Recent Developments of FAST for Modelling Offshore Wind Turbines

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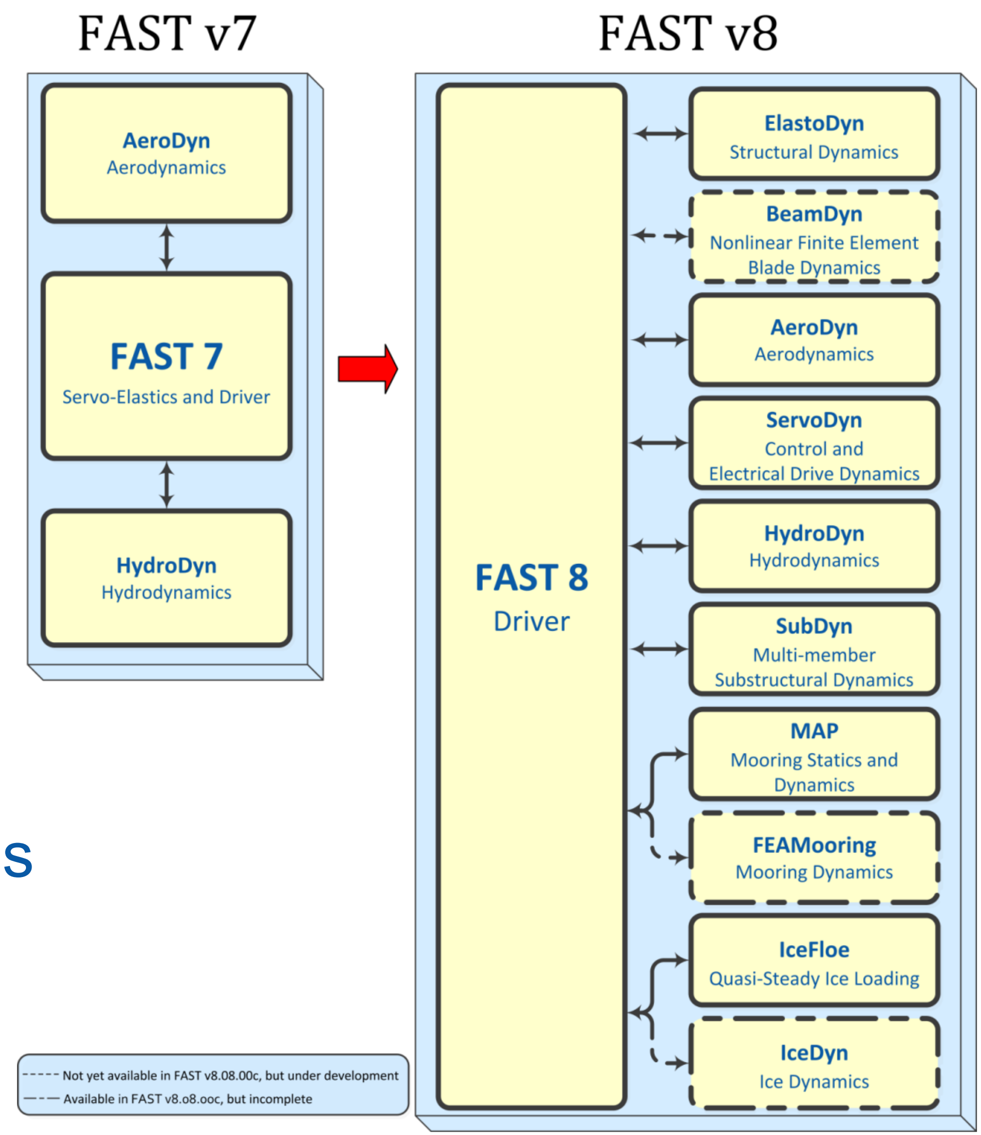
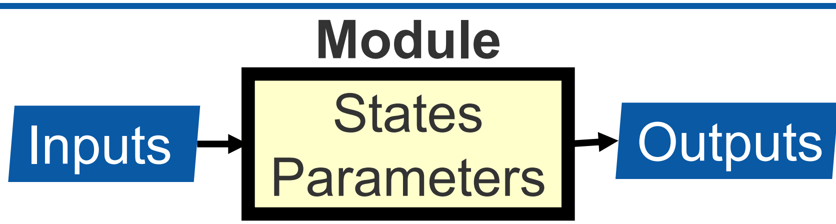
Jason Jonkman, Ph.D.
Senior Engineer, NREL

The FAST Multi-Physics Engineering Tool

- **FAST** is DOE/NREL's premier open-source wind turbine multi-physics engineering tool
- **FAST** is undergoing a major restructuring, with a new modularization framework (v8) & greatly improved capability for offshore fixed-bottom & floating systems
- This presentation summarizes recent efforts to develop, verify, & validate **FAST** for offshore wind

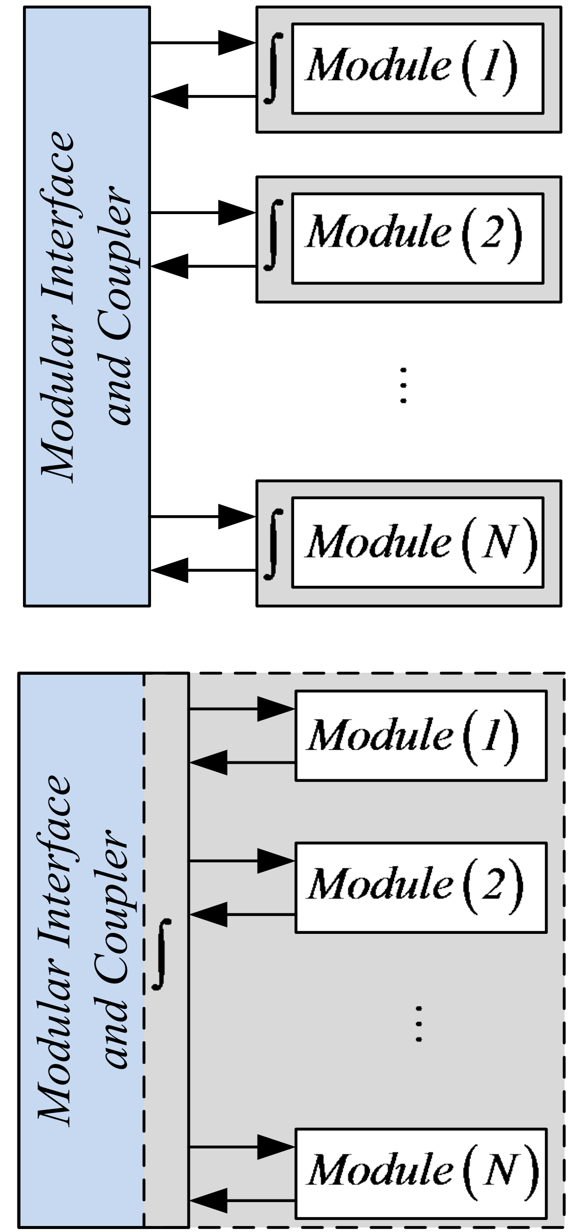


FAST Modularization Framework



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

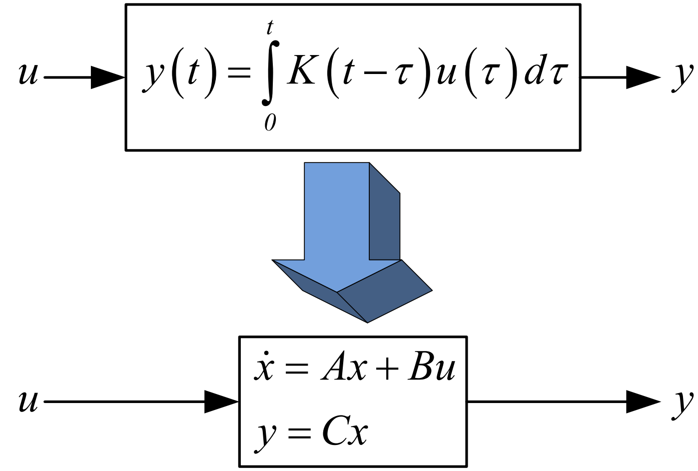
**Not yet available*



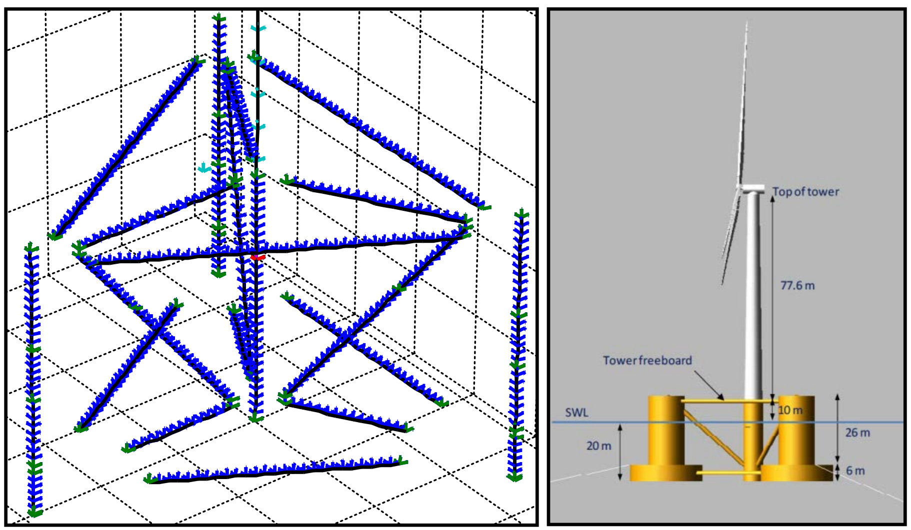
Loose- (Top) & Tight- (Bottom) Coupling Schemes

Hydrodynamic Enhancements (HydroDyn)

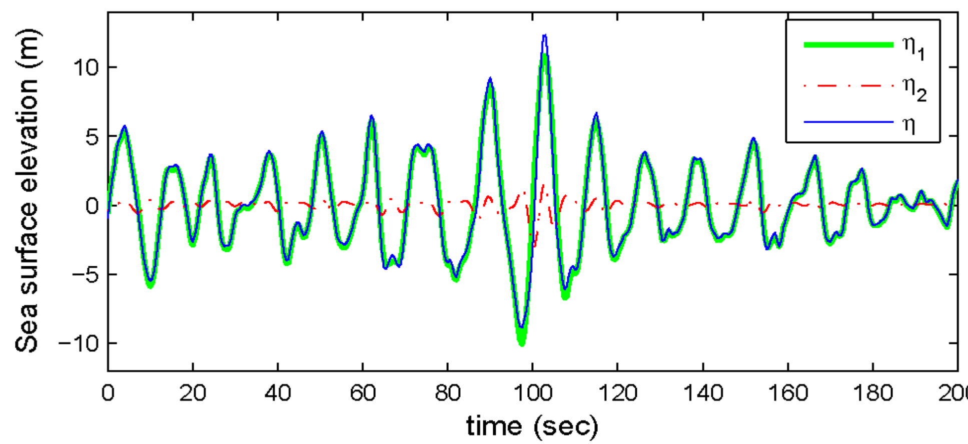
- Multi-member strip theory
- Linear state-space-based radiation formulation alternative to convolution
- Wave directional spreading
- 2nd-order hydrodynamics



Reformulation of Radiation Convolution to Linear SS Form



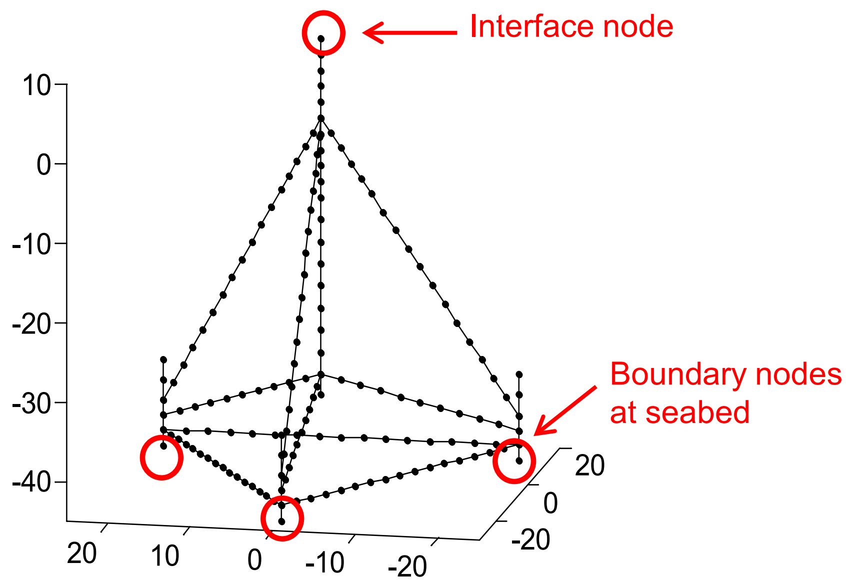
Strip-Theory Nodes for the OC4-DeepCwind Semisubmersible



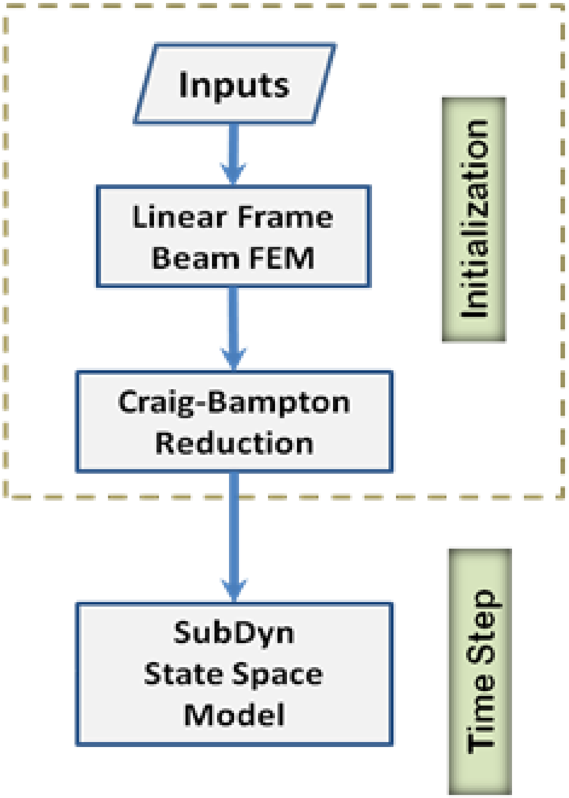
Sea-Surface Elevation (η) from the Summing of 1st- (η_1) & 2nd- (η_2) Order Waves

Substructure Structural-Dynamic Enhancements (SubDyn)

- New **SubDyn** module supports fixed-bottom multi-member substructures:
  - Linear frame finite-element beam model
  - Craig-Bampton dynamic system reduction
  - Static-improvement method



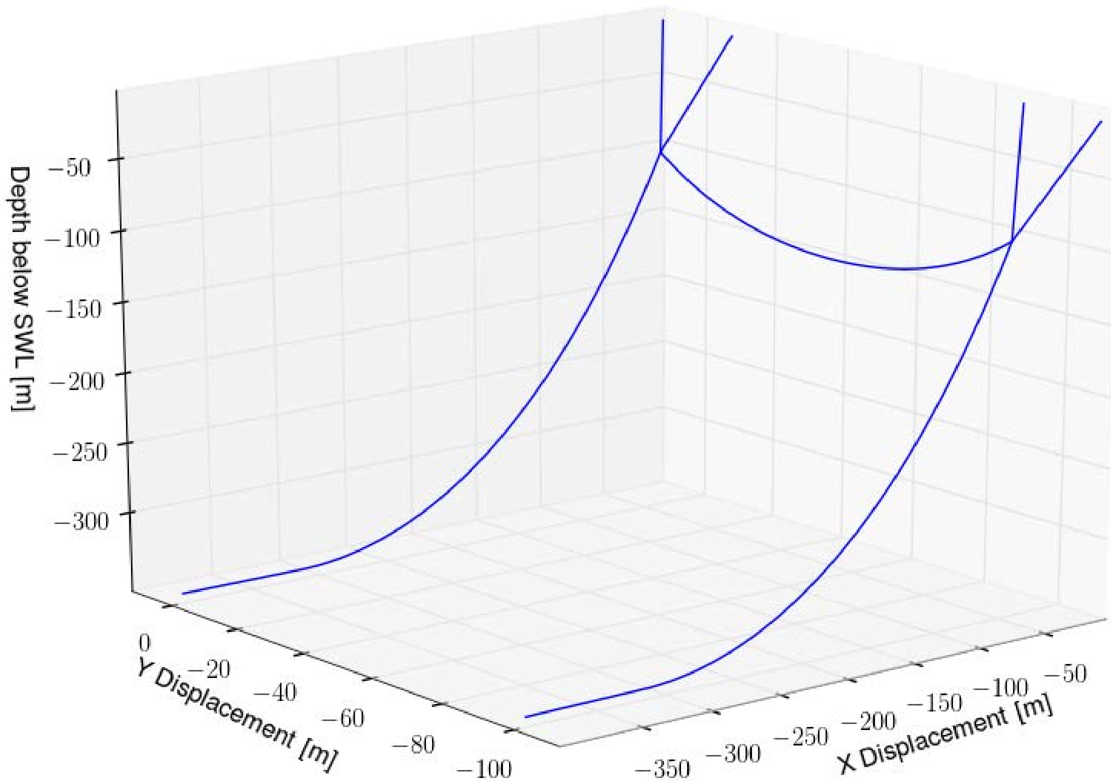
Finite-Element Discretization of the OC3-Tripod



***SubDyn** Flow Chart*

Mooring Enhancements (MAP)

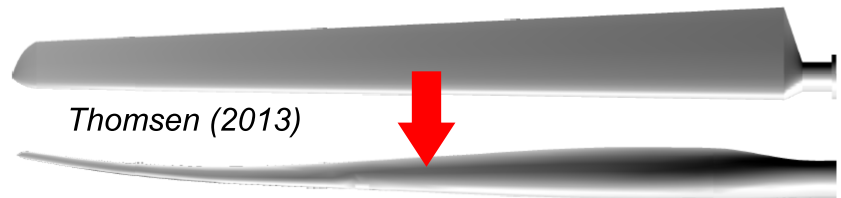
- New **MAP** module supports multi-segmented mooring systems:
  - Quasi static
  - Taut or catenary lines
  - Elastic stretching
  - Apparent weight of lines
  - Clump weights & buoyancy tanks
  - Seabed friction
  - Nonlinear geometric restoring



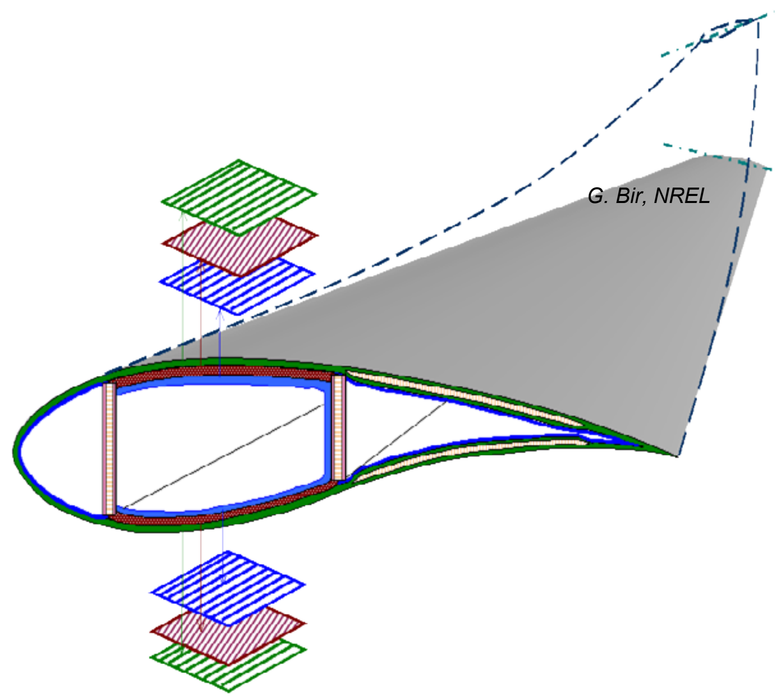
*Example Multi-Segmented Mooring System Analyzed by **MAP***

Ongoing Developments

- Framework:
  - Linearization
  - Transition to a developer community
- Aerodynamics:
  - **AeroDyn** overhaul
  - **FAST**-**OpenFOAM**-**WRF** coupling
  - **DWM** dynamic wake meandering (UMass)
- Hydrodynamics:
  - User-defined wave input
  - **FIT** nonlinear fluid-impulse theory (MIT)
  - **IceFloe** & **IceDyn** ice loading (DNV-GL & UMich)
- Control & electrical drive:
  - **MATLAB/Simulink** interface
  - **TMD** mass-damper DOFs (UMass)
- Structural dynamics:
  - **BeamDyn** nonlinear (geometrically exact) beam spectral finite-element blade dynamics
  - **MoorDyn** lumped-mass mooring dynamics (UMaine)
  - **FEAM** finite-element dynamics (TAMU)
  - **OrcaFlex** interface for mooring dynamics



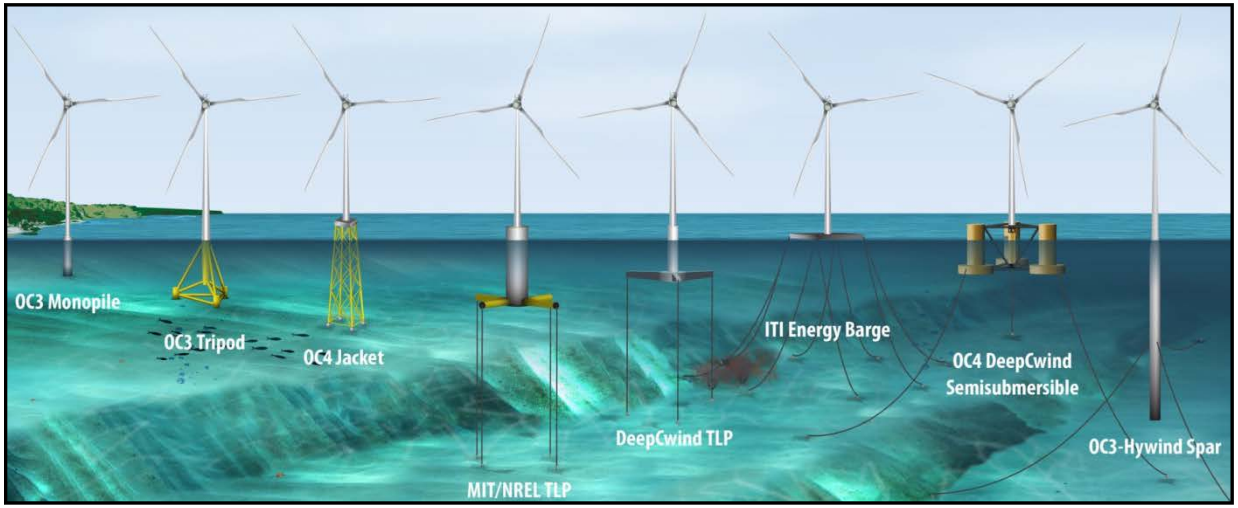
Advancement in Blade Design



Blade Twist Induced By Anisotropic Layup

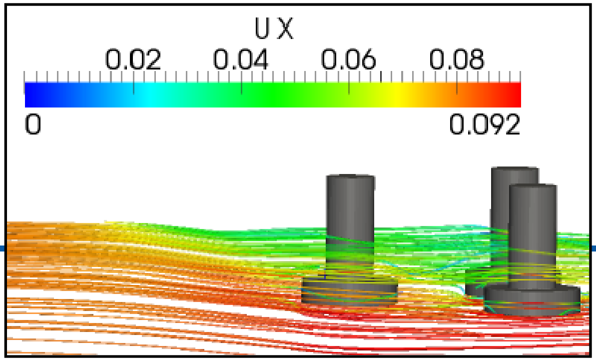
Verification of New Offshore Features

- New offshore fixed-bottom & floating features of **FAST** have been verified against results from OC3 & OC4 projects
- Key findings:
  - Very good agreement to other tools with similar capabilities
  - 2nd-order hydrodynamics important for low-frequency response
  - Future needs in strip theory:
    - Solving loads up to instantaneous free surface
    - Accounting for member overlap at joints



Validation of New Offshore Features

- New floating features of **FAST** are being validated in several projects
- Key findings:
  - Numerical model calibration often needed where data or model uncertainty exist
  - C_D strongly dependent on geometry
  - Strip theory captures mean loads, but neglects vortex shedding
  - 1^{st}-order wave response modeled well
  - 2^{nd}-order wave effects important at low & high frequencies
  - Quasi-steady mooring model good for global response; dynamics needed for mooring loads



OpenFOAM CFD

DeepCwind

SWAY

WindFloat

Hywind

Conclusions & Outlook

- Engineering models required to address design challenges, so that offshore wind turbines are:
  - Innovative
  - Optimized
  - Reliable
  - Cost-effective
- Improved models are needed to address/develop:
  - Upscaling to larger sizes
  - Novel architectures & controls
  - Coupling to offshore platforms
  - Design at the wind-plant level
  - System-wide optimization

SWT-6.0-154 with Airbus A380

Horns Rev Wind Farm

NATIONAL RENEWABLE ENERGY LABORATORY

More information @: https://nwtc.nrel.gov

Carpe Ventum!

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