SAND2012-6517P

CURRENT AND TIDAL DEVICES:

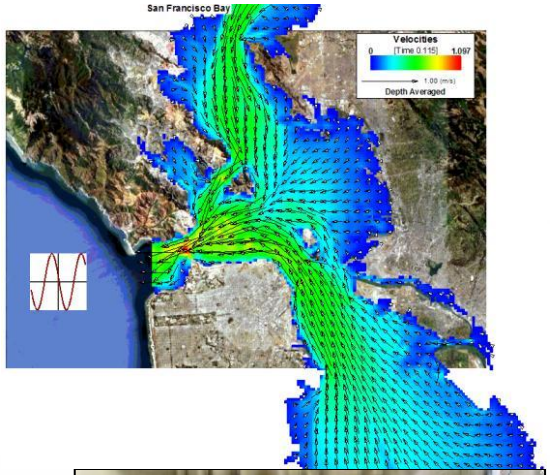
PERFORMANCE AND ENVIRONMENTAL EFFECTS

August 6, 2012

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Key Technological and Environmental issues

- How do you design an appropriate device for a resource
  - Performance and loading
  - Reliability and survivability
    - Debris/mammal strike
    - Geochemical
- What are potential impacts of energy extraction:
  - Near- and far-field changes in flow
  - Far-field changes in water quality (tidal)
  - Changes in sediment transport (wave, riverine, tidal)
- What do MHK devices add to system:
  - Noise
  - Obstructions
  - EMF
  - New habitat



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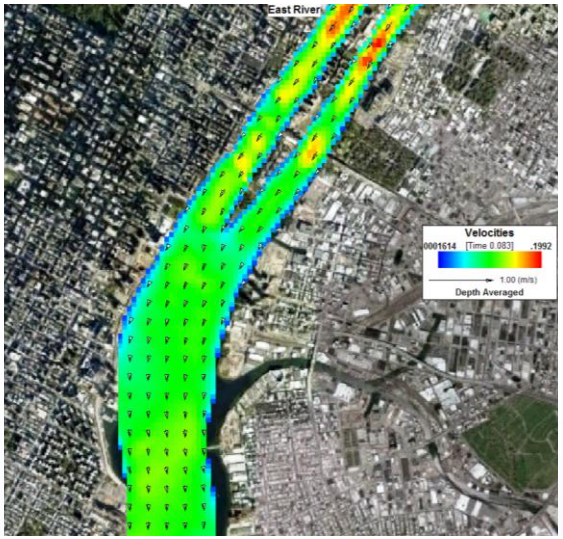
Use measurement tools and computer models to investigate

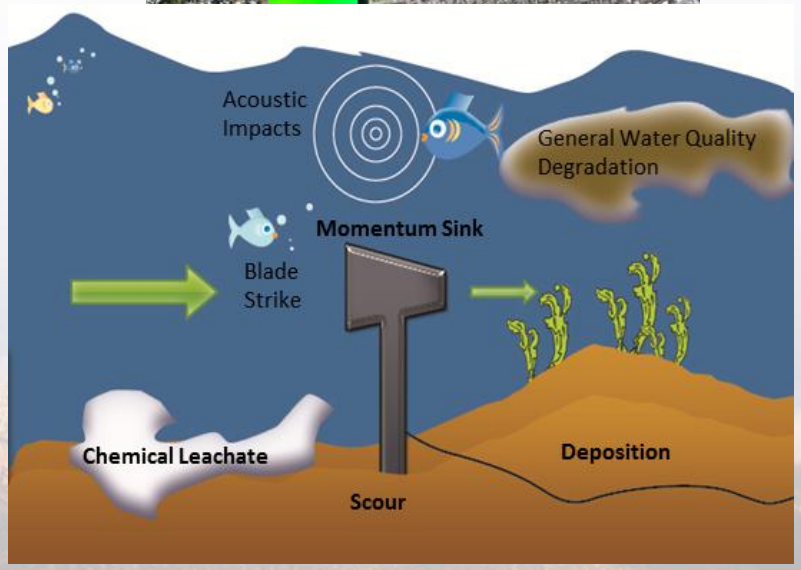
Models and experimentation allow for "what if" scenarios

- Placing "devices" in the flow
- Increasing realism of devices
- Adding more and more devices
- MHK turbine survivability and reliability
  - Debris strike
  - Geochemical interactions

Outcome

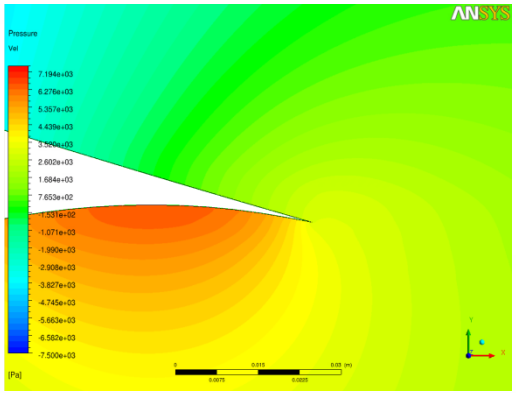
- Reduce costs for MHK build out with predicative simulations
- Understand environmental limits to MHK development
- Provide MHK specific data sets and assessment tools

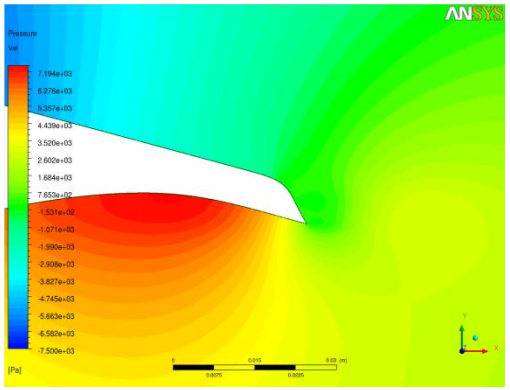




SNL modeling capabilities

- **Resource-scale modeling**
  - SNL-EFDC
    - Sediment transport
    - Water Quality
  - Hydrology models

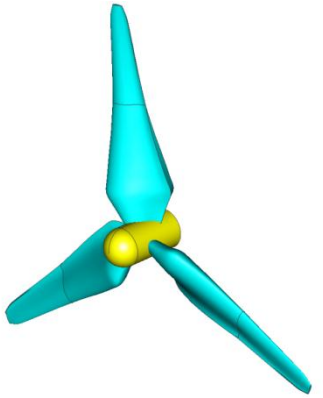


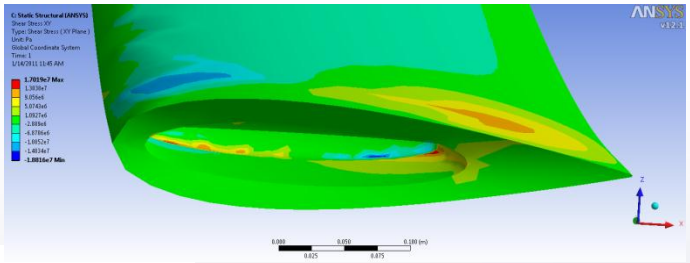


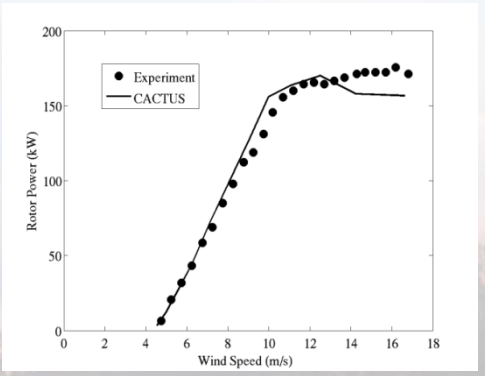
- **Turbine design and performance**
  - CACTUS
  - High-fidelity CFD and HPC access
    - Red Sky is newest HPC at SNL
      - **505 TFlops**
      - **Red Sky UnClassified**
        - 2,816 nodes / 22,528 cores

Turbine Design and Optimization

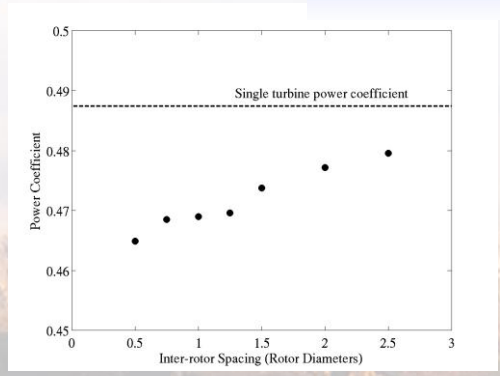
- **Design for resource and physics**
  - Optimal performance for site characteristics
  - Soiling, cavitation, noise
  - Stress and Hydrodynamic analysis
- **Couple CACTUS with SNL optimization code DAKOTA**
  - Large parameter space search
  - Rapid optimization and UQ







Power performance curve



Dual-turbine spacing performance

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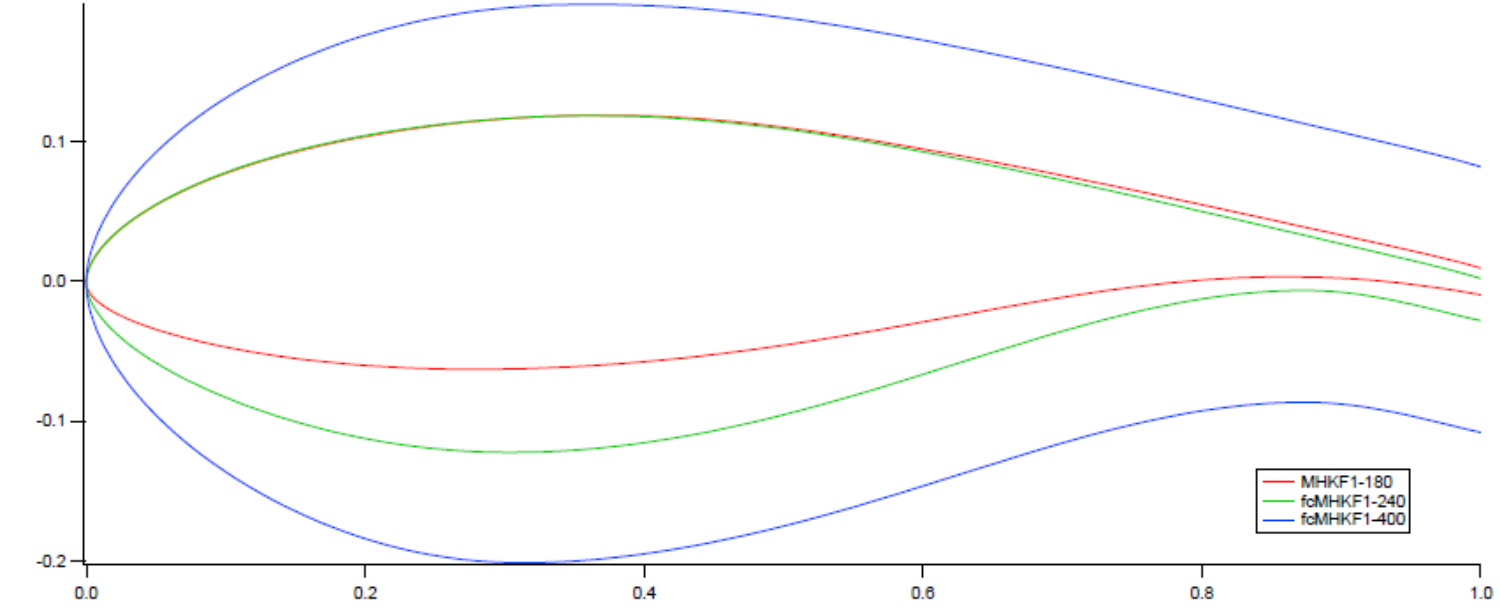
Foil design

- **Collaboration with UC Davis to design a hydrofoil**
  - Leverages SNL wind experience
  - Increased turbine performance
  - Reduced susceptibility to soiling
  - Reduced TE vibration and shedding (anti-singing)



UC DAVIS
UNIVERSITY OF CALIFORNIA

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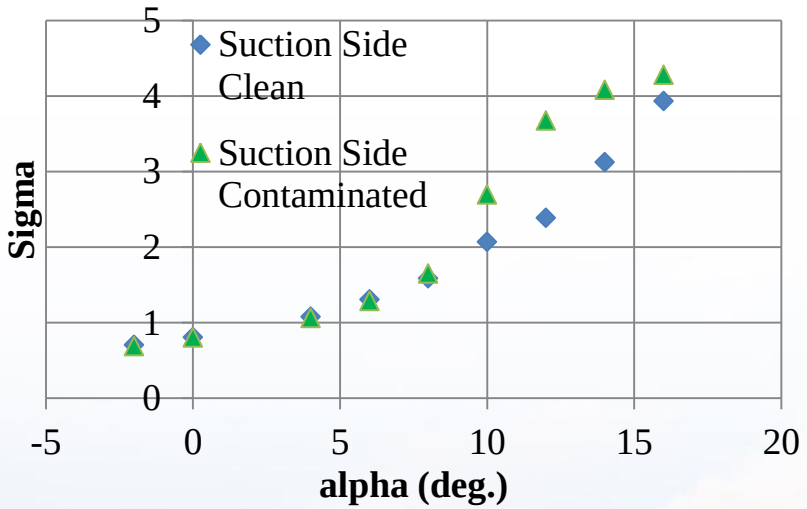
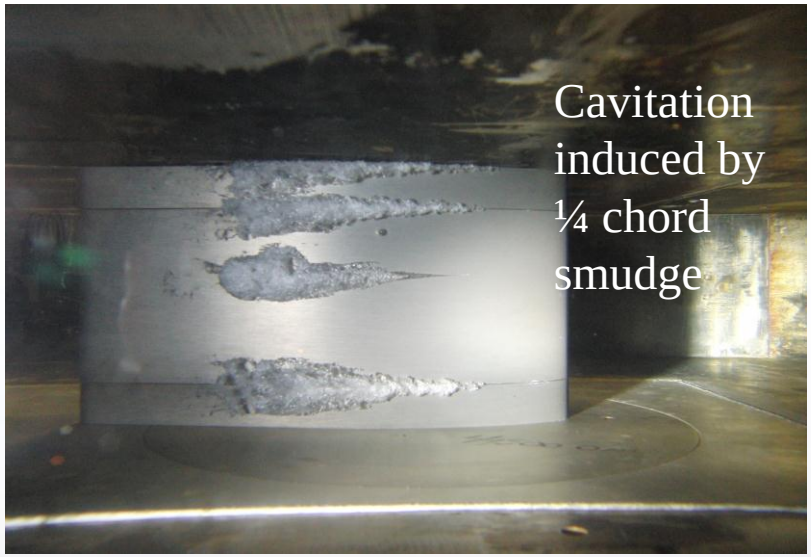
PSU-ARL 12” Tunnel – Cavitation

- **Looking at susceptibility of foils to cavitate in clean and soiled conditions**

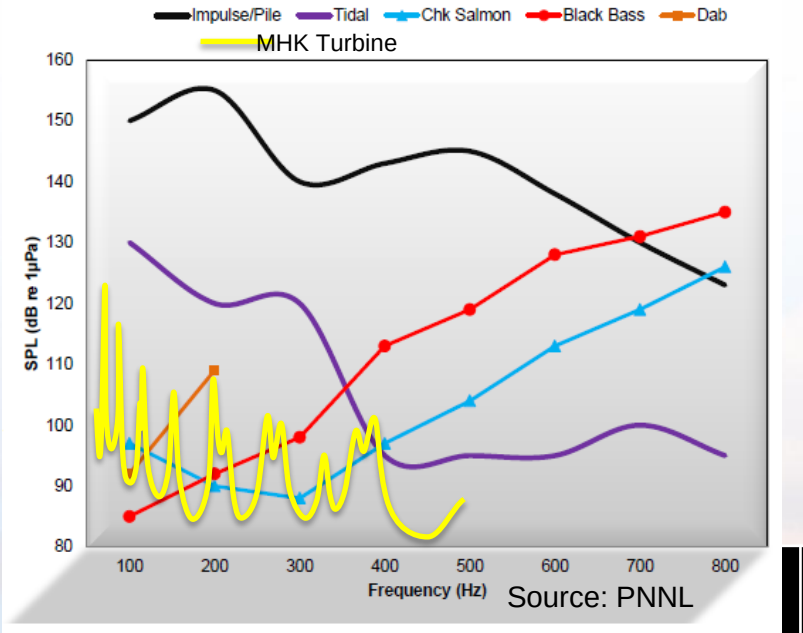




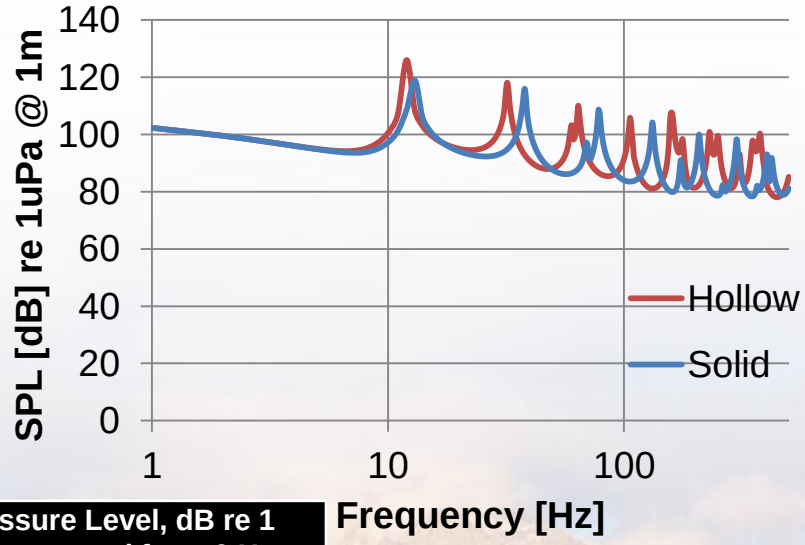
- **ARL is able to study long-term cavitation effects**
  - Coupon samples in 3” tunnel

MHK Turbine Acoustic Analysis

- **Requires RANS+ to calculate integrated values**
  - Friction velocity, displacement thickness, etc.
- **With PSU-ARL's CHAMP framework, looked at a traditionally designed blade**
- **Does not include generator or tower noise**
- **Numerical analyses to be compared against September tunnel tests**



Source: PNNL



	Sound Pressure Level, dB re 1 µPa² at 1 m integrated from 0 Hz to 500 Hz		
	LE	TE	LE&TE
Hollow	127.8	112.1	128.0
Solid	122.9	111.3	123.3

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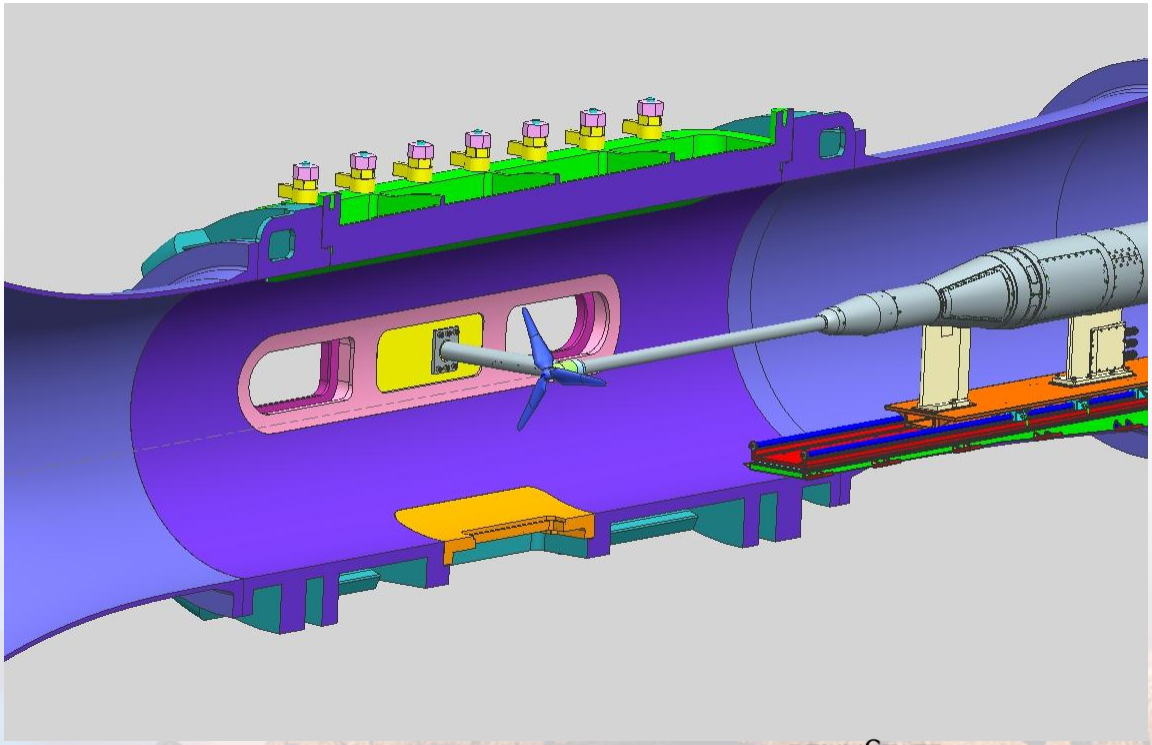
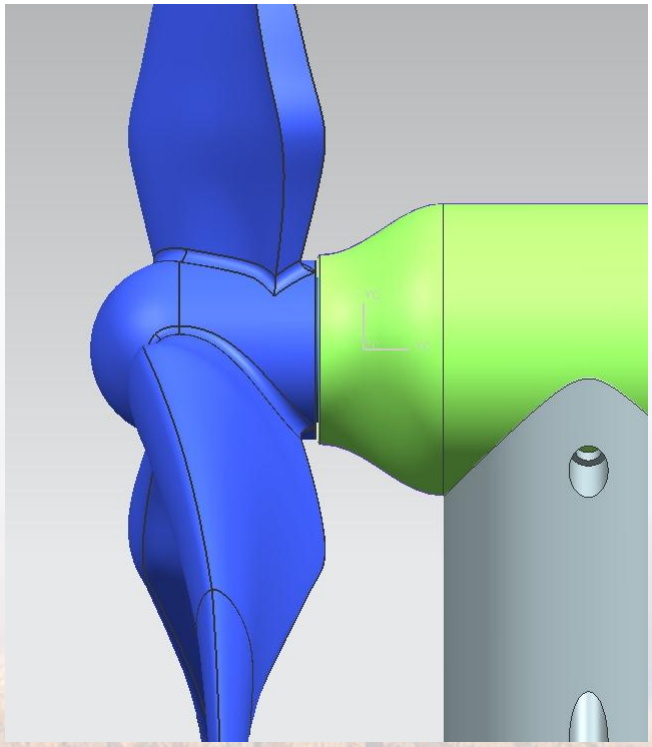
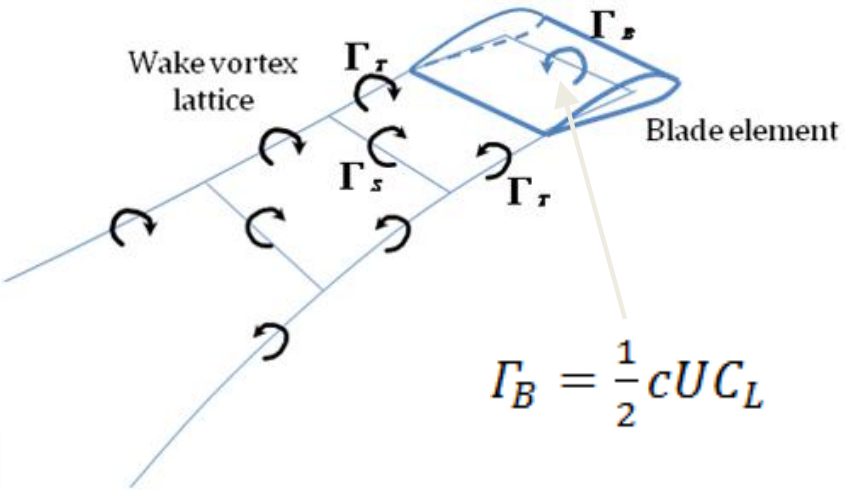
PSU ARL 48” Tunnel Test

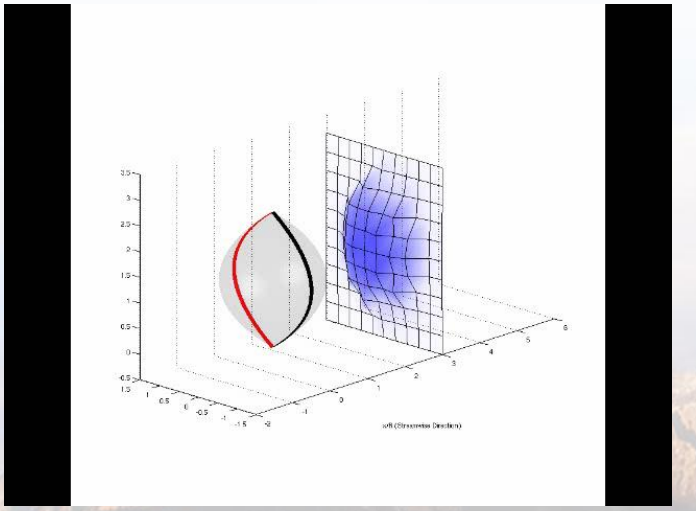
- **Test planned for September, 2012**
  - Load cell, torque/thrust, pressure, acoustic, LDV
  - Machined as monoblock, max 7 m/s @ 900 rpm





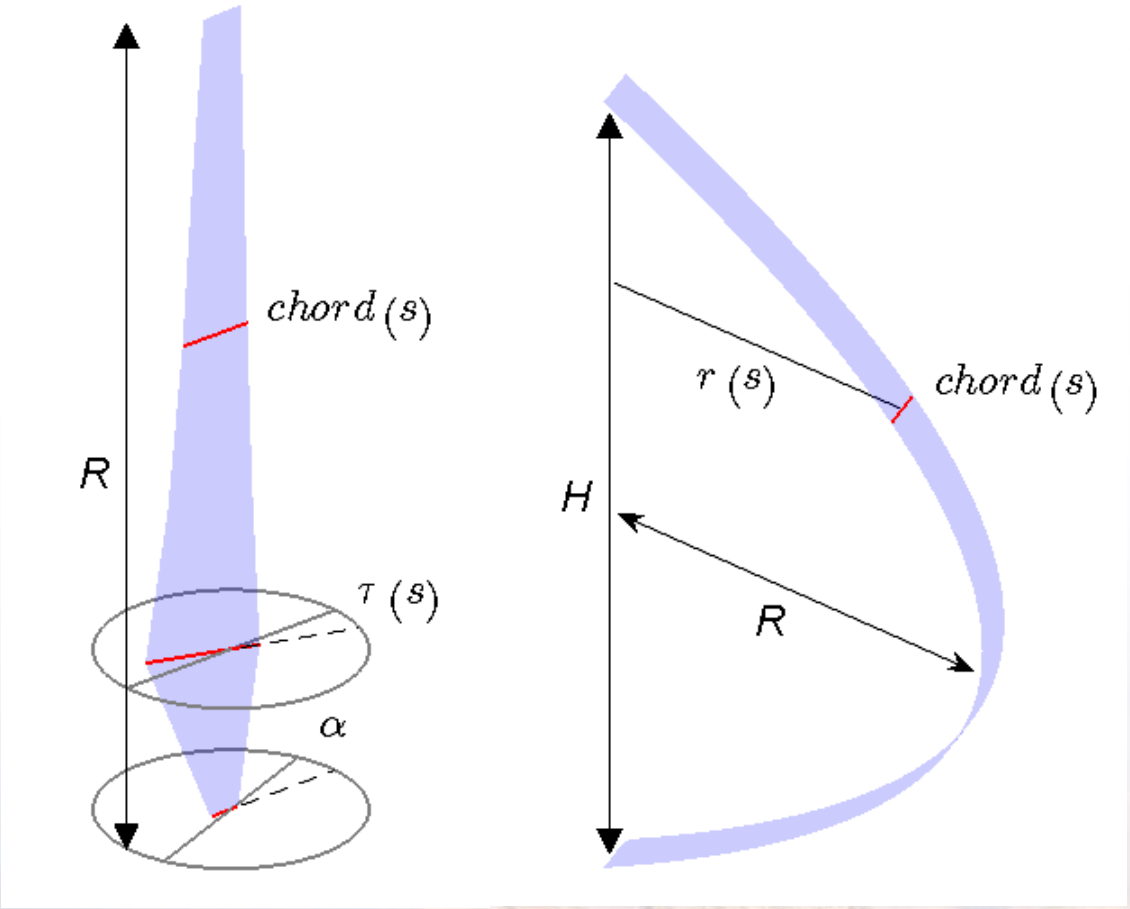
Code for Axial and Cross-flow TUrbine Simulation





- Blades represented as “lifting lines”, divided into blade elements
- Blade forces determined from foil data input
- Rotor wake represented with vortex elements
- Initial model of support drag is included
- Time-domain simulation

Generalized Rotor Geometry

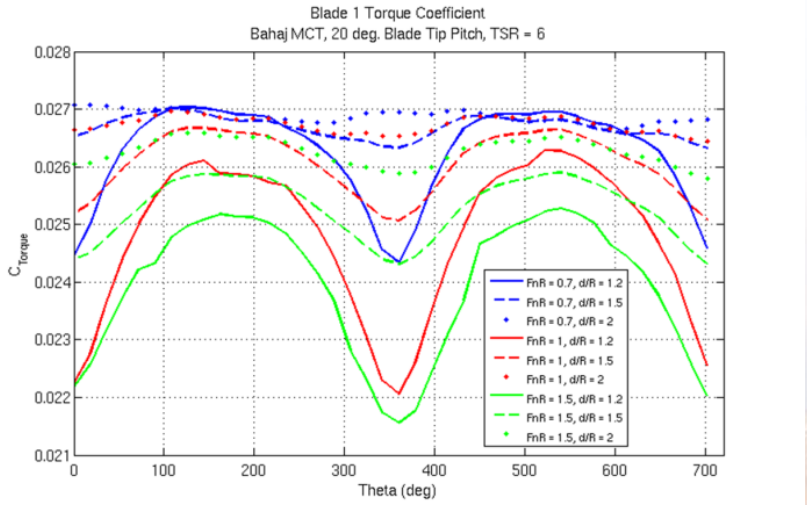


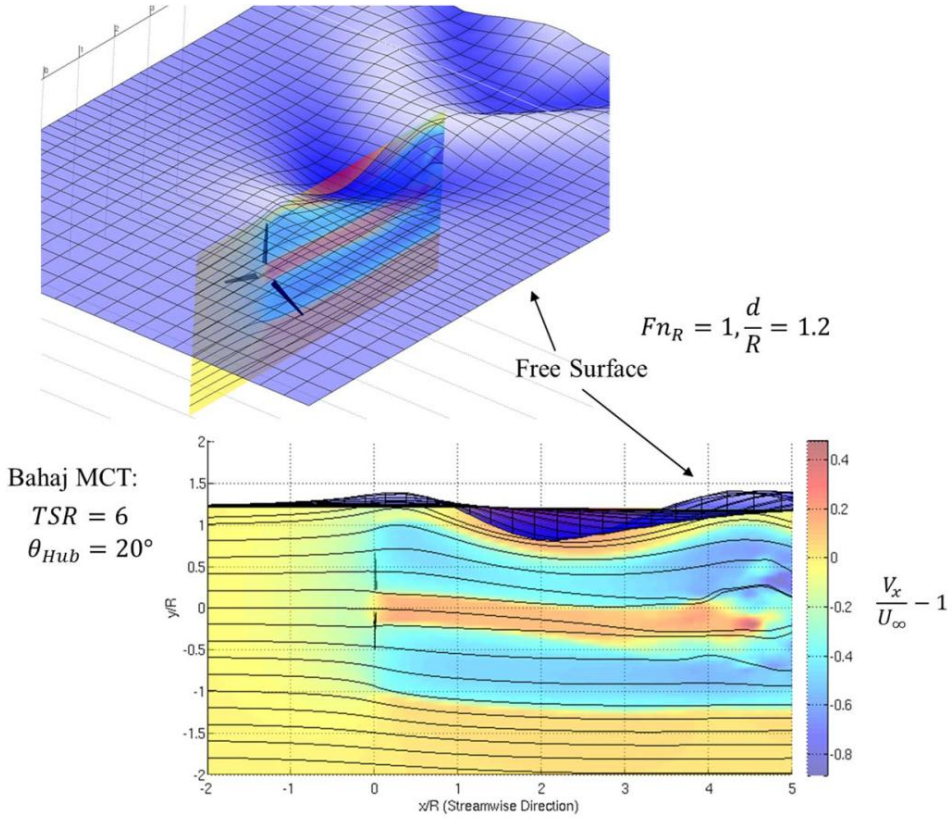
a) Axial turbine blade b) Cross-flow turbine blade

- **Blade geometry input is general. Inputs:**
  - Blade shape (path in space)
  - Chord distribution
  - Twist distribution
- **Some modeling of support strut drag is included**

Free Surface and Dynamic Stall

- Free surface results compared well to Kelvin wave theory
- Beddoes – Leishman dynamic stall model





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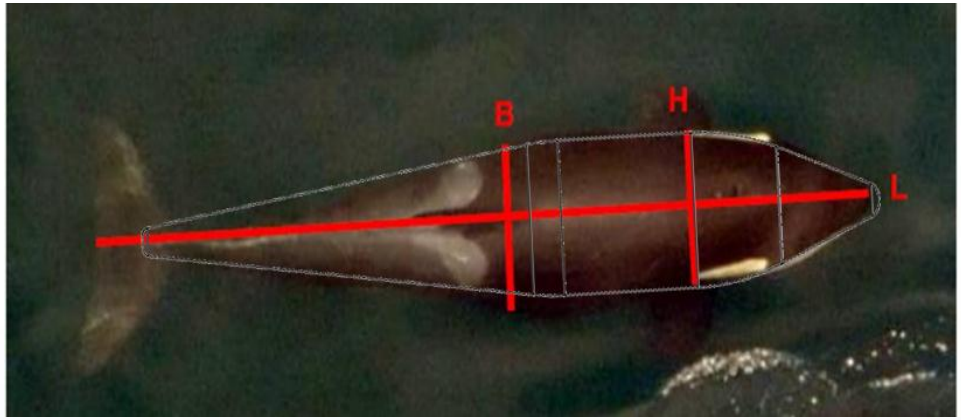
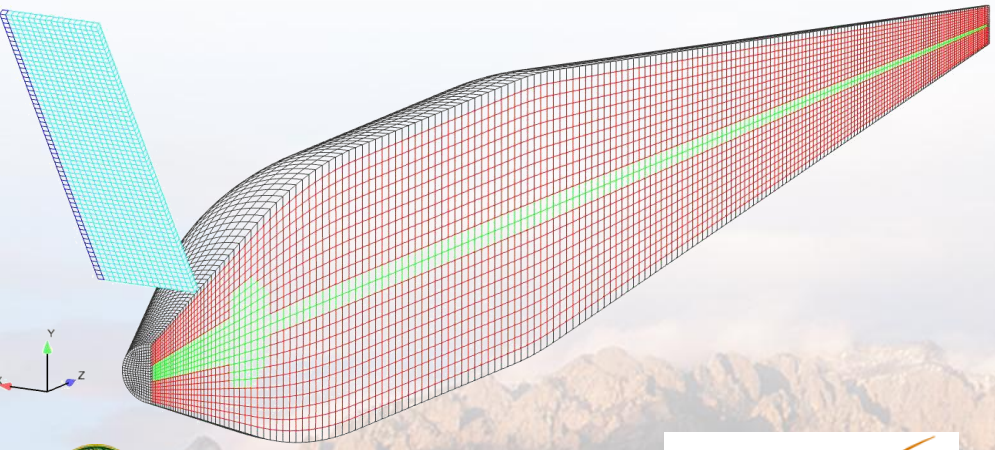
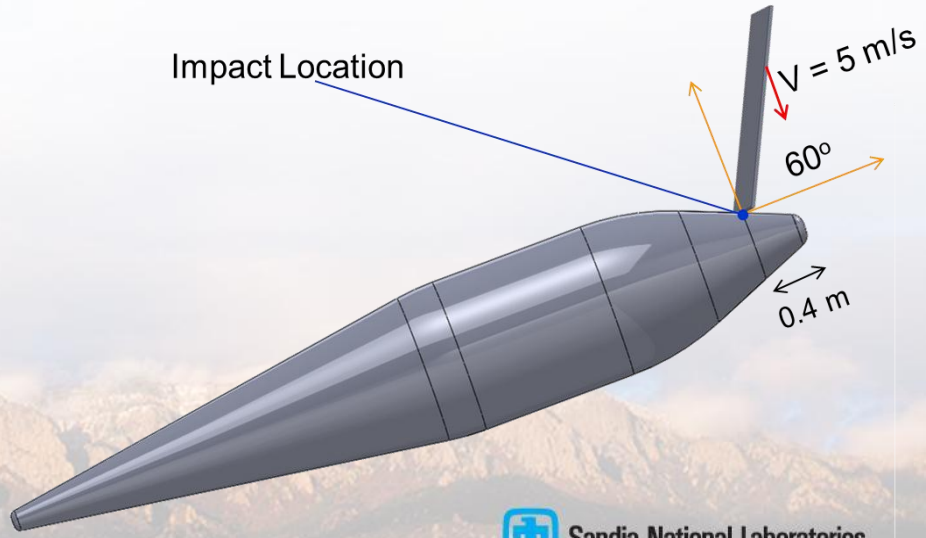
Marine Mammal Strike Analysis:

Assisting with Regulatory Requirements

- Impasse between regulators and SnoPUD project regarding the potential for blade strike of a Southern Resident Killer Whale.
- Joint SNL/PNNL effort provided data/analysis







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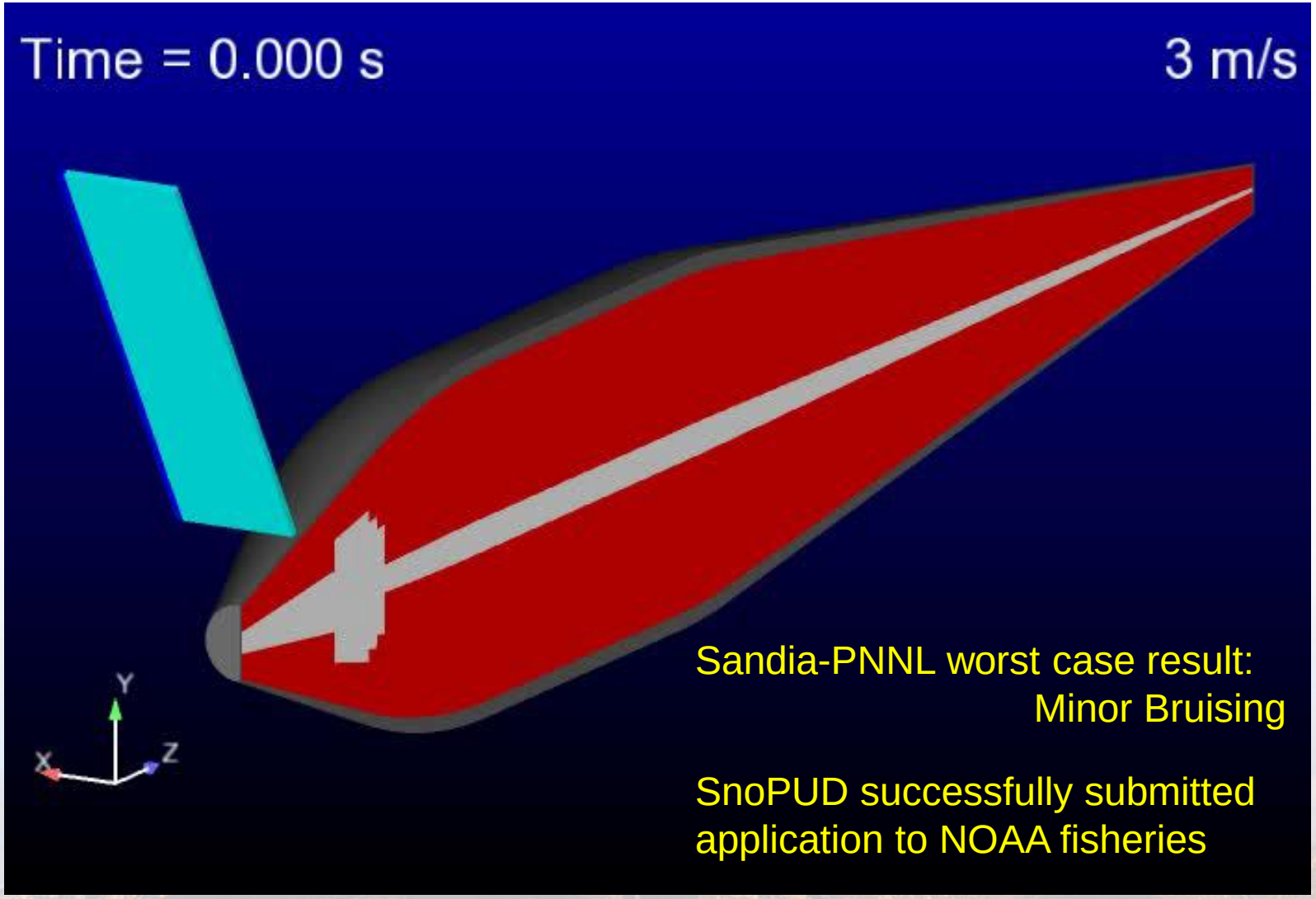
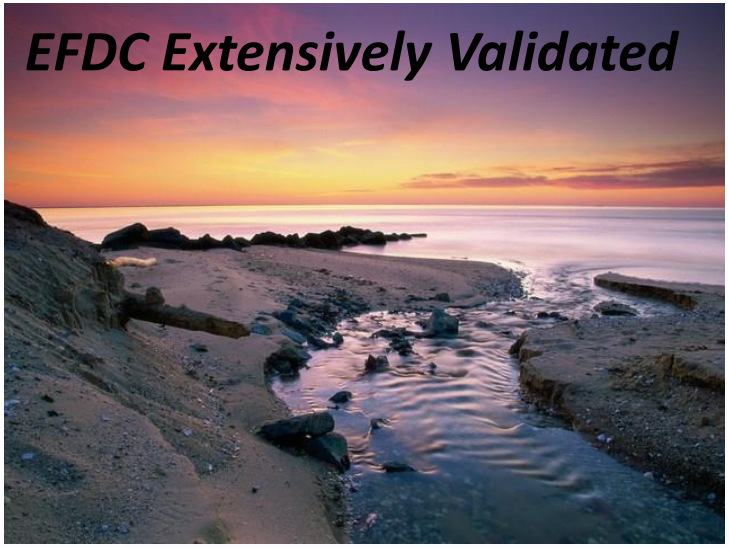
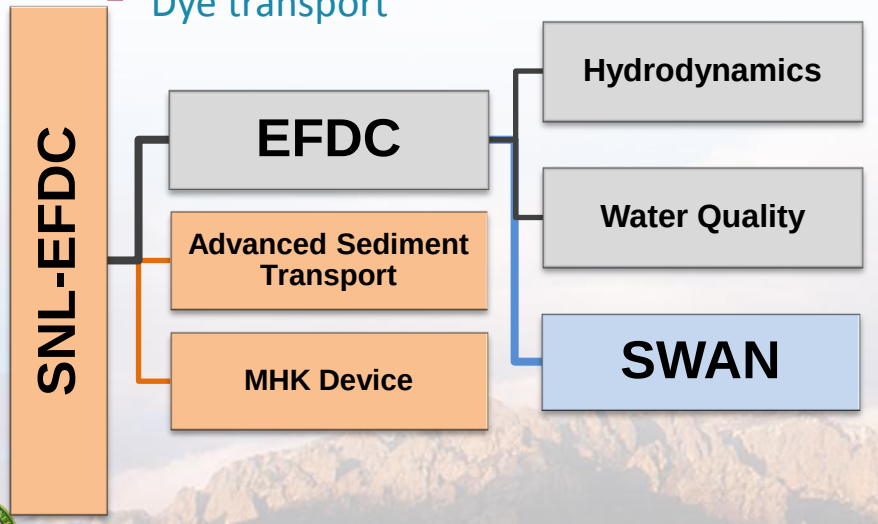
Impact Analysis

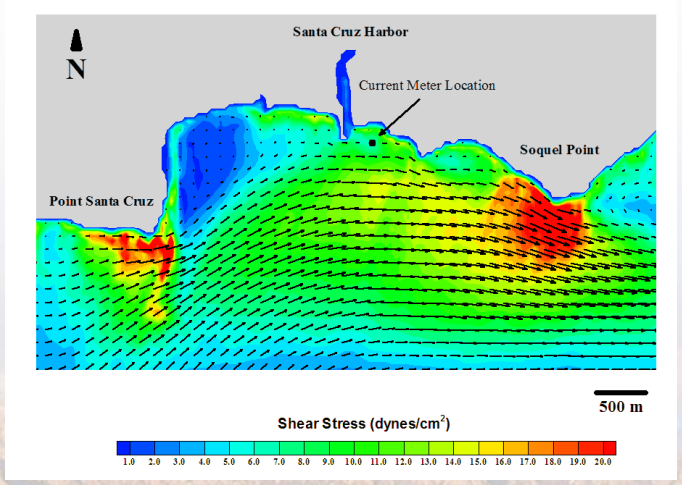


SNL-EFDC – Flow and Transport

- **EPA open-source code**
  - Curvilinear orthogonal grid
  - Coupled-equation solution
    - Mass conservation
    - Momentum conservation
    - *K-ε conservation*
    - Temperature transport
    - Salinity transport
    - Dye transport

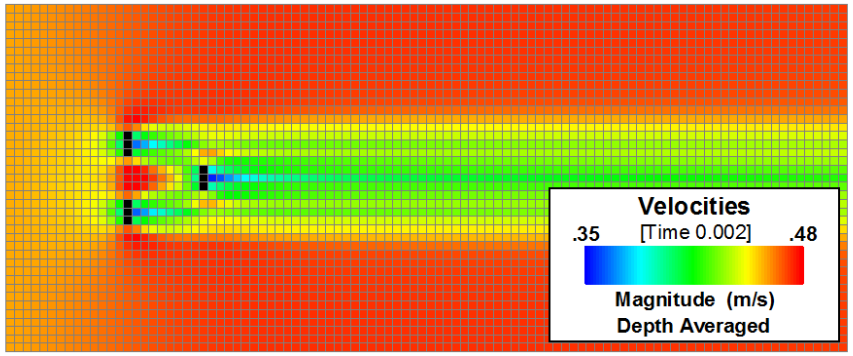


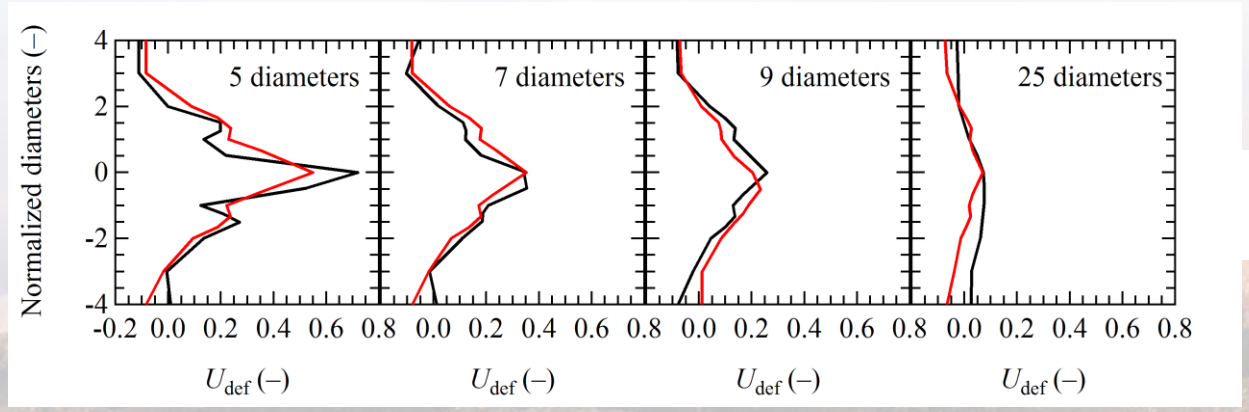




SNL-EFDC Array Validation

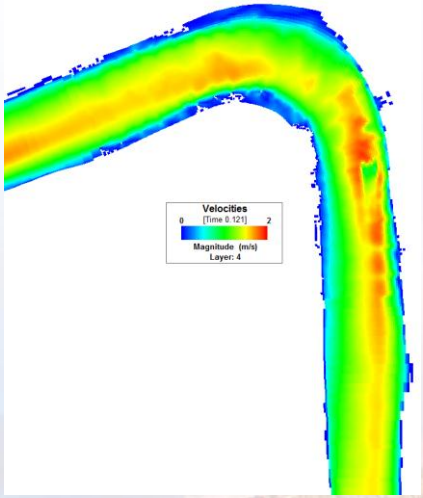
- **Extension of single-device validation**
  - 3 actuator disc measurements from Chilworth Flume [Myers, 2012]
  - Scaled-up model simulated
  - Shear and wake interactions required increase in background and vertical eddy diffusivity relative to single-device



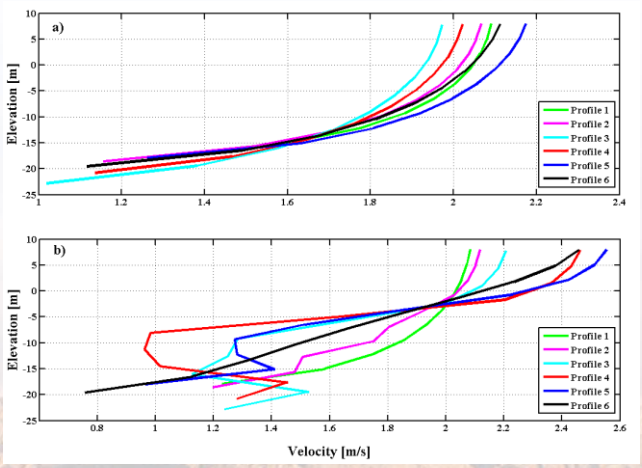


Demonstration Sites

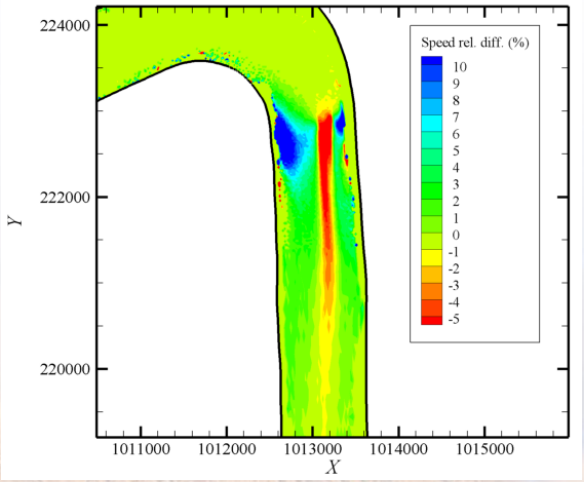
Scotlandville Bend, Mississippi River, Louisiana



Layer 4 (of 10) velocities



Water velocity profiles



Relative (cell-cell) velocity difference

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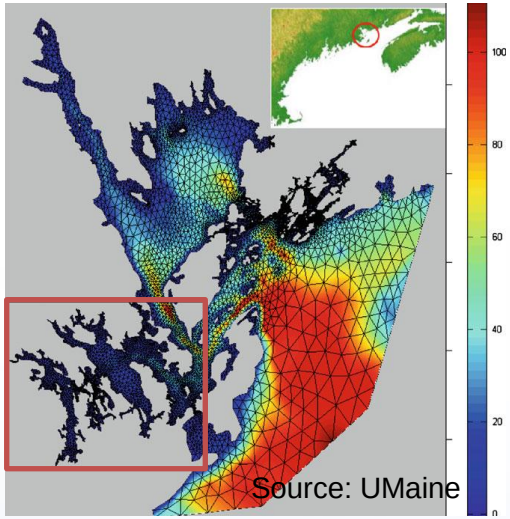
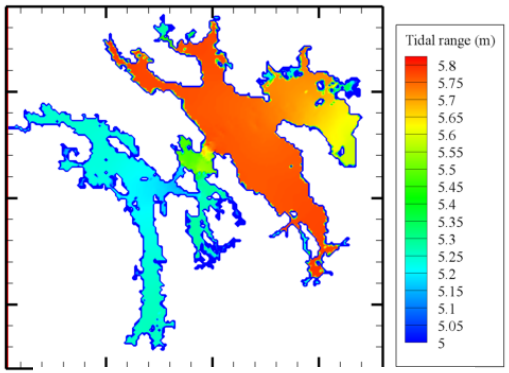
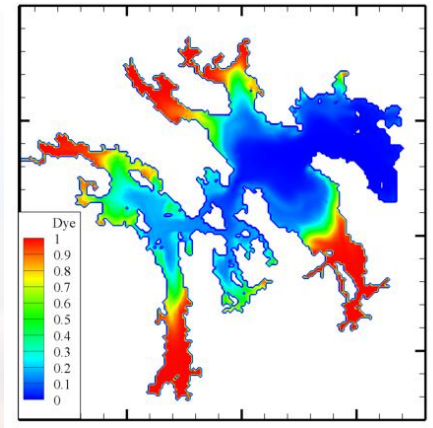
Demonstration Sites

Cobscook Bay, Bay of Fundy, Maine

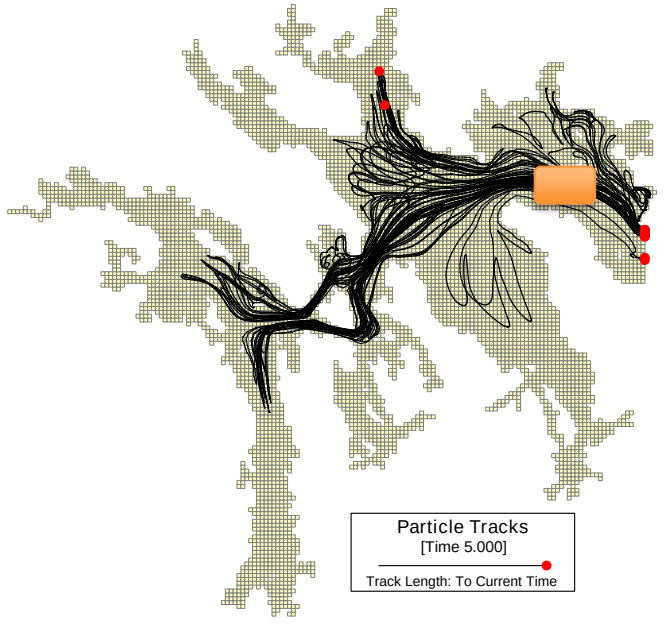


Tidal Range

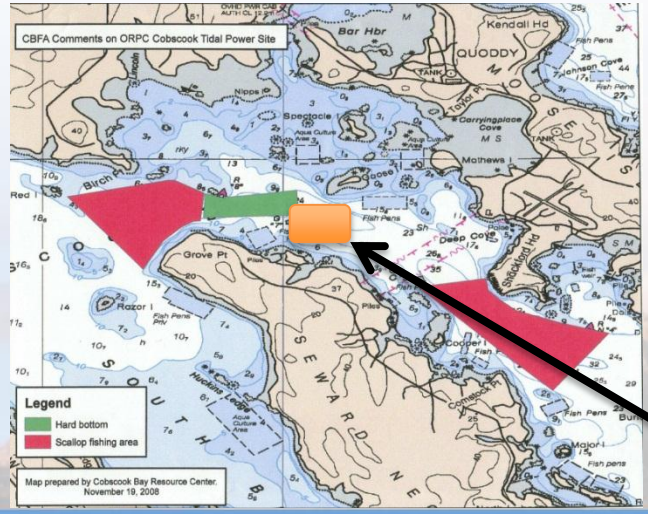




Dye concentration (6 days)



Passive baby-scallop transport



ORPC Array

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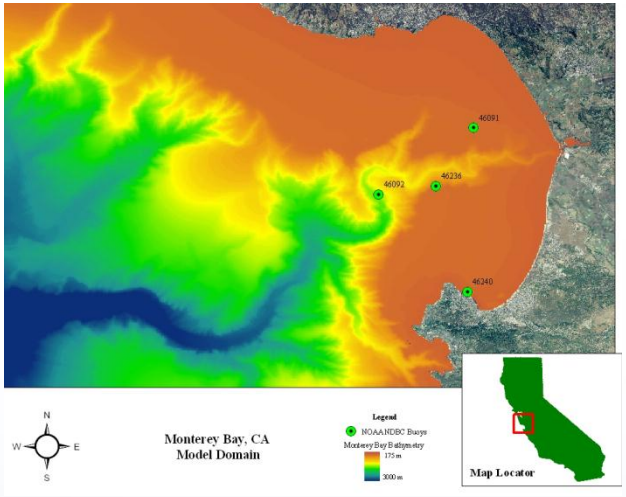
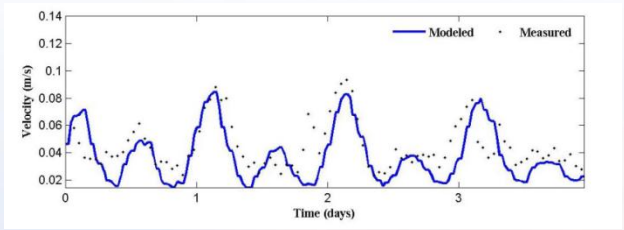
Demonstration Sites

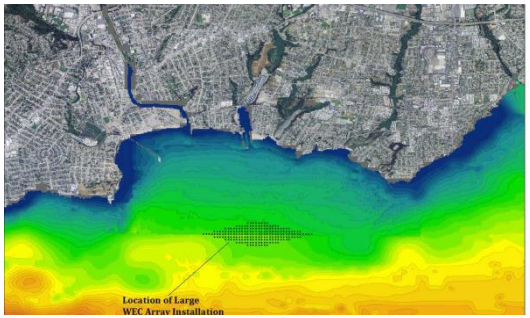
Monterey Bay, California

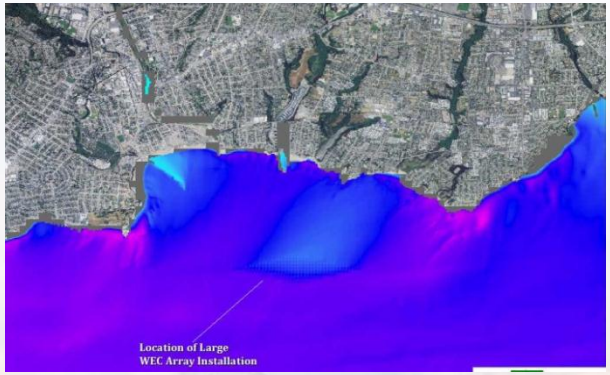




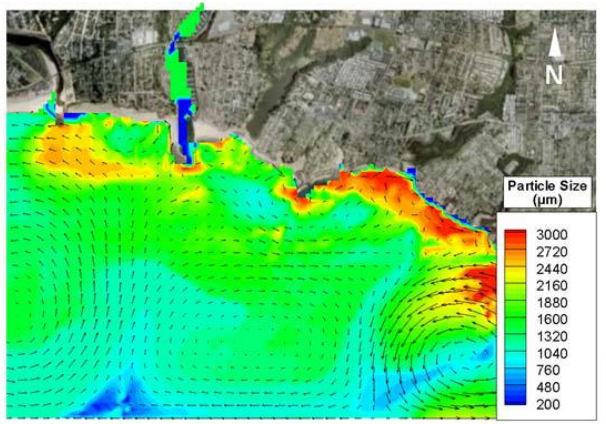
ADCP Near-shore velocity

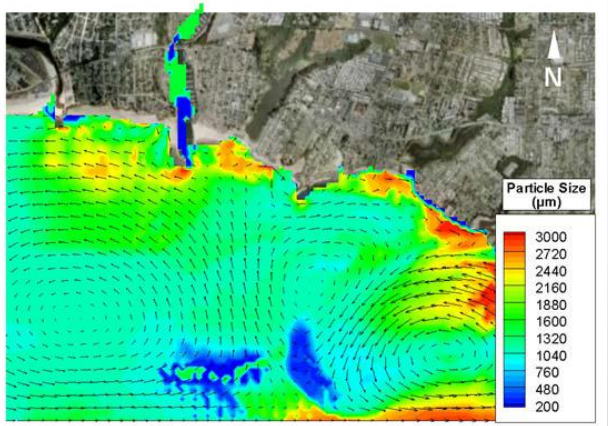
200 WEC Array





Wave Height





Change in sediment distribution.
(bottom) with WEC array

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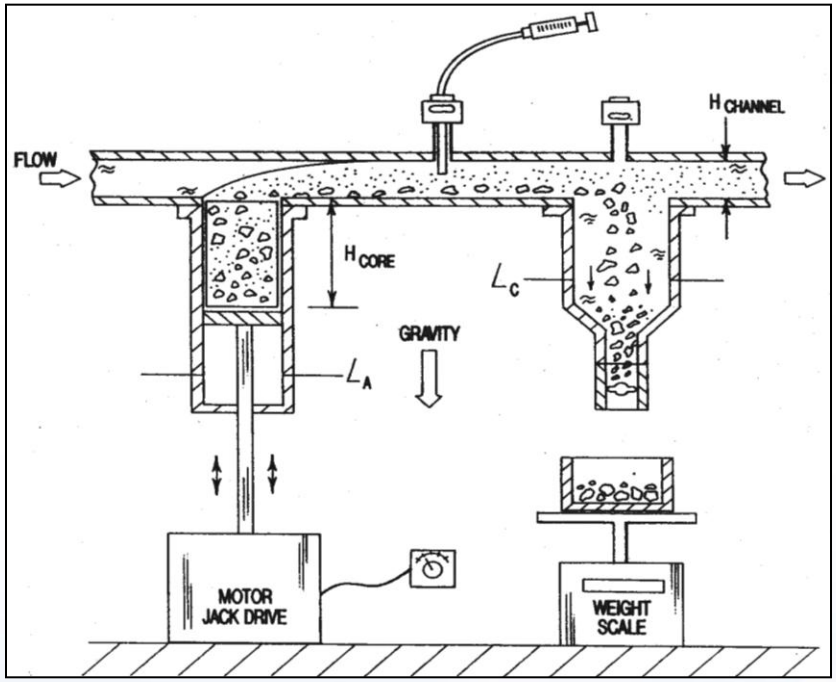
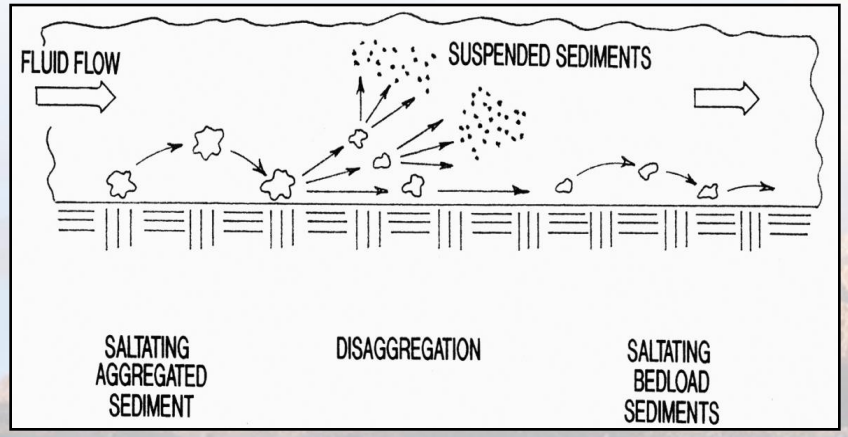
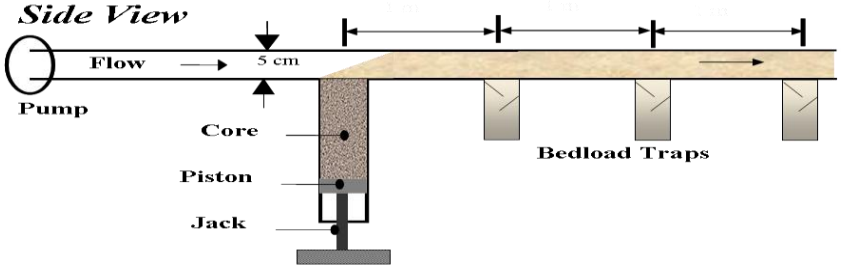
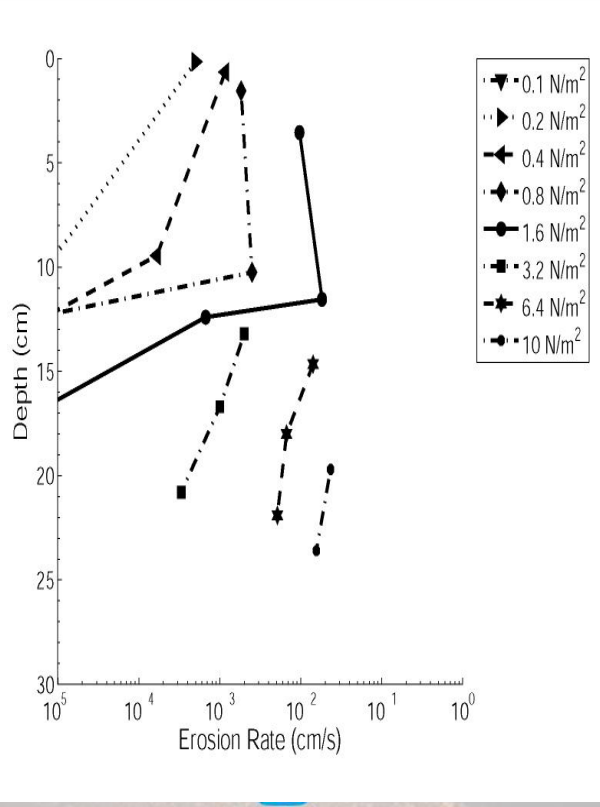
Sediment Field Measurements:

River & Tidal (ASSET)



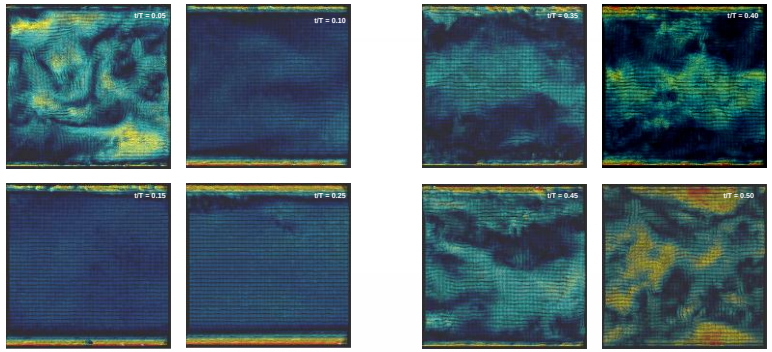




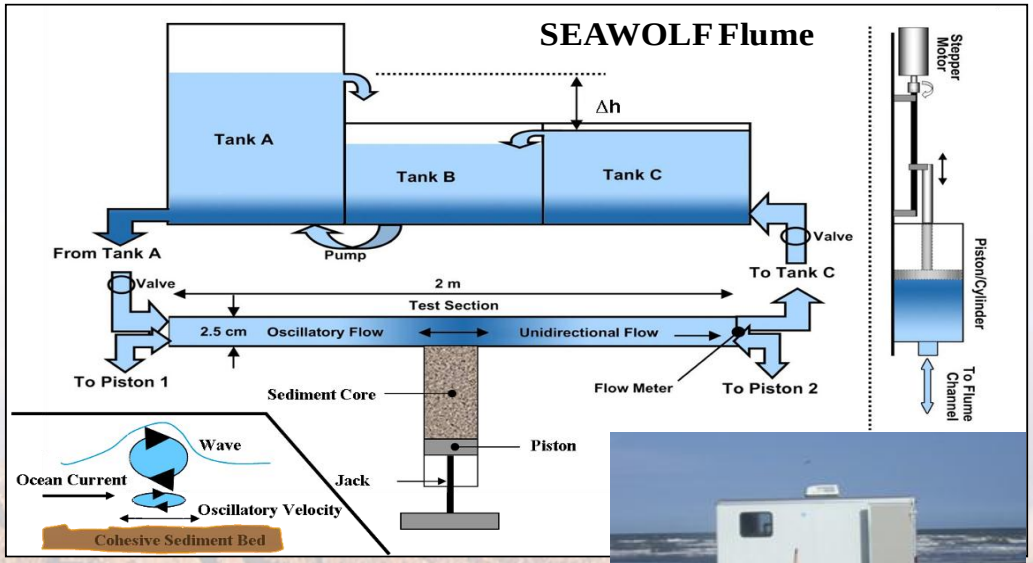


Sediment Field Measurements:
Ocean & Estuary (SEAWOLF)

- **ASSET and SEAWOLF Flumes**
  - Patented Sandia Tools
  - Mobile for onsite measurements
  - Simulate extreme events
  - Measure
    - Erosion rate
    - Critical shear stress
    - Transport mode
    - Stratification
    - Cohesive properties

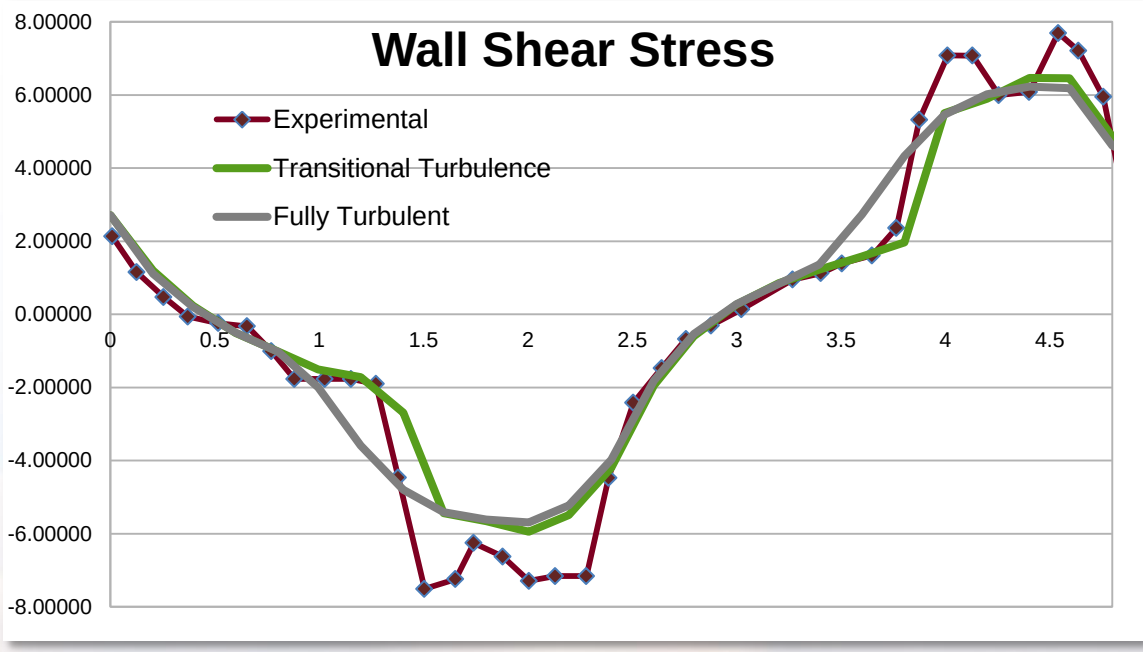


Acceleration Deceleration



Sediment Transport:
Experiment v. Theory

- **Oscillating bed shear**
  - Shear scales with velocity squared
  - Erosion scales with shear squared
  - Blasius-like solution is most common used
    - Assumes fully turbulent flow
    - Does not predict transitional jump
  - CFD with transition model predicts more closely



SNL Sediment and Water Power Experience

Dredge Disposal

- Canaveral ODMDS, **EPA**
- Boston Harbor, **USACE**
- Savannah Harbor, **USACE**
- Long Beach Harbor, **USACE**
- Kivalina Harbor, **USACE**
- Jacksonville Harbor, **USACE**

Contaminated Sediment Transport

- Housatonic River , **EPA**
- Sheboygan River, **Baird and Associates**
- Cedar Lake, **USACE**
- Potomac/Anacostia Rivers, **DOE**

Sediment Load, Flow, and Habitat

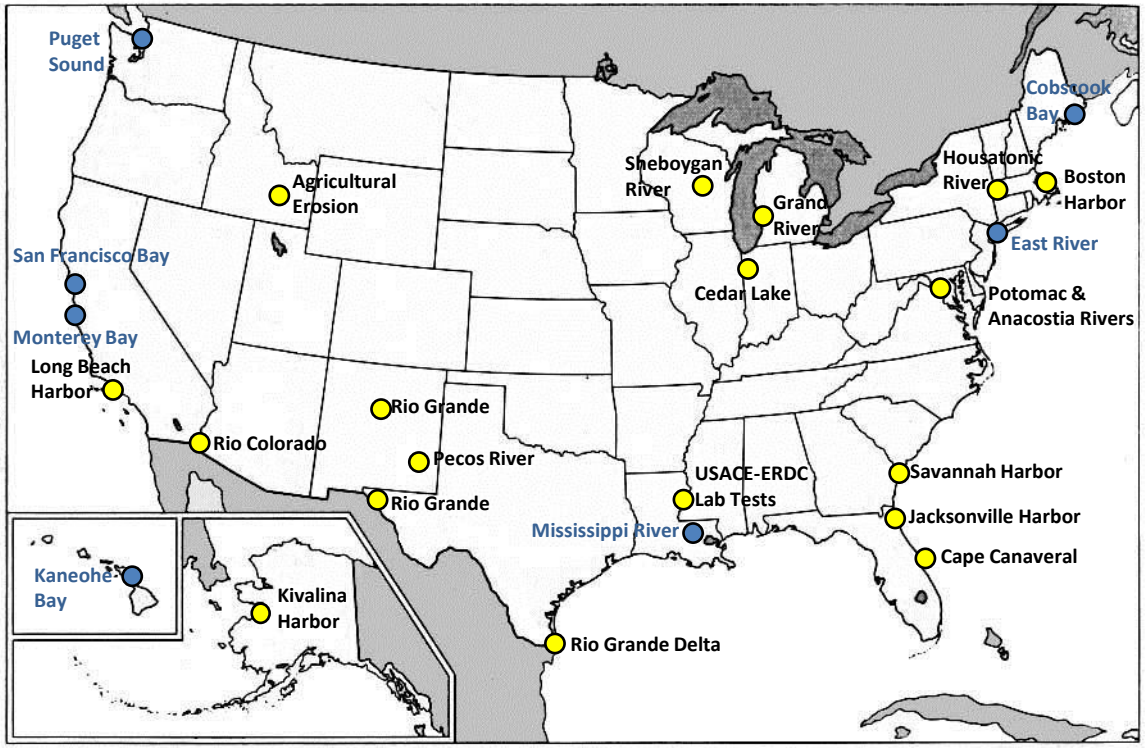
- Rio Grande River, **DOE**
- Rio Grande Delta, **DOE and IBWC**
- Pecos River, **State of New Mexico**
- Rio Colorado, **EPA**

Irrigated Furrow Erosion

- Idaho Agricultural Fields, **USDA ARS**

Water Power – DOE Funded

- Puget Sound, **Sediment and Strike Analysis**
- San Francisco Bay, **Tidal Range & Flushing**
- Monterey Bay, **Wave Propagation, Sediment Stability**
- Kaneohe Bay, **Wave Propagation, Sediment Stability**
- Mississippi River, **Flood Risk, Sediment Stability**
- East River, **Hydrodynamic Modeling**
- Cobscook Bay, **Tidal Range, Flushing, Scallop Dispersion**



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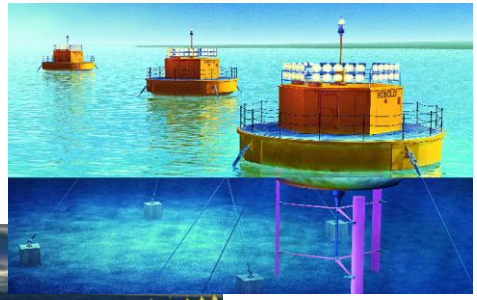
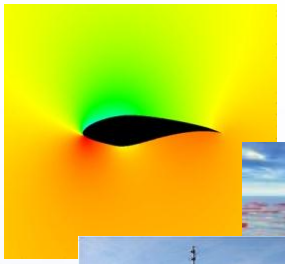
MHK Industry COE Strategy

MHK COE Reduction Pathway

- Large manufacturing product lines
- Large system arrays
- Easy maintenance
- High reliability





- Component evaluation
- Prototype testing
- Component/System analysis
- Material characterization

Cost

Today!

Time

Cost-Competitiveness

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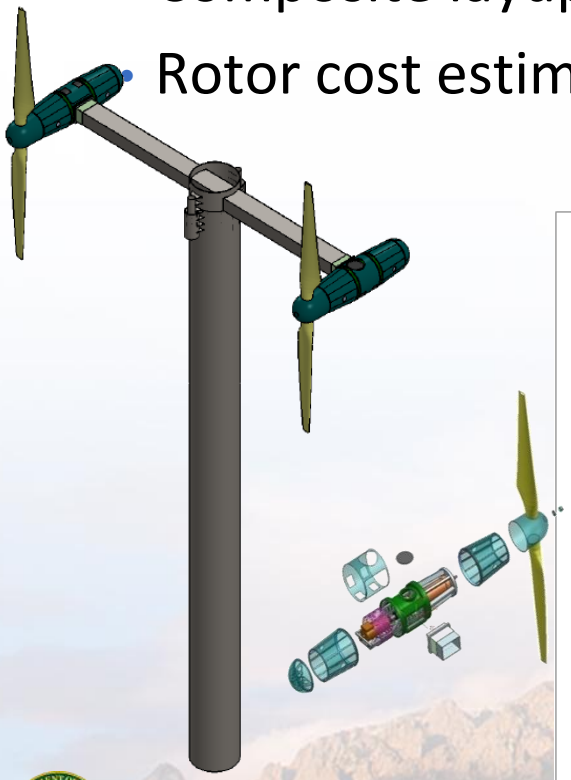
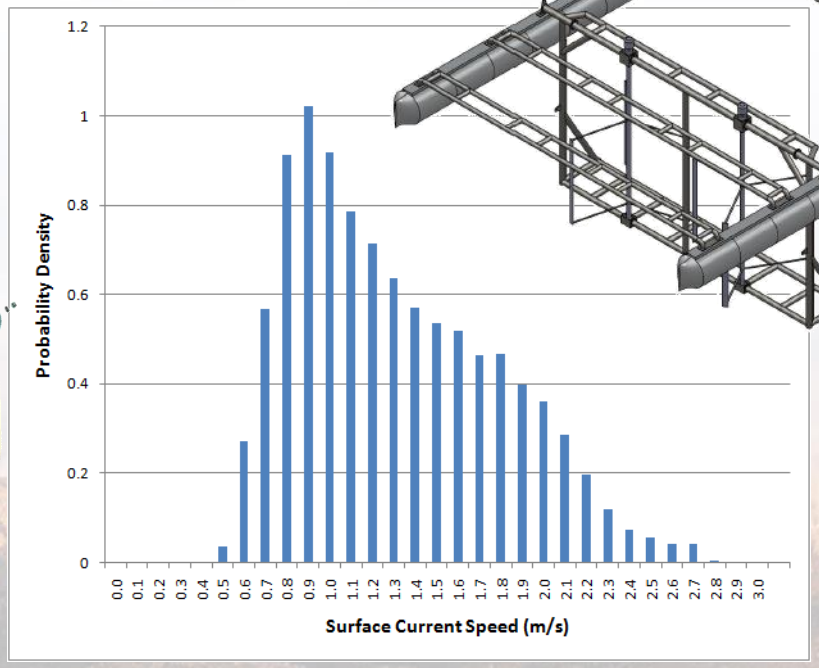
Current and Tidal Reference Models

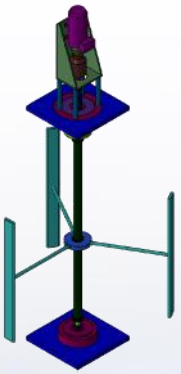
- **Multi-lab effort**
  - SNL: Lead; VAWT turbine design; resource assessment/impact
  - PNNL, ORNL, NREL
- **Produce conservative and robust models**
  - Publicly available
  - Validated
  - Yields baseline LCOE
    - Identify cost drivers
- **Horizontal (RM1) and Vertical (RM2) axis turbines**
- **Tidal and River resources, respectively**

Design and Analysis

- **Dual, counter-rotating turbine on floating platform**
  - Turbine designed to resource and performance analysis
  - Composite layup and structural analysis
  - Rotor cost estimate

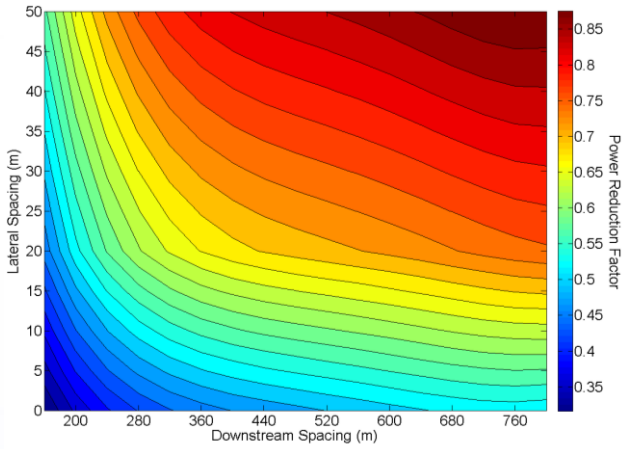


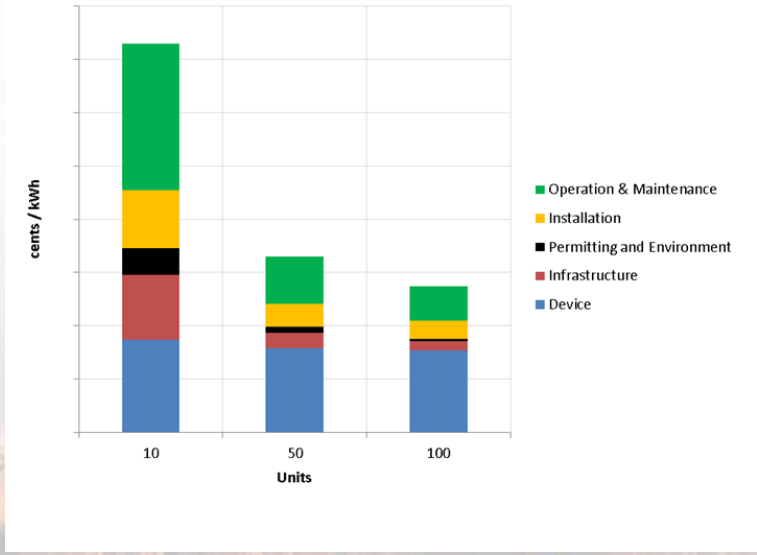




Performance and Cost Analysis

- **Cost analysis based on**
  - Device
    - Materials/components
    - Units produced/deployed
  - Array performance
    - Spacing losses
    - Cabling
  - Installation/Infrastructure
  - O&M





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