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NATIONAL RENEWABLE ENERGY LABORATORY

Overview of the HydroDyn Hydrodynamics Module

CREW/NREL Wind Turbine Design Codes Workshop

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Jason Jonkman, Ph.D.
Senior Engineer, NREL

Outline

- Overview:
  - HydroDyn – What Is It?
- Monopiles:
  - Waves, Currents, & Hydrodynamic Loads
  - Foundation Modeling
- Floating Platforms:
  - Combining Computational Methodologies
  - Waves, Currents, & Hydrodynamic Loads
  - Mooring Systems
- 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**
  - Input settings contained in **FAST**'s platform input file
  - Source code included in **FAST** v7.00.01a-bjj
  - Interfaced to **MSC.ADAMS** via **A2AD** v13.00.00a-bjj
- Support-structure types:
  - Monopiles
  - Floating platforms
- Theory Manual:
  - Jonkman Ph.D. Dissertation (2007)
  - Jonkman, *Wind Energy* (2009)
- Verification:
  - Dissertation, *Wind Energy*
  - Participation in IEA Wind Task 23/30 OC3/OC4 Projects

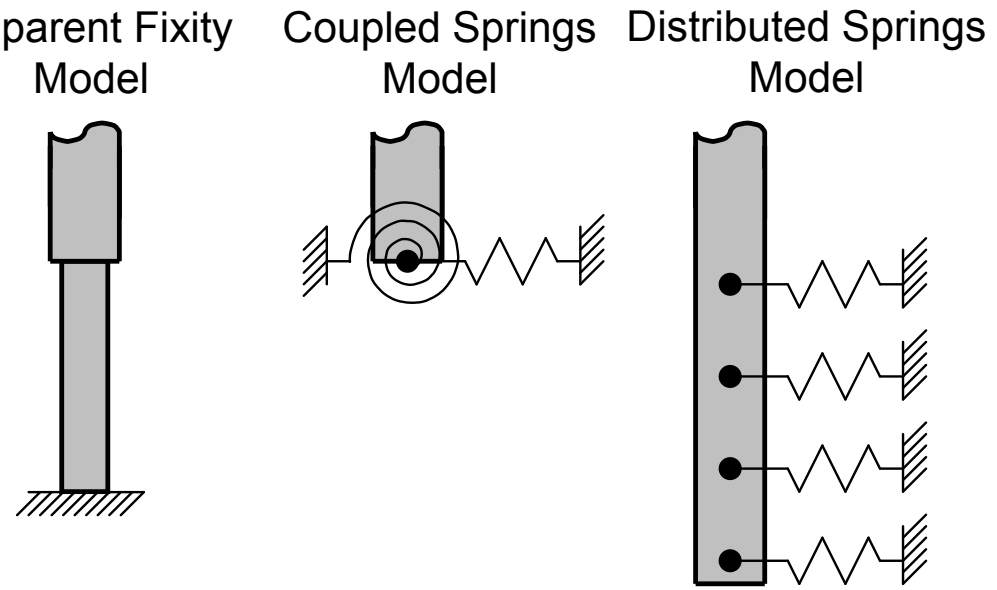
Monopiles

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

Monopiles
Foundation Modeling

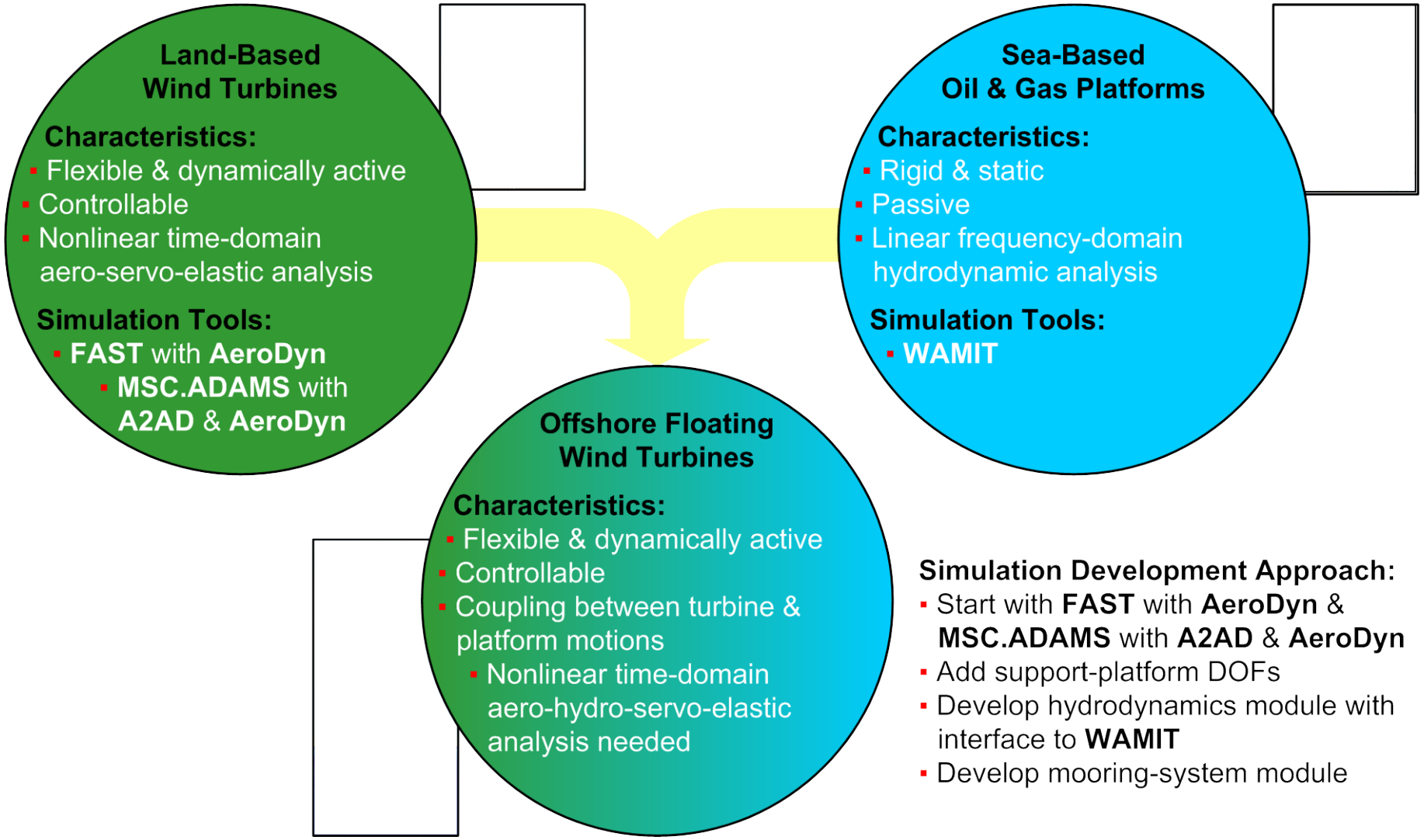
- No built-in foundation models currently available
- Models possible through user-defined routines
- Options for:
  - Apparent fixity
  - Coupled springs
  - Distributed springs
  - Linear or nonlinear (e.g., p-y)
- Simple models typically suitable for full-system analysis



Simplified Models of a Monopile with Flexible Foundation

Floating Platforms

Combining Computation Methodologies



Simulation Development Approach:

- Start with **FAST** with **AeroDyn** & **MSC.ADAMS** with **A2AD** & **AeroDyn**
- Add support-platform DOFs
- Develop hydrodynamics module with interface to **WAMIT**
- Develop mooring-system module

Floating Platforms
Waves & Currents

- Wave kinematics:
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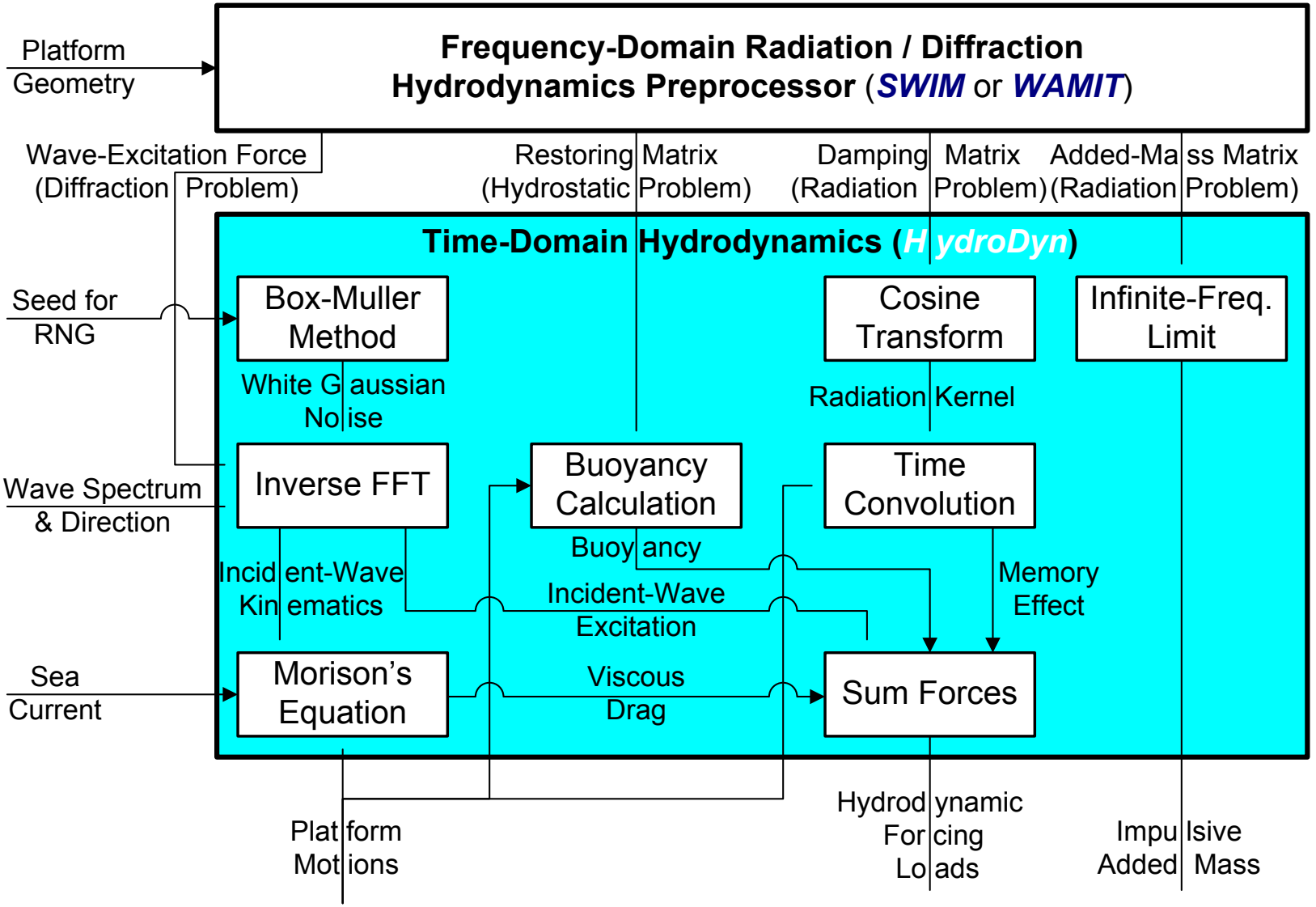
Floating Platforms
Hydrodynamic Loads

- Hydrodynamic loads:
  - Wave-body interaction with rigid platform
  - Arbitrary platform geometry
  - Linear frequency-domain radiation & diffraction solutions imported from **WAMIT** or equivalent:
    - Frequency-to-time domain conversion computed internally
  - 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 (drift) effects neglected
  - Damping in surge, sway, roll, & pitch augmented with nonlinear viscous drag term from Morison's equation:
    - Distributed along platform analysis nodes

Floating Platforms

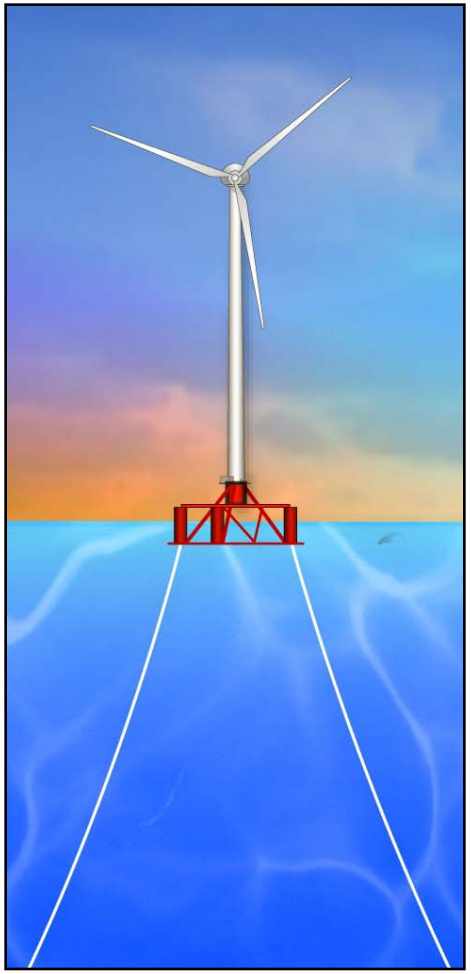
Hydrodynamics Calculation Procedure



Floating Platforms

Mooring Systems – Overview

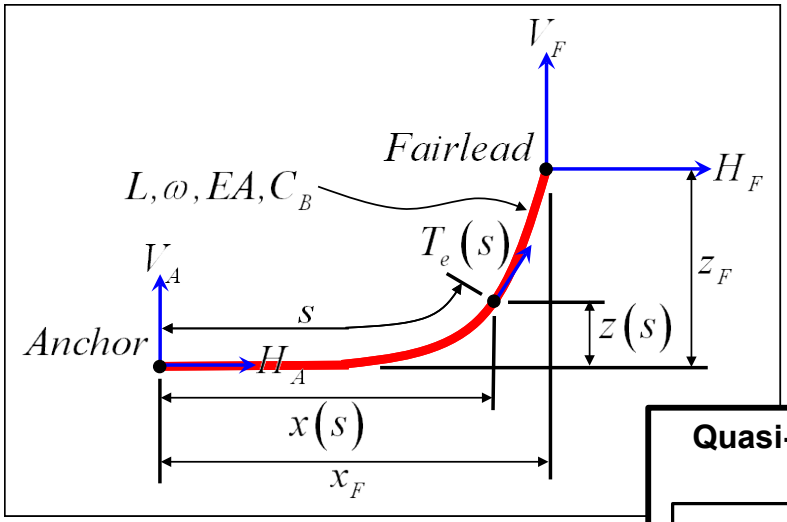
- Quasi-static mooring system module implemented within **HydroDyn**:
  - Solves catenary equations
  - Fairlead tensions applied as reaction forces on platform
- Accounts for:
  - Array of homogenous taut or catenary lines
  - Apparent weight of line in fluid
  - Elastic stretching
  - Seabed friction
  - 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)

Current & Planned Work & Future Opportunities

- Current & planned work:
  - Develop improved interface:
    - Make **HydroDyn**—including inputs—standalone, like **AeroDyn**
  - Write manual & publically release
  - Verify under IEA Wind Task 30 (OC4)
  - Validate through DeepCwind consortium:
    - 1/50th scale wind-wave tank testing & 1/3rd scale open-ocean testing
  - Add additional nonlinear effects:
    - Numerically improve how the stretched wave kinematics are interpolated at the free surface for monopiles
    - Add 2nd-order waves for monopiles (with UT-Austin)
    - Augment floater model with Morison's equation for thin members (e.g., braces)
    - Add drift & sum-frequency loads for floating platforms
  - Extend to space-frame support structures (e.g., tripod, jacket)
  - Add dynamic mooring system module (& make it a standalone)
  - Support coupling to **OrcaFlex**
- Future opportunities:
  - Add stream function waves for monopiles

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Questions?

Jason Jonkman, Ph.D.
+1 (303) 384 – 7026
jason.jonkman@nrel.gov