OpenFAST for Marine Turbines

Development of an Open-Source Modeling Tool

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Motivation

Creation of a validated, open-source modeling tool for marine turbines

- Industry growth has outpaced model development
- Numerical design tools
  - enable efficient design
  - improve robustness and decrease costs
  - allow performance evaluation prior to deployment

Accelerate the pace of technology development

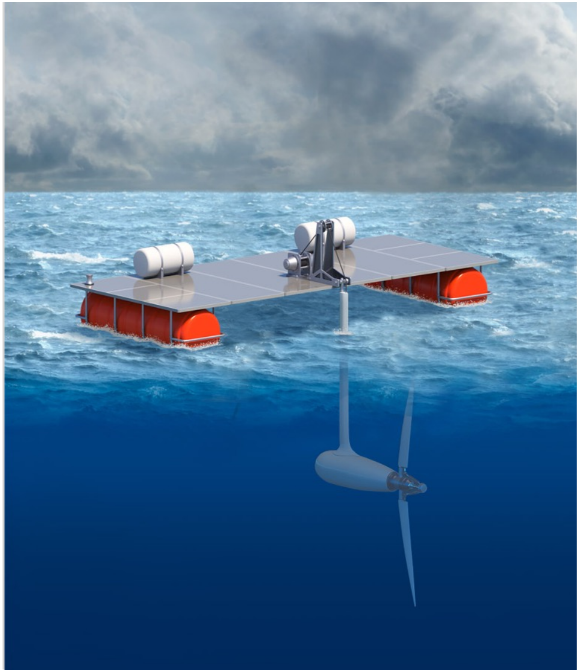
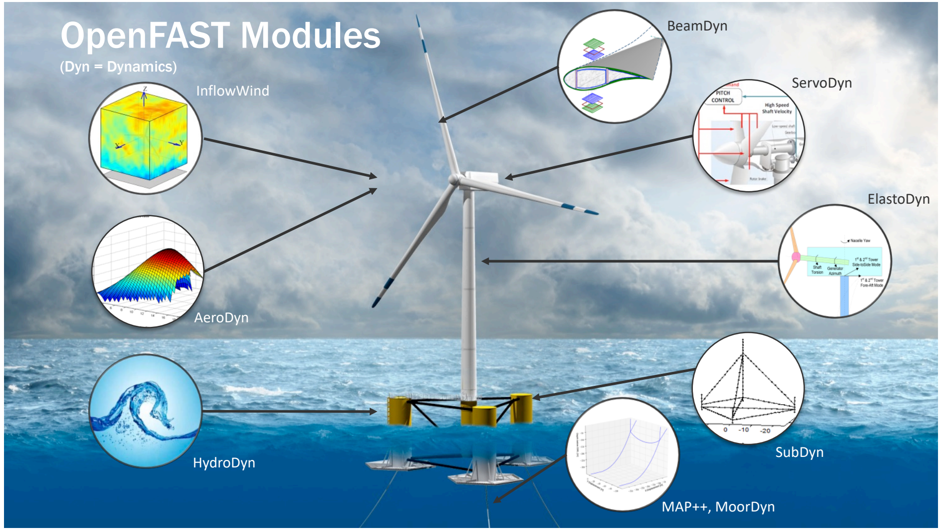


Illustration by Besiki Kazaishvili, NREL

OpenFAST Background

Time-domain model for fixed and floating wind turbines

- Computes nonlinear turbine dynamics in the time domain
- Composed of a glue code that couples independent modules
- Includes functionality to linearize underlying nonlinear equations about an operating point



OpenFAST modules for a floating offshore wind turbine. *Illustration by NREL Communications*

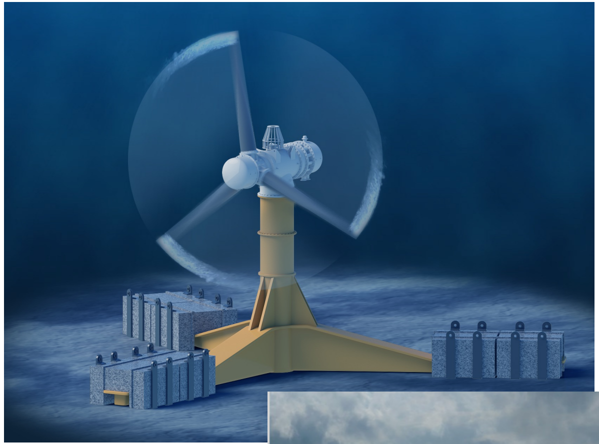
OpenFAST for Marine Turbines

Capturing physics relevant to operation in water

- Cavitation
- Buoyancy
- Added mass
- Inertial loads
- Wave/current coupling

Simulating generalized support structures

- Rotor/tower interactions
- Generalized member shapes
- Lifting loads on faired members



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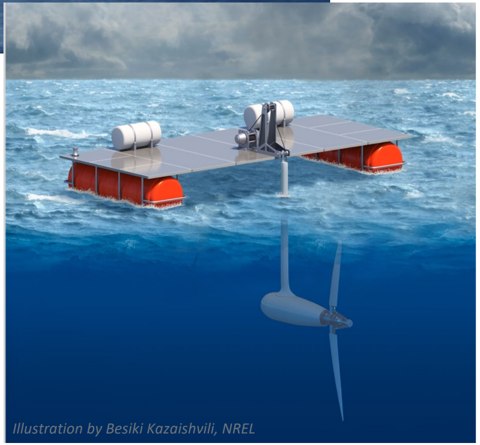

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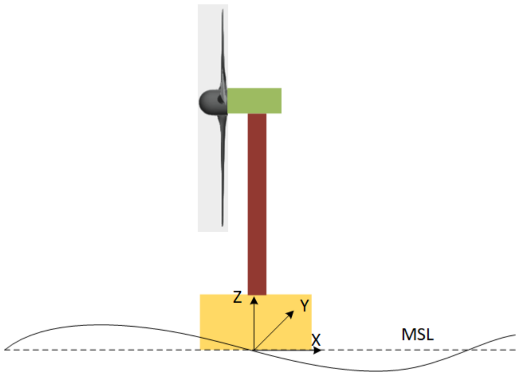
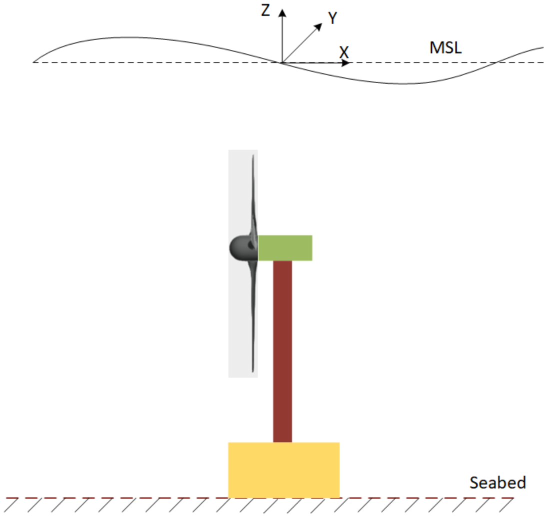
Coordinate Systems

Floating wind

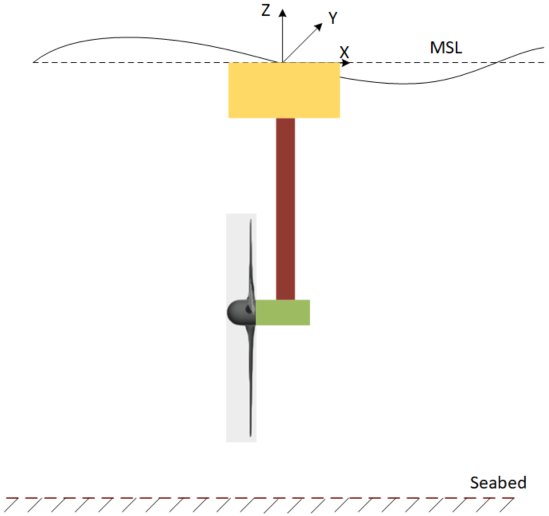


Illustrations by Toan Tran, NREL

Fixed marine



Floating marine



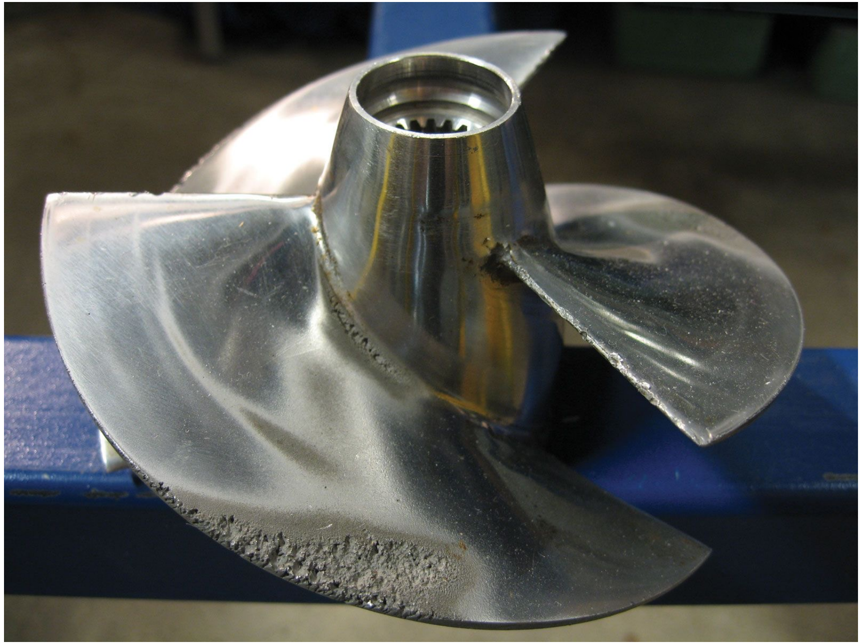
Cavitation

- Checks for cavitation along the span of each blade
- Compares local and critical cavitation numbers
- Cavitation occurs if $\sigma_{crit} < \sigma_l$

Calculated from

- **Atmospheric pressure**
- **Vapor pressure**
- **Fluid density**
- **Gravity**
- **Blade node depth**
- **Relative velocity**

User input



Pitted surface of a boat propeller due to cavitation. *Image from Erik Axdahl, Encyclopedia Britannica*

Buoyancy

- Buoyant forces and moments calculated for the blades, hub, nacelle, and tower
- Offset between load center and center of buoyancy allowed for blades, hub, and nacelle

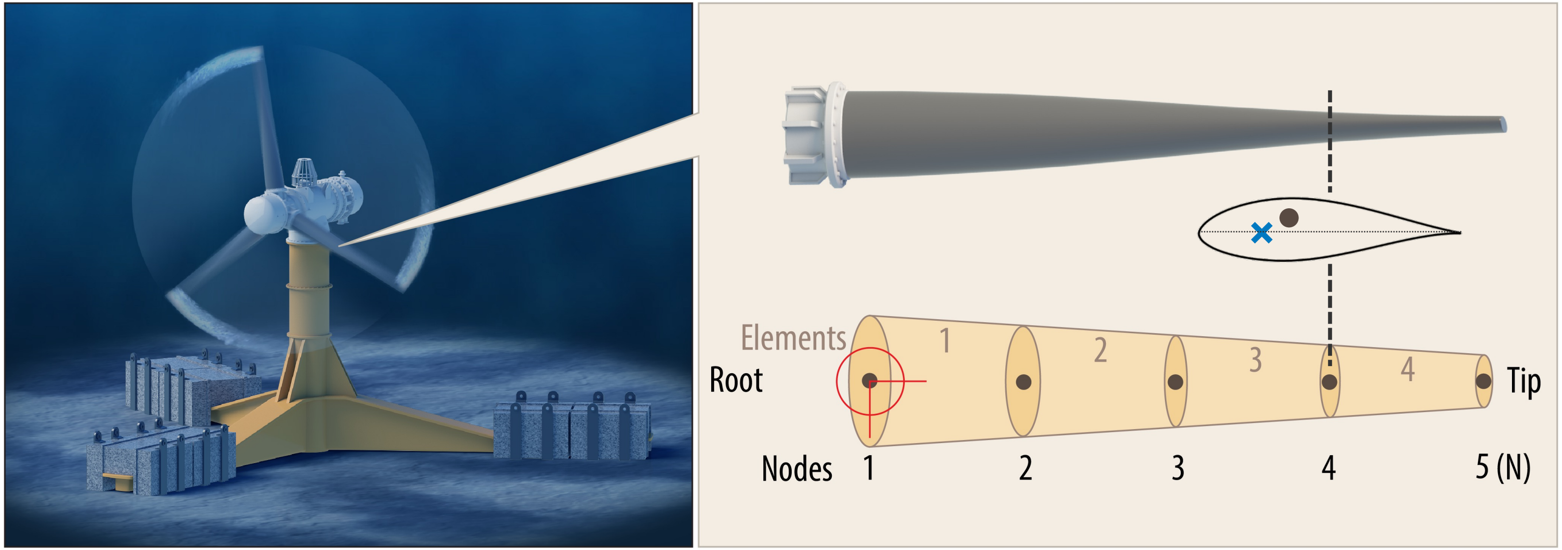
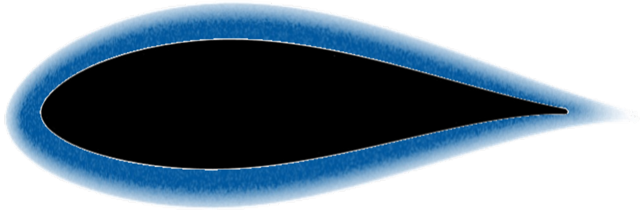


Illustration by Besiki Kazaishvili and Matt Hall, NREL

Added Mass

Added mass loads are considered for

- structure motion
- structure deformation
- blade pitch



Added mass loads are calculated using Morison's equation

$$F = \underbrace{\cancelto{\text{included in BEM}}{\rho V \dot{u}}}_{\text{Froude-Krylov}} + \underbrace{\rho C_a V(\dot{u} - \dot{v})}_{\text{added mass}} + \underbrace{\cancelto{\text{included in BEM}}{\frac{1}{2}\rho C_d A(u - v)|u - v|}}_{\text{drag}}$$

$$F_a = \rho C_a V(\dot{u} - \dot{v})$$

user-defined added mass coefficient

Additional Features

- Multi-rotor platforms
- Flow confinement
  - Multiple rotors
  - Seabed/sea surface
- Hydroacoustics
- Rotor biofouling
- Other topologies
  - Kites
  - Oscillating hydrofoils

Illustration by Besiki Kazaishvili, NREL

Applications

Individual Turbine Design

- Fixed and floating systems
- Performance and loads predictions
- Range of scales

Illustration by Besiki Kazaishvili, NREL

System Optimization (CT-Opt)

- Level 1: **RAFT** (Response Amplitude of Floating Turbines)
- Level 2: **Linearized OpenFAST**
- Level 3: **DFSM** (Derivative Function Surrogate Model)
- Level 4: **OpenFAST**

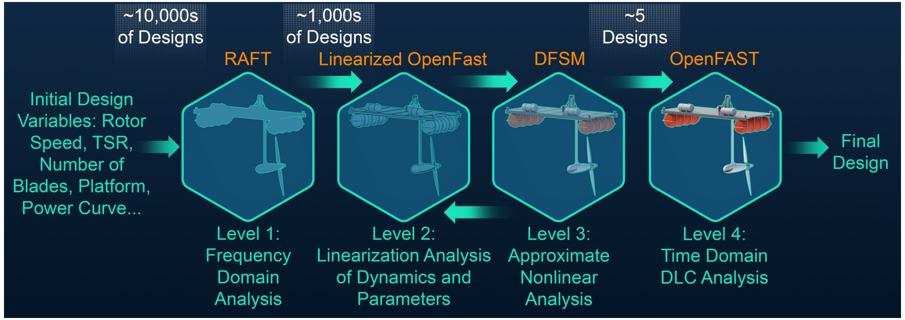


Illustration by Besiki Kazaishvili, NREL

Other Work

Cross-flow turbines

– Double multiple streamtube model
– Vortex model

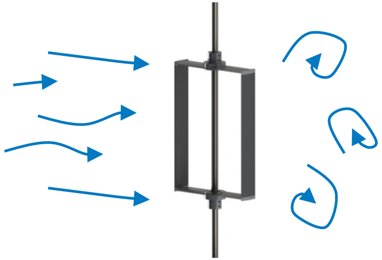
Reference models

– Rotor specification in OpenFAST
– Floating platform design

Verification and validation

– Code comparisons
– Unsteady Loading Tidal Turbine Benchmarking Study

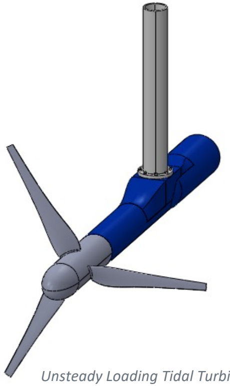
Cross-flow turbine



Spar-type floating platform

Illustration by Ryan Okuda, NREL

Benchmarking turbine



Unsteady Loading Tidal Turbine Benchmarking Study. https://supergen-ore.net/projects/tidal-turbine-benchmarking

Conclusions

- OpenFAST is being adapted for marine turbines
- Additional features will enable the design of fixed and floating systems across a range of scales
- OpenFAST will play a key role in CT-Opt, enabling optimization of marine turbines across multiple fidelity levels
- Other supporting work is ongoing, including cross-flow turbine modeling, reference model specification, and code verification and validation

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