NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Overview of the HydroDyn Hydrodynamics Module

NREL Wind Turbine Modeling Workshop

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Outline

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  - Support Structure Types
- Monopiles:
  - Waves, Currents, & Hydrodynamic Loads
- Floating Platforms:
  - Waves, Currents, & Hydrodynamic Loads
  - Mooring Systems
- Recent Work
- Current & Planned Work
- Future Opportunities

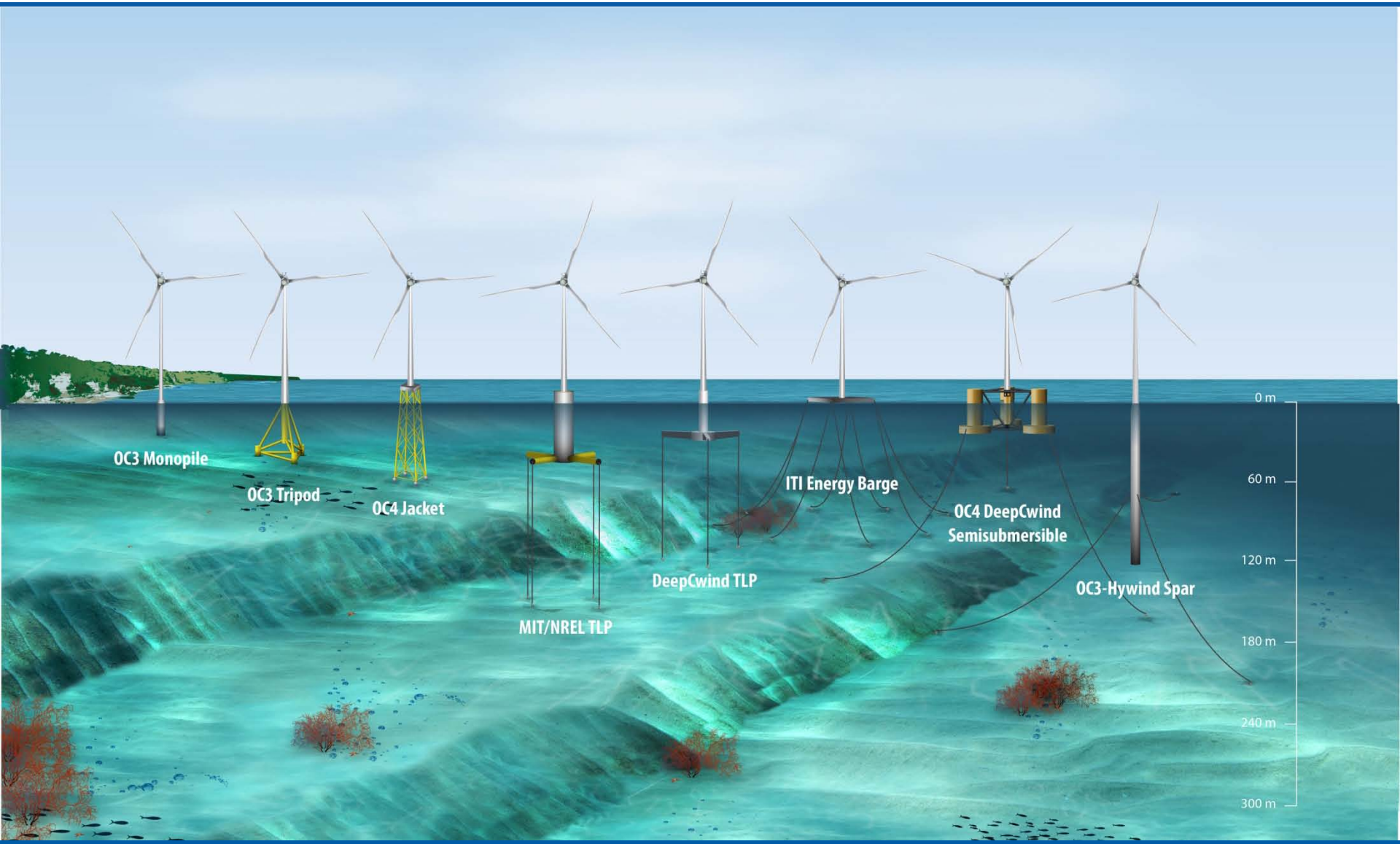
Overview

HydroDyn – What Is It?

- Yet-to-be documented hydrodynamics routines for offshore wind turbines:
  - Currently an undocumented feature in **FAST**, **A2AD**, & **SIMPACK**
  - Input settings contained in **FAST**'s platform input file
  - Source code included in **FAST** v7.00.00a-bjj & newer
  - Interfaced to **MSC.ADAMS** via **A2AD** v13.00.00a-bjj & newer
- Theory Manual:
  - Jonkman Ph.D. Dissertation (2007)
  - Jonkman, *Wind Energy* (2009)

Overview

Support Structure Types



Monopiles

Waves, Currents, & Hydrodynamic Loads

- Wave kinematics:
  - Linear regular (periodic)
  - Linear irregular (stochastic):
    - Pierson-Moskowitz, JONSWAP, or user-defined spectrum
  - With optional stretching:
    - Vertical, extrapolation, or Wheeler
  - Arbitrary choice of wave direction, but no spreading
  - Or routine to read in externally generated wave data:
    - Nonlinear wave option available
- Steady sea currents:
  - IEC-style sub-surface, near-surface, & depth-independent
  - Or user-defined
- Hydrodynamic loads:
  - Relative form of Morison's equation
  - Calculated at each structural node along tower

Floating Platforms
Waves & Currents

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  - Linear regular (periodic)
  - Linear irregular (stochastic):
    - Pierson-Moskowitz, JONSWAP, or user-defined spectrum
  - Arbitrary choice of wave direction, but no spreading
- Steady sea currents:
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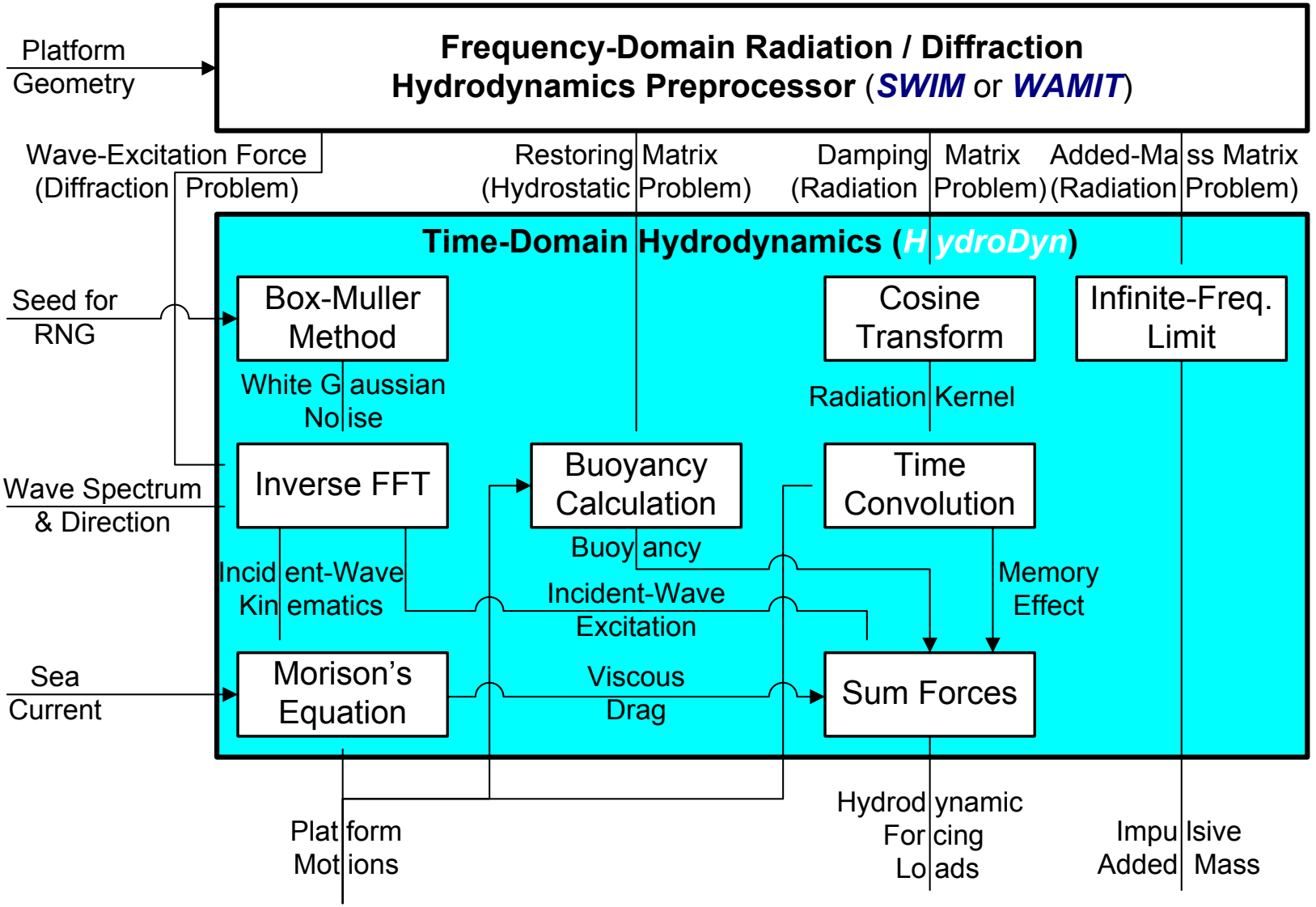
Floating Platforms
Hydrodynamic Loads

- Hydrodynamic loads:
  - Wave-body interaction with rigid platform
  - Arbitrary platform geometry
  - Linear frequency-domain radiation & diffraction solutions imported from **WAMIT** or equivalent:
    - Internal frequency-to-time domain conversion
  - Radiation "memory effect" accounted for by direct time-domain convolution
  - Linear hydrostatic restoring
  - Applied as 6-component (lumped) load on platform at reference point
  - 2nd-order (mean-drift, slow-drift, sum-frequency) effects neglected
  - Damping in surge, sway, roll, & pitch augmented with nonlinear viscous drag term from relative form of Morison's equation:
    - Distributed along platform analysis nodes

Floating Platforms

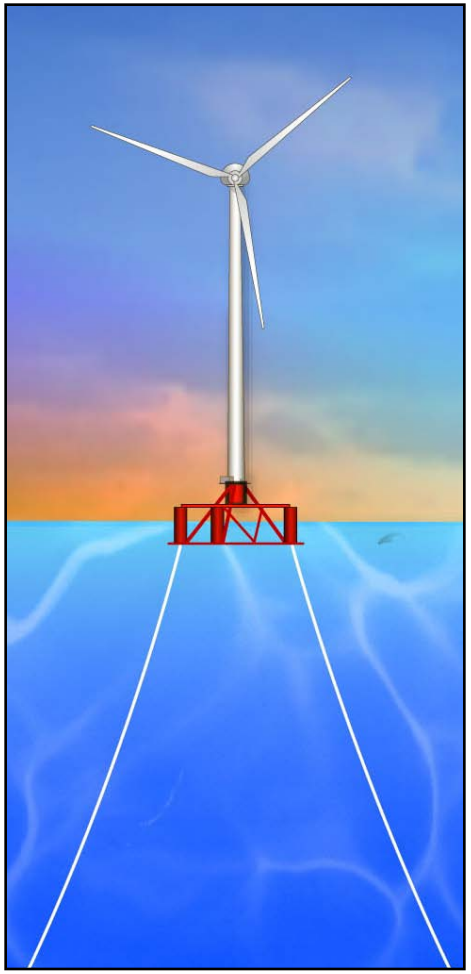
Hydrodynamics Calculation Procedure



Floating Platforms

Mooring Systems – Overview

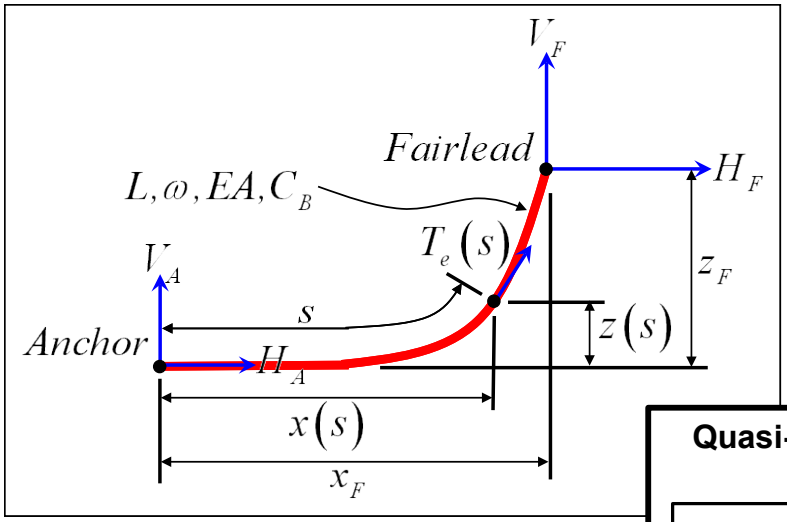
- Continuous quasi-static mooring system module implemented within **HydroDyn**:
  - Solves nonlinear analytical catenary equations
  - Fairlead tensions applied as reaction forces on platform
- Accounts for:
  - Array of homogenous taut or catenary lines
  - Apparent weight of line in fluid
  - Elastic stretching
  - Seabed friction
  - Nonlinear geometric restoring
- Neglects:
  - Line bending stiffness
  - Mooring system inertia
  - Mooring system damping



Dutch Tri-Floater

Floating Platforms

Mooring Systems – Calculation Procedure



Mooring Line Properties
(L, ω, EA, C_B)

Quasi-Static Mooring-System Module (Calculations Shown for Each Line)

Platform Position

Global-to-Local Transformation

Fairlead Location Relative to Anchor (x_F, z_F)

Newton-Raphson Iteration to Find Fairlead Tension

$x_F = F(H_F, V_F, L, \omega, EA, C_B)$

$z_F = F(H_F, V_F, L, \omega, EA)$

Fairlead Tension (H_F, V_F)

Local-to-Global Transformation & Sum Tensions

Compute Configuration of, & Tensions Within, Line

Compute Anchor Tension

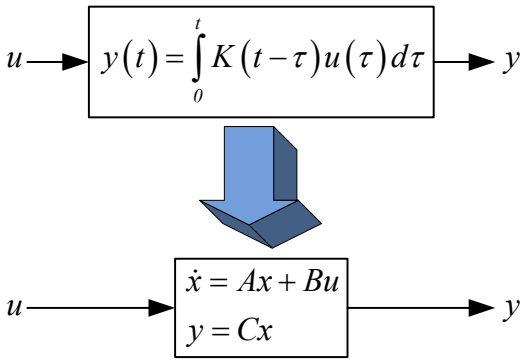
Mooring Restoring

Configuration of, & Tensions Within, Line
$[x(s), z(s), T_e(s)]$

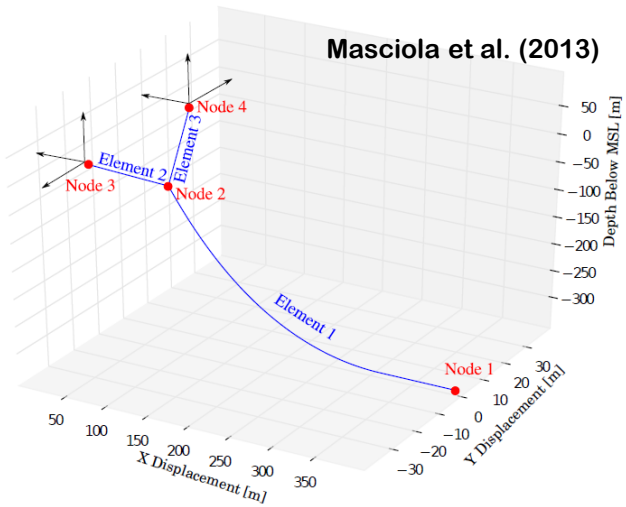
Anchor Tension
(H_A, V_A)

Recent Work (all for FAST v8)

- Converted **HydroDyn** to the new modularization framework:
  - Standalone input file & source code
- Added linear state-space (SS)-based radiation formulation (with IST-Portugal):
  - Developed new **SS_Fitting** preprocessor for deriving SS models from **WAMIT** output through 4 system-identification approaches
  - Developed new **HydroDyn** submodule (**SS_Rdtn**), which uses the output from **SS_Fitting**, as an alternative to convolution
- Developed new multi-segmented quasi-static (**MSQS**) mooring system model



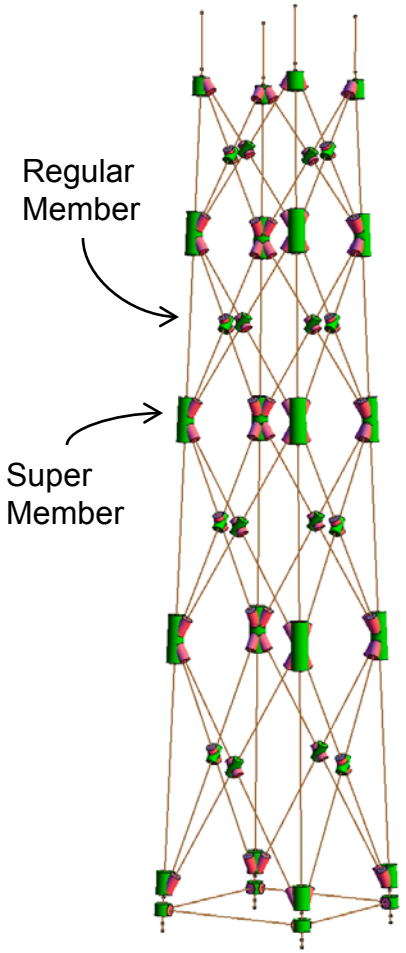
Reformulation of Radiation Convolution to Linear SS Form



Example MSQS Mooring

Recent Work (all for FAST v8) (cont)

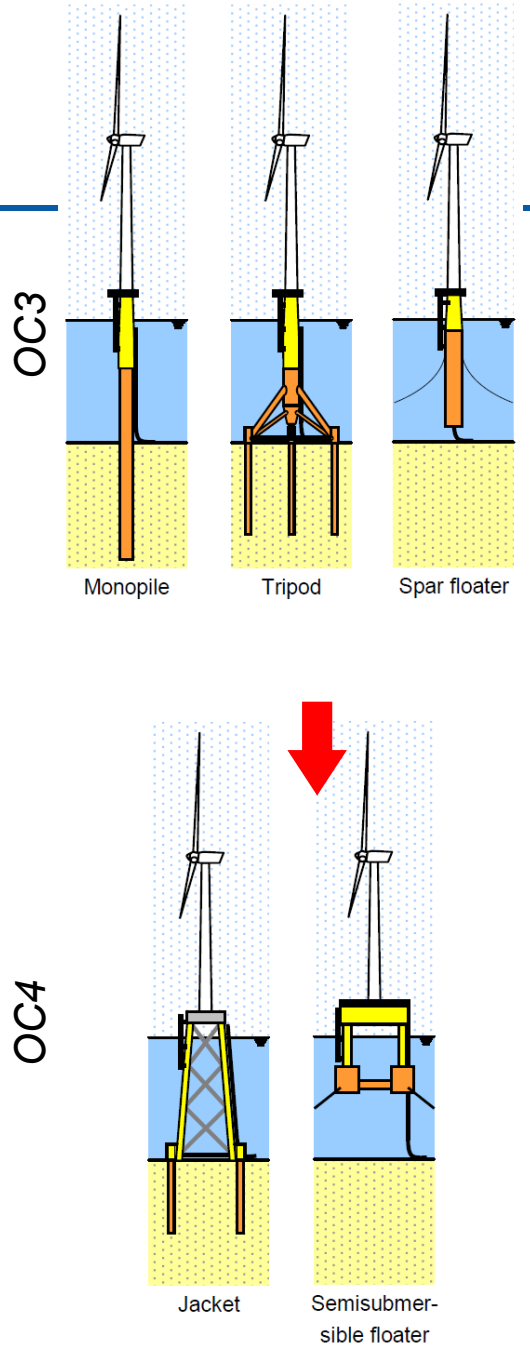
- Extended **HydroDyn** to multi-member substructures:
  - Features:
    - Multiple members & intersecting members at joints
      - Accurate calculation of overlap of intersecting members
    - Inclined & tapered members
    - Flooded & ballasted members
    - Marine growth
  - Hydrodynamic loads:
    - Distributed inertia, added mass, & viscous drag (Morison)
    - Distributed static buoyancy & dynamic pressure
    - Concentrated loads at member ends & joints
  - Applicable to:
    - Fixed-bottom tripod or jacket substructures
    - Thin members (e.g., braces/spokes) of floating platforms
- Developed new **SubDyn** module for multi-member substructure structural dynamics:
  - Linear frame FE
  - Craig-Bampton reduction



Jacket with Regular & Super Members

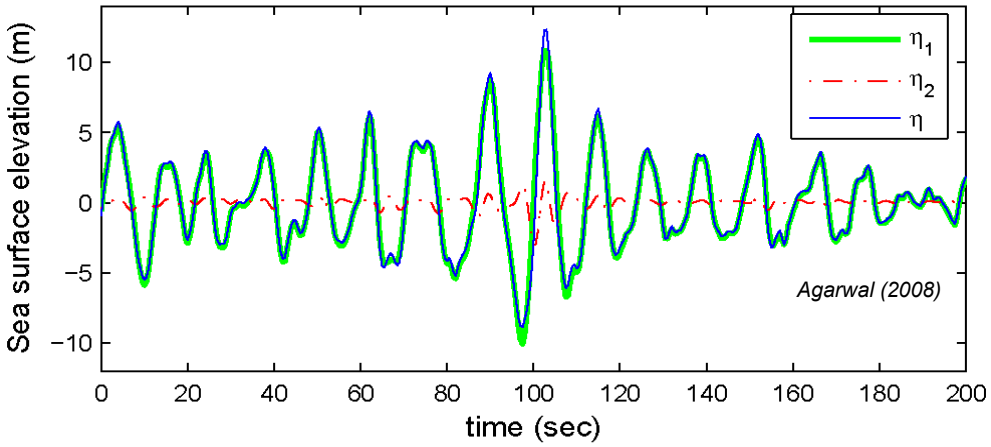
Current & Planned Work

- Interface updated **HydroDyn** & new **SubDyn** & **MSQS** modules into **FAST** v8
- Write **HydroDyn**, **SubDyn**, & **MSQS** user & theory manuals
- Further verify under IEA Wind Task 30 (OC4)
- Verify recent **FAST-OrcaFlex** coupling
- Interface **FAST** to an MIT-developed module with nonlinear fluid-impulse theory
- Interface **FAST** to the TAMU-developed **CHARM3D** dynamic mooring code
- Interface ice-loading modules to FAST (with UMich & DNV)

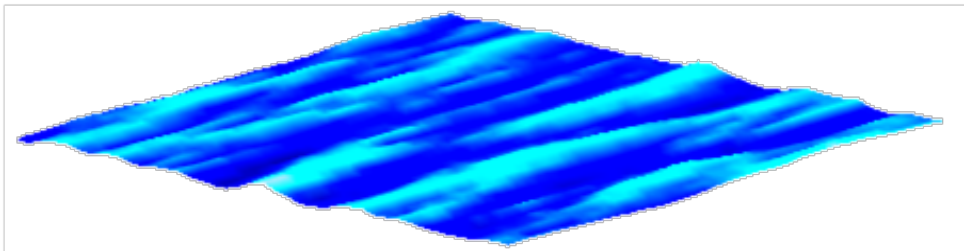


Current & Planned Work (cont)

- Assess & add 2nd-order hydrodynamic effects:
  - Add 2nd-order irregular wave kinematics (with UT-Austin)
  - Assess magnitude of mean-draft, slow-drift, & sum-frequency hydrodynamic loads for floaters (with ETH Zürich & CU-Boulder)
  - Add mean-drift, slow-drift, & sum-frequency hydrodynamic loads for floaters (with IST-Portugal)
- Add wave directional spreading (with IST-Portugal):
  - Both 1st- & 2nd order



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



Multi-Directional Sea State

Current & Planned Work (cont)

- Calibrate & validate floating functionality through:
  - DeepCwind – 1:50 scale of 5-MW atop spar buoy, TLP, & semisubmersible
  - SWAY – 1:6.5 scale of 5-MW downwind turbine atop a TLS
  - WindFloat – Vestas V80 2-MW atop a PPI semisubmersible
  - Hywind – Siemens 2.3-MW atop Statoil spar buoy

DeepCwind TLP

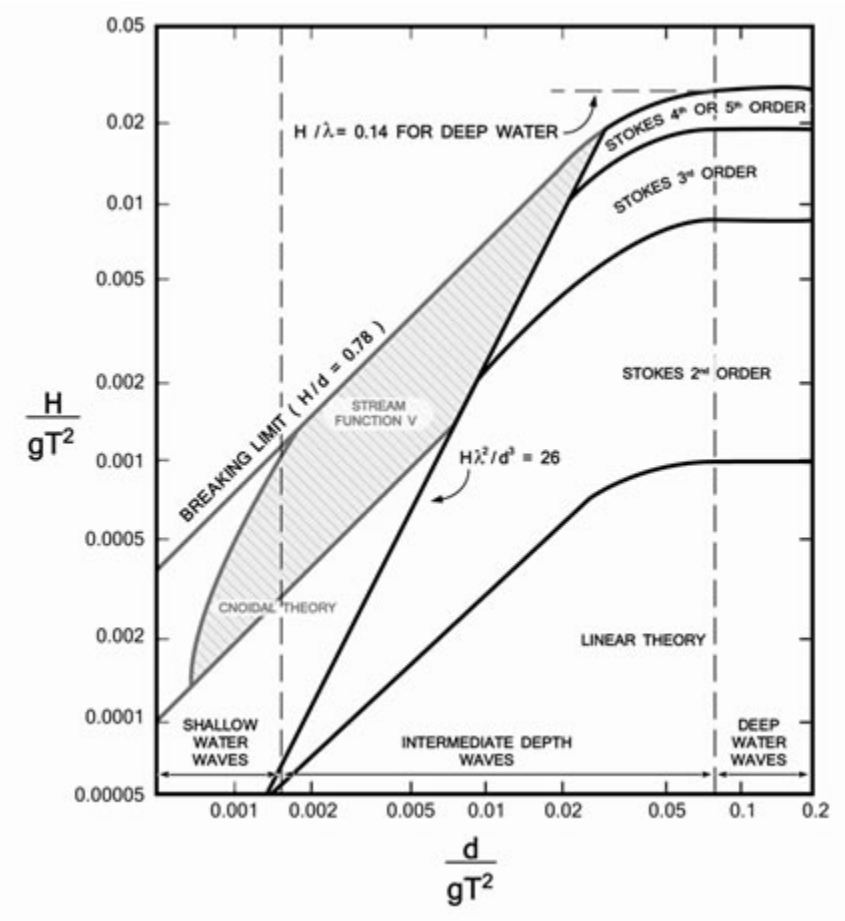
SWAY

WindFloat

Hywind

Future Opportunities

- Develop a standalone dynamic mooring system module (**MAP**)
- Implement joint flexibility in **SubDyn**
- Extend wave stretching approach to multi-member structures
- Add nonlinear regular wave kinematics models for fixed-bottom
- Add ability to prescribe wave time history for floaters
- Floating platform hydro-elastics
- Pressure mapping for floaters



Applicability of Different Wave Theories

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Questions?

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