OpenFAST for Marine Turbines

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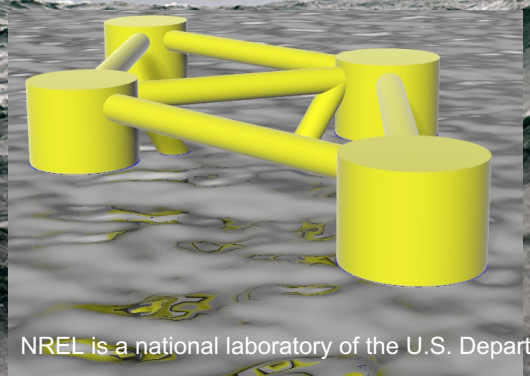
Adapted from material developed by Jason Jonkman
NREL

October 4, 2023
UMERC Conference



NREL Water Power Research

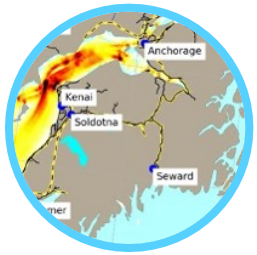
NREL researchers are **leveraging R&D expertise**,
such as numerical modeling, laboratory testing, and open-water validation.

Modeling and analysis


Innovation and design


Laboratory validation


Open-water demonstration



Pilot deployment support

Workforce and infrastructure

NREL:	**~3000** Employees	**$670M+** FY22 project portfolio
NREL Water Power:	**45+** Full-time staff	**$28M+** FY22 project portfolio

Workshop Summary

OpenFAST Overview
2:00 – 2:50

Break (2:50 – 3:00)

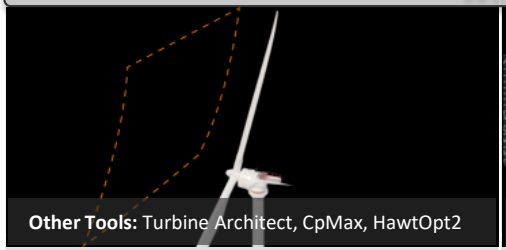
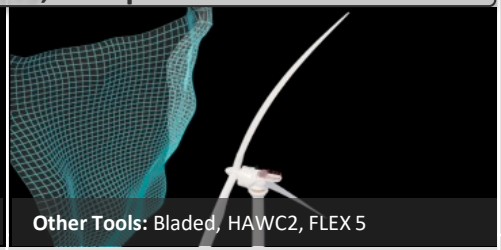
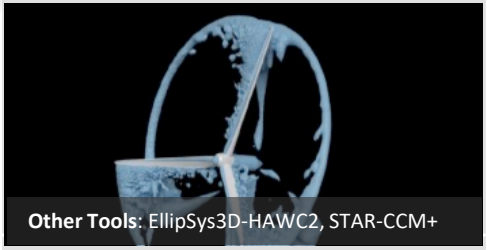
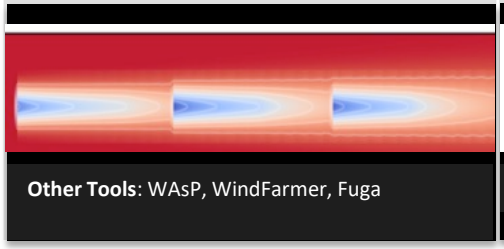
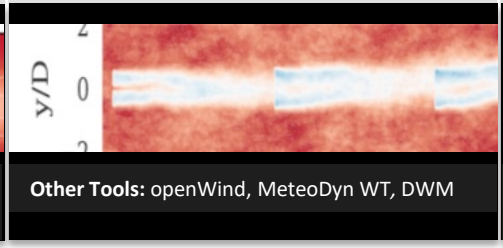
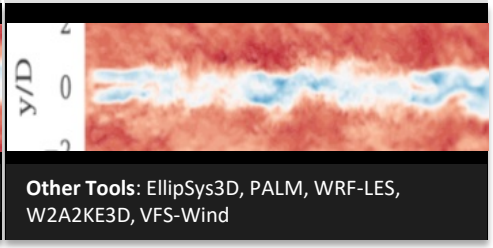
OpenFAST Demonstration
3:00 – 3:45

Outline: OpenFAST Overview

- NREL/DOE open-source modeling tool overview
- Overview of OpenFAST
- OpenFAST modules
- Marine turbine features
  - Feature overview
  - Modifications to OpenFAST modules
- Future development

NREL/DOE Open-Source Modeling Tool Overview

Model Fidelity / Computational Intensity

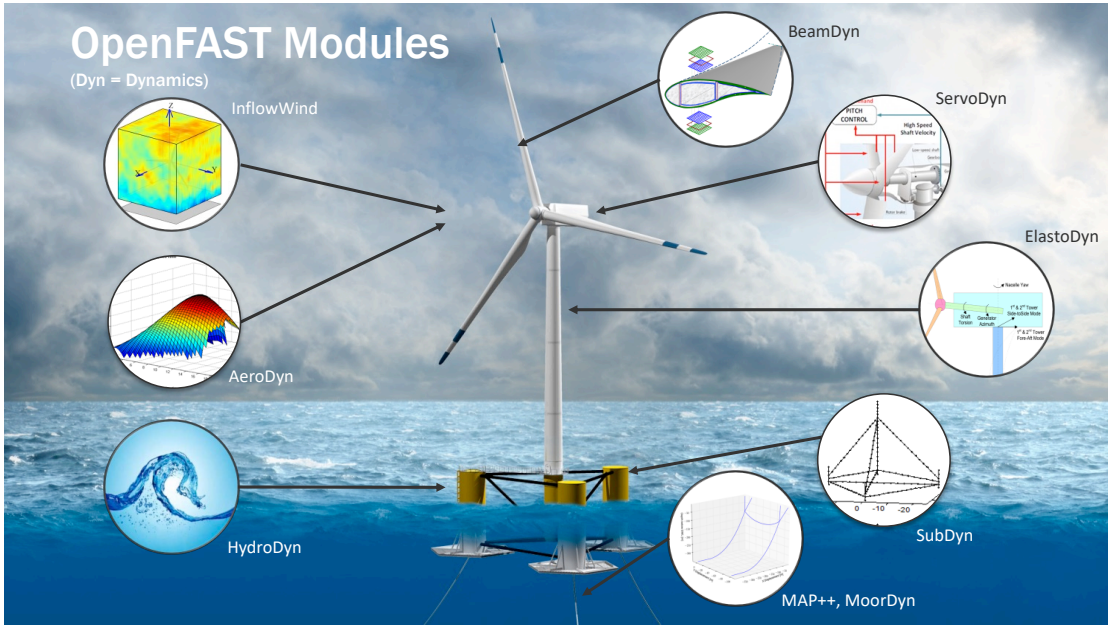
Application	Design Exploration	Detailed Design	Highly Resolving
Single Turbine Performance and Loads	**WISDEM, RAFT** Multidisciplinary design optimization and cost modeling	**OpenFAST** Turbine loads analysis, detailed turbine design, IEC standards	**ExaWind/SOWFA** Understand physics, final turbine design check, calibrate / validate lower fidelity
	WEIS, CT-Opt		
	 **Other Tools:** Turbine Architect, CpMax, HawtOpt2	 **Other Tools:** Bladed, HAWC2, FLEX 5	 **Other Tools**: EllipSys3D-HAWC2, STAR-CCM+
Full Wind-Plant Performance and Loads	**FLORIS** Wind-plant controls and siting optimization	**FAST.Farm, WindSE** Turbine siting within plant, wind-plant controls, plant loads analysis, detailed plant design	**ExaWind/ERF/SOWFA** Understand physics, final plant design check, calibrate / validate lower fidelity
	 **Other Tools**: WAsP, WindFarmer, Fuga	 **Other Tools:** openWind, MeteoDyn WT, DWM	 **Other Tools**: EllipSys3D, PALM, WRF-LES, W2A2KE3D, VFS-Wind

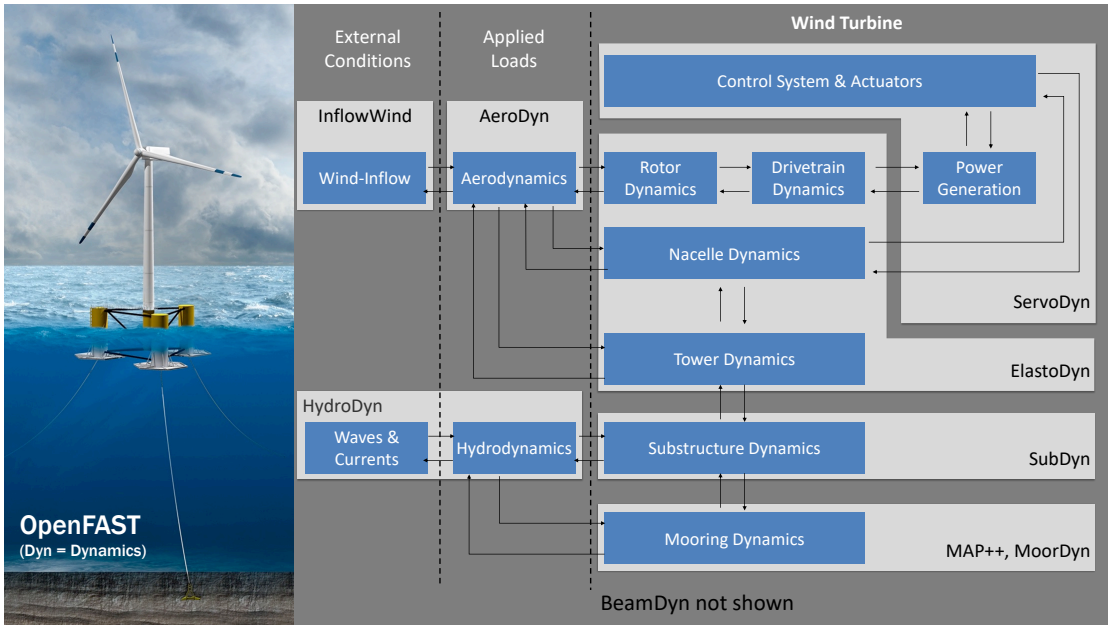
*__Other tools__ are other widely-used tools with similar capabilities

Overview of OpenFAST

OpenFAST Capabilities

- Coupled aero-hydro-servo-elastic simulations
- Individual turbine modeling
- Land-based, fixed-bottom offshore, and floating offshore wind turbines
- Fixed-bottom and floating marine turbines
- Run extensive numbers of nonlinear time-domain simulations in real time to enable standards-based loads analysis for predicting system ultimate and fatigue loads
- Linearize* the underlying nonlinear model about an operating point to understand the system response and enable modal analysis; controls design; and aero-elastic instability studies



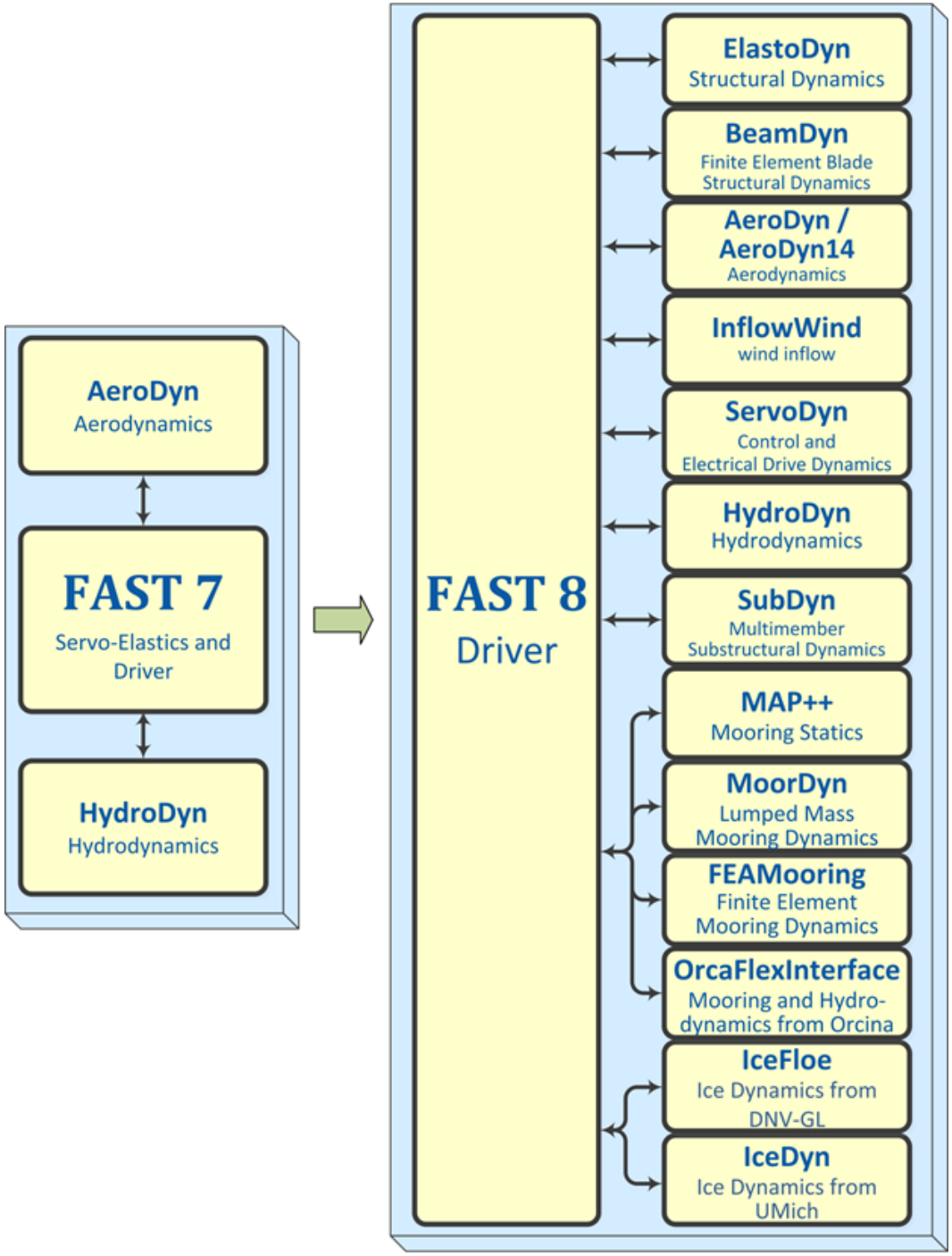


*linearization in progress for marine turbines

OpenFAST History

- **OpenFAST** is DOE / NREL's premier open-source wind/marine turbine physics-based engineering tool
- **FAST** has undergone major restructuring -- new modularization framework (v8)
- Framework supports expanded functionality
- Facilitates the establishment of an open-source code-development community for physics-based engineering models (**OpenFAST***)

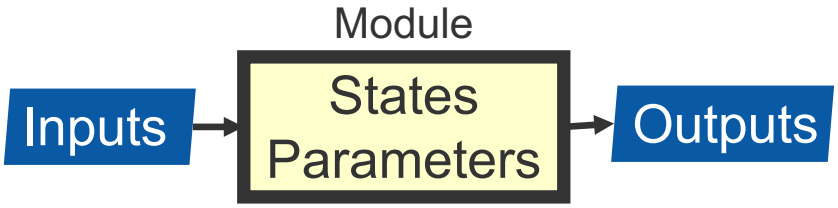
*https://github.com/OpenFAST/openfast/tree/main



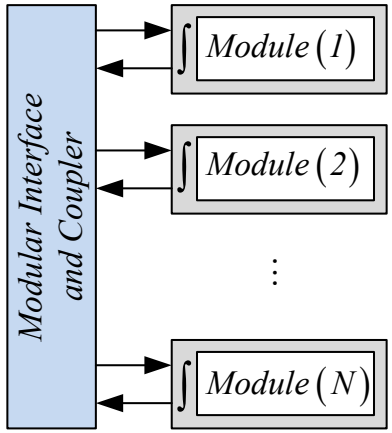
OpenFAST Modularization Framework

- Module-independent inputs, outputs, states, and parameters
- States in continuous-time, discrete-time, constraint, & “other” form
- Loose & tight* coupling
- Independent time & spatial discretizations
- Time marching, operating-point determination, & linearization
- Data encapsulation & dynamic allocation
- Checkpoint/restart capability

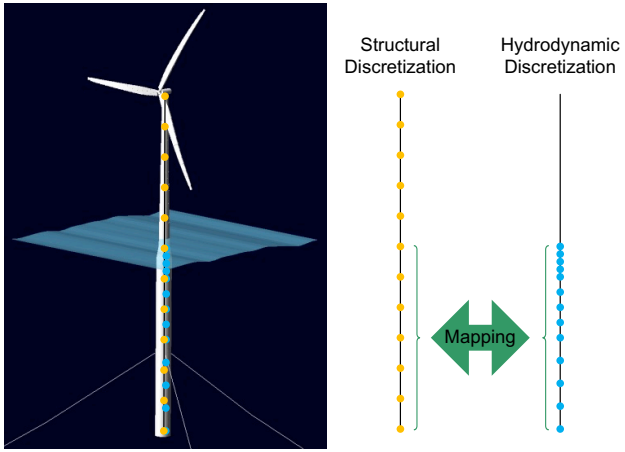
*In progress



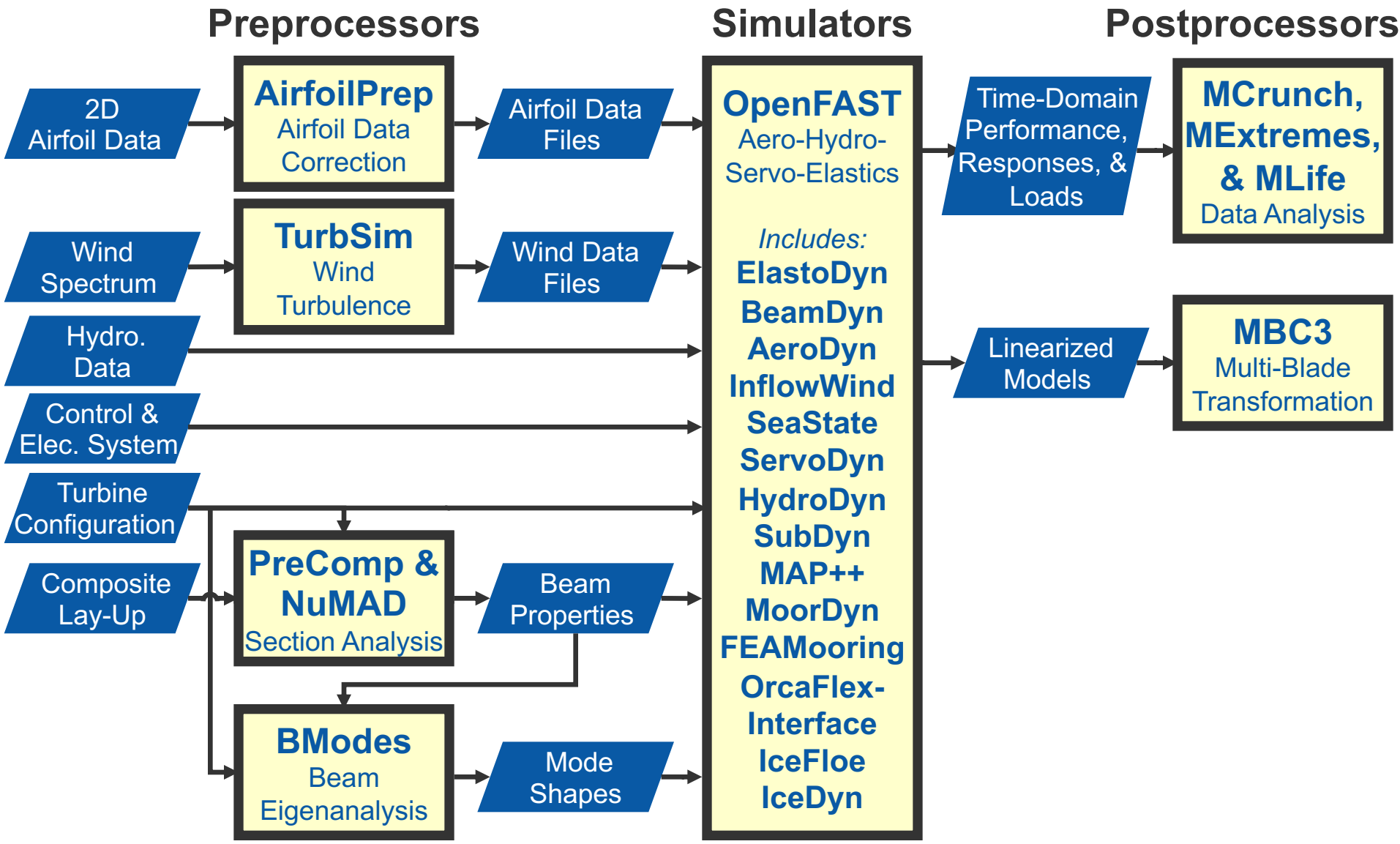
Implicit Loose Coupling Scheme



Mapping Independent Discretizations



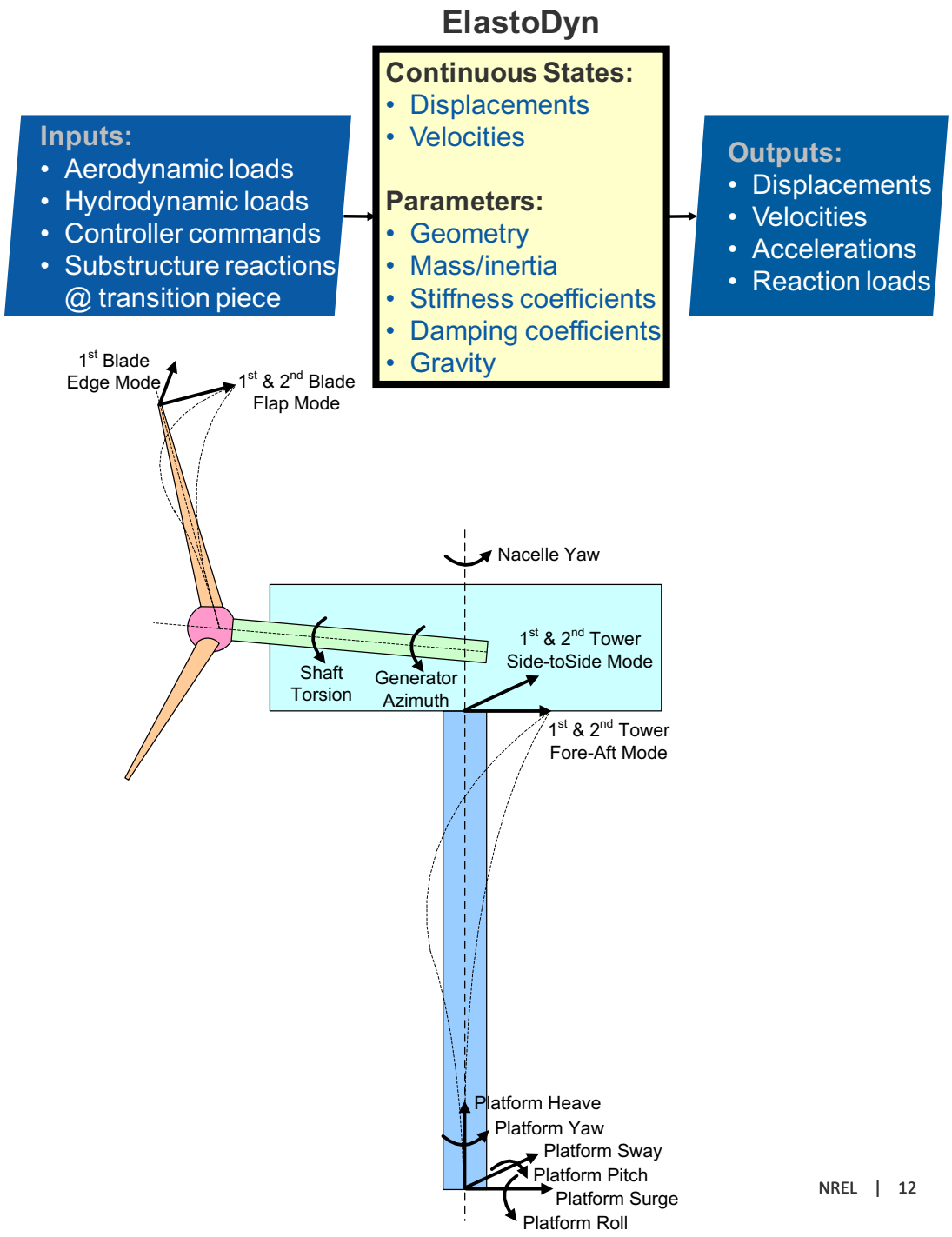
Key DOE/NREL Tools in the Design Process



OpenFAST Modules

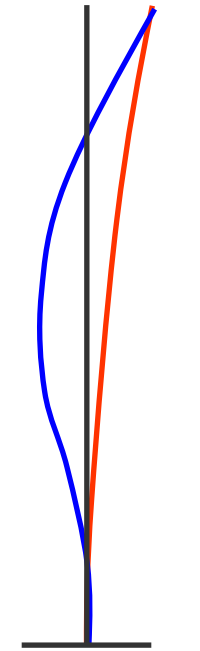
ElastoDyn

- Turbine configuration:
  - Horizontal-axis (HAWT)
  - 2- or 3-bladed rotor
  - Upwind or downwind rotor
  - Rigid or teetering hub
  - Conventional configuration or inclusion of rotor- and/or tail-furling
  - Support structure that includes a tower atop a platform
- Combined modal & multi-body representation through 24 DOFs
  - Modal: blades, tower
  - Multi-body: platform, nacelle, generator, gears, hub, tail

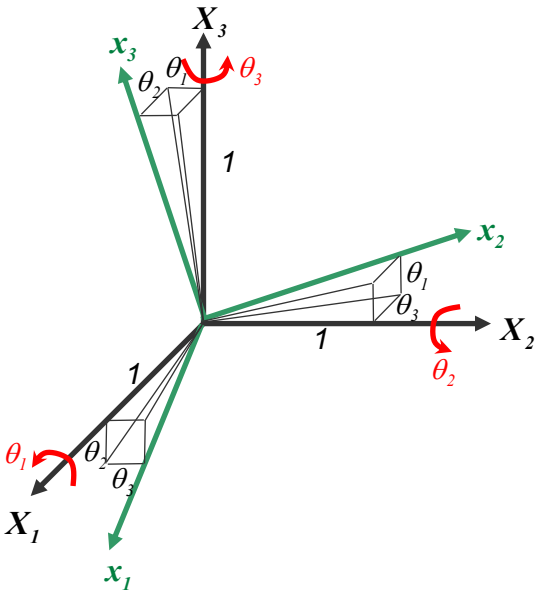


ElastoDyn

- Utilizes relative DOFs w/o constraints:
  - Platform rotations and blade / tower deflections employ small-angle approximations with correction for orthogonality (accuracy drops considerably for angles >> 20˚)
  - All other DOFs may exhibit large motions w/o loss of accuracy
  - *Nonlinear* equations of motion
  - Explicit (RK4) or PC (AB4, ABM4) time integration
- Beam model:
  - Euler-Bernoulli beam
  - Straight & isotropic
  - Bending only (no twist)
  - Assumed-mode method
  - Some geometric nonlinearity



Modal Representation



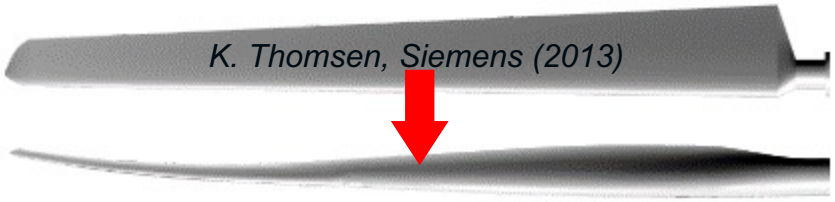
$$\begin{Bmatrix} x_1 \\ x_2 \\ x_3 \end{Bmatrix} \approx \begin{bmatrix} 1 & \theta_3 & -\theta_2 \\ -\theta_3 & 1 & \theta_1 \\ \theta_2 & -\theta_1 & 1 \end{bmatrix} \begin{Bmatrix} X_1 \\ X_2 \\ X_3 \end{Bmatrix}$$

$$\begin{Bmatrix} x_1 \\ x_2 \\ x_3 \end{Bmatrix} = \frac{\begin{bmatrix} \theta_1^2\sqrt{1+\theta_1^2+\theta_2^2+\theta_3^2}+\theta_2^2+\theta_3^2 & \theta_3\left(\theta_1^2+\theta_2^2+\theta_3^2\right)+\theta_1\theta_2\left(\sqrt{1+\theta_1^2+\theta_2^2+\theta_3^2}-1\right) & -\theta_2\left(\theta_1^2+\theta_2^2+\theta_3^2\right)+\theta_1\theta_3\left(\sqrt{1+\theta_1^2+\theta_2^2+\theta_3^2}-1\right) \\ -\theta_3\left(\theta_1^2+\theta_2^2+\theta_3^2\right)+\theta_1\theta_2\left(\sqrt{1+\theta_1^2+\theta_2^2+\theta_3^2}-1\right) & \theta_2^2+\theta_3^2\sqrt{1+\theta_1^2+\theta_2^2+\theta_3^2}+\theta_1^2 & \theta_1\left(\theta_1^2+\theta_2^2+\theta_3^2\right)+\theta_2\theta_3\left(\sqrt{1+\theta_1^2+\theta_2^2+\theta_3^2}-1\right) \\ \theta_2\left(\theta_1^2+\theta_2^2+\theta_3^2\right)+\theta_1\theta_3\left(\sqrt{1+\theta_1^2+\theta_2^2+\theta_3^2}-1\right) & -\theta_1\left(\theta_1^2+\theta_2^2+\theta_3^2\right)+\theta_2\theta_3\left(\sqrt{1+\theta_1^2+\theta_2^2+\theta_3^2}-1\right) & \theta_3^2+\theta_2^2\sqrt{1+\theta_1^2+\theta_2^2+\theta_3^2}+\theta_1^2 \end{bmatrix}}{\left(\theta_1^2+\theta_2^2+\theta_3^2\right)\sqrt{1+\theta_1^2+\theta_2^2+\theta_3^2}} \begin{Bmatrix} X_1 \\ X_2 \\ X_3 \end{Bmatrix}$$

Correction for Orthogonality

BeamDyn

- Geometrically exact beam theory (GEBT)
  - Full 6×6 cross-sectional mass & stiffness
  - Stiffness-proportional damping
  - Curved/swept reference axis (spline based)
  - Nonlinear geometrically exact large deflection
- Legendre spectral finite element (LSFE)
  - Analyze blade w/ single LSFE
- Both Gauss & Trapezoidal-Rule spatial integration
- Both statics & dynamics
  - Time integration via generalized-α



Advancement in Blade Design

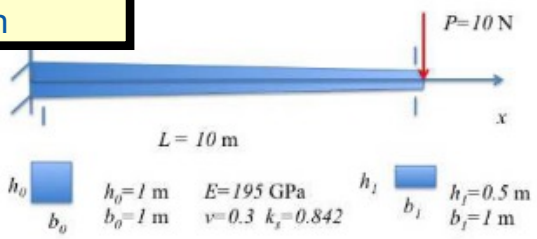
BeamDyn

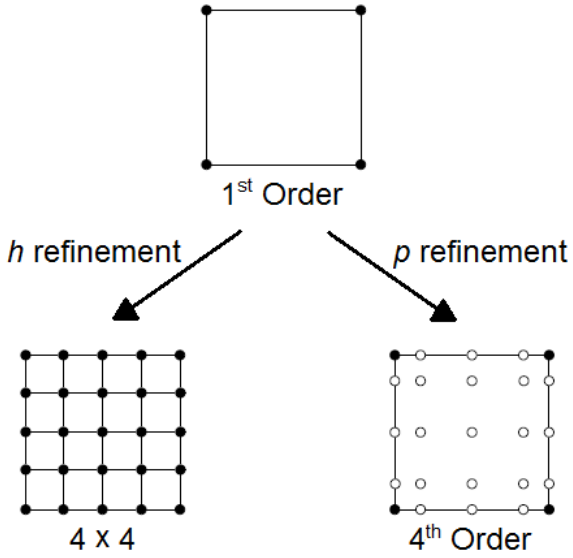
Inputs:
- Aerodynamic loads
- Root motion

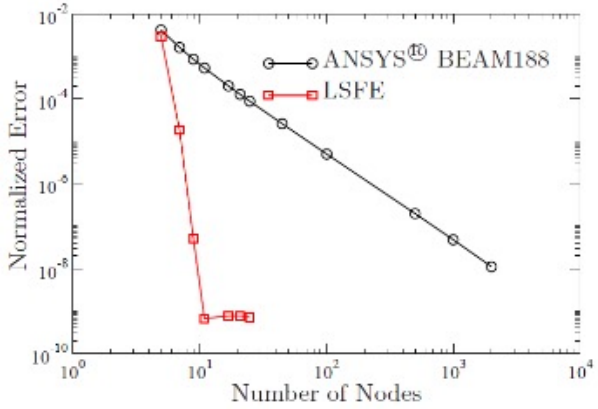
Continuous States:
- Displacements
- Velocities

Parameters:
- Geometry
- Cross-sectional mass & stiffness
- Damping
- Gravity
- Discretization

Outputs:
- Blade motion
- Root reaction loads

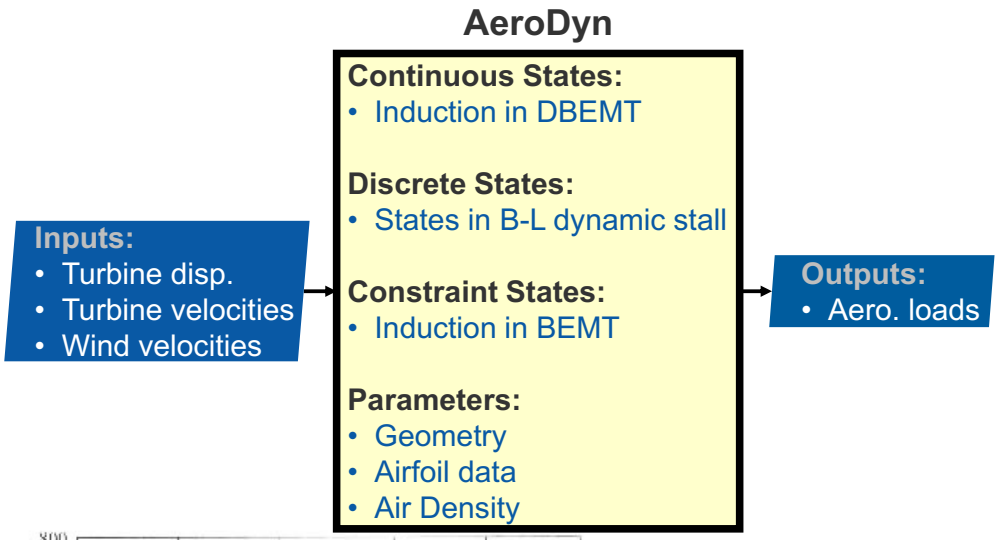


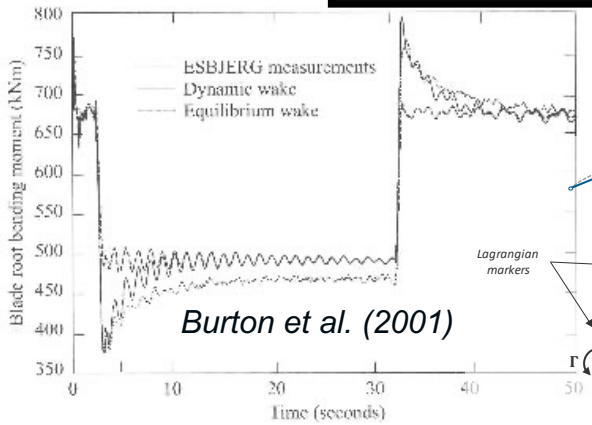




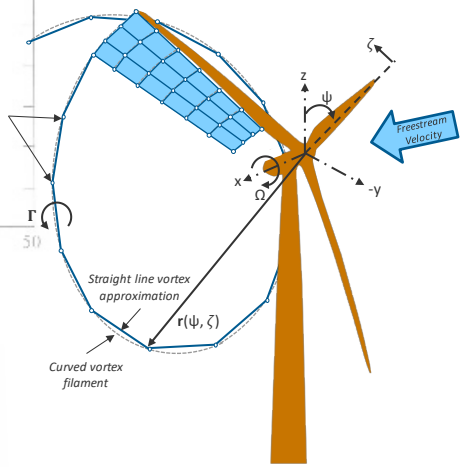
AeroDyn, including OLAF

- Actuator-line physics:
  - Wake / induction: quasi-static momentum (BEM), dynamic wake (DBEMT), or free-vortex wake (OLAF)
  - Airfoil: quasi-steady or unsteady airfoil aerodynamics (BL, HGM) (relies on airfoil polars)
  - Tower drag & influence on wind
- cOnvecting LAgrangian Filaments (OLAF) model:
  - Lagrangian approach – Wake discretized into Lagrangian markers connected by vortex filaments
  - Hybrid lattice / filament (near wake / tip and root vortices) method
  - Biot-Savart law for computed induced velocities
  - Multiple regularization methods
  - Optional OpenMP parallelization

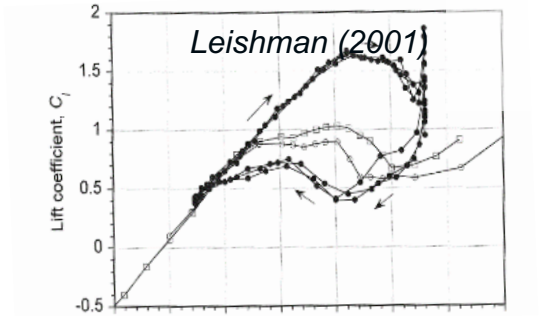




Rapid Pitch Events



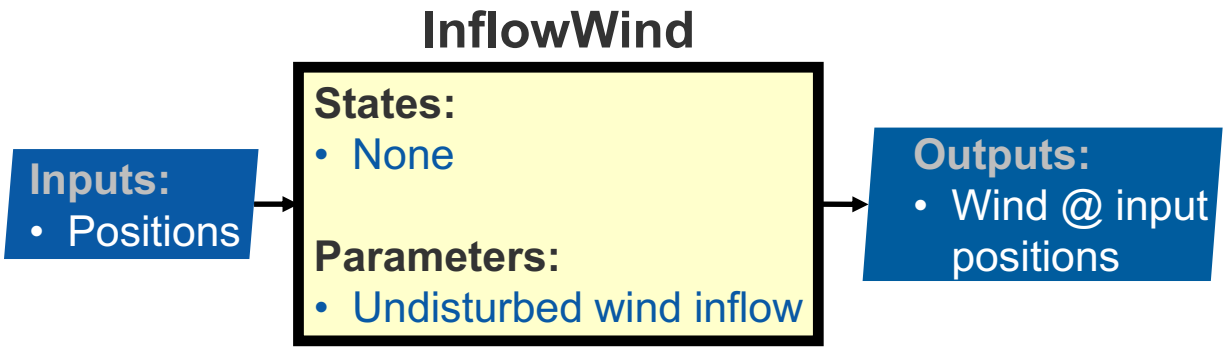
OLAF Model

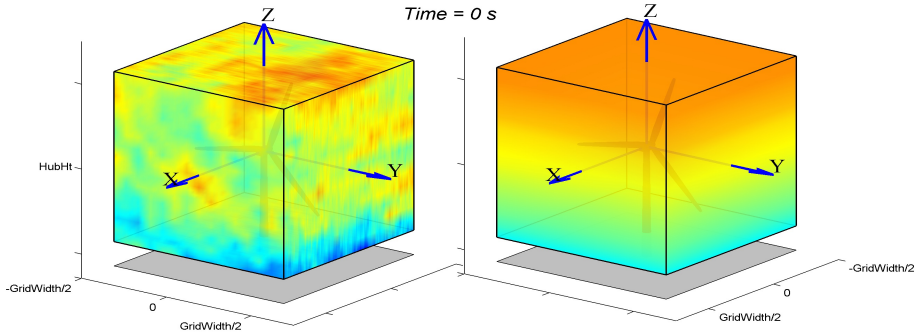


Dynamic Stall of S809 Airfoil

InflowWind

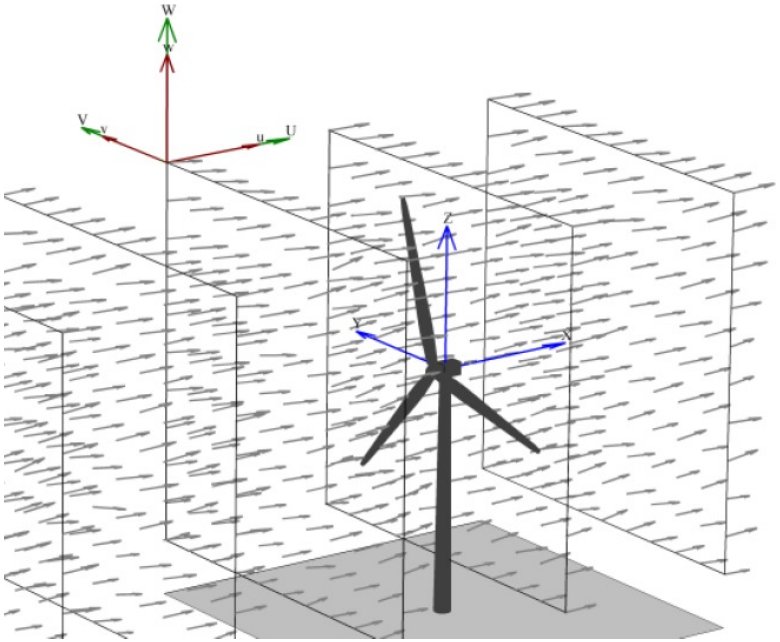
- Undisturbed wind inflow:
  - Steady
  - Uniform, but time-varying (e.g., deterministic gusts from IEC)
  - Full-field (FF) turbulence (TurbSim, Bladed, HAWC2)
  - User-defined





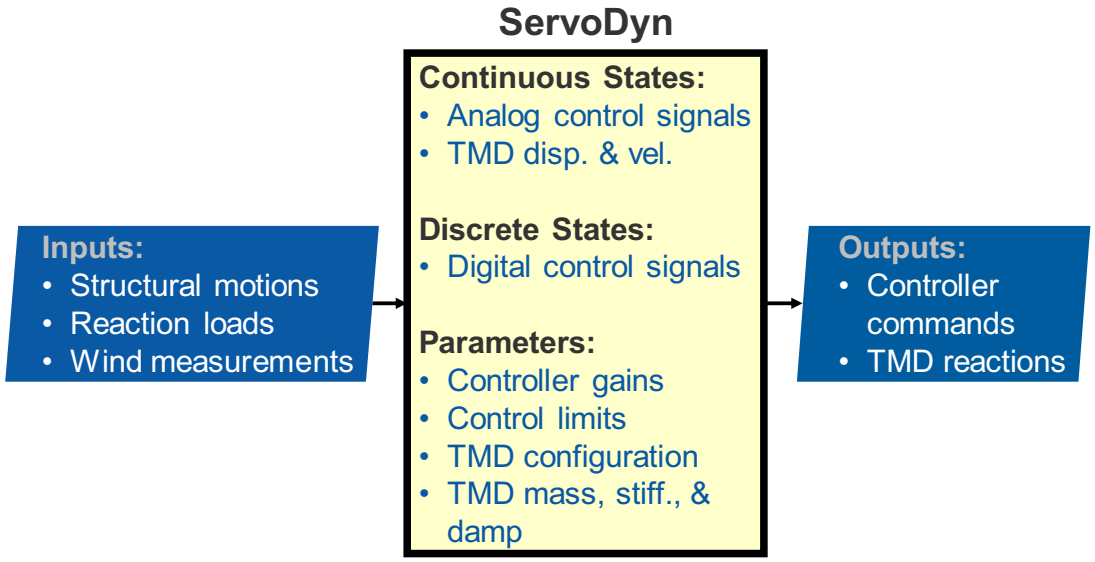
FF Versus Uniform Wind

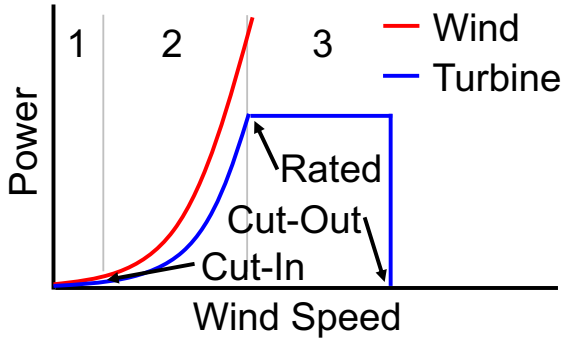
FF Wind Treated w/ Taylor's Frozen Turbulence Hypothesis

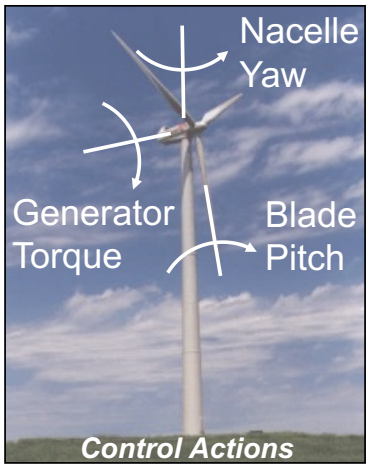


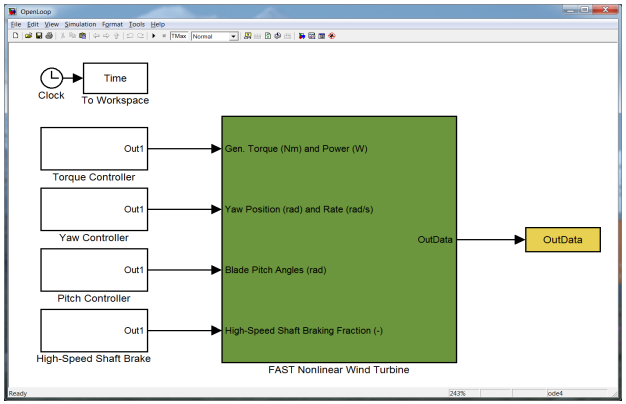
ServoDyn

- Control & electrical-drive functions
- Actuators:
  - Blade pitch
  - Generator torque
  - HSS brake
  - Nacelle yaw
  - Structural controls (TMDs, TLCDs)
- Implementations:
  - Simple built-in
  - User Fortran subroutines
  - Bladed-style dynamic link library (DLL)
  - MATLAB/Simulink interface
  - LabVIEW interface
- Faults







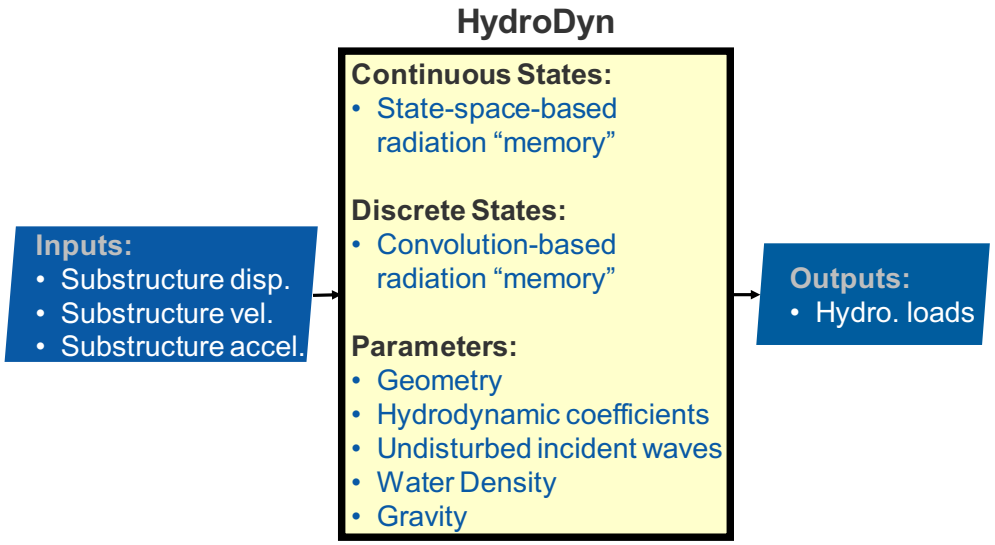


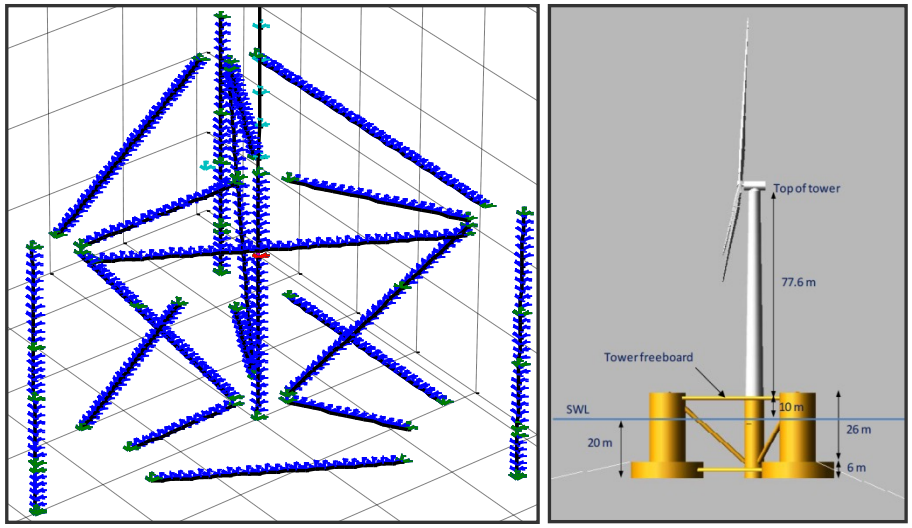
Open-Loop Simulink Model

HydroDyn – Hydrodynamics for fixed & floating substructures

- Strip theory (Morison):
  - For "slender" members
  - Inertia, added mass, viscous, & buoyancy loads
  - Multiple interconnected members
- Potential flow (WAMIT):
  - For "large" platforms
  - Radiation, diffraction, & buoyancy loads
  - Linear state-space-based radiation formulation alternative to convolution
  - 1st- (RAO) & 2nd-order (QTF)
  - 2nd-order via Newman's approximation or full QTF
- Hybrid combination of these two
- Wave stretching*
- Surface tracking*
- Instantaneous hydrostatics and hydrodynamics at surface*

**Coming soon, v4.0*



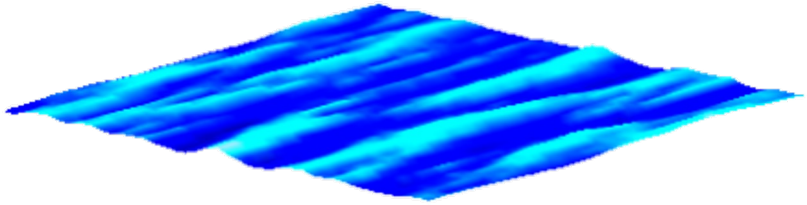


Strip-Theory Nodes for the OC4-DeepCwind Semisubmersible

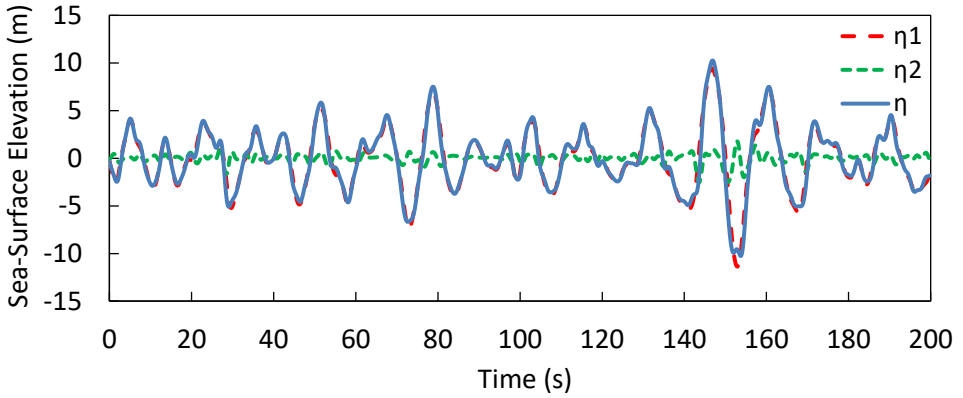
SeaState*

- Regular, irregular, or white noise waves:
  - Pierson-Moskowitz, JONSWAP, white-noise, or user-defined
  - Or externally generated wave elevations or full wave kinematics
- Wave direction & directional spreading:
  - Requires $S(\omega,\beta) = S(\omega)D(\beta)$
- 1^{st}- (Airy) & 2^{nd}-order (Sharma/Dean):
  - Analytical for finite-depth
- Steady sea currents:
  - IEC-style sub-surface, near-surface, & depth-independent
  - Or user-defined
- Grid of velocities and accelerations

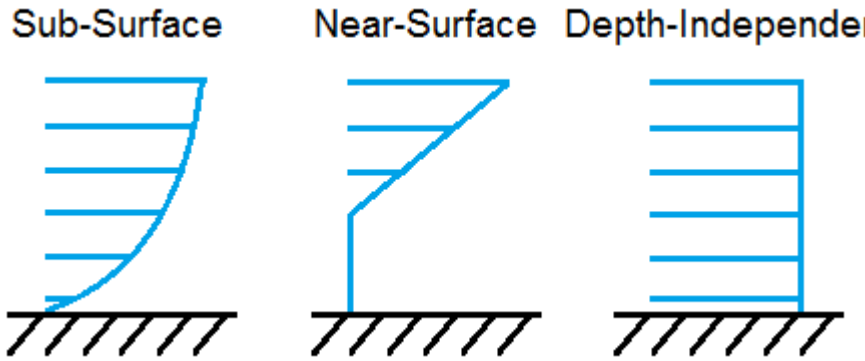
**Coming soon, v4.0*



Multi-Directional Sea State



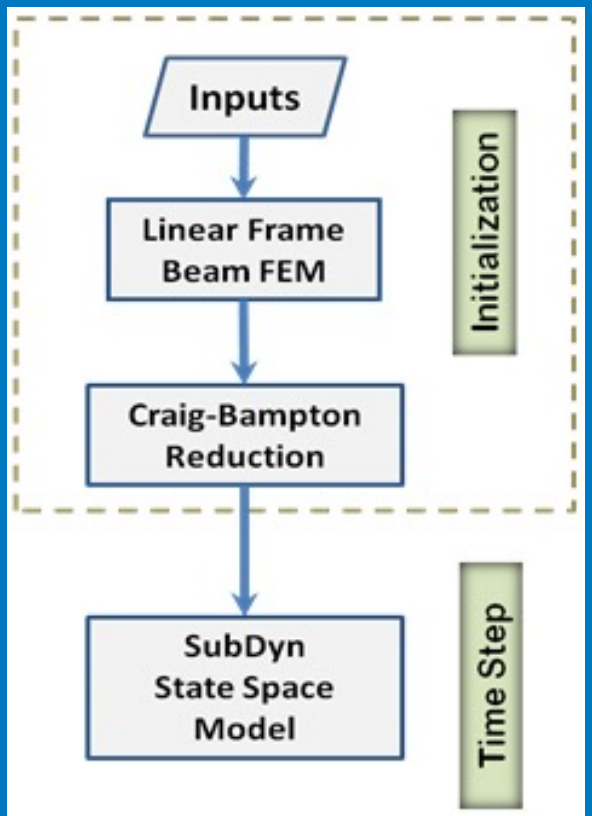
Sea-Surface Elevation (η) from the Summing of 1^{st}- (η_1) & 2^{nd}- (η_2) Order Waves



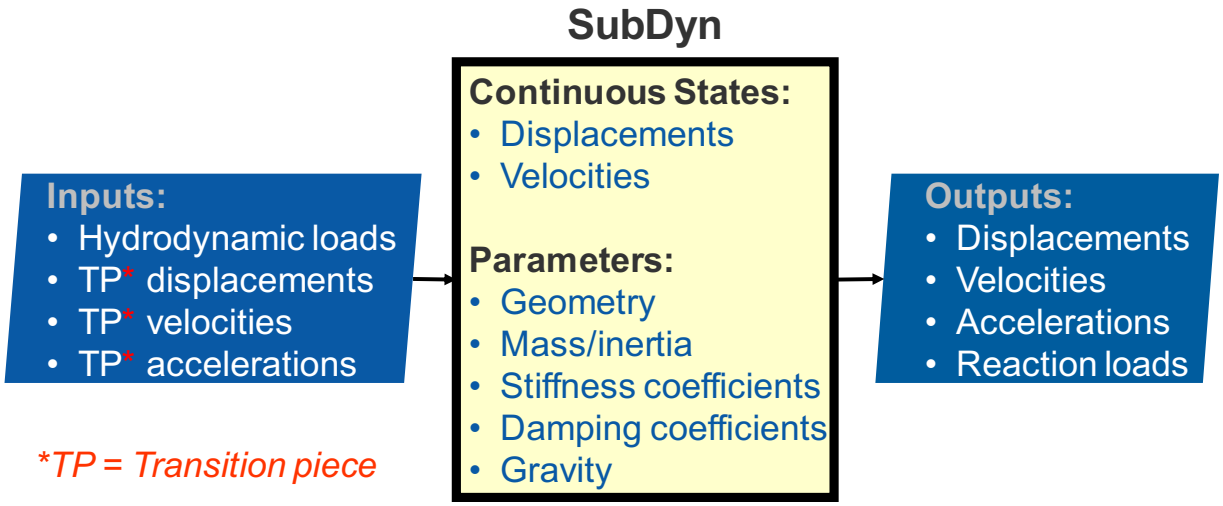
IEC Sea Currents

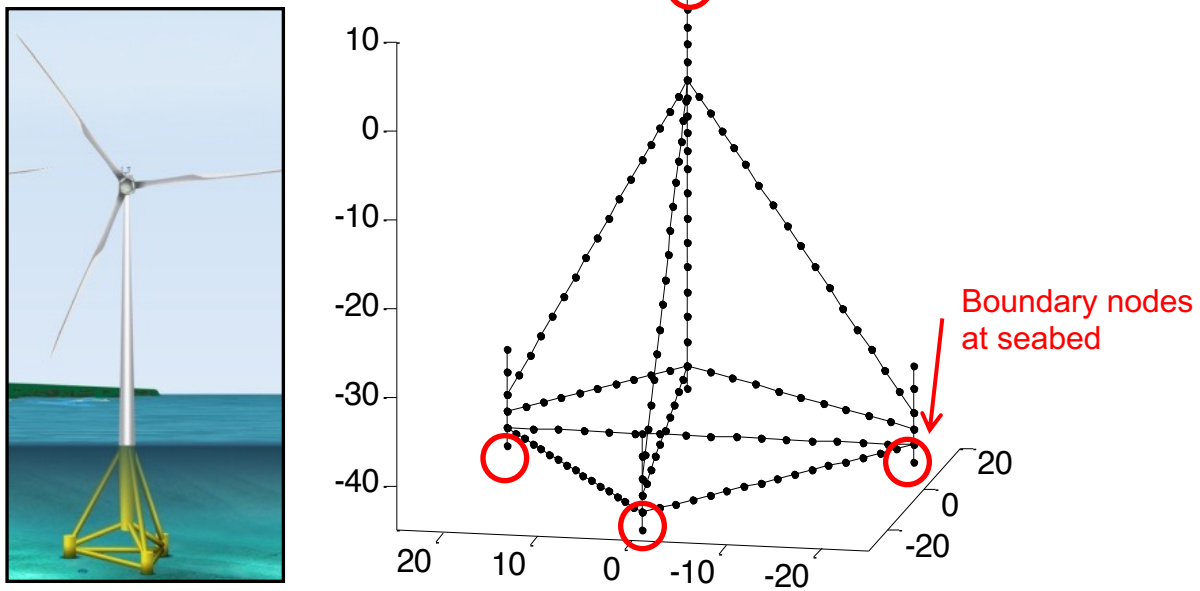
SubDyn

- Linear frame finite-element beam model
- Craig-Bampton dynamic system reduction
- Static-improvement method



***SubDyn** Flow Chart*

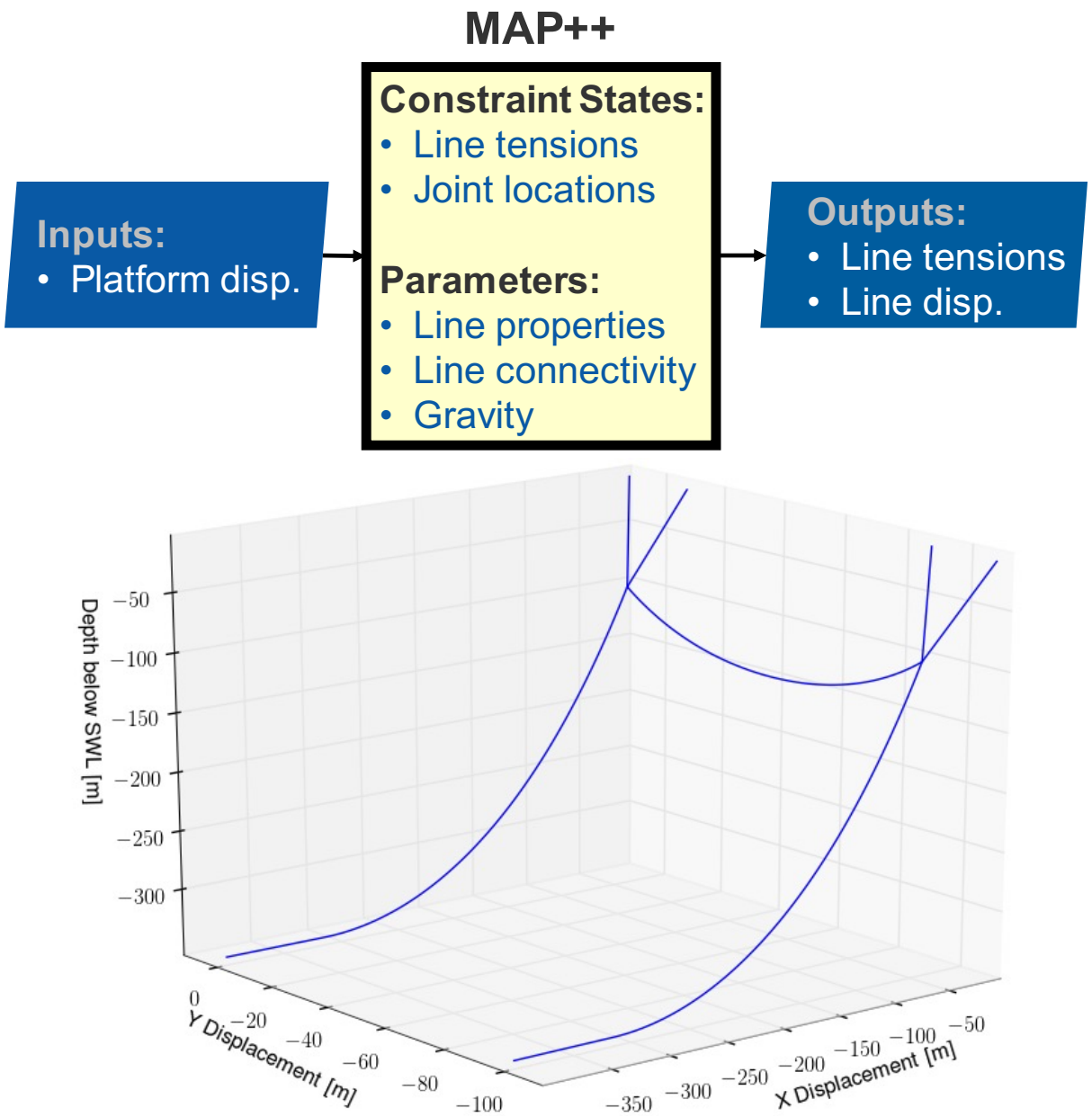




Finite-Element Discretization of the OC3-Tripod

MAP++

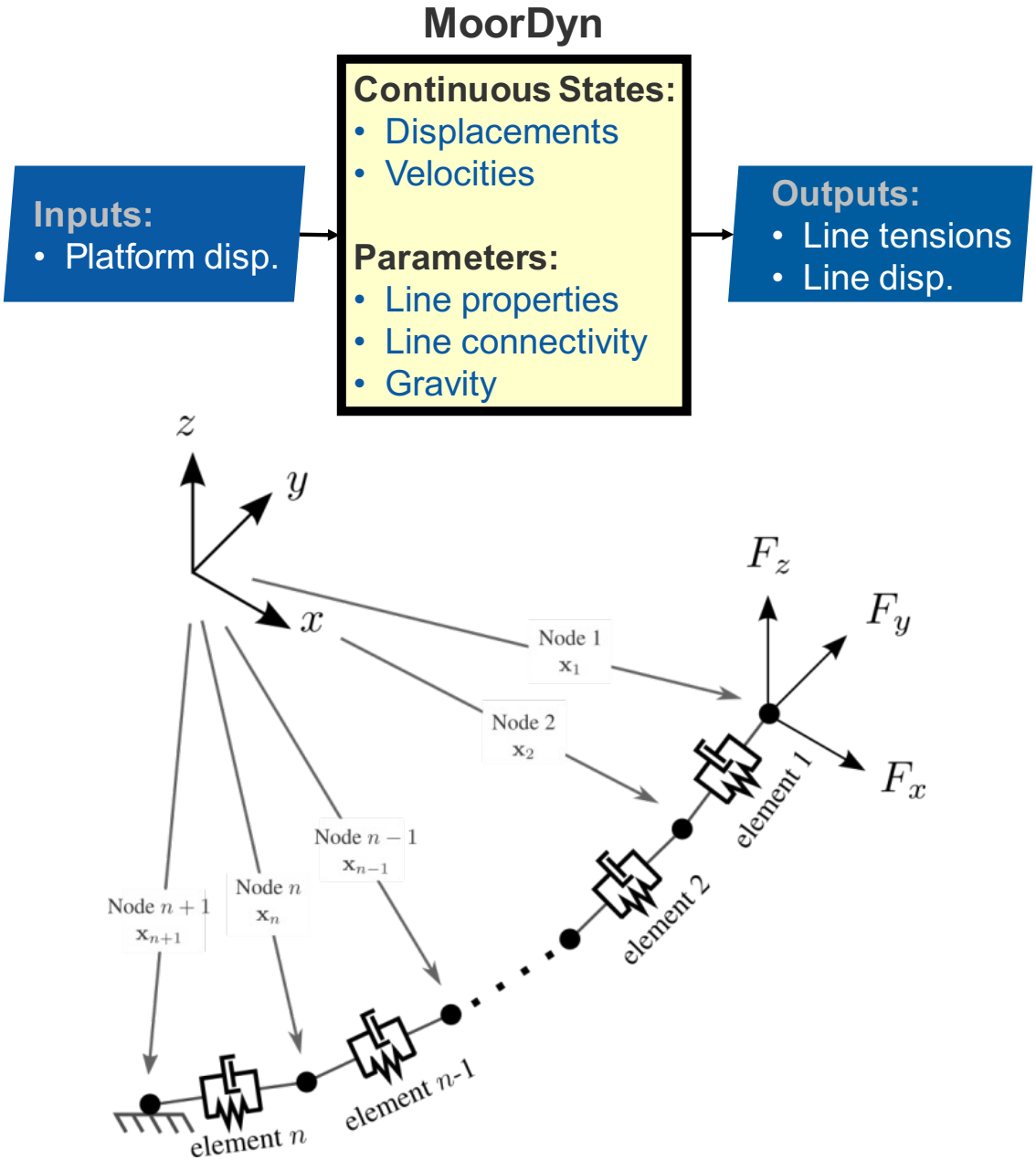
- Quasi static
- Multi-segmented array of taut or catenary lines
- Elastic stretching
- Apparent weight of lines
- Clump weights & buoyancy tanks
- Seabed friction
- Nonlinear geometric restoring



*Example Multi-Segmented Mooring System Analyzed by **MAP++***

MoorDyn

- Lumped-mass dynamics
- Multi-segmented array of taut or catenary lines
- Elastic stretching & damping
- Still-water hydrodynamic added mass & drag
- Apparent weight of lines
- Clump weights & buoyancy tanks
- Seabed friction
- Nonlinear geometric restoring



Lumped-Mass Mooring Dynamics

Marine Turbine Features

Turbine Archetypes: Axial-Flow

Fixed Marine Turbine

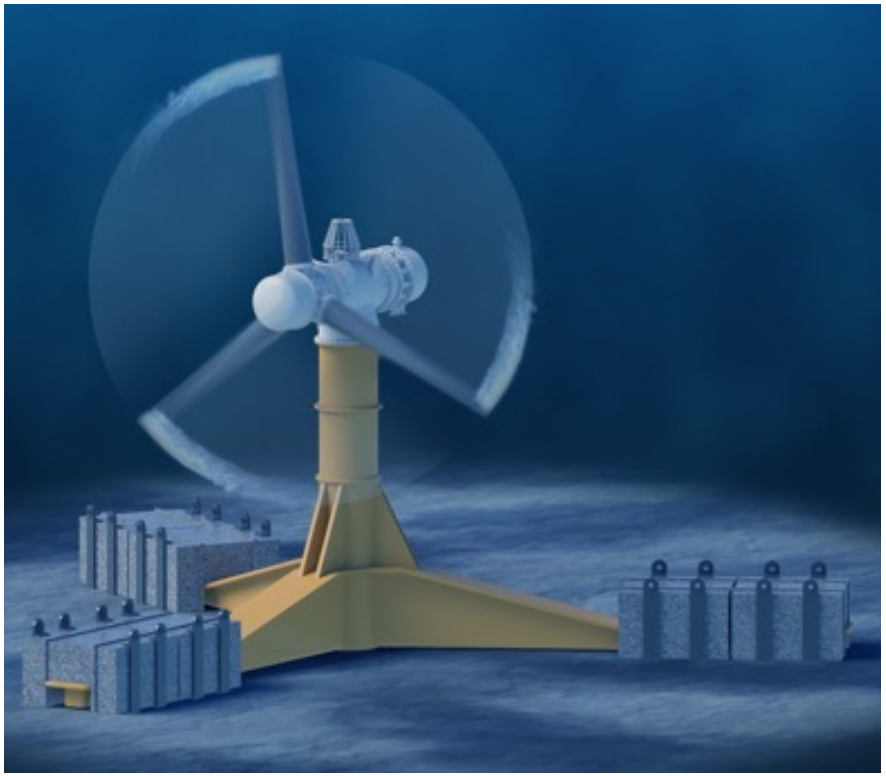


Illustration by Besiki Kazaishvili, NREL

Floating Marine Turbine

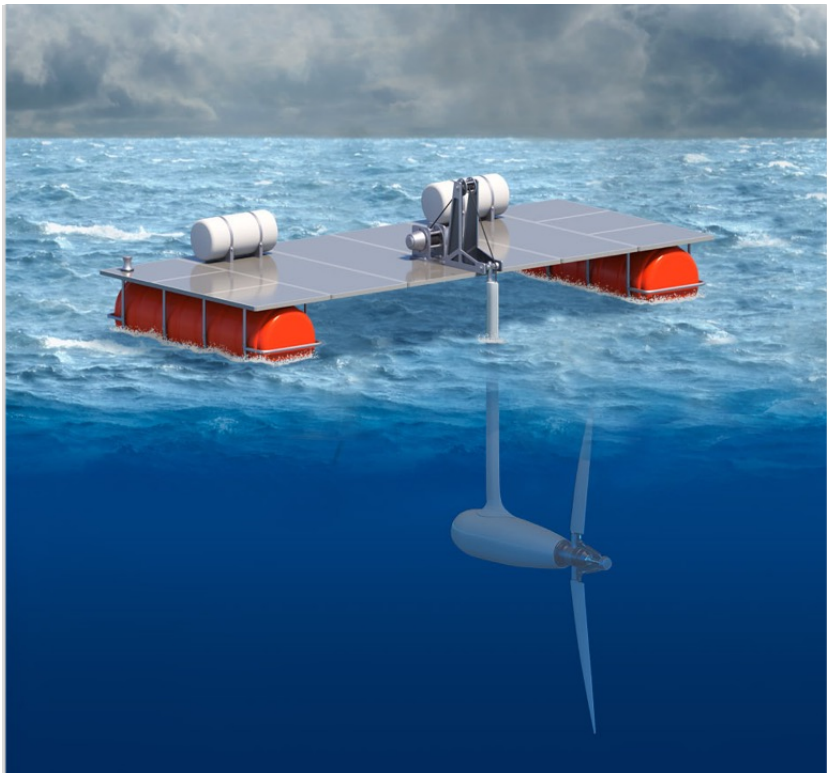


Illustration by Besiki Kazaishvili, NREL

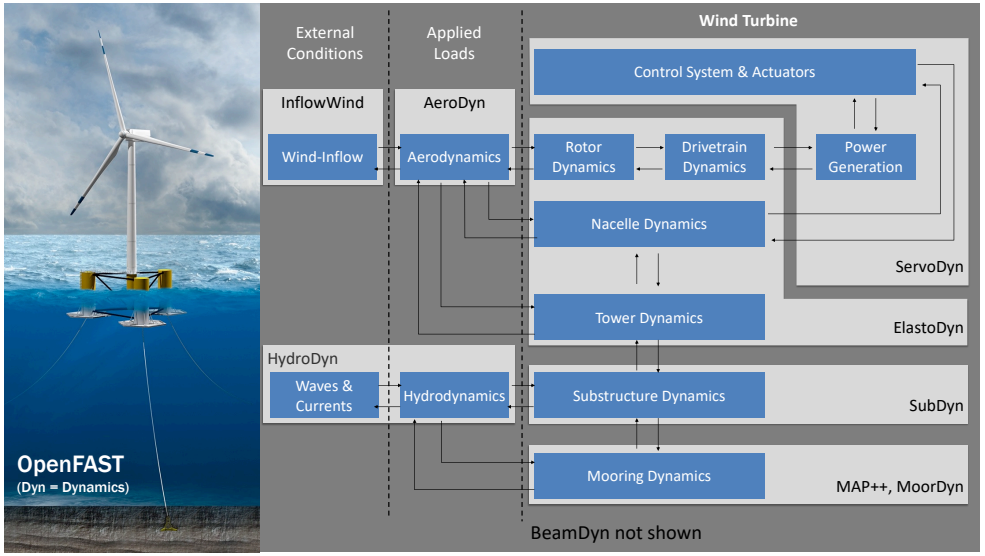
New Capabilities

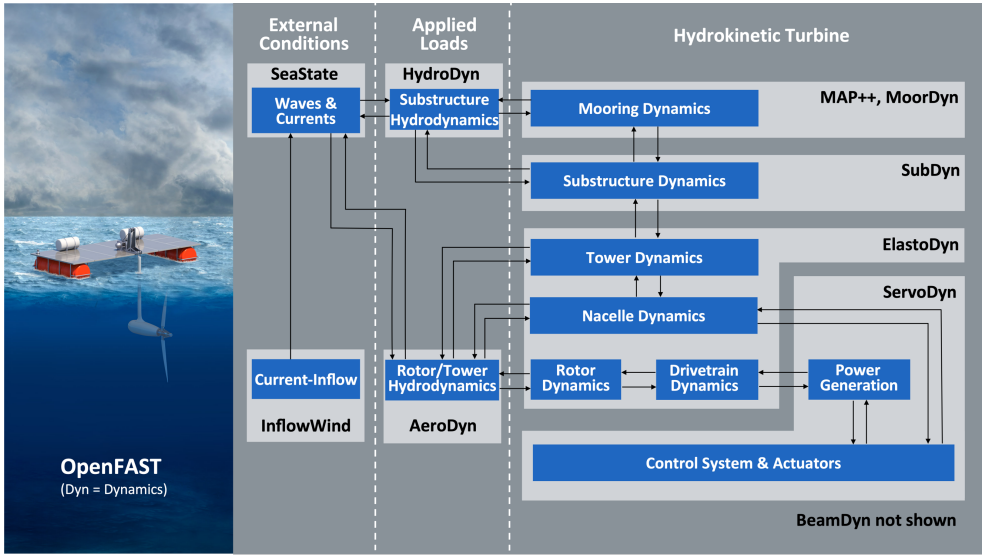
Capture physics of marine turbines

- Cavitation check
- Buoyant loads on blades, support structure, hub, and nacelle
- Added mass loads due to structure motion and deformation (including blade pitch accelerations)
- Inertial loads due to inflow accelerations
- Rotor-nacelle assembly and support structure below sea surface
- Lifting forces on faired components

Account for wave and current loads on system

- Inflow accelerations
- Wave and current velocity superposition/coupling

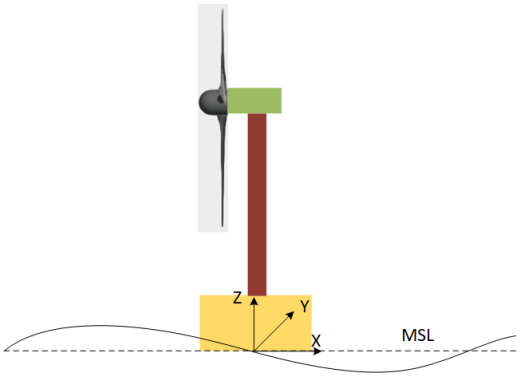




OpenFAST architecture for a floating marine turbine. *Illustration by Besiki Kazaishvili, NREL*

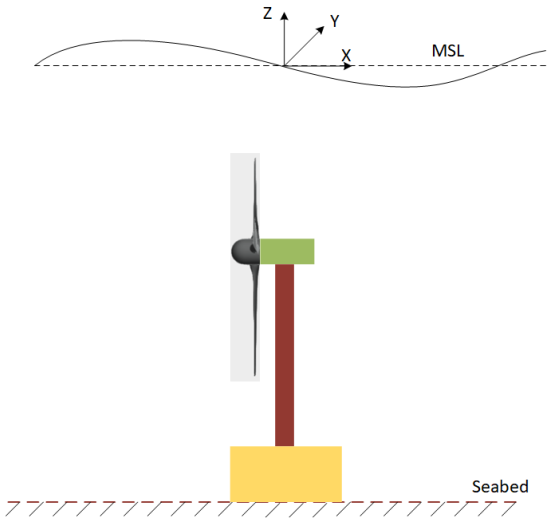
Coordinate Systems

Floating wind

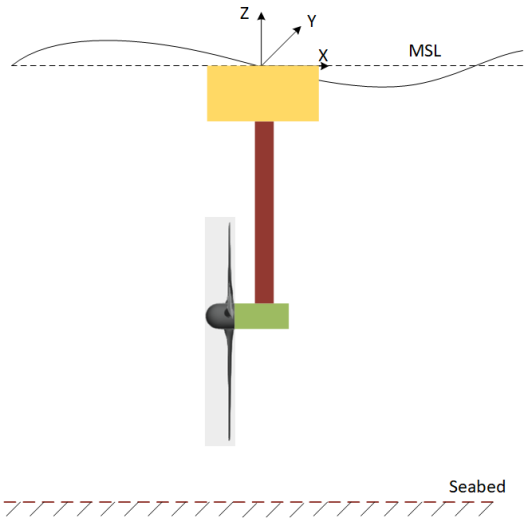


Illustrations by Toan Tran, NREL

Fixed marine



Floating marine

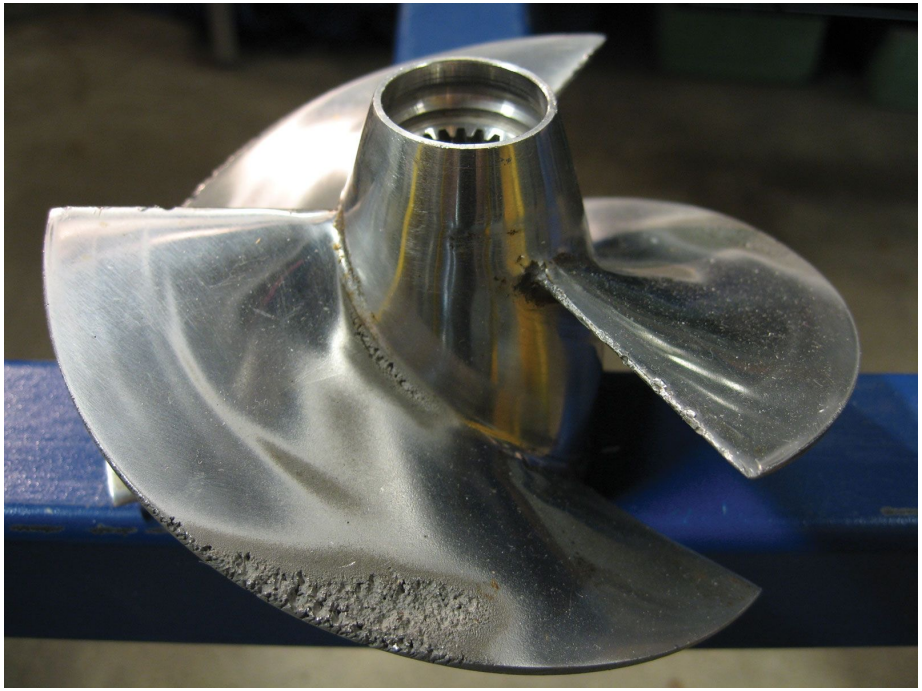


Cavitation Check

- 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**
- **Rotor depth**
- **Relative velocity**

User input



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

**Implemented previously by Robynne Murray (NREL)*

Buoyancy

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

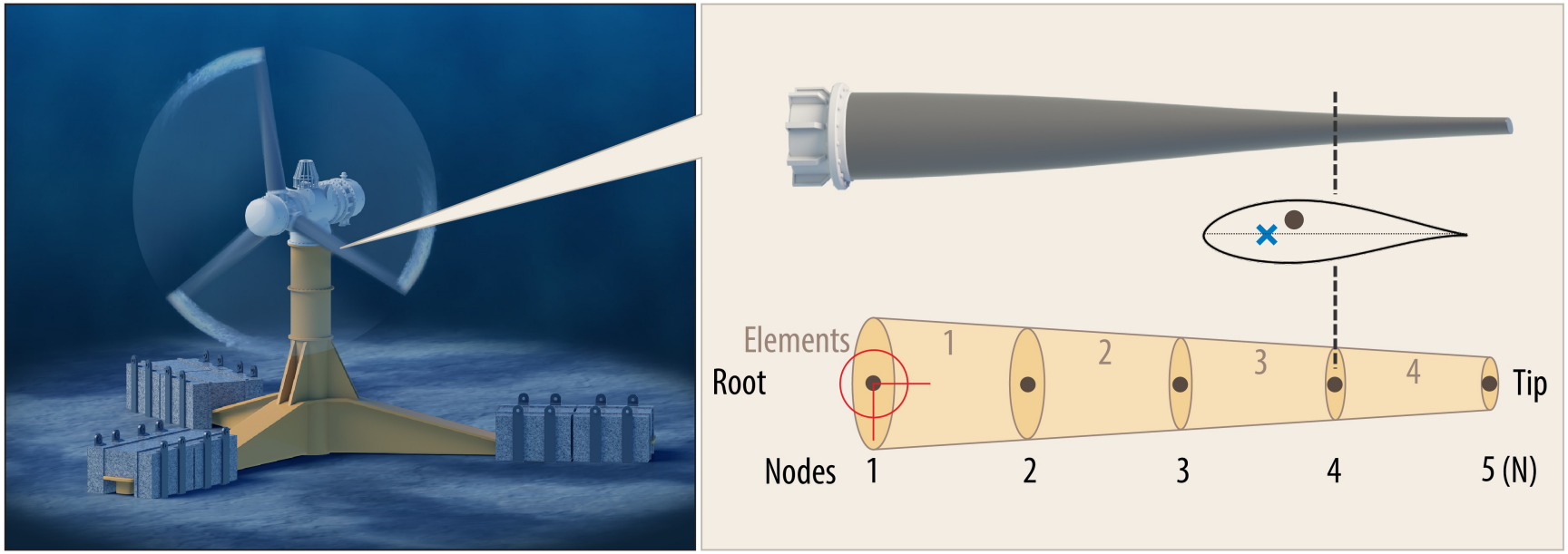
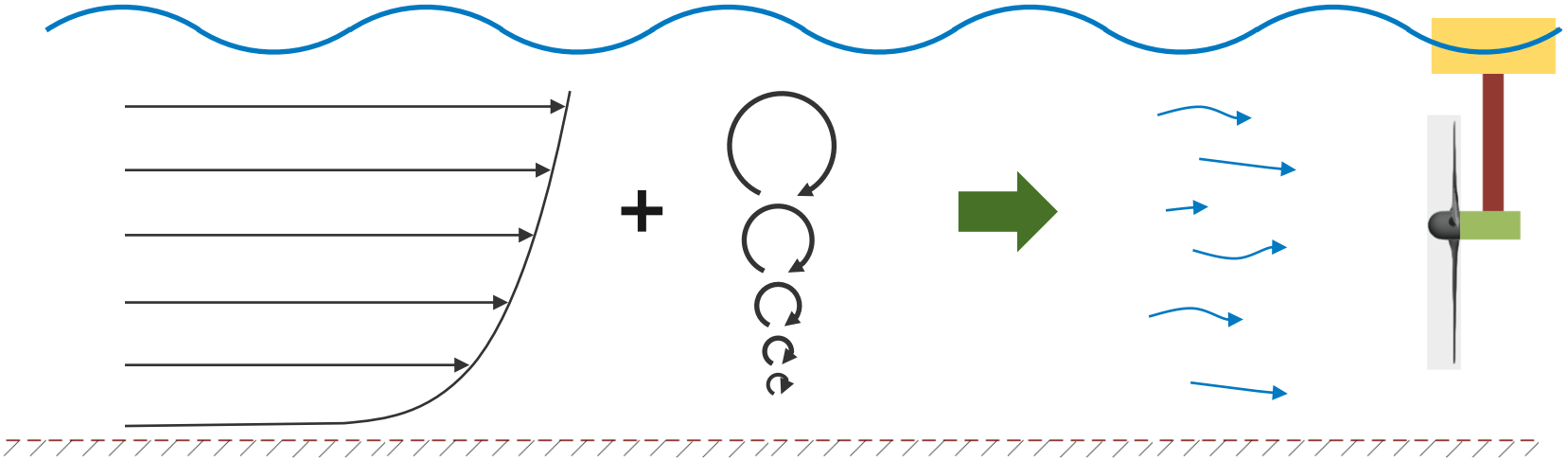


Illustration by Besiki Kazaishvili and Matt Hall, NREL

Inflow Superposition/Coupling



- Entire system sees a consistent flow field that includes current and wave velocities and accelerations

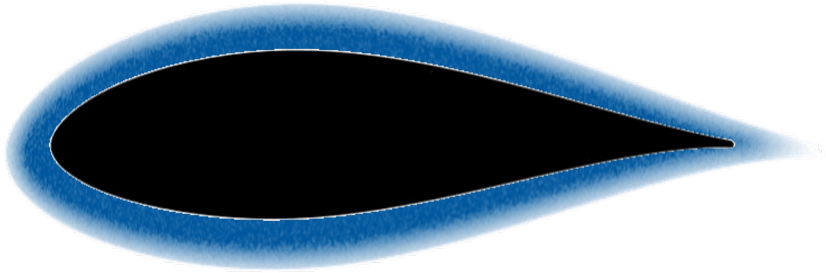
Superposition: Linear summation of current and wave velocities

Coupling: Current velocities affect wave frequencies

Added Mass

Added mass loads are considered for

- structure motion
- structure deformation
- blade pitch



Added mass loads are calculated using Morison's equation

$$F = \underbrace{\rho(C_p + C_a)V\dot{u}}_{\text{inertia}} - \underbrace{\rho C_a V\dot{v}}_{\text{added mass}} + \underbrace{\frac{1}{2}\rho C_d A(u - v)|u - v|}_{\text{drag}}$$

included in BEM

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

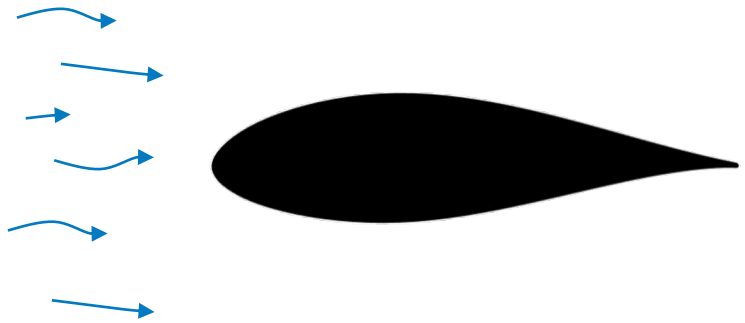
structure acceleration from ElastoDyn/BeamDyn (tight coupling)

user-defined added mass coefficient

Inertial Loads

Inertial loads are considered for

- turbulent inflow



Inertial loads are calculated using Morison's equation

$$F = \underbrace{\rho(C_p + C_a)V\dot{u}}_{\text{inertia}} - \underbrace{\rho C_a V\dot{v}}_{\text{added mass}} + \underbrace{\frac{1}{2}\rho C_d A(u-v)|u-v|}_{\text{drag}}$$

included in BEM

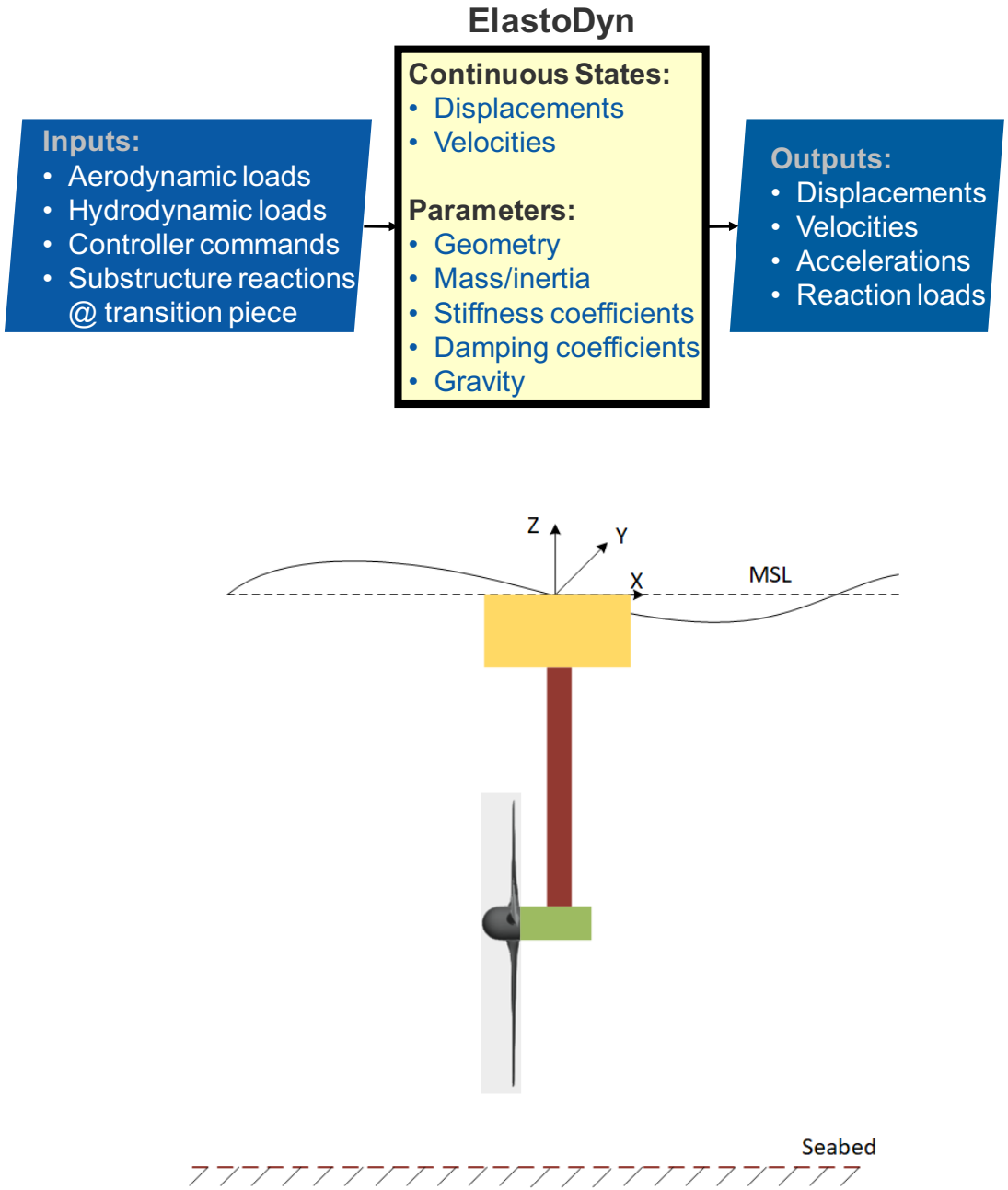
$$F_i = \rho(C_p + C_a)V\dot{u}$$

inflow acceleration from waves and currents

user-defined dynamic pressure coefficient

ElastoDyn

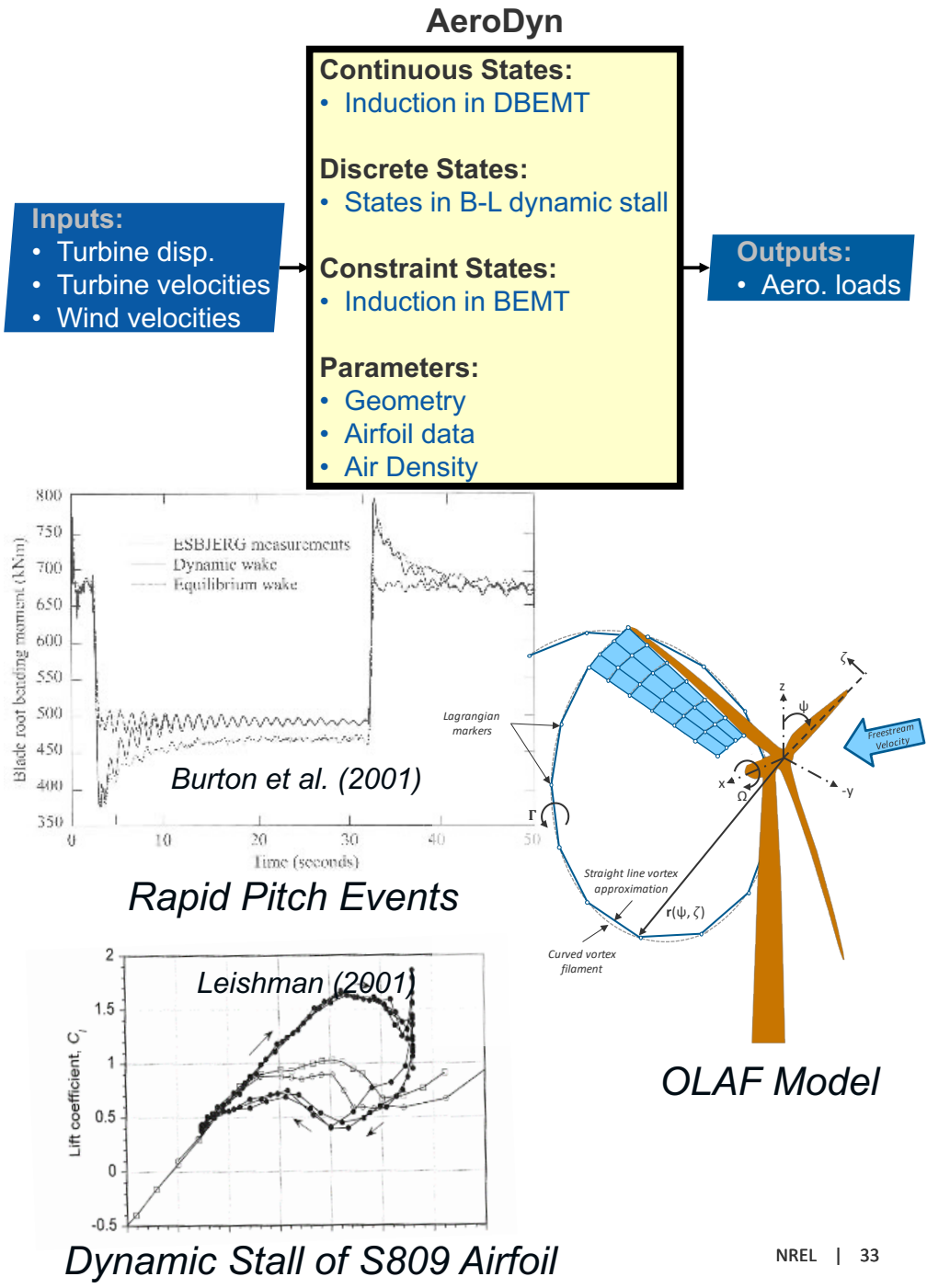
- Turbine configuration:
  - Horizontal-axis (HAWT)
  - 2- or 3-bladed rotor
  - Upwind or downwind rotor
  - Rigid or teetering hub
  - Conventional configuration ~~or inclusion of rotor- and/or tail-furling~~
  - Support structure that includes a (tower) ~~atop~~ above or below a platform
- Combined modal & multi-body representation through 24 DOFs
  - Modal: blades, tower
  - Multi-body: platform, nacelle, generator, gears, hub, tail



AeroDyn, including OLAF

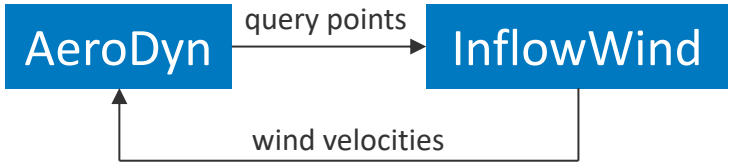
- Actuator-line physics
- cOnvecting LAgrangian Filaments (OLAF) model
- Cavitation check
- Buoyant loads
- Added mass
- Inertial loads

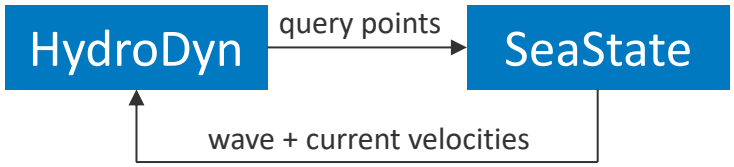
} glue code changes (tight coupling)



InflowWind / SeaState

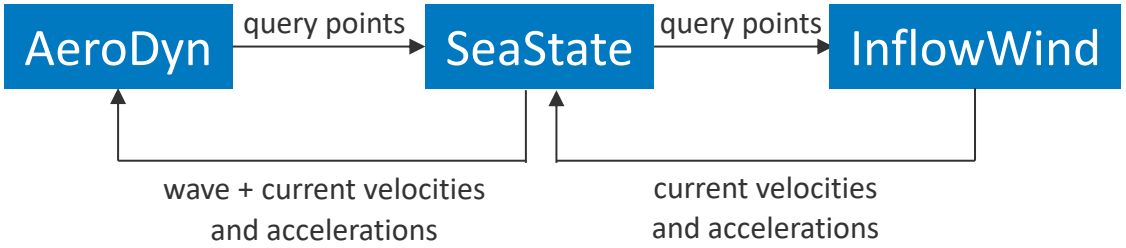
Wind Turbines

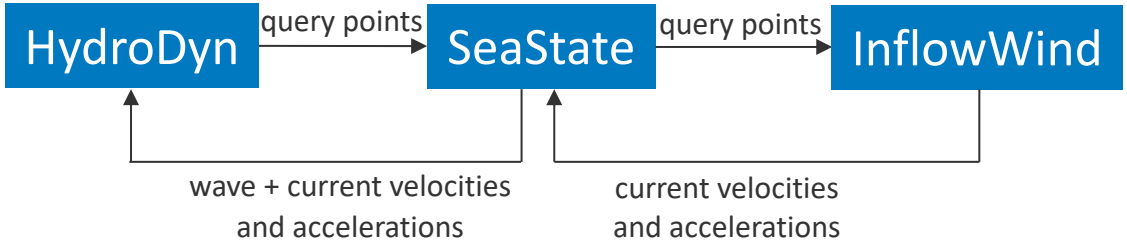




- Rotor and support structure see different flow fields

Marine Turbines





- All components see the same flow field
- SeaState current must always be set to 0
- For current only cases, SeaState flow field will be set to 0
- For wave only cases, InflowWind will not be called
- Superimposed wave + current velocities will be used for all velocities
- Superimposed wave + current accelerations will be used for inertia loads

Future Development

Additional Features

- **Verification and validation**
- **Inclusion of additional modeling capabilities**
  - Cross-flow turbines (in progress for wind)
  - Wave and current coupling
  - Multi-rotor platforms
  - Flow confinement
  - Rotor and mooring biofouling
  - Varied member cross-sectional shapes
  - Hydroacoustics
  - Other device topologies (e.g., foils and kite devices)
- **Other surrogate modeling methods and uses**
- **Coupling with HFM**

Illustration by Besiki Kazaishvili, NREL

OpenFAST Demonstration: Floating Marine Turbine – Floating RM1 Quad

Outline: OpenFAST Demonstration

- Overview of Floating RM1 Quad
- OpenFAST input files (Floating RM1)
  - ElastoDyn
  - AeroDyn
  - HydroDyn
  - SeaState
  - MoorDyn
  - InflowWind
- Demonstrate running OpenFAST
- Output files
- Time series of results

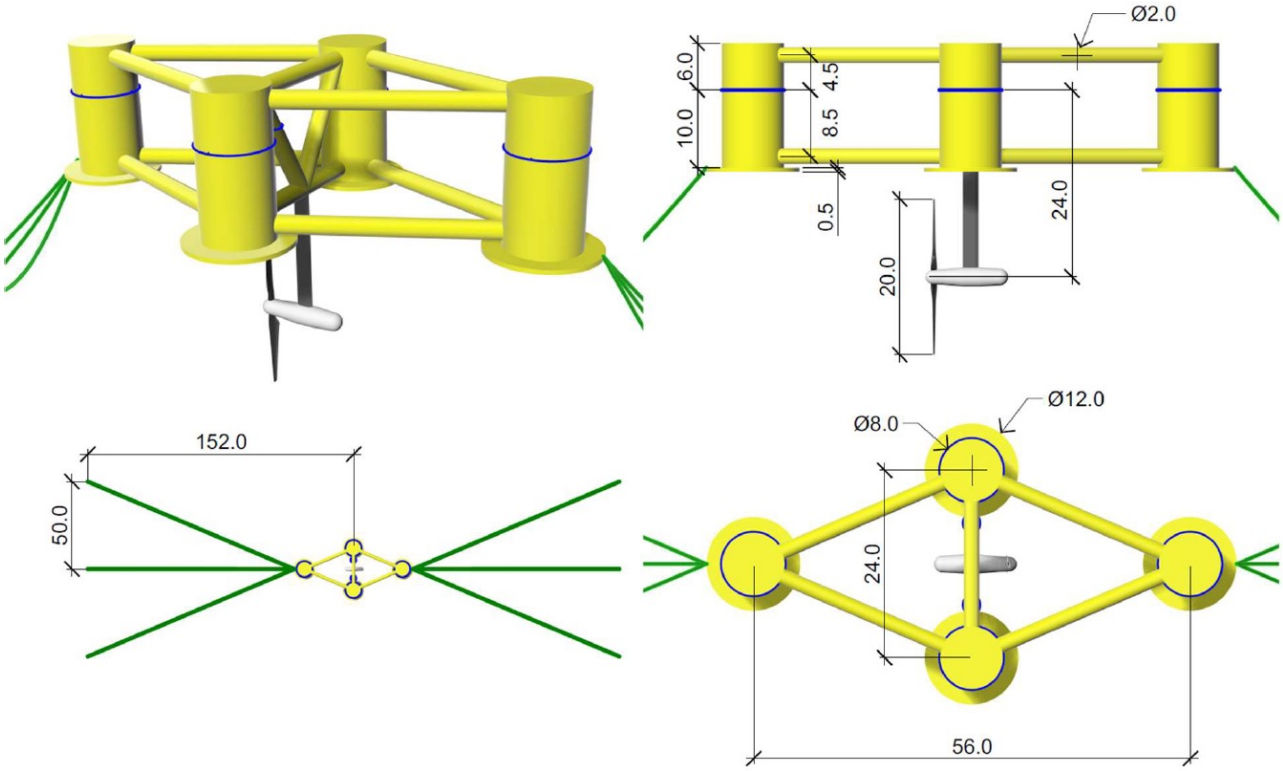
Floating RM1 Quad

RM1 Turbine

- 500 kW reference turbine designed by NREL in 2011
- 2-bladed
- Variable speed – variable pitch
- 20 m rotor diameter
- 1.9 m/s rated speed
- Specifications include:
  - Blade structural + aerodynamic properties
  - Nacelle and hub
  - Drivetrain
  - Operating profile

Floating Quad Platform

- Robust test platform designed by NREL in 2023
- Similar elements to typical FOWT semisubmersible
  - Large diameter columns
  - Heave plates
  - Catenary mooring system
- Faired tower



	Platform Structure	Platform Structure + Ballast	Platform Structure + Ballast + Tower & RNA
Mass [kg]	1.050e6	2.525e6	2.588e6
COG [m]	[0.0, 0.0, -5.63]	[0.0, 0.0, -6.09]	[-0.02, 0.0, -6.52]
Ixx [kg-m^2]	8.866e7	1.952e8	2.155e8
Iyy [kg-m^2]	3.408e8	9.194e8	9.403e8
Izz kg-m^2]	3.691e8	1.054e9	1.054e9

https://github.com/OpenFAST/r-test/tree/dev/glue-codes/openfast/MHK_RM1_Floating

OpenFAST Modules

- ElastoDyn — Structural dynamics
- BeamDyn
- AeroDyn — Turbine hydrodynamics
- InflowWind — Current inflow
- SeaState — Wave and current field
- ServoDyn
- HydroDyn — Platform hydrodynamics
- SubDyn
- MoorDyn — Dynamic mooring
- MAP++
- FEAMooring
- OrcaFlexInterface
- IceFloe
- IceDyn

- Steady, 1.9 m/s current
- Power law shear
- No control
- Fixed rotational speed
- Blade, tower, and drivetrain DOFs

OpenFAST Input File Format

```
------- OpenFAST EXAMPLE INPUT FILE -------------------------------------------
Floating MHK turbine, based on the RM1 tidal current rotor
---------------------- SIMULATION CONTROL --------------------------------------
False          Echo         - Echo input data to <RootName>.ech (flag)
"FATAL"        AbortLevel   - Error level when simulation should abort (string) {"WARNING", "SEVERE", "FATAL"}
       6       TMax         - Total run time (s)
   0.003       DT           - Recommended module time step (s)
       2       InterpOrder  - Interpolation order for input/output time history (-) {1=linear, 2=quadratic}
       5       NumCrctn     - Number of correction iterations (-) {0=explicit calculation, i.e., no corrections}
   99999       DT_UJac      - Time between calls to get Jacobians (s)
 1000000       UJacSclFact  - Scaling factor used in Jacobians (-)
```

- **Description**
  - Brief description, including options/units
- **Keyword**
  - Variable name/identifier
- **Value**
  - Numerical, logical, flag, or string

OpenFAST Driver Input File

```
------- OpenFAST EXAMPLE INPUT FILE -------------------------------------------
Floating MHK turbine, based on the RM1 tidal current rotor
---------------------- SIMULATION CONTROL --------------------------------------
False         Echo            - Echo input data to <RootName>.ech (flag)
"FATAL"       AbortLevel      - Error level when simulation should abort (string) {"WARNING", "SEVERE", "FATAL"}
        6     TMax            - Total run time (s)
    0.003     DT              - Recommended module time step (s)
        2     InterpOrder     - Interpolation order for input/output time history (-) {1=linear, 2=quadratic}
        5     NumCrctn        - Number of correction iterations (-) {0=explicit calculation, i.e., no corrections}
    99999     DT_UJac         - Time between calls to get Jacobians (s)
  1000000     UJacSclFact     - Scaling factor used in Jacobians (-)
---------------------- FEATURE SWITCHES AND FLAGS ------------------------------
        1     CompElast       - Compute structural dynamics (switch) {1=ElastoDyn; 2=ElastoDyn + BeamDyn for blades}
        1     CompInflow      - Compute inflow wind velocities (switch) {0=still air; 1=InflowWind; 2=external from OpenFOAM
        2     CompAero        - Compute aerodynamic loads (switch) {0=None; 1=AeroDyn v14; 2=AeroDyn v15}
        0     CompServo       - Compute control and electrical-drive dynamics (switch) {0=None; 1=ServoDyn}
        1     CompSeaSt       - Compute
        1     CompHydro       - Compute
        0     CompSub         - Compute
        3     CompMooring     - Compute
        0     CompIce         - Compute
        2     MHK             - MHK turb                                                                    ine
---------------------- ENVIRONMENTAL CONDITIONS --------------------------------
  9.80665     Gravity         - Gravitational acceleration (m/s^2)
    1.225     AirDens         - Air density (kg/m^3)
     1025     WtrDens         - Water density (kg/m^3)
 1.06E-06     KinVisc         - Kinematic viscosity of working fluid (m^2/s)
     1500     SpdSound        - Speed of sound in working fluid (m/s)
   101325     Patm            - Atmospheric pressure (Pa) [used only for an MHK turbine cavitation check]
     2500     Pvap            - Vapour pressure of working fluid (Pa) [used only for an MHK turbine cavitation check]
       50     WtrDpth         - Water depth (m)
        0     MSL2SWL         - Offset between still-water level and mean sea level (m) [positive upward]
```

- **TMax** should allow convergence
- **DT** should resolve structural frequencies (≤ 1/10 of the highest frequency DOF)

OpenFAST Driver Input File

```
------- OpenFAST EXAMPLE INPUT FILE -------------------------------------------
Floating MHK turbine, based on the RM1 tidal current rotor
---------------------- SIMULATION CONTROL --------------------------------------
False         Echo            - Echo input data to <RootName>.ech (flag)
"FATAL"       AbortLevel      - Error level when simulation should abort (string) {"WARNING", "SEVERE", "FATAL"}
        6     TMax            - Total run time (s)
    0.003     DT              - Recommended module time step (s)
        2     InterpOrder     - Interpolation order for input/output time history (-) {1=linear, 2=quadratic}
        5     NumCrctn        - Number of correction iterations (-) {0=explicit calculation, i.e., no corrections}
    99999     DT_UJac         - Time between calls to get Jacobians (s)
  1000000     UJacSclFact     - Scaling factor used in Jacobians (-)
---------------------- FEATURE SWITCHES AND FLAGS ------------------------------
        1     CompElast       - Compu
        1     CompInflow      - Compu
        2     CompAero        - Compu
        0     CompServo       - Compu
        1     CompSeaSt       - Compu
        1     CompHydro       - Compu
        0     CompSub         - Compu
        3     CompMooring     - Compu
        0     CompIce         - Compu
        2     MHK             - MHK t
---------------------- ENVIRONMENTAL
  9.80665     Gravity         - Gravi
    1.225     AirDens         - Air density (kg/m^3)
     1025     WtrDens         - Water density (kg/m^3)
 1.06E-06     KinVisc         - Kinematic viscosity of working fluid (m^2/s)
     1500     SpdSound        - Speed of sound in working fluid (m/s)
   101325     Patm            - Atmospheric pressure (Pa) [used only for an MHK turbine cavitation check]
     2500     Pvap            - Vapour pressure of working fluid (Pa) [used only for an MHK turbine cavitation check]
       50     WtrDpth         - Water depth (m)
        0     MSL2SWL         - Offset between still-water level and mean sea level (m) [positive upward]
```

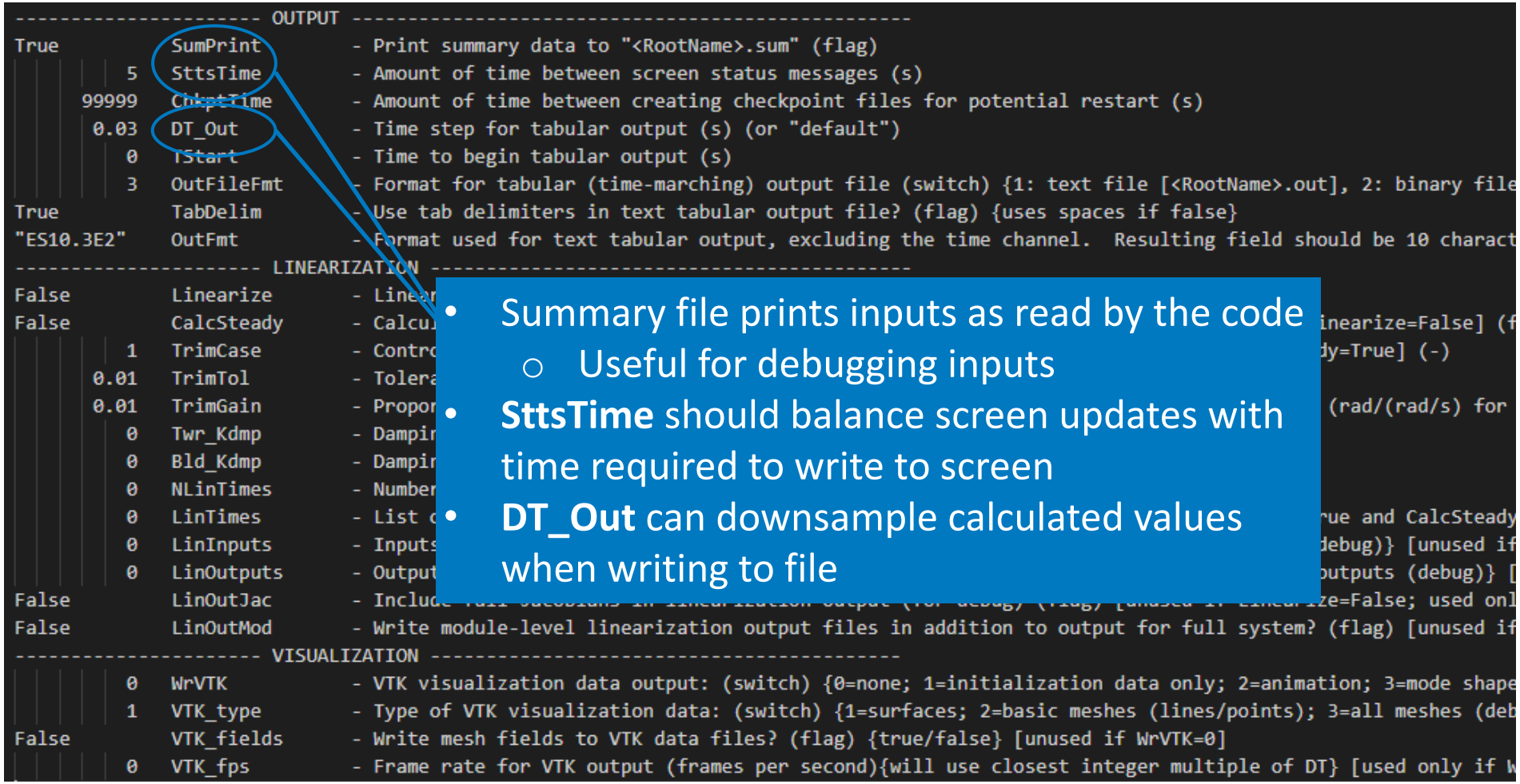
- **CompElast=1**: ElastoDyn without BeamDyn
- **CompInflow=1**: Inflow set by InflowWind
- **CompAero=2**: Aerodynamics computed by AeroDyn15
- **CompSeaSt=1**: Full grid wave field with SeaState
- **CompHydro=1**: Hydrodynamic platform forces
- **CompMooring=3**: Dynamic mooring with MoorDyn
- **MHK=2**: Floating marine turbine

OpenFAST Driver Input File

```
---------------------- FEATURE SWITCHES AND FLAGS ----------------------------
          1   CompElast       - Compute structural dynamics (switch) {1=ElastoDyn; 2=ElastoDyn + BeamDyn for blades}
          1   CompInflow      - Compute inflow wind velocities (switch) {0=still air; 1=InflowWind; 2=external from OpenFOAM
          2   CompAero        - Compute aerodynamic loads (switch) {0=None; 1=AeroDyn v14; 2=AeroDyn v15}
          0   CompServo       - Compute control and electrical-drive dynamics (switch) {0=None; 1=ServoDyn}
          1   CompSeaSt       - Compute sea state information (switch) {0=None; 1=SeaState}
          1   CompHydro       - Compute hydrodynamic loads (switch) {0=None; 1=HydroDyn}
          0   CompSub         - Compute sub-structural dynamics (switch) {0=None; 1=SubDyn; 2=External Platform MCKF}
          3   CompMooring     - Compute mooring system (switch) {0=None; 1=MAP++; 2=FEAMooring; 3=MoorDyn; 4=OrcaFlex}
          0   CompIce         - Compute ice loads (switch) {0=None; 1=IceFloe; 2=IceDyn}
          2   MHK             - MHK turbine type (switch) {0=Not an MHK turbine; 1=Fixed MHK turbine; 2=Floating MHK turbine
---------------------- ENVIRONMENTAL CONDITIONS -------------------------------
    9.80665   Gravity         - Gravitational acceleration (m/s^2)
      1.225   AirDens         - Air density (kg/m^3)
       1025   WtrDens         - Water density (kg/m^3)
   1.06E-06   KinVisc         - Kinematic viscosity of working fluid (m^2/s)
       1500   SpdSound        - Speed of
     101325   Patm            - Atmosphe
       2500   Pvap            - Vapour p
         50   WtrDpth         - Water de
          0   MSL2SWL         - Offset b
---------------------- INPUT FILES ---------
"MHK_RM1_Floating_ElastoDyn.dat"    EDFile          - Name of file containing ElastoDyn input parameters (quoted string)
"unused"      BDBldFile(1)    - Name of file containing BeamDyn input parameters for blade 1 (quoted string)
"unused"      BDBldFile(2)    - Name of file containing BeamDyn input parameters for blade 2 (quoted string)
"unused"      BDBldFile(3)    - Name of file containing BeamDyn input parameters for blade 3 (quoted string)
"MHK_RM1_Floating_InflowWind.dat"    InflowFile      - Name of file containing inflow wind input parameters (quoted string)
"MHK_RM1_Floating_AeroDyn15.dat"    AeroFile        - Name of file containing aerodynamic input parameters (quoted string)
"unused"      ServoFile       - Name of file containing control and electrical-drive input parameters (quoted string)
"SeaState.dat"    SeaStFile       - Name of file containing sea state input parameters (quoted string)
"MHK_RM1_Floating_HydroDyn.dat"    HydroFile       - Name of file containing hydrodynamic input parameters (quoted string)
"unused"      SubFile         - Name of file containing sub-structural input parameters (quoted string)
"MHK_RM1_Floating_MoorDyn.dat"    MooringFile     - Name of file containing mooring system input parameters (quoted string)
"unused"      IceFile         - Name of file containing ice input parameters (quoted string)
```

- Specify module primary input files
  - Path relative to folder containing .fst file
- Unused modules not specified

OpenFAST Driver Input File



- Summary file prints inputs as read by the code
  - Useful for debugging inputs
- **SttsTime** should balance screen updates with time required to write to screen
- **DT_Out** can downsample calculated values when writing to file

OpenFAST Driver Input File

```
---------------------- OUTPUT --------------------------------------------------
True          SumPrint        - Print summary data to "<RootName>.sum" (flag)
         5    SttsTime        - Amount of time between screen status messages (s)
     99999    ChkptTime       - Amount of time between creating checkpoint files for potential restart (s)
      0.03    DT_Out          - Time step for tabular output (s) (or "default")
         0    TStart          - Time to begin tabular output (s)
         3    OutFileFmt      - Format for tabular (time-marching) output file (switch) {1: text file [<RootName>.out], 2: binary file
True          TabDelim        - Use tab delimiters in text tabular output file? (flag) {uses spaces if false}
"ES10.3E2"    OutFmt          - Format used for text tabular output, excluding the time channel.  Resulting field should be 10 charact
---------------------- LINEARIZATION -----------------------------------------
False         Linearize       - Linearization analysis (flag)
False         CalcSteady      - Calculate a steady-state periodic operating point before linearization? [unused if Linearize=False] (f
         1    TrimCase        - Controller parameter to be trimmed {1:yaw; 2:torque; 3:pitch} [used only if CalcSteady=True] (-)
      0.01    TrimTol         - Tolerance for the rotational speed convergence [used only if CalcSteady=True] (-)
      0.01    TrimGain        - Proport                                                                    rad/(rad/s) for
         0    Twr_Kdmp        - Damping
         0    Bld_Kdmp        - Damping
         0    NLinTimes       - Number
         0    LinTimes        - List of                                                                    e and CalcSteady
         0    LinInputs       - Inputs                                                                     bug)} [unused if
         0    LinOutputs      - Outputs                                                                    tputs (debug)} [
False         LinOutJac       - Include                                                                    =False; used onl
False         LinOutMod       - Write module-level linearization output files in addition to output for full system? (flag) [unused if
---------------------- VISUALIZATION -----------------------------------------
         0    WrVTK           - VTK visualization data output: (switch) {0=none; 1=initialization data only; 2=animation; 3=mode shape
         1    VTK_type        - Type of VTK visualization data: (switch) {1=surfaces; 2=basic meshes (lines/points); 3=all meshes (deb
False         VTK_fields      - Write mesh fields to VTK data files? (flag) {true/false} [unused if WrVTK=0]
         0    VTK_fps         - Frame rate for VTK output (frames per second){will use closest integer multiple of DT} [used only if W
```

- **Linearization=True** enables linearization of the full coupled solution
  - Linearized equations can be output for use in other models

OpenFAST Driver Input File

```
---------------------- OUTPUT --------------------------------------------------
True          SumPrint        - Print summary data to "<RootName>.sum" (flag)
           5  SttsTime        - Amount of time between screen status messages (s)
       99999  ChkptTime       - Amount of time between creating checkpoint files for potential restart (s)
        0.03  DT_Out          - Time step for tabular output (s) (or "default")
           0  TStart          - Time to begin tabular output (s)
           3  OutFileFmt      - Format for tabular (time-marching) output file (switch) {1: text file [<RootName>.out], 2: binary file
True          TabDelim        - Use tab delimiters in text tabular output file? (flag) {uses spaces if false}
"ES10.3E2"    OutFmt          - Format used for text tabular output, excluding the time channel.  Resulting field should be 10 charact
---------------------- LINEARIZATION -----------------------------------------
False         Linearize       - Linearization analysis (flag)
False         CalcSteady      - Calculate a steady-state periodic operating point before linearization? [unused if Linearize=False] (f
           1  TrimCase        - Controller parameter to be trimmed {1:yaw; 2:torque; 3:pitch} [used only if CalcSteady=True] (-)
        0.01  TrimTol         - Tolerance for the rotational speed convergence [used only if CalcSteady=True] (-)
        0.01  TrimGain        - Proportional gain for the rotational speed error (>0) [used only if CalcSteady=True] (rad/(rad/s) for
           0  Twr_Kdmp        - Damping factor for the tower [used only if CalcSteady=True] (N/(m/s))
           0  Bld_Kdmp        - Damping factor for the blades [used only if CalcSteady=True] (N/(m/s))
           0  NLinTimes       - Number of times to linearize (-) [>=1] [unused if Linearize=False]
           0  LinTimes        - List of times at which to linearize (s) [1 to NLinTimes] [used only when Linearize=True and CalcSteady
           0  LinInputs       - Inputs included in linearization (switch) {0=none; 1=standard; 2=all module inputs (debug)} [unused if
           0  LinOutputs      - Outputs                                                                    tputs (debug)} [
False         LinOutJac       - Include                                                                    =False; used onl
False         LinOutMod       - Write module-level linearization output files in addition to output for full system? (flag) [unused if
---------------------- VISUALIZATION -----------------------------------------
           0  WrVTK           - VTK visualization data output: (switch) {0=none; 1=initialization data only; 2=animation; 3=mode shape
           1  VTK_type        - Type of VTK visualization data: (switch) {1=surfaces; 2=basic meshes (lines/points); 3=all meshes (deb
False         VTK_fields      - Write mesh fields to VTK data files? (flag) {true/false} [unused if WrVTK=0]
           0  VTK_fps         - Frame rate for VTK output (frames per second){will use closest integer multiple of DT} [used only if W
```

- Visualization using VTK (Visualization ToolKit)

ElastoDyn Primary Input File

- Blade and tower bending DOFs enabled
- Platform 6 DOFs enabled
- Generator and yaw DOFs disabled
  - Fixed RPM specified
- Teeter and platform DOFs not applicable

```
------- ELASTODYN for OpenFAST I
Floating MHK turbine structural
---------------------- SIMULATIO
False          Echo          - Echo
     3         Method        - Inte
"default"      DT            - Inte
---------------------- DEGREES OF FREEDOM --------------------------------------
True           FlapDOF1      - First flapwise blade mode DOF (flag)
True           FlapDOF2      - Second flapwise blade mode DOF (flag)
True           EdgeDOF       - First edgewise blade mode DOF (flag)
False          TeetDOF       - Rotor-teeter DOF (flag) [unused for 3 blades]
True           DrTrDOF       - Drivetrain rotational-flexibility DOF (flag)
False          GenDOF        - Generator DOF (flag)
False          YawDOF        - Yaw DOF (flag)
True           TwFADOF1      - First fore-aft tower bending-mode DOF (flag)
True           TwFADOF2      - Second fore-aft tower bending-mode DOF (flag)
True           TwSSDOF1      - First side-to-side tower bending-mode DOF (flag)
True           TwSSDOF2      - Second side-to-side tower bending-mode DOF (flag)
True           PtfmSgDOF     - Platform horizontal surge translation DOF (flag)
True           PtfmSwDOF     - Platform horizontal sway translation DOF (flag)
True           PtfmHvDOF     - Platform vertical heave translation DOF (flag)
True           PtfmRDOF      - Platform roll tilt rotation DOF (flag)
True           PtfmPDOF      - Platform pitch tilt rotation DOF (flag)
True           PtfmYDOF      - Platform yaw rotation DOF (flag)
```

ElastoDyn Primary Input File

```
---------------------- INITIAL CONDITIONS -------------------------------------
      0   OoPDefl     - Initial out-of-plane blade-tip displacement (meters)
      0   IPDefl      - Initial in-plane blade-tip deflection (meters)
      0   BlPitch(1)  - Blade 1 initial pitch (degrees)
      0   BlPitch(2)  - Blade 2 initial pitch (degrees)
      0   BlPitch(3)  - Blade 3 initial pitch (degrees) [unused for 2 blades]
      0   TeetDefl    - Initial or fixed teeter angle (degrees) [unused for 3 blades]
      0   Azimuth     - Initial azimuth angle for blade 1 (degrees)
   11.5   RotSpeed    - Initial or fixed rotor speed (rpm)
      0   NacYaw      - Initial or fixed nacelle-yaw angle (degrees)
      0   TTDspFA     - Initial fore-aft tower-top displacement (meters)
      0   TTDspSS     - Initial side-to-side tower-top displacement (meters)
     20   PtfmSurge   - Initial or fixed horizontal surge translational displacement of platform (meters)
      0   PtfmSway    - Initial or fixed horizontal sway translational displacement of platform (meters)
      0   PtfmHeave   - Initial or fixed vertical heave translational displacement of platform (meters)
      0   PtfmRoll    - Initial or fixed roll tilt rotational displacement of platform (degrees)
      0   PtfmPitch   - Initial or fixed pitch tilt rotational displacement of platform (degrees)
      0   PtfmYaw     - Initial or fixed yaw rotational displacement of platform (degrees)
```

- Specify initial angles, displacements, and motions
- Fixed rotor speed of rated 11.5 rpm
- Initial surge based on rated thrust

ElastoDyn Primary Input File

```
---------------------- TURBINE CONFIGURATION -------------------------------------
         2   NumBl        - Number of blades (-)
        10   TipRad       - The distance from the rotor apex to the blade tip (meters)
         1   HubRad       - The distance from the rotor apex to the blade root (meters)
         0   PreCone(1)   - Blade 1 cone angle (degrees)
         0   PreCone(2)   - Blade 2 cone angle (degrees)
         0   PreCone(3)   - Blade 3 cone angle (degrees) [unused for 2 blades]
    0.2222   HubCM        - Distance from rotor apex to hub mass [positive downwind] (meters)
         0   UndSling     - Undersling length [distance from teeter pin to the rotor apex] (meters) [unused for 3 blades]
         0   Delta3       - Delta-3 angle for teetering rotors (degrees) [unused for 3 blades]
         0   AzimB1Up     - Azimuth value to use for I/O when blade 1 points up (degrees)
     -4.91   OverHang     - Distance from yaw axis to rotor apex [3 blades] or teeter pin [2 blades] (meters)
         0   ShftGagL     - Distance from rotor apex [3 blades] or teeter pin [2 blades] to shaft strain gages [positive for upwin
         0   ShftTilt     - Rotor shaft tilt angle (degrees)
      0.43   NacCMxn       - Downwind distance from the tower-top to the nacelle CM (meters)
         0   NacCMyn       - Lateral  distance from the tower-top to the nacelle CM (meters)
      -1.2   NacCMzn       - Vertical distance from the tower-top to the nacelle CM (meters)
         0   NcIMUxn       - Downwind distance from the tower-top to the nacelle IMU (meters)
         0   NcIMUyn       - Lateral  distance from the tower-top to the nacelle IMU (meters)
      -1.2   NcIMUzn       - Vertical distance from the tower-top to the nacelle IMU (meters)
      -1.2   Twr2Shft      - Vertical distance from the tower-top to the rotor shaft (meters)
       -24   TowerHt       - Height of tower relative to ground level [onshore], MSL [offshore wind or floating MHK], or seabed [fi
        -9   TowerBsHt     - Height of tower base relative to ground level [onshore], MSL [offshore wind or floating MHK], or seabe
         0   PtfmCMxt      - Downwind distance from the ground level [onshore], MSL [offshore wind or floating MHK], or seabed [fix
         0   PtfmCMyt      - Lateral distance from the ground level [onshore], MSL [offshore wind or floating MHK], or seabed [fixe
     -6.09   PtfmCMzt      - Vertical distance from the ground level [onshore], MSL [offshore wind or floating MHK], or seabed [fix
         0   PtfmRefzt     - Vertical distance from the ground level [onshore], MSL [offshore wind or floating MHK], or seabed [fix
```

- Specify turbine geometry
- Platform COG

ElastoDyn Primary Input File

```
---------------------- MASS AND INERTIA ---------------------------------------
          0   TipMass(1)  - Tip-brake mass, blade 1 (kg)
          0   TipMass(2)  - Tip-brake mass, blade 2 (kg)
          0   TipMass(3)  - Tip-brake mass, blade 3 (kg) [unused for 2 blades]
        140   HubMass     - Hub mass (kg)
       79.6   HubIner     - Hub inertia about rotor axis [3 blades] or teeter axis [2 blades] (kg m^2)
      139.5   GenIner     - Generator inertia about HSS (kg m^2)
      40100   NacMass     - Nacelle mass (kg)
     244643   NacYIner    - Nacelle inertia about yaw axis (kg m^2)
          0   YawBrMass   - Yaw bearing mass (kg)
    2525214   PtfmMass    - Platform mass (kg)
  195242474   PtfmRIner   - Platform inertia for roll tilt rotation about the platform CM (kg m^2)
  919435755   PtfmPIner   - Platform inertia for pitch tilt rotation about the platform CM (kg m^2)
 1053535885   PtfmYIner   - Platform inertia for yaw rotation about the platform CM (kg m^2)
```

- Specify turbine mass and inertia
- Specify platform mass and inertia

ElastoDyn Primary Input File

- Specify blade structural input files
- **BldFile(3)** ignored for 2-bladed rotor

```
---------------------- BLADE -----------------------------------------------
         8   BldNodes    - Number of blade nodes (per blade) used for analysis (-)
"MHK_RM1_ElastoDyn_Blade.dat"    BldFile(1)   - Name of file containing properties for blade 1 (quoted string)
"MHK_RM1_ElastoDyn_Blade.dat"    BldFile(2)   - Name of file containing properties for blade 2 (quoted string)
"unused"      BldFile(3)   - Name of file containing properties for blade 3 (quoted string) [unused for 2 blades]
```

ElastoDyn Primary Input File

```
---------------------- BLADE -----------------------------------------------
         8   BldNodes    - Number of blade nodes (per blade) used for analysis (-)
"MHK_RM1_ElastoDyn_Blade.dat"    BldFile(1)  - Name of file containing properties for blade 1 (quoted string)
"MHK_RM1_ElastoDyn_Blade.dat"    BldFile(2)  - Name of file containing properties for blade 2 (quoted string)
"unused"         BldFile(3)  - Name of file containing properties for blade 3 (quoted string) [unused for 2 blades]
---------------------- ROTOR-TEETER ----------------------------------------
         0   TeetMod     - Rotor-teeter spring/damper model {0: none, 1: standard, 2: user-defined from routine UserTeet} (switch) [u
         0   TeetDmpP    - Rotor-teeter damper position (degrees) [used only for 2 blades and when TeetMod=1]
         0   TeetDmp     - Rotor-teeter damping constant (N-m/(rad/s)) [used only for 2 blades and when TeetMod=1]
         0   TeetCDmp    - Rotor-teeter rate-independent Coulomb-damping moment (N-m) [used only for 2 blades and when TeetMod=1]
         0   TeetSStP    - Rotor-teeter soft-stop position (degrees) [used only for 2 blades and when TeetMod=1]
         0   TeetHStP    - Rotor-teeter hard-stop position (degrees) [used only for 2 blades and when TeetMod=1]
         0   TeetSSSp    - Rotor-teeter soft-stop linear-spring constant (N-m/rad) [used only for 2 blades and when TeetMod=1]
         0   TeetHSSp    - Rotor-teeter hard-stop linear-spring constant (N-m/rad) [used only for 2 blades and when TeetMod=1]
---------------------- DRIVETRAIN ------------------------------------------
        92   GBoxEff     - Gearbox efficiency (%)
        53   GBRatio     - Gearbox ratio (-)
    600000   DTTorSpr    - Drivetrain torsional spring (N-m/rad)
    100000   DTTorDmp    - Drivetrain torsional damper (N-m/(rad/s))
```

- Specifications for teetering rotors

ElastoDyn Primary Input File

```
---------------------- BLADE -----------------------------------------------
         8   BldNodes    - Number of blade nodes (per blade) used for analysis (-)
"MHK_RM1_ElastoDyn_Blade.dat"    BldFile(1)  - Name of file containing properties for blade 1 (quoted string)
"MHK_RM1_ElastoDyn_Blade.dat"    BldFile(2)  - Name of file containing properties for blade 2 (quoted string)
"unused"      BldFile(3)  - Name of file containing properties for blade 3 (quoted string) [unused for 2 blades]
---------------------- ROTOR-TEETER ----------------------------------------
         0   TeetMod     - Rotor-teeter spring/damper model {0: none, 1: standard, 2: user-defined from routine UserTeet} (switch) [u
         0   TeetDmpP    - Rotor-teeter damper position (degrees) [used only for 2 blades and when TeetMod=1]
         0   TeetDmp     - Rotor-teeter damping constant (N-m/(rad/s)) [used only for 2 blades and when TeetMod=1]
         0   TeetCDmp    - Rotor-teeter rate-independent Coulomb-damping moment (N-m) [used only for 2 blades and when TeetMod=1]
         0   TeetSStP    - Rotor-teeter soft-stop position (degrees) [used only for 2 blades and when TeetMod=1]
         0   TeetHStP    - Rotor-teeter hard-stop position (degrees) [used only for 2 blades and when TeetMod=1]
         0   TeetSSSp    - Rotor-teeter soft-stop linear-spring constant (N-m/rad) [used only for 2 blades and when TeetMod=1]
         0   TeetHSSp    - Rotor-teeter hard-stop linear-spring constant (N-m/rad) [used only for 2 blades and when TeetMod=1]
---------------------- DRIVETRAIN ------------------------------------------
        92   GBoxEff     - Gearbox efficiency (%)
        53   GBRatio     - Gearbox ratio (-)
    600000   DTTorSpr    - Drivetrain torsional spring (N-m/rad)
    100000   DTTorDmp    - Drivetrain torsional damper (N-m/(rad/s))
```

- Gearbox and drivetrain specifications, including drivetrain rotational flexibility

ElastoDyn Primary Input File

```
---------- FURLING ---------------------------------------------------
False          Furling     - Read in additional model properties for furling turbine (flag) [must currently be FALSE)
"unused"       FurlFile    - Name of file containing furling properties (quoted string) [unused when Furling=False]
---------- TOWER -----------------------------------------------------
           2   TwrNodes    - Number of tower nodes used for analysis (-)
"MHK_RM1_Floating_ElastoDyn_Tower.dat"    TwrFile     - Name of file containing tower properties (quoted string)
---------- OUTPUT ----------------------------------------------------
True           SumPrint    - Print summary data to "<RootName>.sum" (flag)
           1   OutFile     - Switch to determine where output will be placed: {1: in module output file only; 2: in glue code
True           TabDelim    - Use tab delimiters in text tabular output file? (flag) (currently unused)
"ES10.3E2"     OutFmt      - Format used f                                                              10 characters. (qu
           0   TStart      - Time to begi
           1   DecFact     - Decimation factor for tabular output {1: output every time step} (-) (currently unused)
           0   NTwGages    - Number of tower nodes that have strain gages for output [0 to 9] (-)
           0   TwrGagNd    - List of tower nodes that have strain gages [1 to TwrNodes] (-) [unused if NTwGages=0]
           0   NBlGages    - Number of blade nodes that have strain gages for output [0 to 9] (-)
           0   BldGagNd    - List of blade nodes that have strain gages [1 to BldNodes] (-) [unused if NBlGages=0]
               OutList     - The next line(s) contains a list of output parameters.  See OutListParameters.xlsx for a listing
"PtfmSurge"
"PtfmSway"
"PtfmHeave"
"PtfmRoll"
"PtfmPitch"
"PtfmYaw"
"TwrTpTDxi"
"TwrTpTDyi"
"TwrTpTDzi"
"OoPDefl1"
END of OutList section (the word "END" must appear in the first 3 columns of the last OutList line)
```

- Furling properties (currently unused)

ElastoDyn Primary Input File

```
---------------------- FURLING ---------------------------------------------------
False          Furling      - Read in additional model properties for furling turbine (flag) [must currently be FALSE)
"unused"       FurlFile     - Name of file containing furling properties (quoted string) [unused when Furling=False]
---------------------- TOWER -----------------------------------------------------
           2   TwrNodes     - Number of tower nodes used for analysis (-)
"MHK_RM1_Floating_ElastoDyn_Tower.dat"    TwrFile      - Name of file containing tower properties (quoted string)
---------------------- OUTPUT ----------------------------------------------------
True           SumPrint     - Print summary data to "<RootName>.sum" (flag)
           1   OutFile      - Switch to determine where output will be placed: {1: in module output file only; 2: in glue code
True           TabDelim     - Use tab delimiters in text tabular output file? (flag) (currently unused)
"ES10.3E2"     OutFmt       - Format used for text tabular output (except time).  Resulting field should be 10 characters. (qu
           0   TStart       - Time to begin tabular output (s) (currently unused)
           1   DecFact      - Decimation facto                                                    rrently unused)
           0   NTwGages     - Number of tower
           0   TwrGagNd     - List of tower nodes that have strain gages [1 to TwrNodes] (-) [unused if NTwGages=0]
           0   NBlGages     - Number of blade nodes that have strain gages for output [0 to 9] (-)
           0   BldGagNd     - List of blade nodes that have strain gages [1 to BldNodes] (-) [unused if NBlGages=0]
               OutList      - The next line(s) contains a list of output parameters.  See OutListParameters.xlsx for a listing
"PtfmSurge"
"PtfmSway"
"PtfmHeave"
"PtfmRoll"
"PtfmPitch"
"PtfmYaw"
"TwrTpTDxi"
"TwrTpTDyi"
"TwrTpTDzi"
"OoPDefl1"
END of OutList section (the word "END" must appear in the first 3 columns of the last OutList line)
```

- Specify tower structural input file

ElastoDyn Primary Input File

```
---------------------- FURLING ---------------------------------------------------
False          Furling      - Read in additional model properties for furling turbine (flag) [must currently be FALSE)
"unused"       FurlFile     - Name of file containing furling properties (quoted string) [unused when Furling=False]
---------------------- TOWER -----------------------------------------------------
           2   TwrNodes     - Number of tower nodes used for analysis (-)
"MHK_RM1_Floating_ElastoDyn_Tower.dat"    TwrFile      - Name of file containing tower properties (quoted string)
---------------------- OUTPUT ----------------------------------------------------
True           SumPrint     - Print summary data to "<RootName>.sum" (flag)
           1   OutFile      - Switch t                                utput file only; 2: in glue code
True           TabDelim     - Use tab (                               y unused)
"ES10.3E2"     OutFmt       - Format u                                eld should be 10 characters. (qu
           0   TStart       - Time to
           1   DecFact      - Decimation factor for tabular output {1: output every time step} (-) (currently unused)
           0   NTwGages     - Number of tower nodes that have strain gages for output [0 to 9] (-)
           0   TwrGagNd     - List of tower nodes that have strain gages [1 to TwrNodes] (-) [unused if NTwGages=0]
           0   NBlGages     - Number of blade nodes that have strain gages for output [0 to 9] (-)
           0   BldGagNd     - List of blade nodes that have strain gages [1 to BldNodes] (-) [unused if NBlGages=0]
               OutList      - The next line(s) contains a list of output parameters.  See OutListParameters.xlsx for a listing
"PtfmSurge"
"PtfmSway"
"PtfmHeave"
"PtfmRoll"
"PtfmPitch"
"PtfmYaw"
"TwrTpTDxi"
"TwrTpTDyi"
"TwrTpTDzi"
"OoPDefl1"
END of OutList section (the word "END" must appear in the first 3 columns of the last OutList line)
```

- Specify formatting of outputs written to file

ElastoDyn Primary Input File

```
---------------------- FURLING ---------------------------------------------------
False          Furling      - Read in additional model properties for furling turbine (flag) [must currently be FALSE)
"unused"       FurlFile     - Name of file containing furling properties (quoted string) [unused when Furling=False]
---------------------- TOWER -----------------------------------------------------
           2   TwrNodes     - Number of tower nodes used for analysis (-)
"MHK_RM1_Floating_ElastoDyn_Tower.dat"    TwrFile      - Name of file containing tower properties (quoted string)
---------------------- OUTPUT ----------------------------------------------------
True           SumPrint     - Print summary data to "<RootName>.sum" (flag)
           1   OutFile      - Switch to determine where output will be placed: {1: in module output file only; 2: in glue code
True           TabDelim     - Use tab delimiters in text tabular output file? (flag) (currently unused)
"ES10.3E2"     OutFmt       - Format used for text tabular output (except time).  Resulting field should be 10 characters. (qu
           0   TStart       - Time to begin tabular output (s) (currently unused)
           1   DecFact      - Decimation factor for tabular output {1: output every time step} (-) (currently unused)
           0   NTwGages     - Number of tower nodes that have strain gages for output [0 to 9] (-)
           0   TwrGagNd     - List of tower nodes that have strain gages [1 to TwrNodes] (-) [unused if NTwGages=0]
           0   NBlGages     - Number of blade nodes that have strain gages for output [0 to 9] (-)
           0   BldGagNd     - List of blade nodes that have strain gages [1 to BldNodes] (-) [unused if NBlGages=0]
               OutList      - The next line(s) contains a list of output parameters.  See OutListParameters.xlsx for a listing
"PtfmSurge"
"PtfmSway"
"PtfmHeave"
"PtfmRoll"
"PtfmPitch"
"PtfmYaw"
"TwrTpTDxi"
"TwrTpTDyi"
"TwrTpTDzi"
"OoPDefl1"
END of OutList section (the word "END" must appear in the first 3 columns of the last OutList line)
```

- List of user-selectable outputs (not comprehensive)

AeroDyn Primary Input File

```
------- AERODYN v15 for OpenFAST INPUT FILE ------------------------------------------------
Floating MHK turbine hydrodynamic input properties, based on the RM1 tidal current rotor
======  General Options  ============================================================================
False         Echo                - Echo the input to "<rootname>.AD.ech"?  (flag)
"default"     DTAero              - Time interval for aerodynamic calculations {or "default"} (s)
          2   WakeMod             - Type of wake/induction model (switch) {0=none, 1=BEMT, 2=DBEMT, 3=OLAF} [WakeMod cannot be 2 or
          1   AFAeroMod           - Type of blade airfoil aerodynamics model (switch) {1=steady model, 2=Beddoes-Leishman unsteady m
          1   TwrPotent           - T                                                                                  1=baseli
          0   TwrShadow           - (                                                                                  =Powles m
True          TwrAero             - (
False         FrozenWake          - A                                                                                  arizing]
True          CavitCheck          - P
True          Buoyancy            - T
False         CompAA              - P
"unused"      AA_InputFile        - A
======  Environmental Conditions  ===================================================================
"default"     AirDens             - Air density (kg/m^3)
"default"     KinVisc             - Kinematic viscosity of working fluid (m^2/s)
"default"     SpdSound            - Speed of sound in working fluid (m/s)
"default"     Patm                - Atmospheric pressure (Pa) [used only when CavitCheck=True]
"default"     Pvap                - Vapour pressure of working fluid (Pa) [used only when CavitCheck=True]
======  Blade-Element/Momentum Theory Options  ========================================================== [unused when WakeMod=0 or 3]
          2   SkewMod             - Type of skewed-wake correction model (switch) {1=uncoupled, 2=Pitt/Peters, 3=coupled} [unused wh
"default"     SkewModFactor       - Constant used in Pitt/Peters skewed wake model {or "default" is 15/32*pi} (-) [used only when Sk
True          TipLoss             - Use the Prandtl tip-loss model? (flag) [unused when WakeMod=0 or 3]
True          HubLoss             - Use the Prandtl hub-loss model? (flag) [unused when WakeMod=0 or 3]
True          TanInd              - Include tangential induction in BEMT calculations? (flag) [unused when WakeMod=0 or 3]
True          AIDrag              - Include the drag term in the axial-induction calculation? (flag) [unused when WakeMod=0 or 3]
True          TIDrag              - Include the drag term in the tangential-induction calculation? (flag) [unused when WakeMod=0,3 c
"default"     IndToler            - Convergence tolerance for BEMT nonlinear solve residual equation {or "default"} (-) [unused when
       1000   MaxIter             - Maximum number of iteration steps (-) [unused when WakeMod=0]
```

- **WakeMod** options include steady and dynamic BEM and OLAF (vortex model)
- **AFAeroMod** options include steady and unsteady aerodynamics models

AeroDyn Primary Input File

```
------- AERODYN v15 for OpenFAST INPUT FILE ------------------------------------------------
Floating MHK turbine hydrodynamic input properties, based on the RM1 tidal current rotor
======  General Options  ============================================================================
False         Echo                - Echo the input to "<rootname>.AD.ech"?  (flag)
"default"     DTAero              - Time interval for aerodynamic calculations {or "default"} (s)
          2   WakeMod             - Type of wake/induction model (switch) {0=none, 1=BEMT, 2=DBEMT, 3=OLAF} [WakeMod cannot be 2 or
          1   AFAeroMod           - Type of blade airfoil aerodynamics model (switch) {1=steady model, 2=Beddoes-Leishman unsteady m
          1   TwrPotent           - Type tower influence on wind based on potential flow around the tower (switch) {0=none, 1=baseli
          0   TwrShadow           - Calculate tower influence on wind based on downstream tower shadow? (switch) {0=none, 1=Powles m
True          TwrAero             - Calculate tower aerodynamic loads? (flag)
False         FrozenWake          - Ass                                                        n linearizing]
True          CavitCheck          - Per
True          Buoyancy            - Include buoyancy effects? (flag)
False         CompAA              - Flag to compute AeroAcoustics calculation [used only when WakeMod = 1 or 2]
"unused"      AA_InputFile        - AeroAcoustics input file [used only when CompAA=true]
======  Environmental Conditions  ===================================================================
"default"     AirDens             - Air density (kg/m^3)
"default"     KinVisc             - Kinematic viscosity of working fluid (m^2/s)
"default"     SpdSound            - Speed of sound in working fluid (m/s)
"default"     Patm                - Atmospheric pressure (Pa) [used only when CavitCheck=True]
"default"     Pvap                - Vapour pressure of working fluid (Pa) [used only when CavitCheck=True]
======  Blade-Element/Momentum Theory Options  ========================================================== [unused when WakeMod=0 or 3]
          2   SkewMod             - Type of skewed-wake correction model (switch) {1=uncoupled, 2=Pitt/Peters, 3=coupled} [unused wh
"default"     SkewModFactor       - Constant used in Pitt/Peters skewed wake model {or "default" is 15/32*pi} (-) [used only when Sk
True          TipLoss             - Use the Prandtl tip-loss model? (flag) [unused when WakeMod=0 or 3]
True          HubLoss             - Use the Prandtl hub-loss model? (flag) [unused when WakeMod=0 or 3]
True          TanInd              - Include tangential induction in BEMT calculations? (flag) [unused when WakeMod=0 or 3]
True          AIDrag              - Include the drag term in the axial-induction calculation? (flag) [unused when WakeMod=0 or 3]
True          TIDrag              - Include the drag term in the tangential-induction calculation? (flag) [unused when WakeMod=0,3 c
"default"     IndToler            - Convergence tolerance for BEMT nonlinear solve residual equation {or "default"} (-) [unused when
       1000   MaxIter             - Maximum number of iteration steps (-) [unused when WakeMod=0]
```

- Options to calculate tower influence and loads

AeroDyn Primary Input File

```
------- AERODYN v15 for OpenFAST INPUT FILE ------------------------------------------------
Floating MHK turbine hydrodynamic input properties, based on the RM1 tidal current rotor
======  General Options  ============================================================================
False         Echo                - Echo the input to "<rootname>.AD.ech"?  (flag)
"default"     DTAero              - Time interval for aerodynamic calculations {or "default"} (s)
          2   WakeMod             - Type of wake/induction model (switch) {0=none, 1=BEMT, 2=DBEMT, 3=OLAF} [WakeMod cannot be 2 or
          1   AFAeroMod           - Type of blade airfoil aerodynamics model (switch) {1=steady model, 2=Beddoes-Leishman unsteady m
          1   TwrPotent           - Type tower influence on wind based on potential flow around the tower (switch) {0=none, 1=baseli
          0   TwrShadow           - Calculate tower influence on wind based on downstream tower shadow? (switch) {0=none, 1=Powles m
True          TwrAero             - Calculate tower aerodynamic loads? (flag)
False         FrozenWake          - Assume frozen wake during linearization? (flag) [used only when WakeMod=1 and when linearizing]
True          CavitCheck          - Perform cavitation check? (flag) [AFAeroMod must be 1 when CavitCheck=true]
True          Buoyancy            - Include buoyancy effects? (flag)
False         CompAA              - Flag to compute AeroAcoustics calculation [used only when WakeMod = 1 or 2]
"unused"      AA_InputFile        - AeroA
======  Environmental Conditions  =====
"default"     AirDens             - Air
"default"     KinVisc             - Kine
"default"     SpdSound            - Speed
"default"     Patm                - Atmos
"default"     Pvap                - Vapou
======  Blade-Element/Momentum Theory Op                                                  d=0 or 3]
          2   SkewMod             - Type of skewed-wake correction model (switch) {1=uncoupled, 2=Pitt/Peters, 3=coupled} [unused wh
"default"     SkewModFactor       - Constant used in Pitt/Peters skewed wake model {or "default" is 15/32*pi} (-) [used only when Sk
True          TipLoss             - Use the Prandtl tip-loss model? (flag) [unused when WakeMod=0 or 3]
True          HubLoss             - Use the Prandtl hub-loss model? (flag) [unused when WakeMod=0 or 3]
True          TanInd              - Include tangential induction in BEMT calculations? (flag) [unused when WakeMod=0 or 3]
True          AIDrag              - Include the drag term in the axial-induction calculation? (flag) [unused when WakeMod=0 or 3]
True          TIDrag              - Include the drag term in the tangential-induction calculation? (flag) [unused when WakeMod=0,3 c
"default"     IndToler            - Convergence tolerance for BEMT nonlinear solve residual equation {or "default"} (-) [unused when
       1000   MaxIter             - Maximum number of iteration steps (-) [unused when WakeMod=0]
```

- Cavitation check for MHK turbines
- Buoyancy for MHK turbines
- Future releases will include options to calculate added mass

AeroDyn Primary Input File

```
------- AERODYN v15 for OpenFAST INPUT FILE ------------------------------------------------
Floating MHK turbine hydrodynamic input properties, based on the RM1 tidal current rotor
======  General Options  ============================================================================
False         Echo                - Echo the input to "<rootname>.AD.ech"?  (flag)
"default"     DTAero              - Time interval for aerodynamic calculations {or "default"} (s)
          2   WakeMod             - Type of wake/induction model (switch) {0=none, 1=BEMT, 2=DBEMT, 3=OLAF} [WakeMod cannot be 2 or
          1   AFAeroMod           - Type of blade airfoil aerodynamics model (switch) {1=steady model, 2=Beddoes-Leishman unsteady m
          1   TwrPotent           - Type tower influence on wind based on potential flow around the tower (switch) {0=none, 1=baseli
          0   TwrShadow           - Calculate tower influence on wind based on downstream tower shadow? (switch) {0=none, 1=Powles m
True          TwrAero             - Calculate tower aerodynamic loads? (flag)
False         FrozenWake          - Assume frozen wake during linearization? (flag) [used only when WakeMod=1 and when linearizing]
True          CavitCheck          - Perform cavitation check? (flag) [AFAeroMod must be 1 when CavitCheck=true]
True          Buoyancy            - Include buoyancy effects? (flag)
False         CompAA
"unused"      AA_InputFile
======  Environmental Conditions  ===================================================================
"default"     AirDens             - Air density (kg/m^3)
"default"     KinVisc             - Kinematic viscosity of working fluid (m^2/s)
"default"     SpdSound            - Speed of sound in working fluid (m/s)
"default"     Patm                - Atmospheric pressure (Pa) [used only when CavitCheck=True]
"default"     Pvap                - Vapour pressure of working fluid (Pa) [used only when CavitCheck=True]
======  Blade-Element/Momentum Theory Options  ========================================================== [unused when WakeMod=0 or 3]
          2   SkewMod             - Type of skewed-wake correction model (switch) {1=uncoupled, 2=Pitt/Peters, 3=coupled} [unused wh
"default"     SkewModFactor       - Constant used in Pitt/Peters skewed wake model {or "default" is 15/32*pi} (-) [used only when Sk
True          TipLoss             - Use the Prandtl tip-loss model? (flag) [unused when WakeMod=0 or 3]
True          HubLoss             - Use the Prandtl hub-loss model? (flag) [unused when WakeMod=0 or 3]
True          TanInd              - Include tangential induction in BEMT calculations? (flag) [unused when WakeMod=0 or 3]
True          AIDrag              - Include the drag term in the axial-induction calculation? (flag) [unused when WakeMod=0 or 3]
True          TIDrag              - Include the drag term in the tangential-induction calculation? (flag) [unused when WakeMod=0,3 c
"default"     IndToler            - Convergence tolerance for BEMT nonlinear solve residual equation {or "default"} (-) [unused when
       1000   MaxIter             - Maximum number of iteration steps (-) [unused when WakeMod=0]
```

- Environmental conditions in driver input files

AeroDyn Primary Input File

```
------- AERODYN v15 for OpenFAST INPUT FILE ------------------------------------------------
Floating MHK turbine hydrodynamic input properties, based on the RM1 tidal current rotor
======  General Options  ============================================================================
False         Echo                - Echo the input to "<rootname>.AD.ech"?  (flag)
"default"     DTAero              - Time interval for aerodynamic calculations {or "default"} (s)
          2   WakeMod             - Type of wake/induction model (switch) {0=none, 1=BEMT, 2=DBEMT, 3=OLAF} [WakeMod cannot be 2 or
          1   AFAeroMod           - Type of blade airfoil aerodynamics model (switch) {1=steady model, 2=Beddoes-Leishman unsteady m
          1   TwrPotent           - Type tower influence on wind based on potential flow around the tower (switch) {0=none, 1=baseli
          0   TwrShadow           - Calculate tower influence on wind based on downstream tower shadow? (switch) {0=none, 1=Powles m
True          TwrAero             - Calculate tower aerodynamic loads? (flag)
False         FrozenWake          - Assume frozen wake during linearization? (flag) [used only when WakeMod=1 and when linearizing]
True          CavitCheck          - Perform cavitation check? (flag) [AFAeroMod must be 1 when CavitCheck=true]
True          Buoyancy            - Include buoyancy effects? (flag)
False         CompAA                                                                          2]
"unused"      AA_InputFile
======  Environmental Conditi
"default"     AirDens
"default"     KinVisc             - Kinematic viscosity of working fluid (m^2/s)
"default"     SpdSound            - Speed of sound in working fluid (m/s)
"default"     Patm                - Atmospheric pressure (Pa) [used only when CavitCheck=True]
"default"     Pvap                - Vapour pressure of working fluid (Pa) [used only when CavitCheck=True]
======  Blade-Element/Momentum Theory Options  ========================================== [unused when WakeMod=0 or 3]
          2   SkewMod             - Type of skewed-wake correction model (switch) {1=uncoupled, 2=Pitt/Peters, 3=coupled} [unused wh
"default"     SkewModFactor       - Constant used in Pitt/Peters skewed wake model {or "default" is 15/32*pi} (-) [used only when Sk
True          TipLoss             - Use the Prandtl tip-loss model? (flag) [unused when WakeMod=0 or 3]
True          HubLoss             - Use the Prandtl hub-loss model? (flag) [unused when WakeMod=0 or 3]
True          TanInd              - Include tangential induction in BEMT calculations? (flag) [unused when WakeMod=0 or 3]
True          AIDrag              - Include the drag term in the axial-induction calculation? (flag) [unused when WakeMod=0 or 3]
True          TIDrag              - Include the drag term in the tangential-induction calculation? (flag) [unused when WakeMod=0,3 c
"default"     IndToler            - Convergence tolerance for BEMT nonlinear solve residual equation {or "default"} (-) [unused when
       1000   MaxIter             - Maximum number of iteration steps (-) [unused when WakeMod=0]
```

- BEM options, including optional correction models

AeroDyn Primary Input File

- Dynamic BEM, OLAF, and unsteady aerodynamics model options

```
======  Dynamic Blade-Element/Momentur                                                  nly when
          2   DBEMT_Mod           - Typ                                                , 3=const
          4   tau1_const          - Ti                                                 ]
======  OLAF -- cOnvecting LAgrangian Filaments (Free Vortex Wake) Theory Options  ------------------ [used only when
"unused"      OLAFInputFileName   - Input file for OLAF [used only when WakeMod=3]
======  Beddoes-Leishman Unsteady Airfoil Aerodynamics Options  ================================== [used only when
          3   UAMod               - Unsteady Aero Model Switch (switch) {2=B-L Gonzalez, 3=B-L Minnema/Pierce, 4=B-L H
True          FLookup             - Flag to indicate whether a lookup for f' will be calculated (TRUE) or whether best
          0   UAStartRad          - Starting radius for dynamic stall (fraction of rotor radius [0.0,1.0]) [used only
          1   UAEndRad            - Ending radius for dynamic stall (fraction of rotor radius [0.0,1.0]) [used only wh
======  Airfoil Information ========================================================================
          2   AFTabMod            - Interpolation method for multiple airfoil tables {1=1D interpolation on AoA (first
          1   InCol_Alfa          - The column in the airfoil tables that contains the angle of attack (-)
          2   InCol_Cl            - The column in the airfoil tables that contains the lift coefficient (-)
          3   InCol_Cd            - The column in the airfoil tables that contains the drag coefficient (-)
          0   InCol_Cm            - The column in the airfoil tables that contains the pitching-moment coefficient; us
          4   InCol_Cpmin         - The column in the airfoil tables that contains the Cpmin coefficient; use zero if
          9   NumAFfiles          - Number of airfoil files used (-)
"Airfoils/NACA6_1000.dat"    AFNames             - Airfoil file names (NumAFfiles lines) (quoted strings)
"Airfoils/NACA6_0864.dat"
"Airfoils/NACA6_0629.dat"
"Airfoils/NACA6_0444.dat"
"Airfoils/NACA6_0329.dat"
"Airfoils/NACA6_0276.dat"
"Airfoils/NACA6_0259.dat"
"Airfoils/NACA6_0247.dat"
"Airfoils/NACA6_0240.dat"
```

AeroDyn Primary Input File

```
======  Dynamic Blade-Element/Momentum Theory Options  ============================================ [used only when
          2   DBEMT_Mod          - Type of dynamic BEMT (DBEMT) model {1=constant tau1, 2=time-dependent tau1, 3=const
          4   tau1_const         - Time constant for DBEMT (s) [used only when WakeMod=2 and DBEMT_Mod=1 or 3]
======  OLAF -- cOnvecting LAgrangian Filaments (Free Vortex Wake) Theory Options  ================== [used only when
"unused"      OLAFInputFileName  - Input file for OLAF [used only when WakeMod=3]
======  Beddoes-Leishman Unsteady Airfoil Aerodynamics Options  ==================================== [used only when
          3   UAMod              - Unsteady Aero Model Switch (switch) {2=B-L Gonzalez, 3=B-L Minnema/Pierce, 4=B-L H
True          FLookup            - Flag to indicate whether a lookup for f' will be calculated (TRUE) or whether best
          0   UAStartRad         - Starting radius for dynamic stall (fraction of rotor radius [0.0,1.0]) [used only
          1   UAEndRad           - Ending radius for dynamic stall (fraction of rotor radius [0.0,1.0]) [used only wh
======  Airfoil Information ========================================================================
          2   AFTabMod           - Interpolation method for multiple airfoil tables {1=1D interpolation on AoA (first
          1   InCol_Alfa         - The column in the airfoil tables that contains the angle of attack (-)
          2   InCol_Cl           - The column in the airfoil tables that contains the lift coefficient (-)
          3   InCol_Cd           - The column in the airfoil tables that contains the drag coefficient (-)
          0   InCol_Cm           - The column in the airfoil tables that contains the pitching-moment coefficient; us
          4   InCol_Cpmin        - The column in the airfoil tables that contains the Cpmin coefficient; use zero if
          9   NumAFfiles         - Number of airfoil files used (-)
"Airfoils/NACA6_1000.dat"    AFNames            - Airfoil file names (NumAFfiles lines) (quoted strings)
"Airfoils/NACA6_0864.dat"
"Airfoils/NACA6_0629.dat"
"Airfoils/NACA6_0444.dat"
"Airfoils/NACA6_0329.dat"
"Airfoils/NACA6_0276.dat"
"Airfoils/NACA6_0259.dat"
"Airfoils/NACA6_0247.dat"
"Airfoils/NACA6_0240.dat"
```

- Specify airfoil input file format and names

AeroDyn Primary Input File

- Specify blade input files

```
======  Rotor/Blade Properties  ============================================================
False         UseBlCm             - Include aerodynamic pitching moment in calculations?  (flag)
"MHK_RM1_AeroDyn15_Blade.dat"    ADBlFile(1)         - Name of file containing distributed aerodynamic properties
"MHK_RM1_AeroDyn15_Blade.dat"    ADBlFile(2)         - Name of file containing distributed aerodynamic properties
"unused"      ADBlFile(3)         - Name of file containing distributed aerodynamic properties for Blade #3 (-) [
======  Hub Properties ======================================================================== [used only
        7.2   VolHub             - Hub volume (m^3)
     0.2222   HubCenBx           - Hub center of buoyancy x direction offset (m)
======  Nacelle Properties ==================================================================== [used only
       38.6   VolNac             - Nacelle volume (m^3)
       0.43,          0,          0    NacCenB            - Position of nacelle center of buoyancy from yaw bear
======  Tail Fin Aerodynamics ========================================================
False         TFinAero            - Calculate tail fin aerodynamics model (flag)
"unused"      TFinFile            - Input file for tail fin aerodynamics [used only when TFinAero=True]
======  Tower Influence and Aerodynamics ============================================================ [used only
         4    NumTwrNds          - Number of tower nodes used in the analysis  (-) [used only when TwrPotent/=0,
TwrElev         TwrDiam         TwrCd           TwrTI           TwrCb  ! TwrTI used only when TwrShadow=2; TwrCb us
(m)               (m)            (-)             (-)            (-)
-9.0000000E+00   3.2530000E-01  2.0000000E-01  0.0000000E+00  1.0000000E+00
-1.4000000E+01   3.2530000E-01  2.0000000E-01  0.0000000E+00  1.0000000E+00
-1.9000000E+01   3.2530000E-01  2.0000000E-01  0.0000000E+00  1.0000000E+00
-2.4000000E+01   3.2530000E-01  2.0000000E-01  0.0000000E+00  1.0000000E+00
```

AeroDyn Primary Input File

```
======  Rotor/Blade Properties  ===================================================================
False         UseBlCm             - Include aero
"MHK_RM1_AeroDyn15_Blade.dat"    ADBlFile(1)
"MHK_RM1_AeroDyn15_Blade.dat"    ADBlFile(2)
"unused"      ADBlFile(3)         - Name of file
======  Hub Properties ============================
      7.2   VolHub               - Hub volume (
   0.2222   HubCenBx             - Hub center of buoyancy x direction offset (m)
======  Nacelle Properties ========================================================================== [used only
     38.6   VolNac               - Nacelle volume
     0.43,          0,           0    NacCenB
======  Tail Fin Aerodynamics ====================
False         TFinAero            - Calculate tail fin aerodynamics model (flag)
"unused"      TFinFile            - Input file for tail fin aerodynamics [used only when TFinAero=True]
======  Tower Influence and Aerodynamics ============================================================ [used only
        4   NumTwrNds           - Number of tower nodes used in the analysis  (-) [used only when TwrPotent/=0,
TwrElev         TwrDiam         TwrCd           TwrTI           TwrCb  ! TwrTI used only when TwrShadow=2; TwrCb us
(m)               (m)           (-)             (-)             (-)
-9.0000000E+00  3.2530000E-01  2.0000000E-01  0.0000000E+00  1.0000000E+00
-1.4000000E+01  3.2530000E-01  2.0000000E-01  0.0000000E+00  1.0000000E+00
-1.9000000E+01  3.2530000E-01  2.0000000E-01  0.0000000E+00  1.0000000E+00
-2.4000000E+01  3.2530000E-01  2.0000000E-01  0.0000000E+00  1.0000000E+00
```

- Specify hub buoyant properties
- Note that VolHub must ≠ 0 or blade root forces will be incorrect

- Specify nacelle buoyant properties

AeroDyn Primary Input File

```
======  Rotor/Blade Properties  ===================================================================
False         UseBlCm             - Include aerodynamic pitching moment in calculations?  (flag)
"MHK_RM1_AeroDyn15_Blade.dat"    ADBlFile(1)         - Name of file containing distributed aerodynamic properties
"MHK_RM1_AeroDyn15_Blade.dat"    ADBlFile(2)         - Name of file containing distributed aerodynamic properties
"unused"      ADBlFile(3)         - Name of file containing distributed aerodynamic properties for Blade #3 (-) [
======  Hub Properties ============================================================================ [used only
       7.2    VolHub              - Hub volume (m^3)
    0.2222    HubCenBx            - Hub center of buoyancy x direction offset (m)
======  Nacelle Properties ======================================================================== [used only
      38.6    VolNac              - Nacelle volume (m^3)
      0.43,          0,          0    NacCenB             - Position of nacelle center of buoyancy from yaw bear
======  Tail Fin Aerodynamics ====================================================================
False         TFinAero            - Calculate tail fin aerodynamics model (flag)
"unused"      TFinFile            - Input file for tail fin aerodynamics [used only when TFinAero=True]
======  Tower Influence and Aerodynamics ========================================================== [used only
         4    NumTwrNds           - Number of tower nodes used in the analysis  (-) [used only when TwrPotent/=0,
TwrElev         TwrDiam         TwrCd           TwrTI           TwrCb  ! TwrTI used only when TwrShadow=2; TwrCb us
(m)               (m)            (-)             (-)            (-)
-9.0000000E+00   3.2530000E-01  2.0000000E-01  0.0000000E+00  1.0000000E+00
-1.4000000E+01   3.2530000E-01  2.0000000E-01  0.0000000E+00  1.0000000E+00
-1.9000000E+01   3.2530000E-01  2.0000000E-01  0.0000000E+00  1.0000000E+00
-2.4000000E+01   3.2530000E-01  2.0000000E-01  0.0000000E+00  1.0000000E+00
```

- Tower geometric, hydrodynamic, and buoyant properties

AeroDyn Primary Input File

```
======  Outputs  ======================================================================================
True          SumPrint            - Generate a summary file listing input options and interpolated properties to "<root
          9   NBlOuts             - Number of blade node outputs [0 - 9] (-)
          1,         5,          9,         13,         17,         21,         25,         27,         30    BlOutNd
          4   NTwOuts             - Number of tower node outputs [0 - 9]  (-)
          1,         2,          3,          4    TwOutNd             - Tower nodes whose values will be output  (-)
              OutList             - The next line(s) contains a list of output parameters.  See OutListParameters.xlsx
"TwN1Fbx"                 - x-component of buoyant force per unit length at Tw node 1
"TwN3Fby"                 - y-component of buoyant force per unit length at Tw node 3
"TwN4Fbz"                 - z-component of buoyant force per unit length at Tw node 4
"TwN1Mbx"                 - x-component of buoyant moment per unit length at Tw node 6
"TwN2Mby"                 - y-component of buoyant moment per unit length at Tw node 5
"TwN3Mbz"                 - z-component of buoyant moment per unit length at Tw node 2
"B2N4Fbn"                 - Buoyant force normal to chord per unit length at blade 2 node 4
"B1N7Fbt"                 - Buoyant force tangential to chord per unit length at blade 1 node 7
"B2N8Fbs"                 - Buoyant spanwise force per unit length at blade 2 node 8
"B1N2Mbn"                 - Buoyant moment normal to chord per unit length at blade 1 node 2
"B2N3Mbt"                 - Buoyant moment tangential to chord per unit length at blade 2 node 3
"B1N6Mbs"                 - Buoyant spanwise mo
"B1FldFz"                 - Total blade aerodyn
"B2FldMx"                 - Total blade aerodyn
"HbFbx"                   - x-component of buoy
"HbFby"                   - y-component of buoy
"HbFbz"                   - z-component of buoy
"HbMbx"                   - x-component of buoy
"HbMby"                   - y-component of buoyant moment at hub node
"HbMbz"                   - z-component of buoyant moment at hub node
"NcFbx"                   - x-component of buoyant force at nacelle node
"NcFby"                   - y-component of buoyant force at nacelle node
"NcFbz"                   - z-component of buoyant force at nacelle node
"NcMbx"                   - x-component of buoyant moment at nacelle node
"NcMby"                   - y-component of buoyant moment at nacelle node
"NcMbz"                   - z-component of buoyant moment at nacelle node
"RtFldFxh"                - Total rotor aerodynamic/hydrodynamic and buoyant load (force in x direction)
"RtFldFyh"                - Total rotor aerodynamic/hydrodynamic and buoyant load (force in y direction)
"RtFldFzg"                - Total rotor aerodynamic/hydrodynamic and buoyant load (force in global z direction)
"RtFldMxh"                - Total rotor aerodynamic/hydrodynamic and buoyant load (moment in x direction)
"RtFldMyg"                - Total rotor aerodynamic/hydrodynamic and buoyant load (moment in global y direction)
"RtFldMzh"                - Total rotor aerodynamic/hydrodynamic and buoyant load (moment in z direction)
"B1N3SigCr"               - Critical cavitation number blade 1 node 3
"B2N5SigCr"               - Critical cavitation number blade 2 node 5
"B1N2SgCav"               - Cavitation number blade 1 node 2
"B2N6SgCav"               - Cavitation number blade 2 node 6
```

- Specify formatting of outputs written to file
- Select blade/tower nodes for output

InflowWind Primary Input File

```
------- InflowWind INPUT FILE ------------------------------------------------------------------------
Steady 1.9 m/s inflow for floating MHK turbine, based on the RM1 tidal current rotor
------------------------------------------------------------------------------------------------------
False         Echo           - Echo input data to <RootName>.ech (flag)
          1   WindType       - switch for wind file type (1=steady; 2=uniform; 3=binary TurbSim FF; 4=binary Bladed-st
          0   PropagationDir - Direction of wind propagation (meteorological rotation from aligned with X (positive ro
          0   VFlowAng       - Upflow angle (degrees) (not used for native Bladed format WindType=7)
False         VelInterpCubic - Use cubic interpolation for velocity in time (false=linear, true=cubic) [Used with Wind
          1   NWindVel       - Numbe                                                              o 9)
          0   WindVxiList    - List
          0   WindVyiList    - List
       24.8   WindVziList    - List
================== Parameters for St                                                             1] ========================
        1.9   HWindSpeed     - Horiz                                                              )
       24.8   RefHt           - Refer
     0.1429   PLExp           - Power
================== Parameters for Un                                                             ============================
"unused"      FileName_Uni    - Filen                                                                  (-)
         30   RefHt_Uni       - Refer                                                                  (m)
     125.88   RefLength       - Refer                                                                  sheer (-)
================== Parameters for Binary TurbSim Full-Field files   [used only for WindType = 3] ==============
"unused"      FileName_BTS    - Name of the Full field wind file to use (.bts)
================== Parameters for Binary Bladed-style Full-Field files   [used only for WindType = 4 or WindType = 7]
"unused"      FileNameRoot    - WindType=4: Rootname of the full-field wind file to use (.wnd, .sum); WindType=7: name
False         TowerFile       - Have tower file (.twr) (flag) ignored when WindType = 7
================== Parameters for HAWC-format binary files  [Only used with WindType = 5] ====================
"unused"      FileName_u      - name of the file containing the u-component fluctuating wind (.bin)
"unused"      FileName_v      - name of the file containing the v-component fluctuating wind (.bin)
"unused"      FileName_w      - name of the file containing the w-component fluctuating wind (.bin)
```

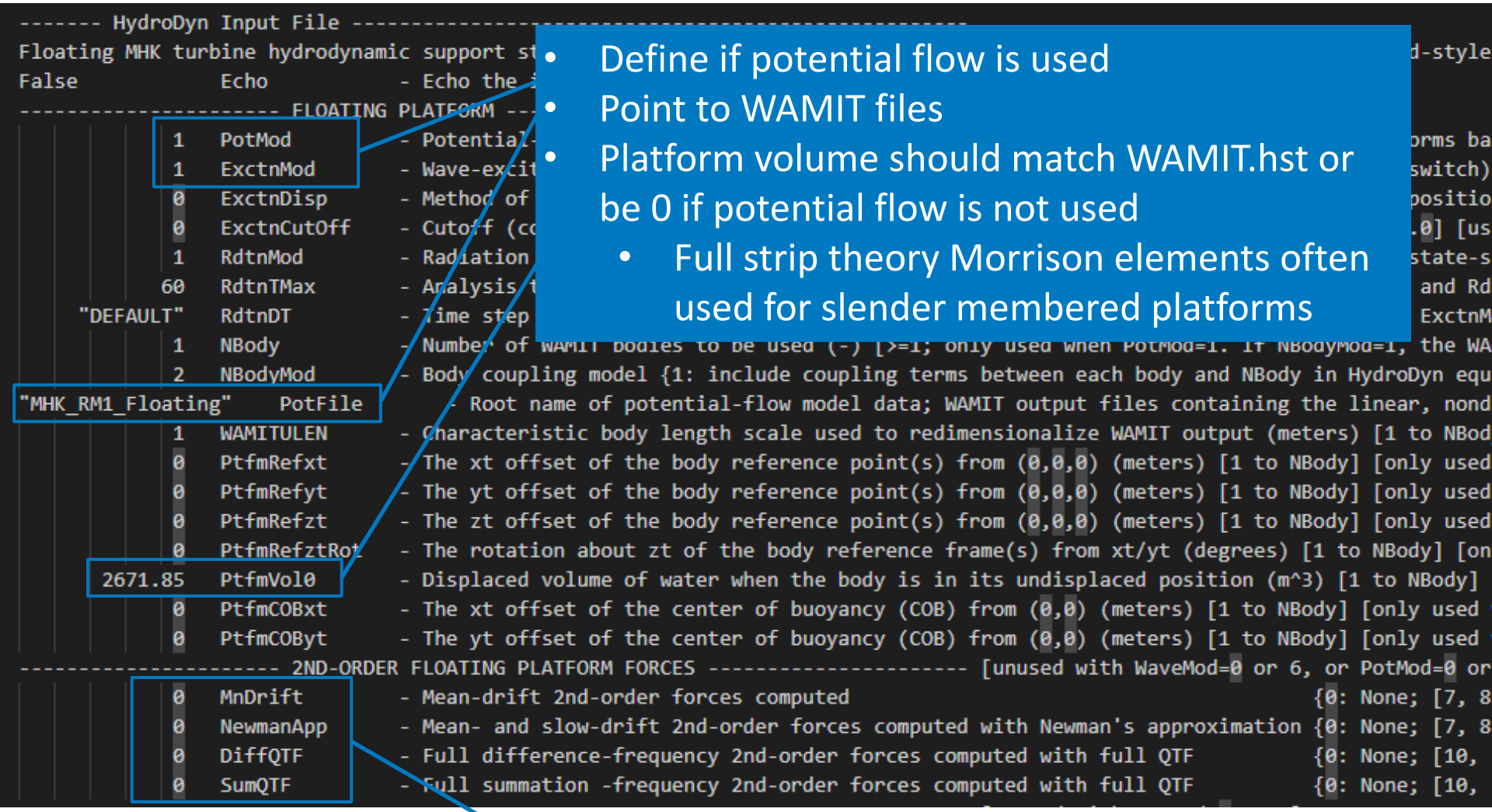
- Type of wind specification
  - Steady
  - Uniform
  - TurbSim
  - Bladed
  - HAWC
  - Etc.

InflowWind Primary Input File

```
------- InflowWind INPUT FILE ------------------------------------------------------------------------
Steady 1.9 m/s inflow for floating MHK turbine, based on the RM1 tidal current rotor
------------------------------------------------------------------------------------------------------
False         Echo           - Echo input data to <RootName>.ech (flag)
          1   WindType       - switch for wind file type (1=steady; 2=uniform; 3=binary TurbSim FF; 4=binary Bladed-st
          0   PropagationDir - Direction of wind propagation (meteorological rotation from aligned with X (positive ro
          0   VFlowAng       - Upflow angle (degrees) (not used for native Bladed format WindType=7)
False         VelInterpCubic - Use cubic interpolation for velocity in time (false=linear, true=cubic) [Used with Wind
          1   NWindVel       - Number of points to output the wind velocity    (0 to 9)
          0   WindVxiList    - List of coordinates in the inertial X direction (m)
          0   WindVyiList    - List of coordinates in the inertial Y direction (m)
       24.8   WindVziList    - List of coordinates in the inertial Z direction (m)
================== Parameters for Steady Wind Conditions [used only for WindType = 1] =========================
        1.9   HWindSpeed     - Horizontal wind speed                           (m/s)
       24.8   RefHt          - Reference height for horizontal wind speed      (m)
     0.1429   PLExp          - Power law exponent                              (-)
================== Parameters for Uniform wind file   [used only for WindType = 2] ============================
"unused"      FileName_Uni   - Filename of time series data for uniform wind field      ( )
         30   RefHt_Uni      - Reference
     125.88   RefLength      - Reference
================== Parameters for Binary
"unused"      FileName_BTS   - Name of th
================== Parameters for Binary                                                                  7]
"unused"      FileNameRoot   - WindType=4                                                               ame
False         TowerFile      - Have tower
================== Parameters for HAWC-fo
"unused"      FileName_u     - name of th
"unused"      FileName_v     - name of th
"unused"      FileName_w     - name of the file containing the w-component fluctuating wind (.bin)
```

- Steady current speed
  - Should match current speed in SeaState
  - Future release will couple the current from inflow wind and waves from SeaState
- Reference height
- Shear exponent

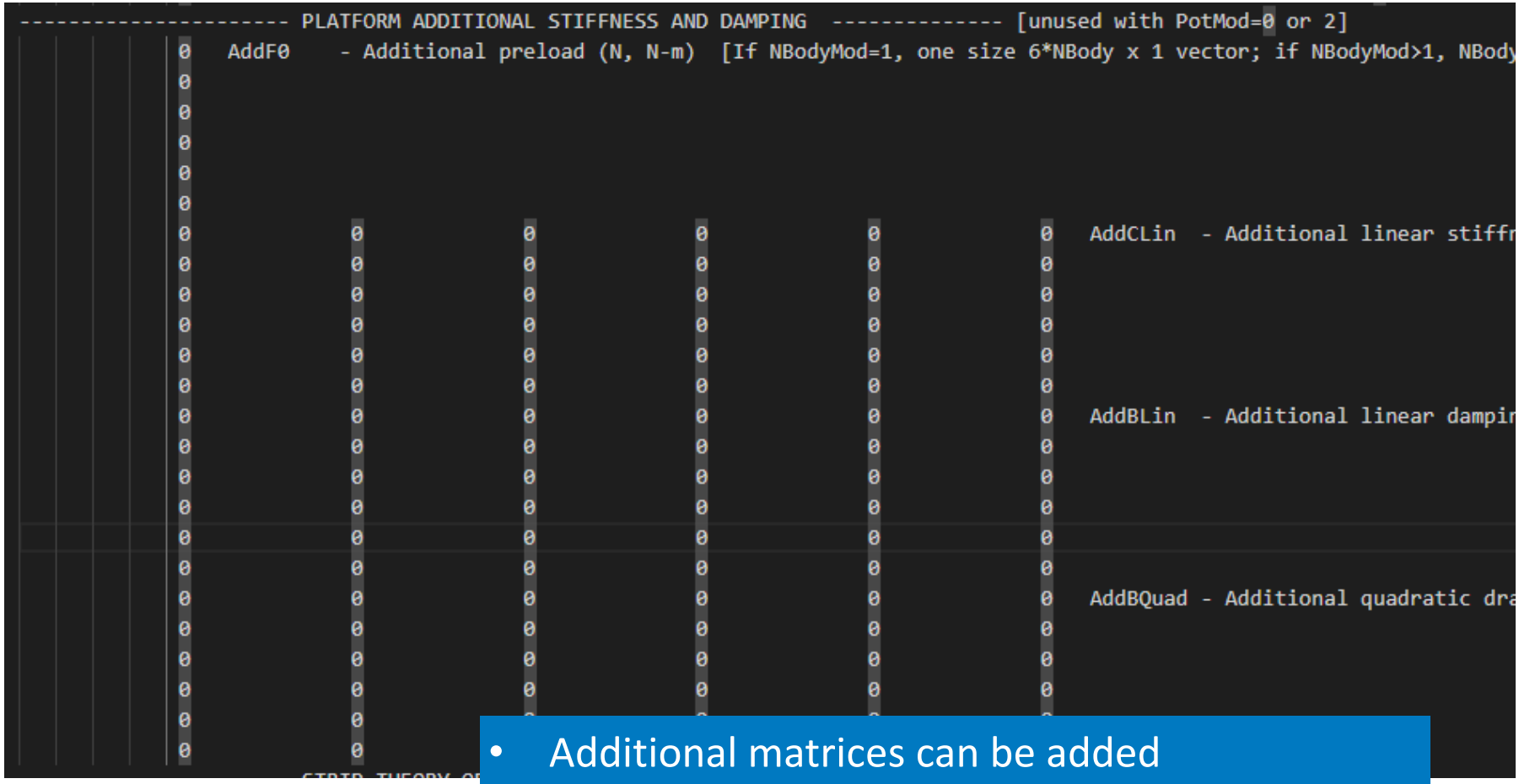
HydroDyn Primary Input File



- Define if potential flow is used
- Point to WAMIT files
- Platform volume should match WAMIT.hst or be 0 if potential flow is not used
  - Full strip theory Morrison elements often used for slender membered platforms

- 2nd order potential flow forces available

HydroDyn Primary Input File



- Additional matrices can be added
  - Often used to tune to free decays
- Only applied if potential flow files are present
- Dummy files can be used if additional matrices are desired with full strip theory elements

HydroDyn Primary Input File

```
---------------------- AXIAL COEFFICIENTS -------------------------------------
           2   NAxCoef        - Number of axial coefficients (-)
AxCoefID  AxCd      AxCa      AxCp      AxFDMod   AxVnCOff  AxFDLoFSc
   (-)    (-)       (-)       (-)       (-)       (-)       (-)
    1     0.00      0.00      0.00      0         -1.00     1.00     ! Columns / Braces (r
    2     1.00      1.00      1.00      0         -1.00     1.00     ! Heave Plates
---------------------- MEMBER JOINTS ------------------------------------------
          33   NJoints        - Number of joints (-)   [must be exactly 0 or at least 2]
JointID   Jointxi     Jointyi     Jointzi   JointAxID   JointOvrlp   [JointOvrlp= 0: do nothing
   (-)     (m)         (m)         (m)       (-)       (switch)
    0    28.00000     0.00000   -10.00000     1           0          ! Downstream Column
    1    28.00000     0.00000     6.00000     1           0
    2   -28.00000     0.00000   -10.00000     1           0          ! Upstream Column
    3   -28.00000     0.00000     6.00000     1           0
    4     0.00000   -12.00000   -10.00000     1           0          ! Starboard Column
    5     0.00000   -12.00000     6.00000     1           0
    6     0.00000    12.00000   -10.00000     1           0          ! Port Column
    7     0.00000    12.00000     6.00000     1           0
    8     3.67658    10.42430     4.50000     1           0          ! Upper Braces
    9    24.32340     1.57568     4.50000     1           0
   10     3.67658   -10.42430     4.50000     1           0
   11    24.32340    -1.57568     4.50000     1           0
   12    -3.67658    10.42430     4.50000     1           0
   13   -24.32340     1.57568     4.50000     1           0
   14    -3.67658   -10.42430     4.50000     1           0
   15   -24.32340    -1.57568     4.50000     1           0
   16     3.67658    10.42430    -8.50000     1           0          ! Lower Brace
   17    24.32340     1.57568    -8.50000     1           0
   18     3.67658   -10.42430    -8.50000     1           0
   19    24.32340    -1.57568    -8.50000     1           0
   20    -3.67658    10.42430    -8.50000     1           0
   21   -24.32340     1.57568    -8.50000     1           0
   22    -3.67658   -10.42430    -8.50000     1           0
   23   -24.32340    -1.57568    -8.50000     1           0
   24     0.00000    -8.00000     4.50000     1           0          ! Tower Braces
   25     0.00000     8.00000     4.50000     1           0
   26     0.00000    -8.00000    -8.50000     1           0
   27     0.00000     8.00000    -8.50000     1           0
   28     0.00000     0.00000    -8.50000     1           0
   29    28.00000     0.00000   -10.50000     2           0          ! Heave Plates
   30   -28.00000     0.00000   -10.50000     2           0
   31     0.00000   -12.00000   -10.50000     2           0
   32     0.00000    12.00000   -10.50000     2           0
```

- Member axial drag and added mass forces

- Define location of all platform joints
- Corresponding axial force ID
- Ovrlp turns off axial forces for members that intersect other members

HydroDyn Primary Input File

```
---------------------- MEMBER CROSS-SECTION PROPERTIES ------------------------
           4   NPropSets      - Number of member property sets (-)
PropSetID     PropD          PropThck
   (-)         (m)             (m)
    0        8.00000         0.02000    ! Columns
    1        2.00000         0.02000    ! Braces
    2        2.00000         0.08100    ! Flooded Braces (not flooded in hydrodyn)
    3       12.00000         0.39250 ! Flooded Heave Plates (not flooded in hydrodyn)
---------------------- SIMPLE HYDRODYNAMIC COEFFICIENTS (model 1) --------------
    SimplCd     SimplCdMG     SimplCa     SimplCaMG     SimplCp     SimplCpMG     SimplAxCd     SimplAxCdMG     SimplAxCa     SimplAxCaMG     SimplAxCp     SimplAxCpMG
      (-)         (-)           (-)         (-)           (-)         (-)           (-)           (-)             (-)           (-)             (-)           (-)
     1.20        0.00          1.00        0.00          1.00        1.00          0.00          0.00            0.00          0.00            1.00          1.00
---------------------- DEPTH-BASED HYDRODYNAMIC COEFFICIENTS (model 2) ---------
           0   NCoefDpth      - Number of depth-dependent coefficients (-)
Dpth      DpthCd    DpthCdMG    DpthCa    DpthCaMG      DpthCp    DpthCpMG    DpthAxCd    DpthAxCdMG    DpthAxCa    DpthAxCaMG    DpthAxCp    DpthAxCpMG    Dp
(m)       (-)       (-)         (-)       (-)           (-)       (-)         (-)         (-)           (-)         (-)           (-)         (-)           (
---------------------- MEMBER-BASED HYDRODYNAMIC COEFFICIENTS (model 3) --------
           0   NCoefMembers      - Number of member-based coefficients (-)
MemberID    MemberCd1     MemberCd2     MemberCdMG1    MemberCdMG2    MemberCa1     MemberCa2     MemberCaMG1    MemberCaMG2    MemberCp1     MemberCp2
   (-)         (-)           (-)           (-)            (-)            (-)           (-)           (-)            (-)            (-)           (-)
                MEMBERS
```

- Member ID with diameter

- Member hydrodynamic coefficients
- Can apply to all members
- Can be grouped by member ID or by depth

HydroDyn Primary Input File

```
---------------------- MEMBERS -----------------------------------------------
        20   NMembers       - Number of members (-)
MemberID  MJointID1  MJointID2  MPropSetID1  MPropSetID2  MDivSize   MCoefMod   MHstLMod  PropPot   [MCoefMod=1: use simp
  (-)        (-)        (-)         (-)          (-)         (m)     (switch)   (switch)  (flag)
    0          0          1           0            0        0.1000       1          1       TRUE     ! Columns
    1          2          3           0            0        0.1000       1          1       TRUE
    2          4          5           0            0        0.1000       1          1       TRUE
    3          6          7           0            0        0.1000       1          1       TRUE
    4          8          9           1            1        0.1000       1          1       TRUE     ! Upper Braces
    5         10         11           1            1        0.1000       1          1       TRUE
    6         12         13           1            1        0.1000       1          1       TRUE
    7         14         15           1            1        0.1000       1          1       TRUE
    8         16         17           2            2        0.1000       1          1       TRUE     ! Lower Braces
    9         18         19           2            2        0.1000       1          1       TRUE
   10         20         21           2            2        0.1000       1          1       TRUE
   11         22         23           2            2        0.1000       1          1       TRUE
   12         24         25           1            1        0.1000       1          1       TRUE     ! Tower Braces
   13         26         27           1            1        0.1000       1          1       TRUE
   14         24         28           1            1        0.1000       1          1       TRUE
   15         25         28           1            1        0.1000       1          1       TRUE
   16          0         29           3            3        0.1000       1          1       TRUE     ! Heave Plates
   17          2         30           3            3        0.1000       1          1       TRUE
   18          4         31           3            3        0.1000       1          1       TRUE
   19          6         32           3
```

- Members connect between defined joints
- Assign property ID

HydroDyn Primary Input File

```
---------------------- FILLED MEMBERS --------------------------------------------
          0   NFillGroups      - Number of filled member groups (-) [If FillDens = DEFAULT, then FillDens = WtrDens;
FillNumM FillMList             FillFSLoc     FillDens
(-)      (-)                   (m)           (kg/m^3)
---------------------- MARINE GROWTH ---------------------------------------------
          0   NMGDepths        - Number of marine-growth depths specified (-)
MGDpth     MGThck       MGDens
(m)        (m)          (kg/m^3)
---------------------- MEMBER OUTPUT LIST ----------
          0   NMOutputs        - Number of member ou
MemberID   NOutLoc    NodeLocs [NOutLoc < 10; node lo                                                        and
  (-)        (-)        (-)
---------------------- JOINT OUTPUT LIST -----------------------------------------
          0   NJOutputs        - Number of joint outputs [Must be < 10]
          0   JOutLst          - List of JointIDs which are to be output (-)[unused if NJOutputs=0]
---------------------- OUTPUT ----------------------------------------------------
True              HDSum          - Output a summary file [flag]
False             OutAll         - Output all user-specified member and joint loads (only at each member end, not inter
          2   OutSwtch         - Output requested channels to: [1=Hydrodyn.out, 2=GlueCode.out, 3=both files]
"E15.7e2"         OutFmt         - Output format for numerical results (quoted string) [not checked for validity!]
"A11"             OutSFmt        - Output format for header strings (quoted string) [not checked for validity!]
---------------------- OUTPUT CHANNELS -------------------------------------------
Wave1Elev                   - Wave elevation at the platform reference point (0,  0)
HydroFxi                    - Buoyancy force [N
HydroFyi                    - Buoyancy force [N
HydroFzi                    - Buoyancy force [N] in the vertical direction (Z).
END of output channels and end of file. (the word "END" must appear in the first 3 columns of this line)
```

- Ballast included in platform mass and inertia instead of filled members
- List outputs

SeaState Primary Input File

```
------- SeaState Input File ----------------------------------------------------
Floating MHK turbine hydrodynamic support structure input properties, based on the RM1 tidal current rotor with a
False            Echo           - Echo the input file data (flag)
---------------------- ENVIRONMENTAL CONDITIONS -------------------------------
"DEFAULT"        WtrDens        - Water density (kg/m^3)
"DEFAULT"        WtrDpth        - Water depth (meters) relative to MSL
"DEFAULT"        MSL2SWL        - Offset between still-water level and mean sea level (meters) [positive upward;
---------------------- SPATIAL DISCRETIZATION ---------------------------------------------------
          30   X_HalfWidth     - Half-width of the domain in the X direction (m) [>0, NOTE: X[nX] = nX*dX, where
          30   Y_HalfWidth     - Half-width of the domain in the Y direction (m) [>0, NOTE: Y[nY] = nY*dY, where
          50   Z_Depth         - Depth of the domain the Z direction (m) relative to SWL [0 < Z_Depth <= WtrDpth
          11   NX              - Number of nodes in half of the X-direction domain (-) [>=2]
          11   NY              - Number of nodes in half of the Y-direction domain (-) [>=2]
          10   NZ              - Number of nodes in the Z direction (-) [>=2]
```

- Define grid for wave generation
- Should cover full expected range of displacements

SeaState Primary Input File

```
---------------------- WAVES ------------------------------------------------
           1   WaveMod        - Incident wave kinematics model {0: none=still water, 1: regular (periodic), 1P#: regular with user-specified phase, 2
           0   WaveStMod      - Model for stretching incident wave kinematics to instantaneous free surface {0: none=no stretching, 1: vertical stret
         600   WaveTMax       - Analysis time for incident wave calculations (sec) [unused when WaveMod=0; determines WaveDOmega=2Pi/WaveTMax in the
         0.1   WaveDT         - Time step for incident wave calculations     (sec) [unused when WaveMod=0 or 7; 0.1<=WaveDT<=1.0 recommended; determi
         2.0   WaveHs         - Significant wave height of incident waves (meters) [used only when WaveMod=1, 2, or 3]
        6.75   WaveTp         - Peak-spectral period of incident waves       (sec) [used only when WaveMod=1 or 2]
"DEFAULT"      WavePkShp      - Peak-shape parameter of incident wave spectrum (-) or DEFAULT (string) [used only when WaveMod=2; use 1.0 for Pierson
    0.314159   WvLowCOff      - Low  cut-off frequ                                                                                          ed (rad/s)
    1.570796   WvHiCOff       - High cut-off frequ                                                                                          ed (rad/s)
           0   WaveDir        - Incident wave prop                                                                                          7]
           0   WaveDirMod     - Directional spread                                                                                          or 4]
           1   WaveDirSpread  - Wave direction spr                                                                                          or 4 and W
           1   WaveNDir       - Number of wave dir                                                                                          or 4 and W
           0   WaveDirRange   - Range of wave directions (full range: WaveDir +/- 1/2*WaveDirRange) (degrees) [only used when WaveMod=2,3,or 4 and Wa
   123456789   WaveSeed(1)    - First  random seed of incident waves [-2147483648 to 2147483647]    (-)       [unused when WaveMod=0, 5, or 6]
"RANLUX"       WaveSeed(2)    - Second random seed of incident waves [-2147483648 to 2147483647] for intrinsic pRNG, or an alternative pRNG: "RanLux"
FALSE          WaveNDAmp      - Flag for normally distributed amplitudes                          (flag)    [only used when WaveMod=2, 3, or 4]
""             WvKinFile      - Root name of externally generated wave data file(s)       (quoted string)    [used only when WaveMod=5, 6 or 7]
---------------------- 2ND-ORDER WAVES ------------------------------------------ [unused with WaveMod=0 or 6]
FALSE          WvDiffQTF      - Full difference-frequency 2nd-order wave kinematics (flag)
FALSE          WvSumQTF       - Full summation-frequency  2nd-order wave kinematics (flag)
           0   WvLowCOffD     - Low  frequency cutoff used in the difference-frequencies (rad/s) [Only used with a difference-frequency method]
    1.256637   WvHiCOffD      - High frequency cutoff used in the difference-frequencies (rad/s) [Only used with a difference-frequency method]
    0.618319   WvLowCOffS     - Low  frequency cutoff used in the summation-frequencies  (rad/s) [Only used with a summation-frequency  method]
    3.141593   WvHiCOffS      - High frequency cutoff used in the summation-frequencies  (rad/s) [Only used with a summation-frequency  method]
```

- Regular wave
- Options for irregular wave and user input time series

SeaState Primary Input File

```
---------------------- CURRENT ------------------------------------------------ [unused with WaveMod=6]
           1   CurrMod         - Current profile model {0: none=no current, 1: standard, 2: user-defined from routine User
           0   CurrSSV0        - Sub-surface current velocity at still water level  (m/s) [used only when CurrMod=1]
           0   CurrSSDir       - Sub-surface current heading direction (degrees) or DEFAULT (string) [used only when CurrM
        12.2   CurrNSRef       - Near-surface current reference depth           (meters) [used only when CurrMod=1]
           0   CurrNSV0        - Near-surface current velocity at still water level (m/s) [used only when CurrMod=1]
           0   CurrNSDir       - Near-surface current heading direction        (degrees) [used only when CurrMod=1]
         1.9   CurrDIV         - Depth-independent current velocity                (m/s) [used only when CurrMod=1]
           0   CurrDIDir       - Depth-independent current heading direction    (degrees) [used only when CurrMod=1]
---------------------- MacCamy-Fuchs diffraction model ------------------------
           0   MCFD            - MacCamy-Fuchs member radius (ignored if radius <= 0) [must be 0 when WaveMod 0 or 6]
---------------------- OUTPUT -------------
True           SeaStSum        - Output a
           2   OutSwtch        - Output re
"E15.7e2"      OutFmt          - Output fo
"A11"          OutSFmt         - Output fo
           1   NWaveElev       - Number of                                                              imum of
           0   WaveElevxi      - List of xi-coordinates for points where the incident wave elevations can be output (meter
           0   WaveElevyi      - List of yi-coordinates for points where the incident wave elevations can be output (meter
           2   NWaveKin        - Number of points where the wave kinematics can be output (-)       [maximum of 9 output l
    14.43376,     -18.4752     WaveKinxi - List of xi-coordinates for points where the wave kinematics can be output (met
          25,           -6     WaveKinyi - List of yi-coordinates for points where the wave kinematics can be output (met
         -14,          -17     WaveKinzi - List of zi-coordinates for points where the wave kinematics can be output (met
---------------------- OUTPUT CHANNELS -----------------------------------------
"Wave1Elev"                - Wave elevation at the platform reference point
END of output channels and end of file. (the word "END" must appear in the first 3 columns of this line)
```

- Current speed
  - Should match inflow wind
- Future release will couple to inflow wind

MoorDyn Primary Input File

```
---------------------- MoorDyn Input File ------------------------------------
Floating MHK turbine mooring input properties, based on the RM1 tidal current rotor with a quad-sty
FALSE     Echo      - echo the input file data (flag)
---------------------- LINE TYPES Chain studless 0.018m ----------------------
Name      Diam      MassDen      EA         BA/-zeta    EI    Cd    Ca    CdAx    CaAx
(-)       (m)       (kg/m)       (N)        (N-s/-)     (-)   (-)   (-)   (-)     (-)
main      0.324     644.8        85.4e8     -0.8        0.8   2.4   1.0   1.15    0.5
---------------------- POINTS ------------------------------------------------
Node      Type      X         Y         Z         M        V         CdA       CA
(-)       (-)       (m)       (m)       (m)       (kg)     (m^3)     (m^2)     (-)
1         Fixed     -152.0    -50.0     -50.0     0        0         0         0
2         Fixed     -152.0    0.0       -50.0     0        0         0         0
3         Fixed     -152.0    50.0      -50.0     0        0         0         0
4         Fixed     152.0     -50.0     -50.0     0        0         0         0
5         Fixed     152.0     0.0       -50.0     0        0         0         0
6         Fixed     152.0     50.0      -50.0     0        0         0         0
7         Vessel    -34.0     0.0       -10.0     0        0         0         0
8         Vessel    -34.0     0.0       -10.0     0        0         0         0
9         Vessel    -34.0     0.0       -10.0     0        0         0         0
10        Vessel    34.0      0.0       -10.0     0        0         0         0
11        Vessel    34.0      0.0       -10.0     0        0         0         0
12        Vessel    34.0      0.0       -10.0     0        0         0         0
```

- Define line properties
- New release includes bending

- Define fairlead and anchor locations
- If multiple line types or mooring components are used – define initial location

MoorDyn Primary Input File

```
---------------------- LINES ---------------------------------------------
Line     LineType  AttachA  AttachB   UnstrLen   NumSegs   Outputs
(-)      (-)       (-)      (-)       (m)        (-)       (-)
1        main      1        7         160.0      30        -
2        main      2        8         152.0      30        -
3        main      3        9         160.0      30        -
4        main      4        10        160.0      30        -
5        main      5        11        152.0      30        -
6        main      6        12        160.0      30        -
---------------------- SOLVER OPTIONS ---------------------------------------
0.5e-4   dtM       - time step to use in mooring integration (s)
3.0e6    kbot      - bottom stiffness (Pa/m)
3.0e5    cbot      - bottom damping (Pa-s/m)
1.0      dtIC      - time interval for analyzing convergence during IC gen (s)
10.0     TmaxIC    - max time for ic gen (s)
4.0      CdScaleIC - factor by which to scale drag coefficients during dynamic relaxation (-)
0.1      threshIC  - threshold for IC convergence (-)
```

- Lines connect between defined points

- Bottom stiffness must support chain
- Time and time step used in initialization convergence

Supporting Files

- ElastoDyn blade structural properties
  - Pre-calculated mode shapes (BModes)
- ElastoDyn tower structural properties
  - Pre-calculated mode shapes (BModes)
- AeroDyn blade geometric properties
- AeroDyn blade aerodynamic properties
- Airfoil polars

Running OpenFAST

- In a terminal, navigate to the folder containing the relevant OpenFAST executable for your system and the simulation input files
- For Mac users, run OpenFAST using the following command for the example
  - ./openfast_Mac “Onshore/ MHK_RM1_Floating.fst”
- For Windows users, run OpenFAST using the following command for the example
  - openfast_Windows.exe Onshore\ MHK_RM1_Floating.fst
- For Linux users, run OpenFAST using the following command for the example
  - ./openfast_Linux Onshore/MHK_RM1_Floating.fst

OpenFAST Outputs

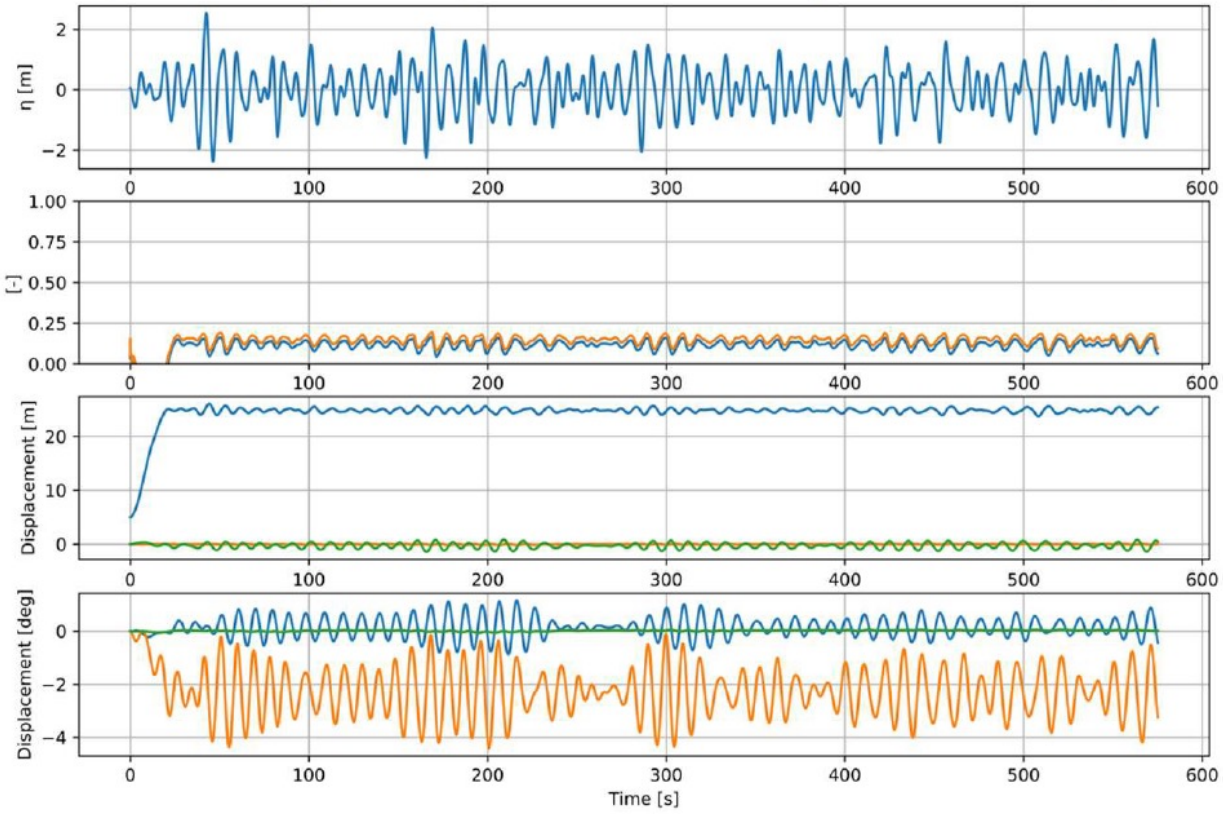
- Summary files
  - OpenFAST (MHK_RM1_Floating.sum)
  - ElastoDyn (MHK_RM1_Floating.sum)
  - AeroDyn (MHK_RM1_Floating.sum)
- Output file
  - MHK_RM1_Floating.out

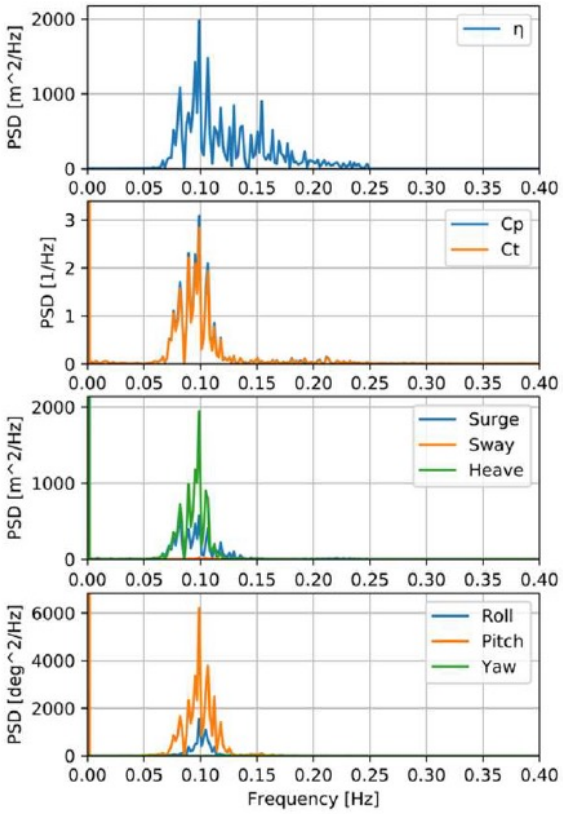
```
Predictions were generated on 16-Jan-2022 at 20:07:40 using OpenFAST, compiled as a 64-bit application using double precision at commit v3.0.0
 linked with  NWTC Subroutine Library; ElastoDyn; InflowWind; AeroDyn

Description from the FAST input file: MECC OpenFAST Webinar: NREL 5.0 MW Baseline Wind Turbine (Onshore)

Time     Wind1VelX   Wind1VelY   Wind1VelZ    OoPDefl1     IPDefl1 TwstDefl1    BldPitch1    Azimuth RotSpeed     GenSpeed     TTDspFA TTDspSS TTDspTwst    Spn2MLxb1    Spn2MLyb1    RootFxb1     RootFyb1
(s) (m/s)    (m/s)    (m/s)    (m) (m) (deg)    (deg)    (deg)    (rpm)    (rpm)    (m) (m) (deg)    (kN-m)   (kN-m)   (kN)     (kN)     (kN)     (kN-m)   (kN-m)   (kN-m)   (kN-m)   (kN-m)   (kN)     (kN)
    0.0000   8.000E+00  -0.000E+00   0.000E+00   0.000E+00   0.000E+00   0.000E+00   0.000E+00   0.000E+00   0.000E+00   9.000E+00   8.730E+02   0.000E+00  -0.000E+00   0.000E+00   3.179E+00  -8.463E+00
    0.0125   8.000E+00  -0.000E+00   0.000E+00   4.536E-03  -7.934E-05   0.000E+00   0.000E+00   6.752E-01   9.005E+00   8.730E+02  -6.648E-06  -9.360E-08   0.000E+00   2.637E+00  -1.772E+01
    0.0250   8.000E+00  -0.000E+00   0.000E+00   1.753E-02  -2.317E-04   0.000E+00   0.000E+00   1.351E+00   9.010E+00   8.730E+02  -2.619E-05  -1.031E-06   0.000E+00  -4.740E+00  -1.089E+01
    0.0375   8.000E+00  -0.000E+00   0.000E+00   3.791E-02  -3.428E-04   0.000E+00   0.000E+00   2.027E+00   9.014E+00   8.730E+02  -5.740E-05  -3.834E-06   0.000E+00  -1.259E+01  -1.121E+00
    0.0500   8.000E+00  -0.000E+00   0.000E+00   6.530E-02  -5.111E-04   0.000E+00   0.000E+00   2.703E+00   9.018E+00   8.730E+02  -9.823E-05  -9.546E-06   0.000E+00  -2.322E+01   1.254E+01
    0.0625   8.000E+00  -0.000E+00   0.000E+00   9.902E-02  -8.166E-04   0.000E+00   0.000E+00   3.379E+00   9.020E+00   8.730E+02  -1.460E-04  -1.920E-05   0.000E+00  -3.524E+01   2.920E+01
    0.0750   8.000E+00  -0.000E+00   0.000E+00   1.385E-01  -1.409E-03   0.000E+00   0.000E+00   4.056E+00   9.021E+00   8.730E+02  -1.973E-04  -3.379E-05   0.000E+00  -4.819E+01   4.890E+01
    0.0875   8.000E+00  -0.000E+00   0.000E+00   1.833E-01  -2.459E-03   0.000E+00   0.000E+00   4.732E+00   9.020E+00   8.730E+02  -2.481E-04  -5.421E-05   0.000E+00  -6.136E+01   7.130E+01
    0.1000   8.000E+00  -0.000E+00   0.000E+00   2.329E-01  -4.153E-03   0.000E+00   0.000E+00   5.409E+00   9.018E+00   8.730E+02  -2.940E-04  -8.127E-05   0.000E+00  -7.405E+01   9.622E+01
    0.1125   8.000E+00  -0.000E+00   0.000E+00   2.869E-01  -6.672E-03   0.000E+00   0.000E+00   6.085E+00   9.014E+00   8.730E+02  -3.300E-04  -1.156E-04   0.000E+00  -8.555E+01   1.235E+02
    0.1250   8.000E+00  -0.000E+00   0.000E+00   3.448E-01  -1.018E-02   0.000E+00   0.000E+00   6.761E+00   9.010E+00   8.730E+02  -3.508E-04  -1.577E-04   0.000E+00  -9.529E+01   1.529E+02
    0.1375   8.000E+00  -0.000E+00   0.000E+00   4.063E-01  -1.481E-02   0.000E+00   0.000E+00   7.436E+00   9.004E+00   8.730E+02  -3.510E-04  -2.078E-04   0.000E+00  -1.028E+02   1.843E+02
    0.1500   8.000E+00  -0.000E+00   0.000E+00   4.711E-01  -2.066E-02   0.000E+00   0.000E+00   8.112E+00   8.999E+00   8.730E+02  -3.249E-04  -2.660E-04   0.000E+00  -1.083E+02   2.174E+02
    0.1625   8.000E+00  -0.000E+00   0.000E+00   5.388E-01  -2.777E-02   0.000E+00   0.000E+00   8.786E+00   8.994E+00   8.730E+02  -2.670E-04  -3.322E-04   0.000E+00  -1.102E+02   2.520E+02
    0.1750   8.000E+00  -0.000E+00   0.000E+00   6.086E-01  -3.611E-02   0.000E+00   0.000E+00   9.461E+00   8.989E+00   8.730E+02  -1.719E-04  -4.059E-04   0.000E+00  -1.085E+02   3.070E+02
    0.1875   8.000E+00  -0.000E+00   0.000E+00   6.799E-01  -4.561E-02   0.000E+00   0.000E+00   1.013E+01   8.985E+00   8.730E+02  -3.381E-05  -4.866E-04   0.000E+00  -1.063E+02   3.219E+02
    0.2000   8.000E+00  -0.000E+00   0.000E+00   7.532E-01  -5.617E-02   0.000E+00   0.000E+00   1.081E+01   8.983E+00   8.730E+02   1.537E-04  -5.737E-04   0.000E+00  -1.006E+02   3.656E+02
    0.2125   8.000E+00  -0.000E+00   0.000E+00   8.280E-01  -6.764E-02   0.000E+00   0.000E+00   1.148E+01   8.983E+00   8.730E+02   3.964E-04  -6.664E-04   0.000E+00  -9.368E+01   4.036E+02
    0.2250   8.000E+00  -0.000E+00   0.000E+00   9.044E-01  -7.987E-02   0.000E+00   0.000E+00   1.216E+01   8.984E+00   8.730E+02   6.999E-04  -7.639E-04   0.000E+00  -8.589E+01   4.420E+02
    0.2375   8.000E+00  -0.000E+00   0.000E+00   9.823E-01  -9.269E-02   0.000E+00   0.000E+00   1.283E+01   8.986E+00   8.730E+02   1.069E-03  -8.651E-04   0.000E+00  -7.733E+01   4.803E+02
    0.2500   8.000E+00  -0.000E+00   0.000E+00   1.061E+00  -1.059E-01   0.000E+00   0.000E+00   1.350E+01   8.990E+00   8.730E+02   1.510E-03  -9.692E-04   0.000E+00  -6.742E+01   5.224E+02
```

OpenFAST Outputs





OpenFAST Post Processing

openfast Public

Main repository for the NREL-supported OpenFAST whole-turbine and FAST.Farm wind farm simulation codes.

Fortran ☆ 326 ⑂ 292

matlab-toolbox Public

Collection of Matlab tools developed for use with OpenFAST

MATLAB ☆ 28 ⑂ 47

python-toolbox Public

Python ☆ 25 ⑂ 22

r-test Public

Roff ☆ 22 ⑂ 53

KiteFAST Public

KiteFAST is a simulator for airborne wind energy systems based on the OpenFAST whole turbine simulator.

Fortran

openfast-feedstock Public

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A crossplatform GUI to plot tabulated data from files (e.g. CSV, Excel, OpenFAST, HAWC2, Flex...), or python pandas dataframes

Python ☆ 81 ⑂ 32 MIT License Updated 11 hours ago

Star

openfast Public

Forked from OpenFAST/openfast

Main repository for the NREL-supported OpenFAST whole-turbine simulation code. Documentation is avaiable at http://openfast.readthedocs.io

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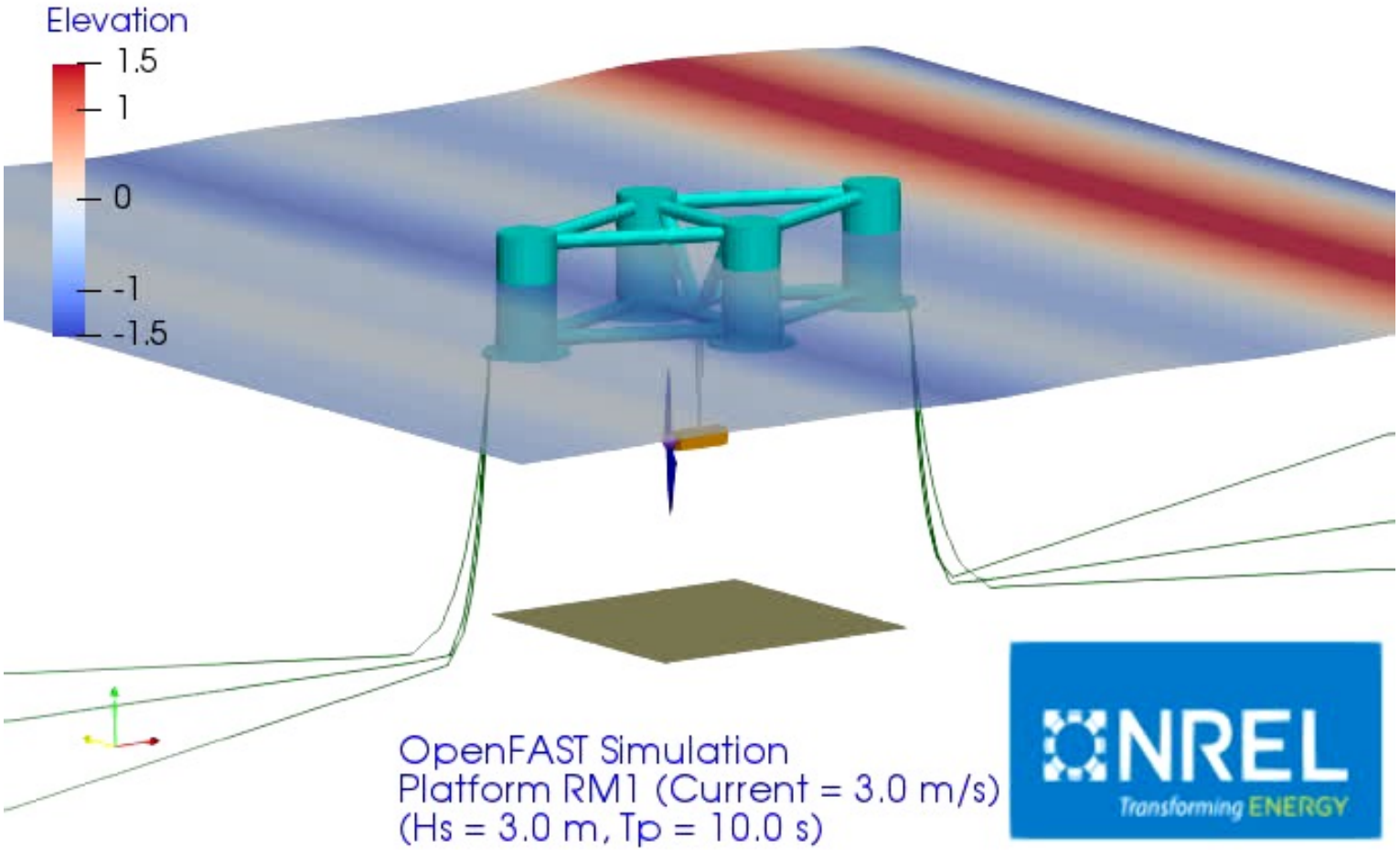
Star

Demonstration

- GitHub pages
- Documentation
- Forum
- Floating RM1 input files
  - Total run time, DT (OpenFAST driver), NumCrctn
  - DOFs (ElastoDyn)
  - Irregular waves
- Run OpenFAST
  - ./openfast_Mac “Onshore/ MHK_RM1_Floating.fst”
  - openfast_Windows.exe Onshore\ MHK_RM1_Floating.fst
- PyDatView
- Simulation visualization (vtk)*

*full capabilities in dev branch

Floating RM1 Quad Animation



Thank you!

OpenFAST Code: https://github.com/OpenFAST/openfast
OpenFAST Documentation: https://openfast.readthedocs.io/en/main/
OpenFAST Examples: https://github.com/OpenFAST/r-test
OpenFAST Data Visualization: https://github.com/ebranlard/pyDatView
Wind and Water Forum: https://forums.nrel.gov/t/welcome-to-discourse-based-wind-water-forum/7

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