Overview of the HydroDyn Hydrodynamics Module

CREW/NREL Wind Turbine Design Codes Workshop

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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:

• 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
Floating Platforms
Combining Computation Methodologies

Land-Based Wind Turbines
Characteristics:
- Flexible & dynamically active
- Controllable
- Nonlinear time-domain aero-servo-elastic analysis
Simulation Tools:
- FAST with AeroDyn
  - MSC.ADAMS with A2AD & AeroDyn

Offshore Floating Wind Turbines
Characteristics:
- Flexible & dynamically active
- Controllable
- Coupling between turbine & platform motions
- Nonlinear time-domain aero-hydro-servo-elastic analysis needed

Sea-Based Oil & Gas Platforms
Characteristics:
- Rigid & static
- Passive
- Linear frequency-domain hydrodynamic analysis
Simulation Tools:
- WAMIT

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

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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

Frequency-Domain Radiation / Diffraction
Hydrodynamics Preprocessor (SWIM or WAMIT)

Time-Domain Hydrodynamics (HydroDyn)

- Box-Muller Method
- Inverse FFT
- Morison's Equation
- Platform Motions
- Incident-Wave Kinematics
- Wave Spectrum & Direction

- Restoring Matrix (Hydrostatic Problem)
- Damping Matrix (Radiation Problem)
- Added-Mass Matrix (Radiation Problem)

- Wave-Excitation Force (Diffraction Problem)
- Platform Geometry
- Seed for RNG

- Cosine Transform
- Time Convolution
- Sum Forces
- Memory Effect
- Infinite-Freq. Limit
- Radiation Kernel

- White Gaussian Noise
- Buoyancy Calculation
- Incident-Wave Excitation
- Viscous Drag
- Morison's Equation

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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

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

- Global-to-Local Transformation
- Fairlead Location Relative to Anchor \( (x_F, z_F) \)
- Newton-Raphson Iteration to Find Fairlead Tension
  \[
  x_F = F(H_F, V_F, L, \omega, E_A, C_B) \\
  z_F = F(H_F, V_F, L, \omega, E_A)
  \]
- Fairlead Tension \( (H_F, V_F) \)
- Compute Configuration of, & Tensions Within, Line
- Local-to-Global Transformation & Sum Tensions
- Compute Anchor Tension
- Configuration of, & Tensions Within, Line
  \[
  [x(s), z(s), T_c(s)]
  \]
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:
    • 1/50\textsuperscript{th} scale wind-wave tank testing & 1/3\textsuperscript{rd} scale open-ocean testing
  - Add additional nonlinear effects:
    • Numerically improve how the stretched wave kinematics are interpolated at the free surface for monopiles
    • Add 2\textsuperscript{nd}-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
Questions?

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