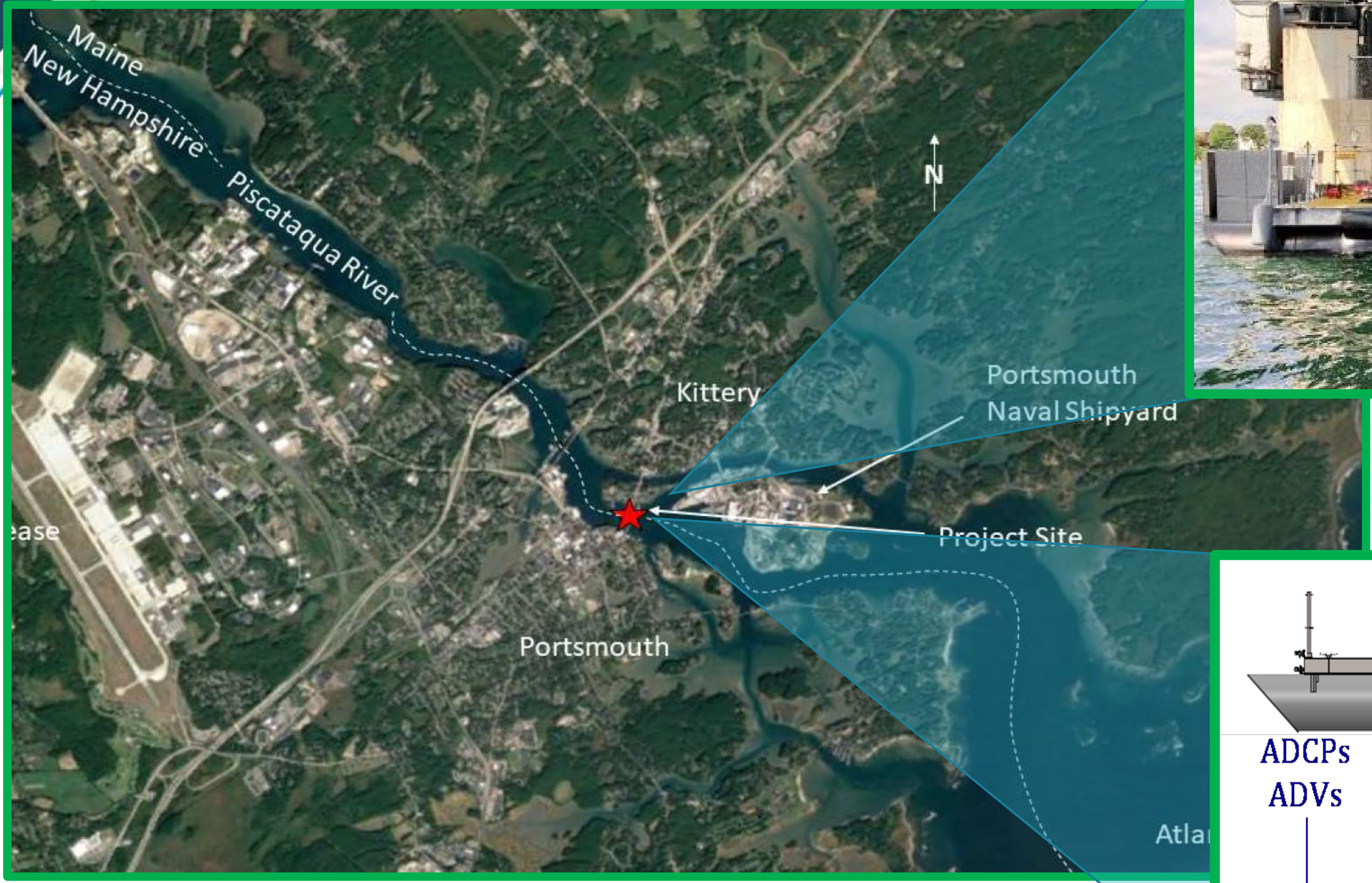
Design, fabricate, deploy, and test 2.5-m fully-instrumented reference model hydrokinetic turbine to collect, analyze and archive a complete load and performance characterization dataset

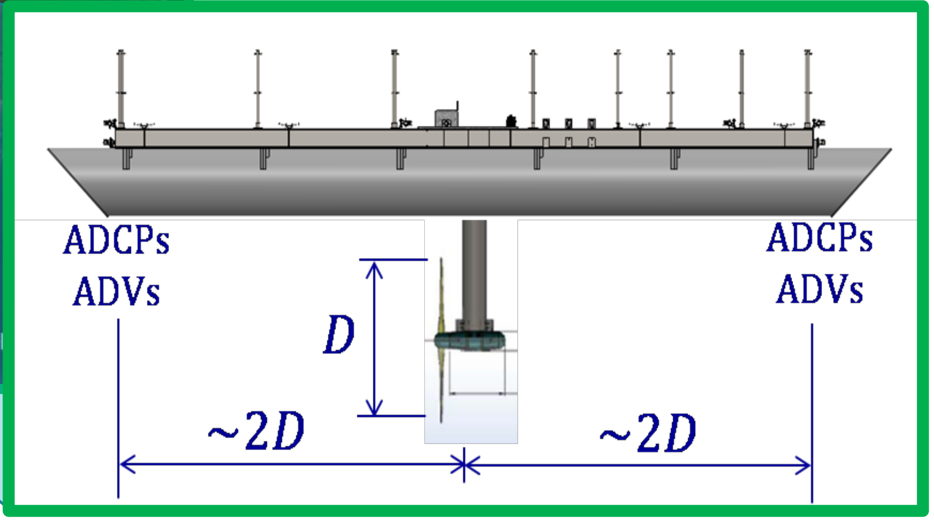
Tidal inflow, load, structural health, and performance data collected and published in the open-source Portal and Repository for Information on Marine Renewable Energy (PRIMRE)

The data collected will help to inform the International Electrotechnical Commission's (IEC) standards for marine energy (TC 114)

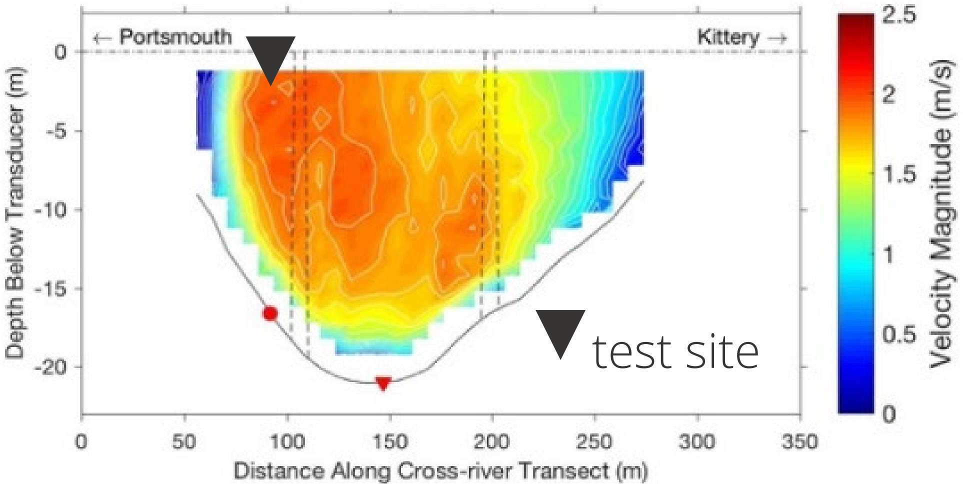


Tidal energy test site





Tidal inflow characteristics



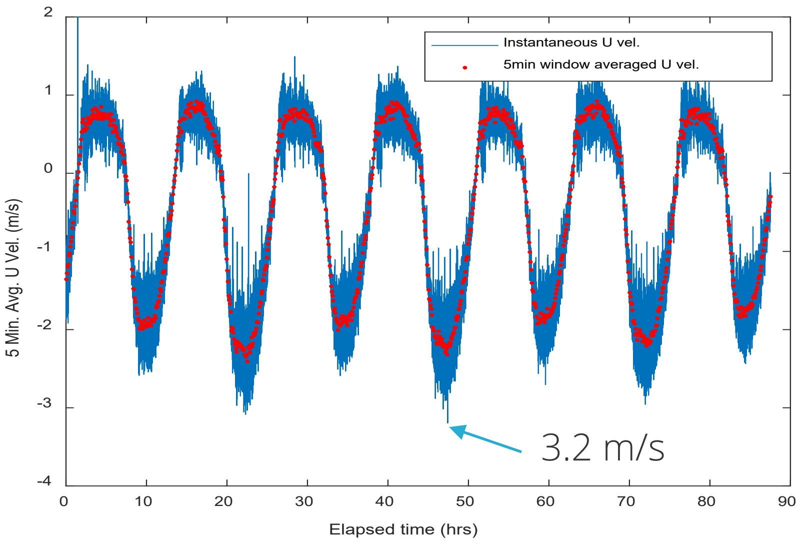
Spatial distribution of tidal current speeds (facing up-river) at spring ebb tide

Max instantaneous current = 3.2 m/s

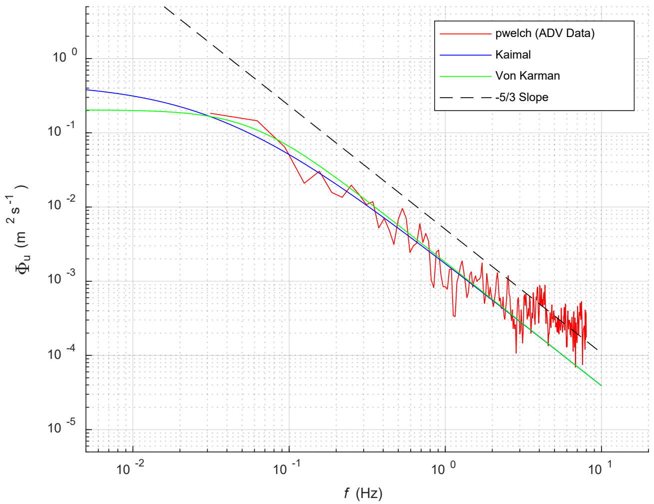
Max 5-min avg current = 2.4 m/s

TI (50-percentile stdev) = 6.4%

TI (95-percentile stdev) = 9.6%



Inflow velocity sampled at 16 Hz with an ADV



Turbulence spectra at 16 Hz with an ADV

Standard deviation and/or TI

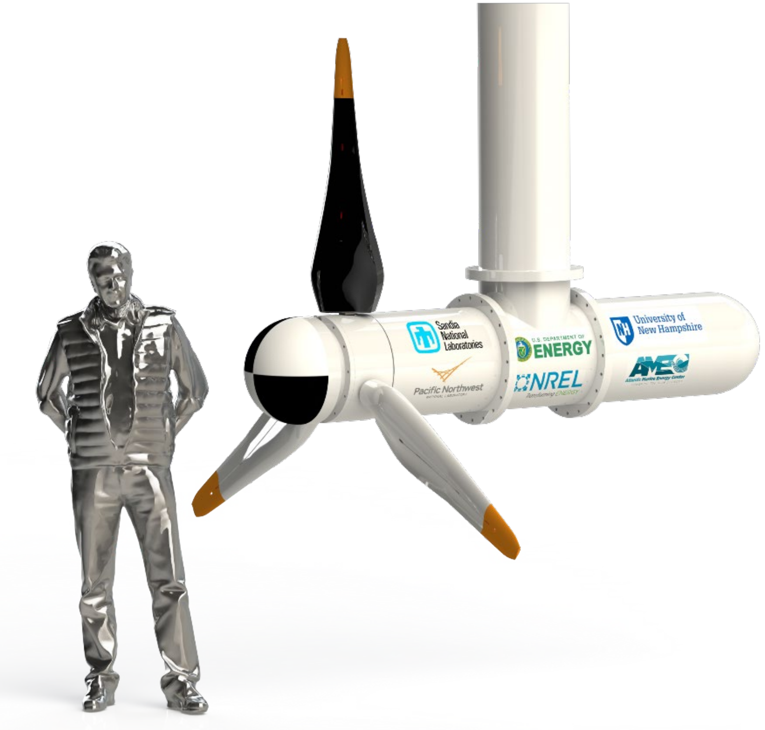
MHKF1 Tidal Turbine

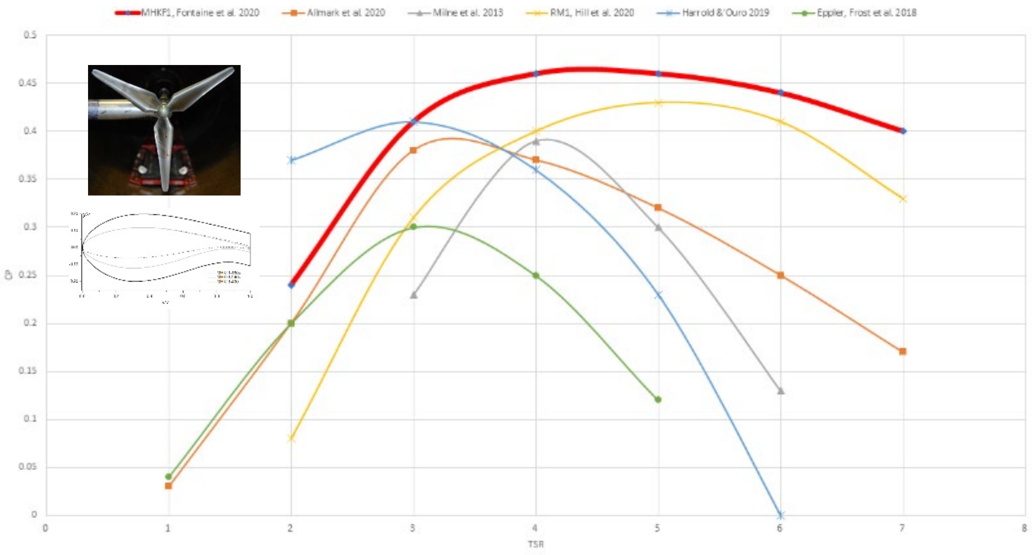
The 2.5-meter 25 kW rated-power (at 2.8 m/s)

Adopted Sandia’s advanced marine hydrokinetic family 1 (MHKF1) rotor design for marine environments

Hub diameter doubled to accommodate sensor equipment

Blade thickness increased in board to accommodate blade-hub clamping system and sensor system





Modeled power performance and loads

Design Load Cases Simulated

1.1 Normal operation …

6.1 Parked ….

Add plots with all power performance curves on one plot

Add plots with all load data for structural design

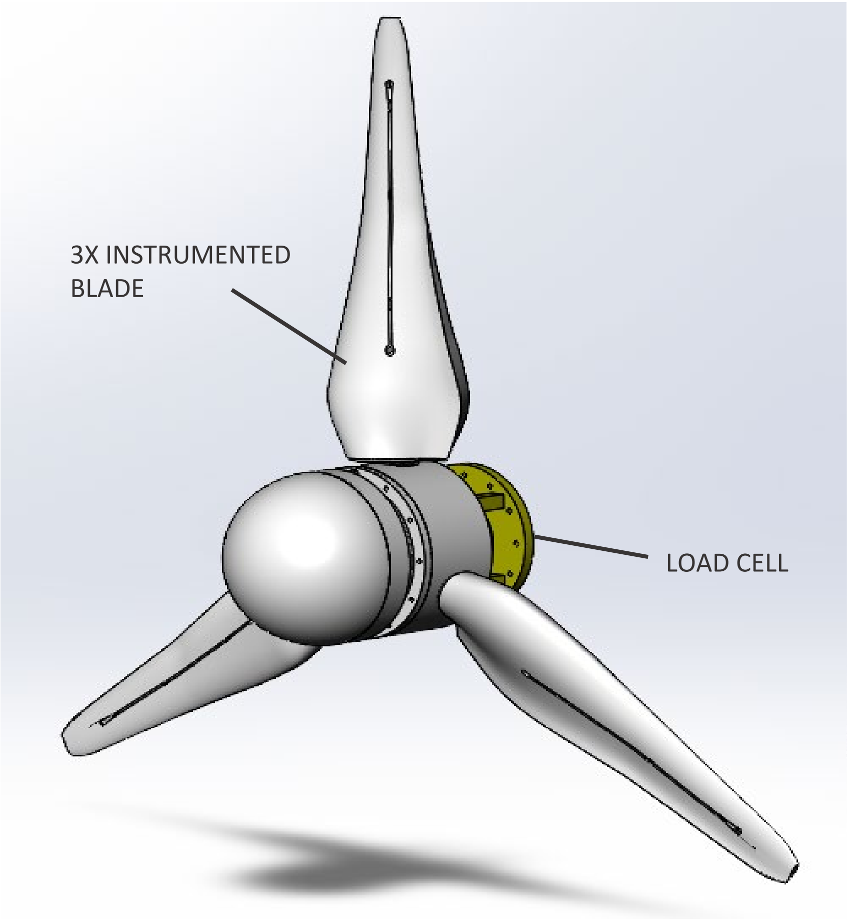
Max flapwise bending moment = X N-m

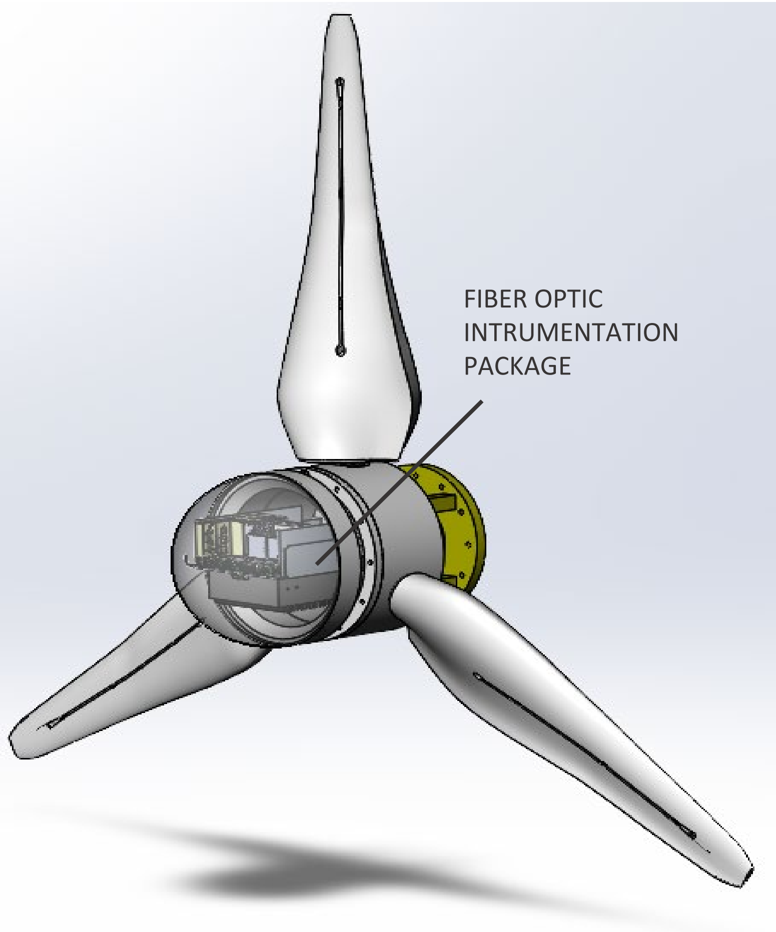
Max edgewise bending moment = X N-m

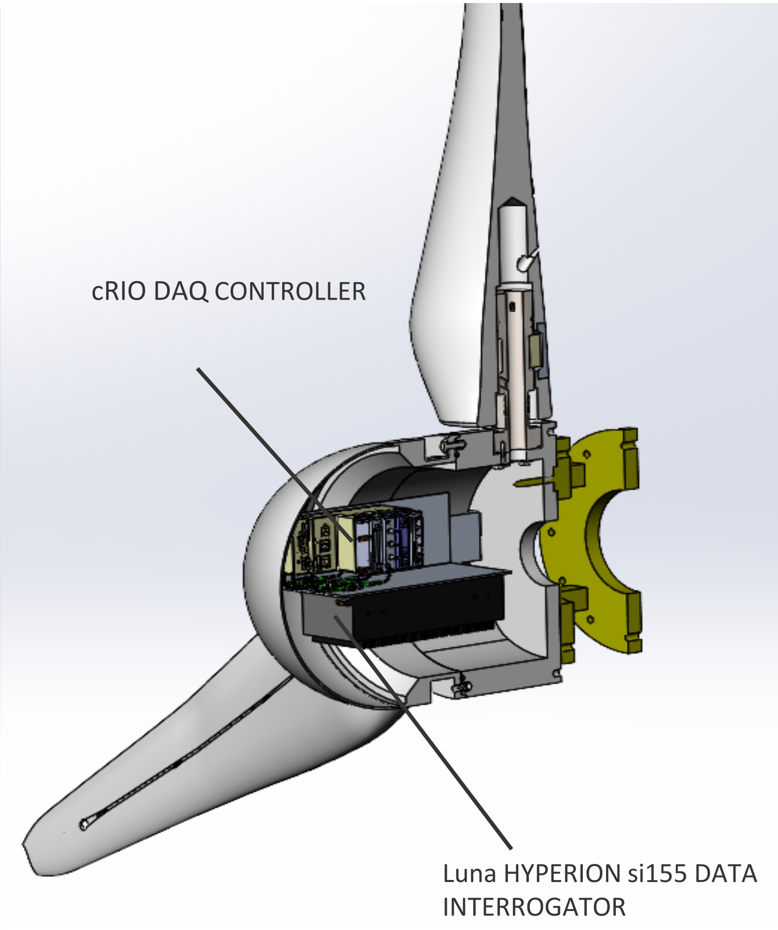
Max twisting moment = Y N-m

Max thrust distribution blade = Y N

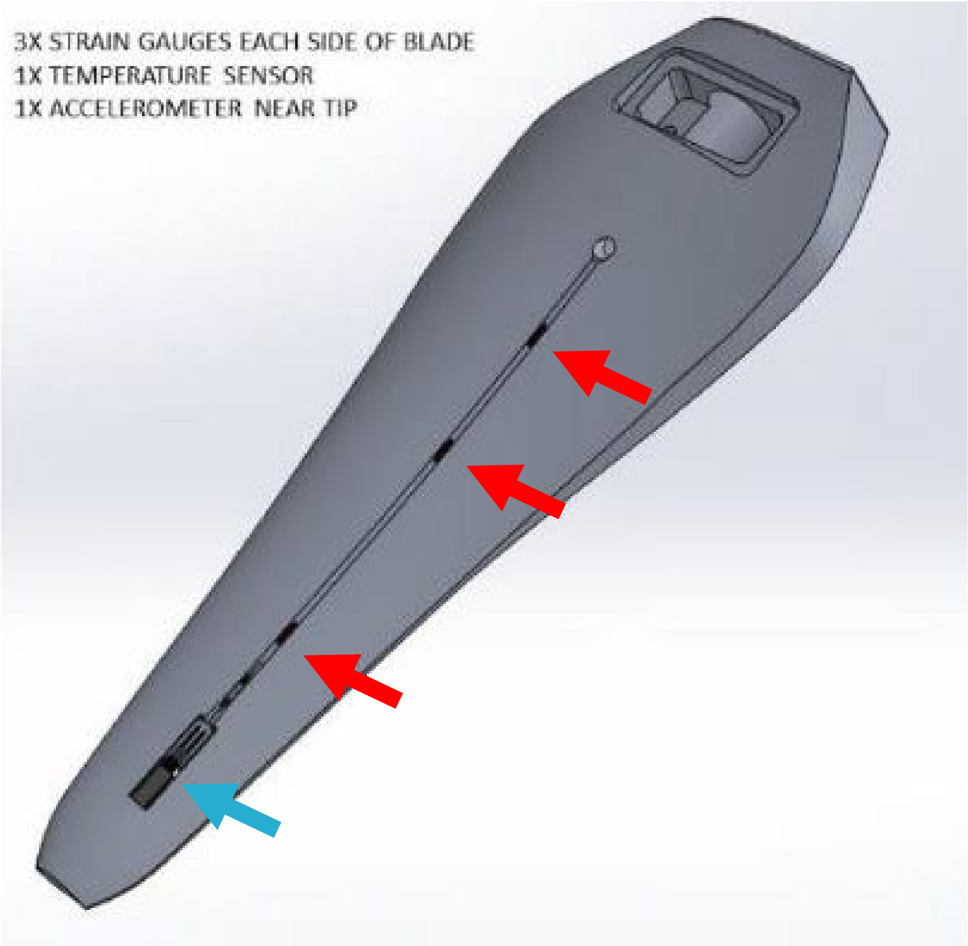
Sensors: Fiber optic system for blade strain and load cell for torque, thrust and off-axis loads

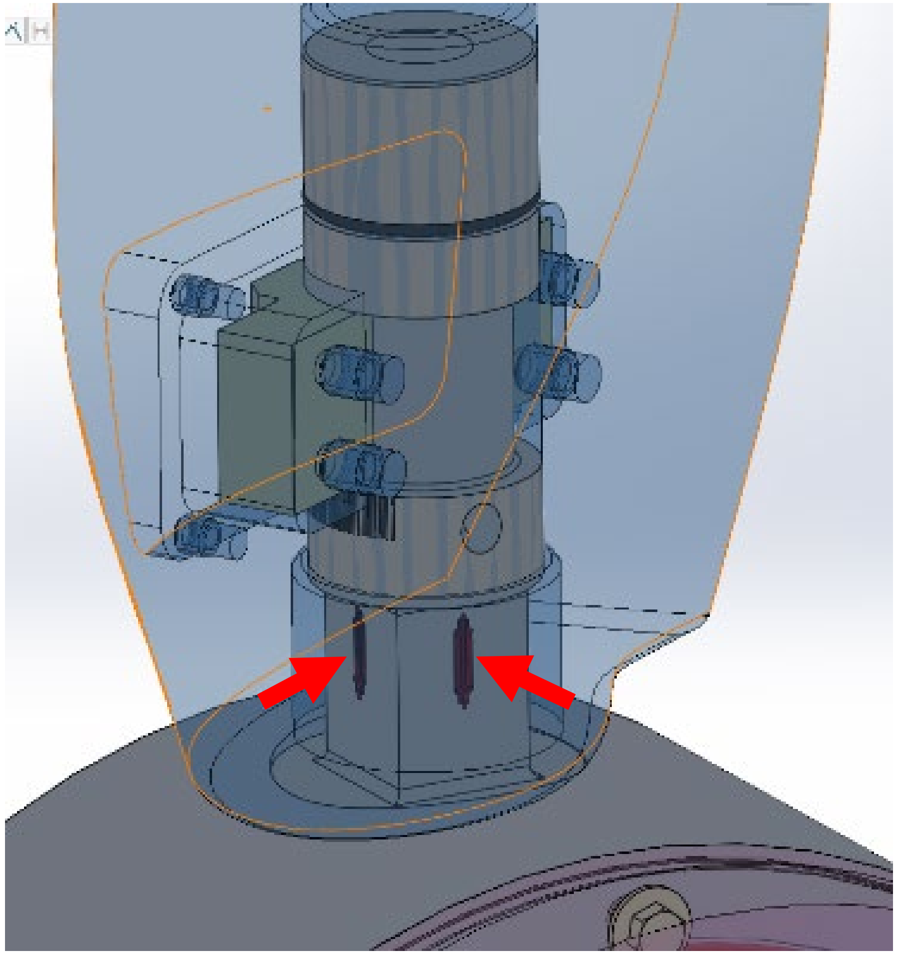






MHKF1 Tidal Turbine, strain measurements: blade span, flapwise, edgewise bending moments at root





Strain Gauge

Accelerometer

IEC Marine Energy Standards

International Electrotechnical Commission

IEC 62600-2: Design requirements for marine energy systems

- The performance of the MHKT under various loading conditions and failure modes will be tested

IEC 62600-200: Power Performance Assessment of Electricity Producing Tidal Energy Converters

- Metrics such as the power coefficient, capacity factor, and total power will be measured on this grid-connected MHKT

IEC 62600-201: Tidal energy resource assessment and characterization

- Key environmental factors such as the flow speed, salinity, and temperature will be measured

IEC 62600-202: Early-stage development of tidal energy converters

- Stage 3, field-scale testing with a Technology Readiness Level of 5-6

Measurements Summary

Turbine Load/Motion	• Blade Root Bending Moments (flat and edge-wise) • Rotor Torque, Thrust, Tilt and Yaw • Blade Strain • Blade Modal Frequencies • Rotational Position • Rotational Velocity • Platform Motion • Platform Loads • Yaw Misalignments
Power Take Off System	• Generator Power, Voltage, Current • Generator Speed • Operational State of the Control System • Control system input Data and Status
Oceanographic Quantities	• Current Speed (high-frequency point source and low frequency shear profiles) • Current inflow direction • Wake Characteristics • Water Temperature • Water Depth • Salinity/Conductivity • Waves
System Operational Monitoring	• Hub and Nacelle temperature • Hub Humidity • Critical Seal Leaks

Test Matrix

MLC	Turbine condition	DLCs IEC TS 62600-2:2019	Target frequencies	Description
1.1	Power production	1	NA	Steady state operation MLC. In this mode of operation, the MEC is running and connected to the grid
1.2	Parked	6	NA	Steady state operation MLC. When the MEC is parked, the prime mover may be either in a standstill or idling
2.1	Start up	3	NA	Transient load MLC. Turbine undergoing normal start up. Target around 10 % of rated power and rated power
2.2	Normal shutdown	4	NA	Transient load MLC. Turbine undergoing normal shutdown. Target around 10 % of rated power and rated power
2.3	Emergency shutdown (by pushbutton)	5	NA	Transient load MLC. From rated power
2.4	Normal operation with fault	2	NA	Transient load MLC. 2.1 Normal - Simulated Grid loss, grid failure, fault in controller, i.e. faults triggering the control system. 2.2 – Abnormal - Safety system relevant faults, short circuit, brake failure
3.1	Power production (Normal operation)	1	Blade, drivetrain and substructure frequencies	Dynamic characterization MLC. Normal operation with relatively steady rotational speed
3.2	Parked	6	Blade and substructure frequencies	Dynamic characterization MLC. Turbine parked (standstill or idling). Consider one MLC with rotor yaw misalignment.
3.3	Emergency stop	5	Blade, drivetrain and substructure frequencies	Dynamic characterization MLC. Emergency stop from rated power
3.4	Artificial excitation	Low water speed and wave energy flux	Blade frequencies	Dynamic characterization MLC. Artificial excitation can be performed under control conditions

THANK YOU

Questions? Comments?

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