NATIONAL RENEWABLE ENERGY LABORATORY

FAST: A Developer-Community Environment for Wind Turbine Multi-Physics Engineering Modeling

NAWEA 2015 Symposium

June 8, 2015

Blacksburg, VA (USA)

Jason Jonkman, Ph.D.
Senior Engineer, NREL

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Outline

- Introduction & Background:
- FAST Modularization Framework
- Structural Dynamics (ElastoDyn)
- Aerodynamics (AeroDyn)
- Control & Electrical-Drive Dynamics (ServoDyn)
- Hydrodynamics & Offshore Features (HydroDyn, SubDyn, & MAP)
- Transition to a Developer Community
- Outlook

NATIONAL RENEWABLE ENERGY LABORATORY

Introduction & Background

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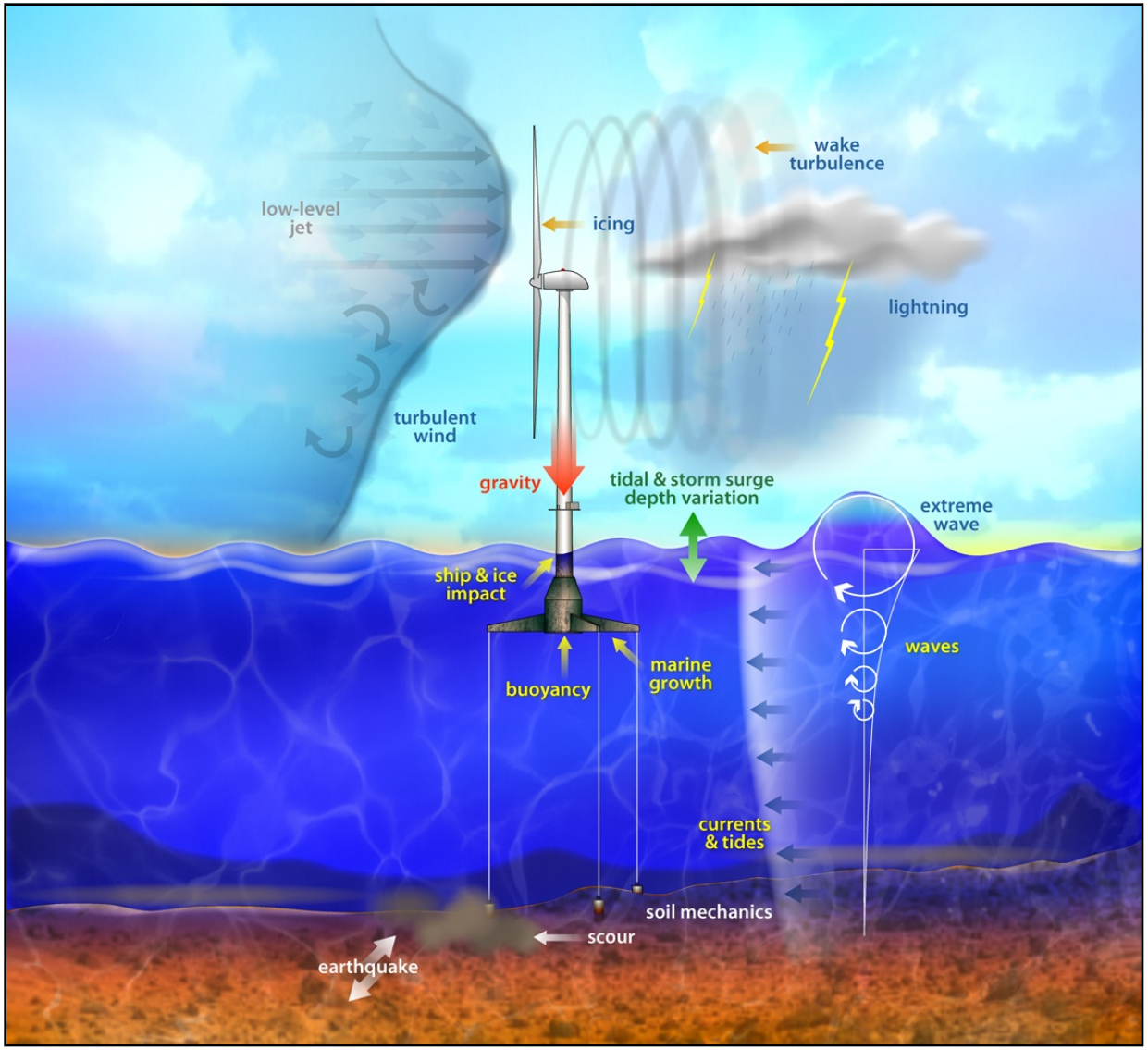
Introduction & Background

Modeling Requirements

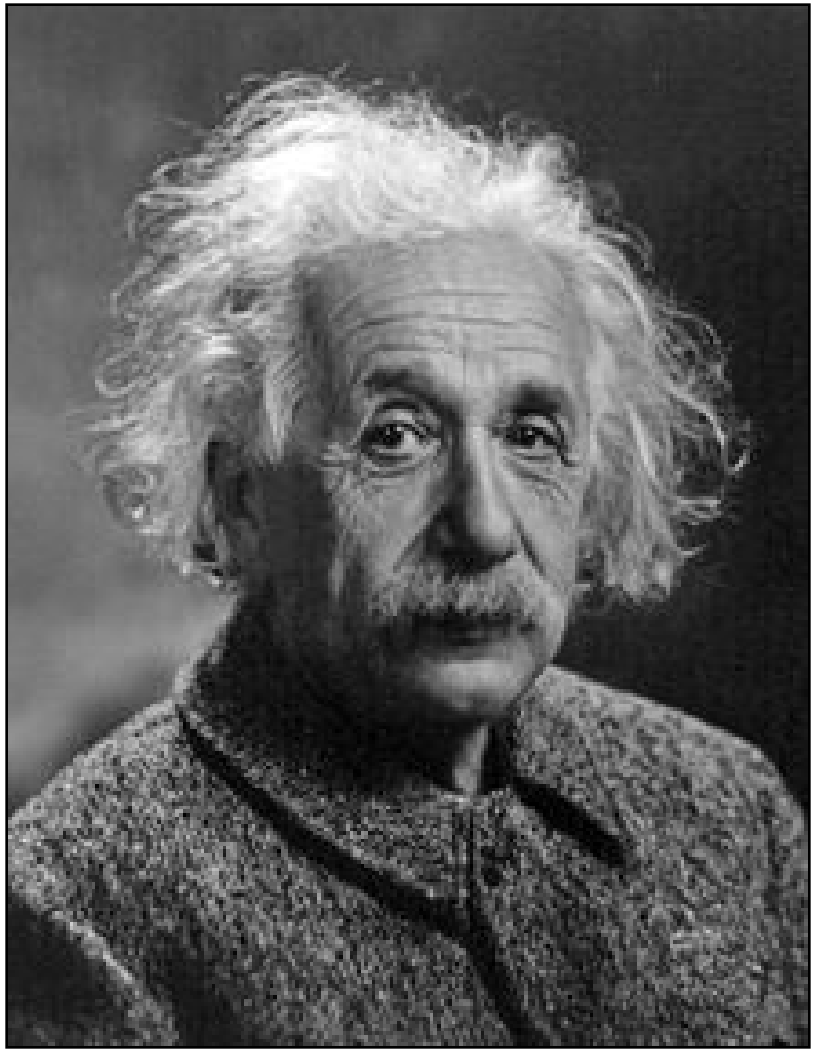


- Coupled aero-hydro-servo-elastic interaction
- Wind-inflow:
  - –Discrete events
  - –Turbulence
- Waves:
  - –Regular
  - –Irregular
- Aerodynamics:
  - –Induction
  - –Rotational augmentation
  - –Skewed wake
  - –Dynamic stall
- Hydrodynamics:
  - –Diffraction
  - –Radiation
  - –Hydrostatics
- Structural dynamics:
  - –Gravity / inertia
  - –Elasticity
  - –Foundations / moorings
- Control system:
  - –Yaw, torque, pitch

Introduction & Background

Einstein Principle

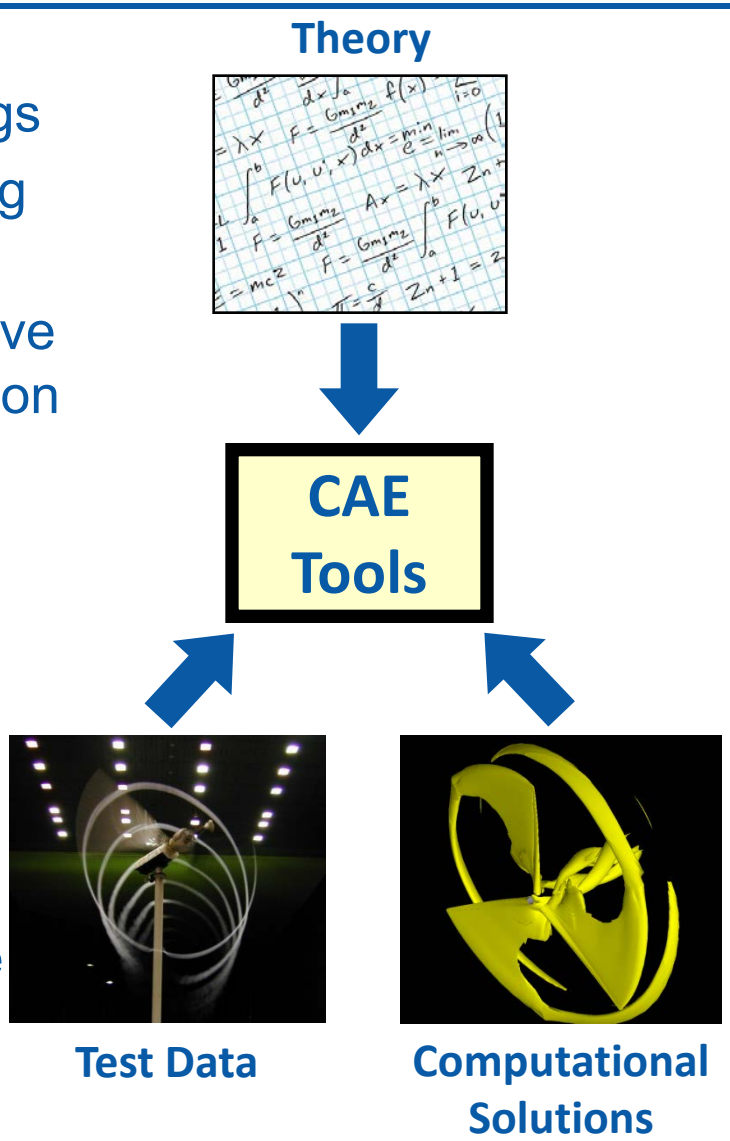
"A model should be as simple as possible, but no simpler."



Introduction & Background

Physics Modeling Needs for Engineering Design

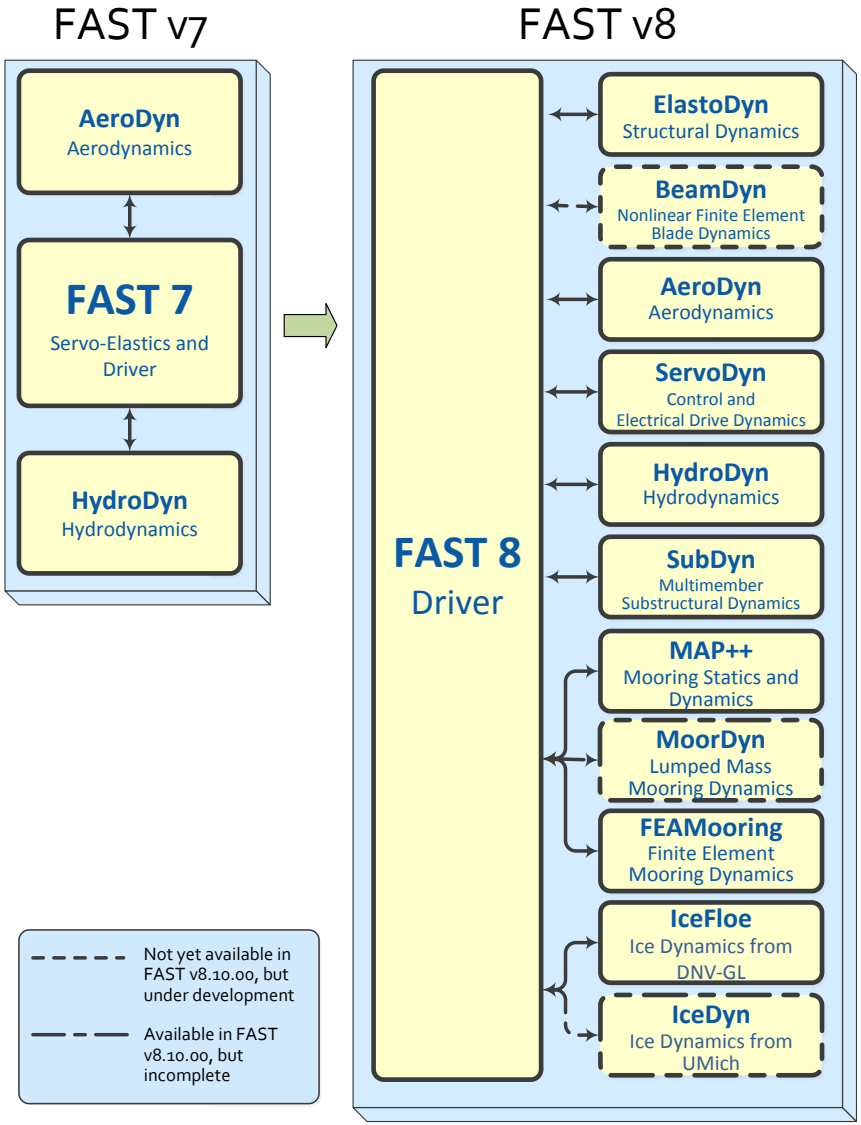
- Capture important system physics & couplings
- Range of fidelity to target specific engineering problems in industry & research
- Computational efficiency to support an iterative & probabilistic design processes & optimization
- Nonlinear time-domain for standards-based load analysis
- Linearization for eigenanalysis, controls design, stability analysis, & gradients for optimization
- Support for new technology, including unique needs of nascent offshore industry
- Verification & validation to understand where models are suitable & where they are not



Introduction & Background

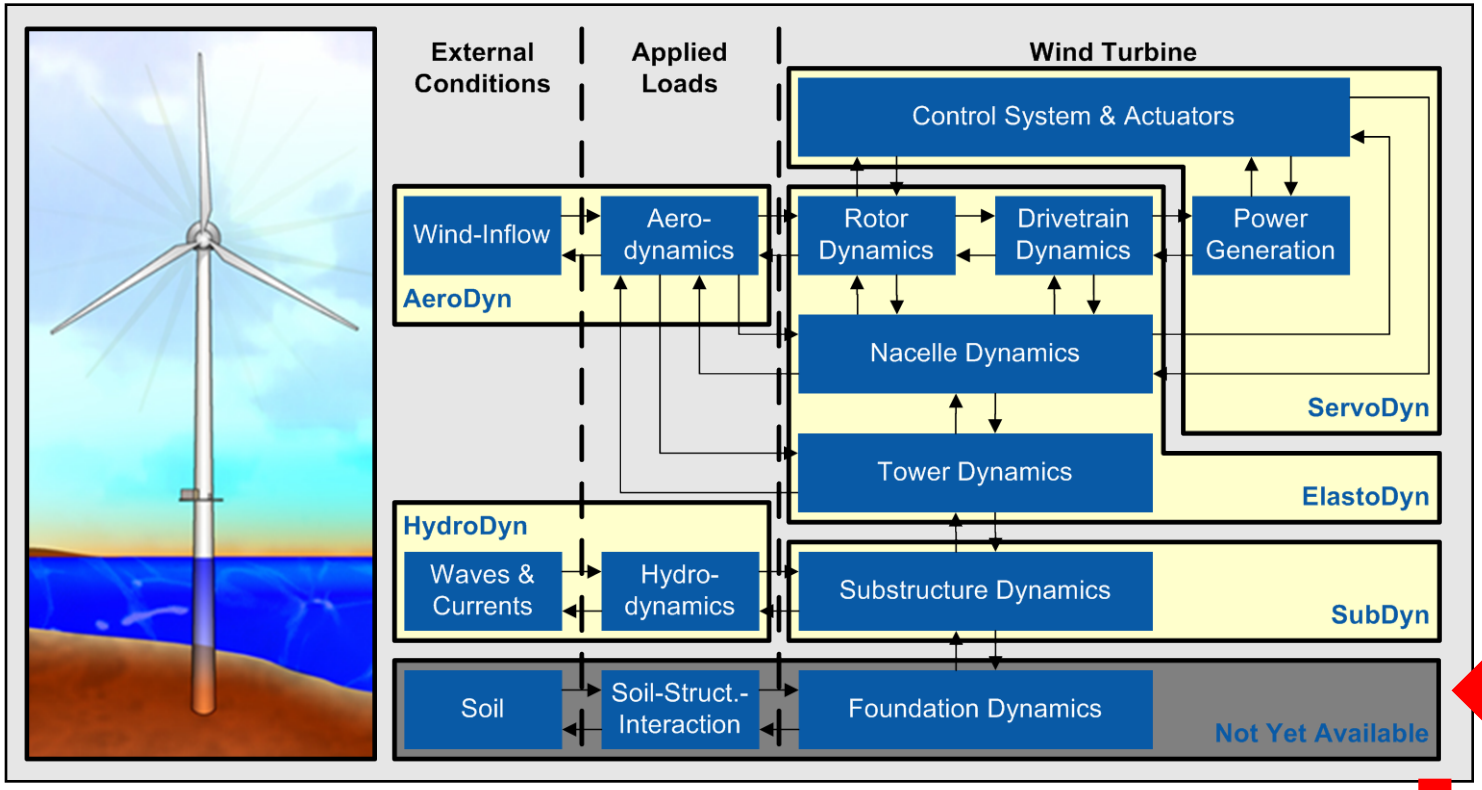
The FAST Multi-Physics Engineering Tool

- **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)
- Not only is the new framework supporting expanded functionality, but it is facilitating the establishment of a code-development community for multi-physics engineering models



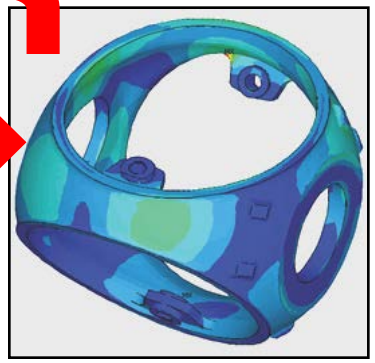
Introduction & Background

FAST Module Control Volumes – Fixed-Bottom



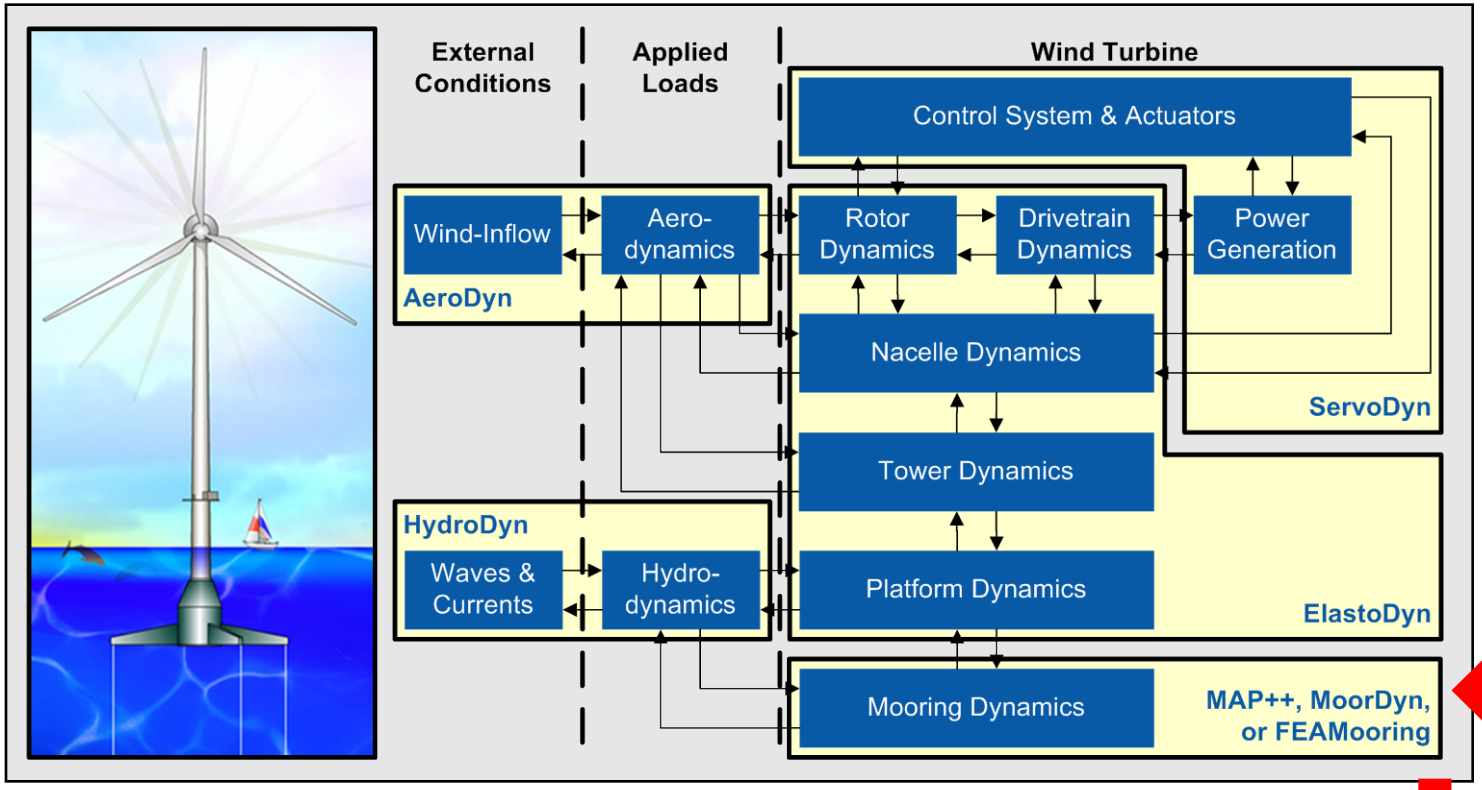
Full-System Level (Surface Ice Not Shown)

Component Level



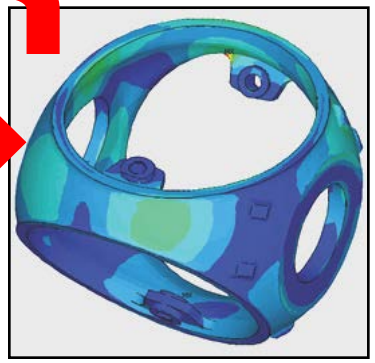
Introduction & Background

FAST Module Control Volumes – Floating



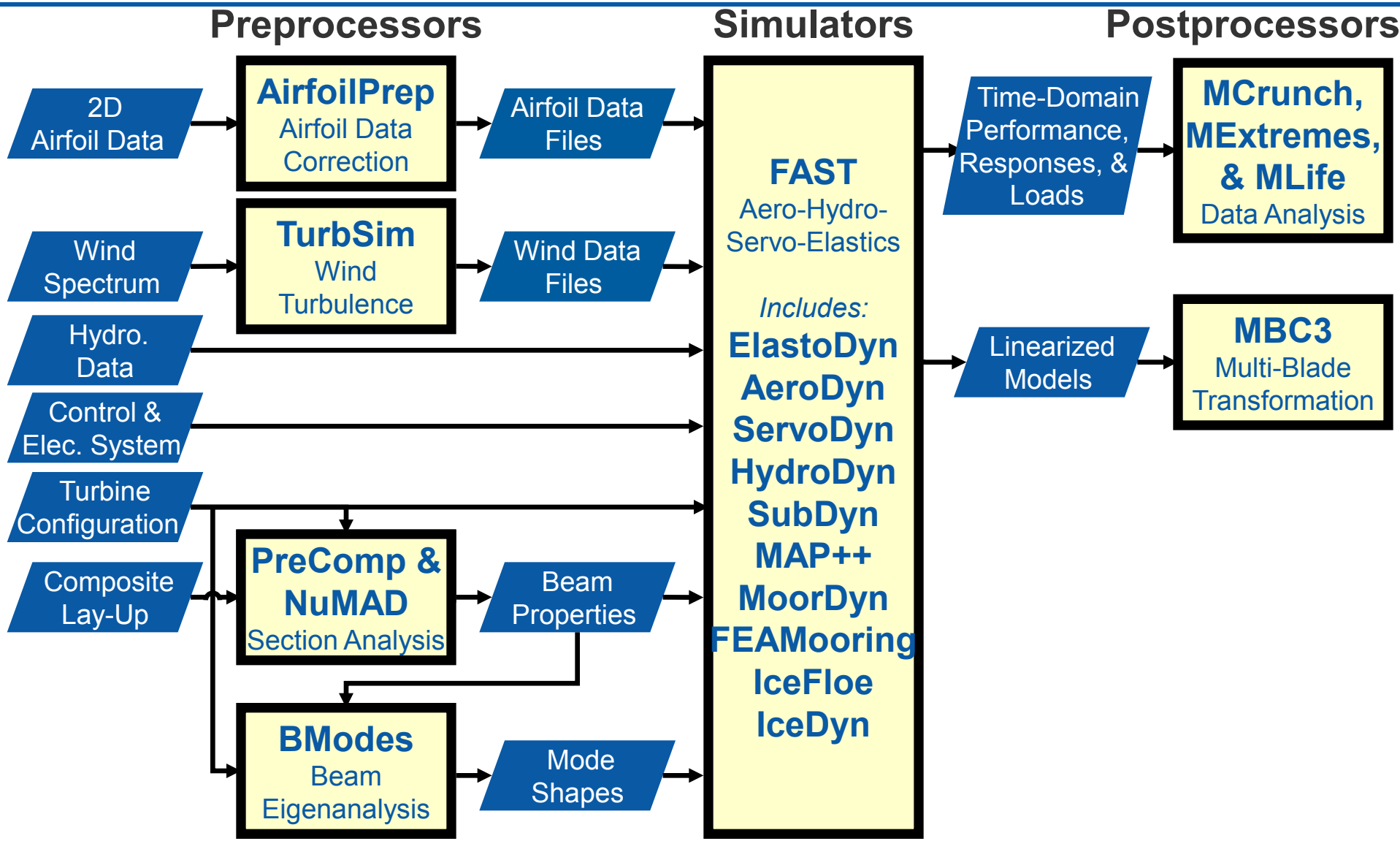
Full-System Level

Component Level



Introduction & Background

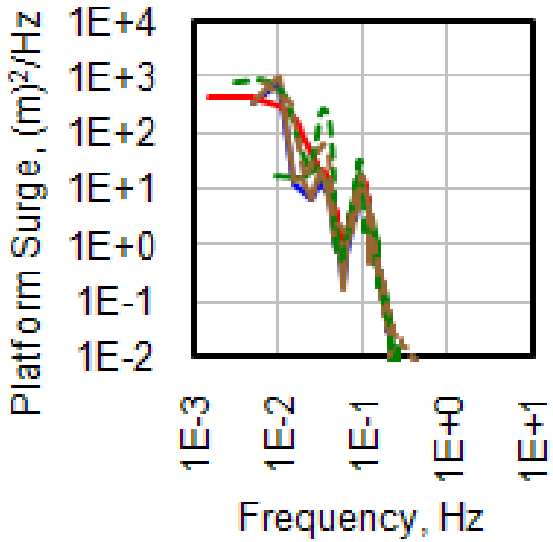
Key DOE/NREL Tools in the Design Process



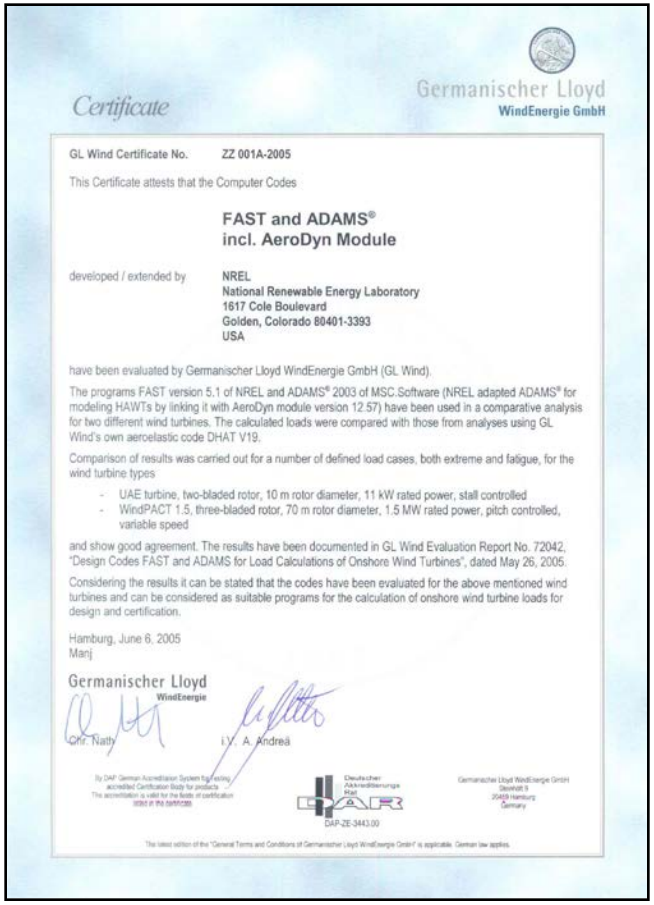
Introduction & Background

Verification (Code-to-Code)

- VEWTDC
- Many 1-on-1 collaborations (e.g.):
  - GL GH
  - ECN
  - DTU Wind
- Evaluated by GL against **Bladed**
- IEA Wind Task 23 OC3 & Task 30 OC4 projects
- Frequent comparisons of **FAST** to **MSC.ADAMS**
- Collaboration with Siemens ongoing



OC3 Full-System Test



Certificate

Germanischer Lloyd
WindEnergie GmbH

GL Wind Certificate No. ZZ 001A-2005

This Certificate attests that the Computer Codes

FAST and ADAMS®
incl. AeroDyn Module

developed / extended by

NREL
National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, Colorado 80401-3393
USA

have been evaluated by Germanischer Lloyd WindEnergie GmbH (GL Wind).

The programs FAST version 5.1 of NREL and ADAMS® 2003 of MSC.Software (NREL adapted ADAMS® for modeling HAWTs by linking it with AeroDyn module version 12.57) have been used in a comparative analysis for two different wind turbines. The calculated loads were compared with those from analyses using GL Wind's own aeroelastic code DHAT V19.

Comparison of results was carried out for a number of defined load cases, both extreme and fatigue, for the wind turbine types

- UAE turbine, two-bladed rotor, 10 m rotor diameter, 11 kW rated power, stall controlled
- WindPACT 1.5, three-bladed rotor, 70 m rotor diameter, 1.5 MW rated power, pitch controlled, variable speed

and show good agreement. The results have been documented in GL Wind Evaluation Report No. 72042, "Design Codes FAST and ADAMS for Load Calculations of Onshore Wind Turbines", dated May 26, 2005.

Considering the results it can be stated that the codes have been evaluated for the above mentioned wind turbines and can be considered as suitable programs for the calculation of onshore wind turbine loads for design and certification.

Hamburg, June 6, 2005
Manj

Germanischer Lloyd
WindEnergie

Chr. Nath i.V. A. Andreä

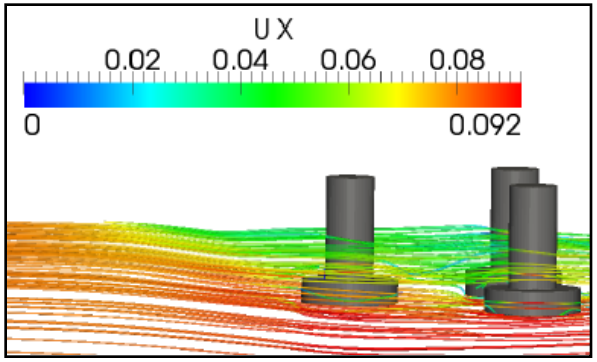
DAP-ZE-3443.00

GL Certificate Approving ***FAST*** *&* ***ADAMS*** *with* ***AeroDyn***

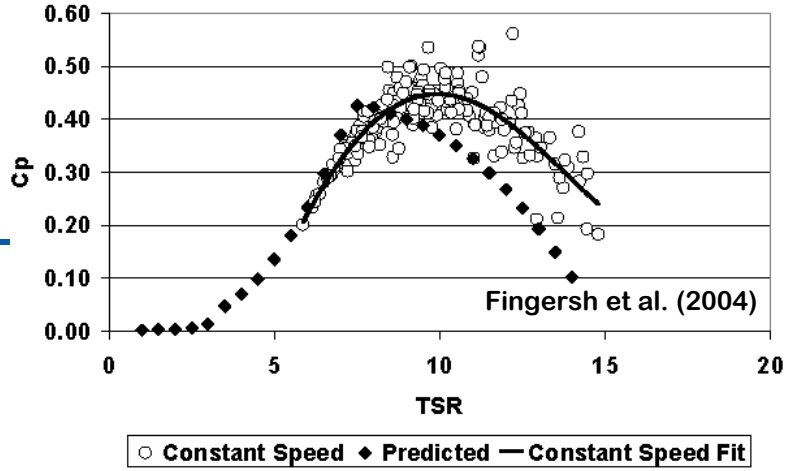
Introduction

Validation (Code-to-Data)

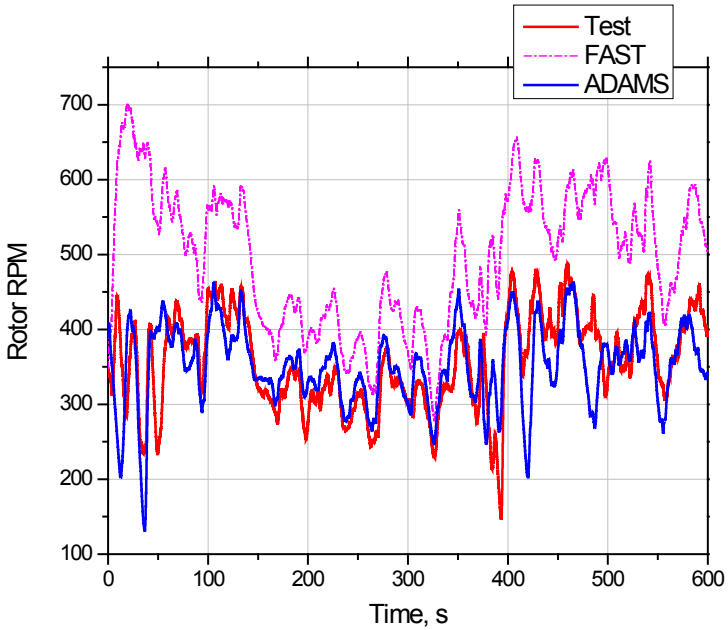
- UAE Phase VI
- SWRT
- CART2 & CART3
- Collaboration with Siemens ongoing
- Floating validation in progress:
  - CFD, DeepCwind, SWAY, WindFloat, & Hywind



***OpenFOAM** CFD*



*Comparison of Uncalibrated **WT_Perf** Prediction to CART2 Data*



*SWRT in high winds – **ADAMS** has Blade Torsion, **FAST** doesn't*

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FAST Modularization Framework

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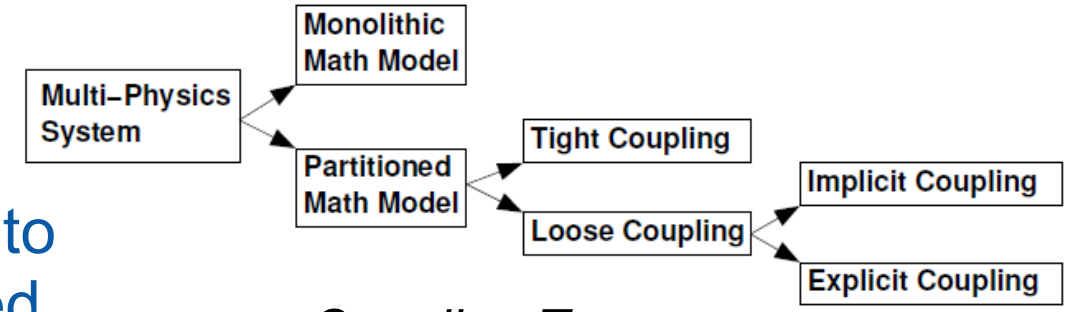
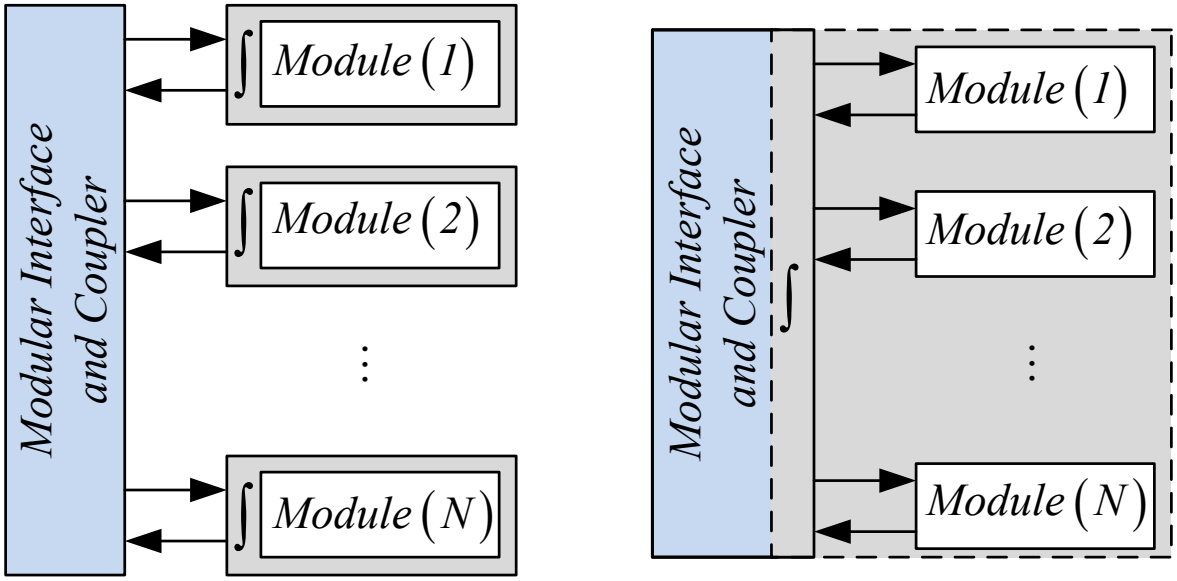
FAST Modularization Framework

What is the FAST Modularization Framework?

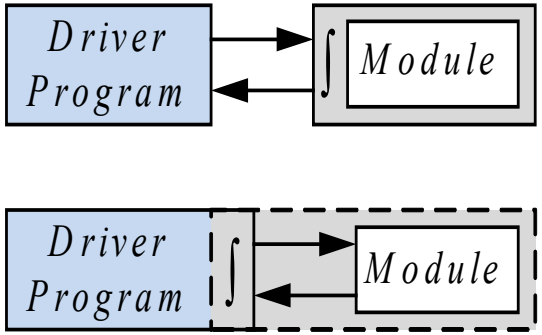
- A means by which various mathematical models are implemented in distinct modules & interconnected to solve for the global, coupled, dynamic response of a system



Coupling Taxonomy



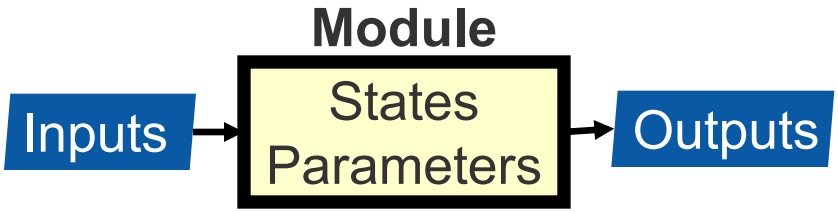
Loose- (Left) & Tight- (Right) Coupling Schemes



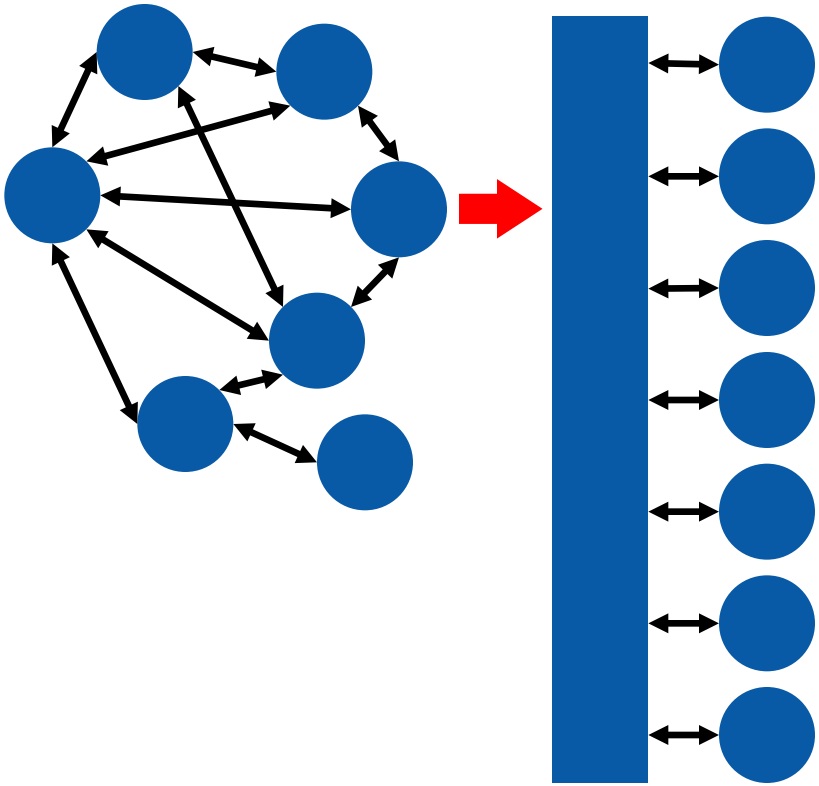
Uncoupled Solution of a Module Intended for Loose (Top) & Tight (Bottom) Coupling

FAST Modularization Framework

Design Features of the Framework



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



Interconnected Physics Domains, Coupled Through a Driver

**Not yet available*

FAST Modularization Framework

Functions of the FAST Driver ("Glue Code")

FAST

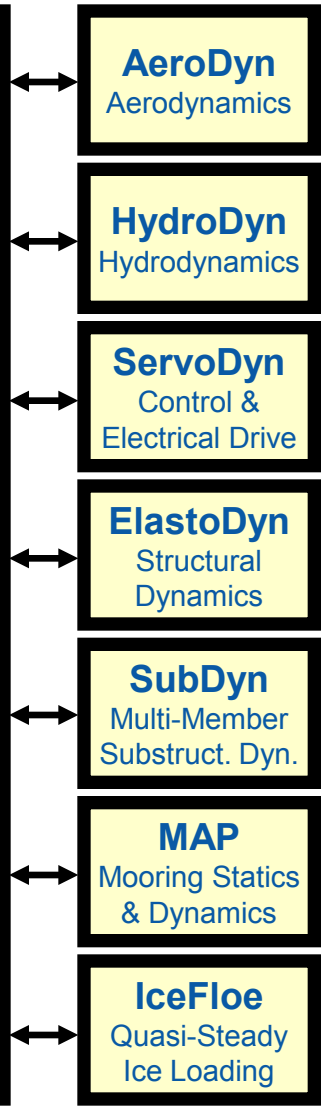
Driver ("Glue Code")

Loose coupling:

- Drives time-domain solution forward
- Calls individual modules
- Derives module inputs from outputs:
  - Including mesh-to-mesh mapping
  - Including interpolation/extrapolation in time

Tight coupling*:

- All of the above, plus
- Integrates coupled system equations using a common solver
- Determines operating points
- Performs model linearization



There are no current plans to implement tight coupling, but linearization is planned

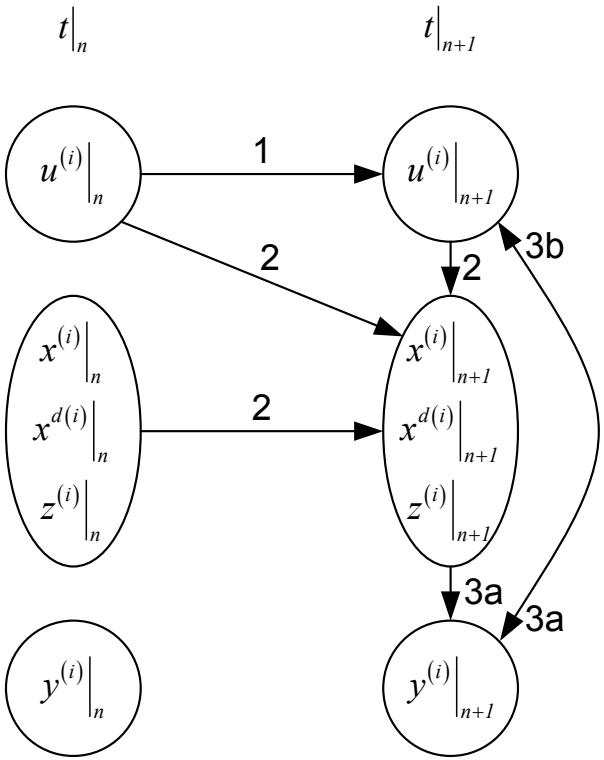
FAST Modularization Framework

Loose-Coupling Algorithm

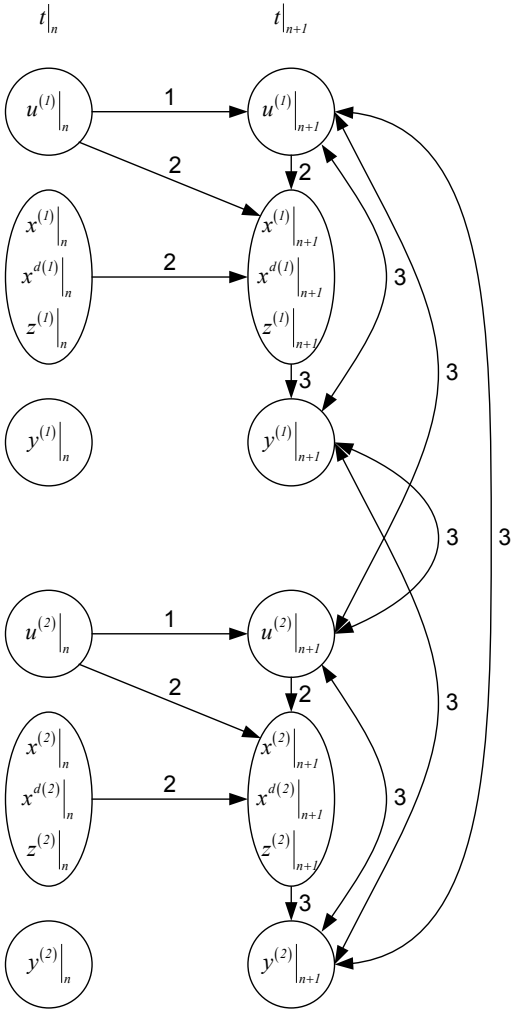
- Predictor-Corrector (PC)-based with time-step subcycling of modules
- Set-up for future parallelization (steps 1, 2, & 3a)

```
For Each Time Step
(From t_n):
1) Extrapolate Inputs to
   t_n+1
2) Advance States to t_n+1
3) Solve for Outputs &
   Inputs @ t_n+1:
   3a) Calculate Outputs
   3b) Derive Inputs
       From Outputs
   3c) Iterate (Go Back
       to 3a) or Save
4) Correct (Go Back to 2)
   or Save
```

PC-Based Loose-Coupling Algorithm



Within an Individual Module

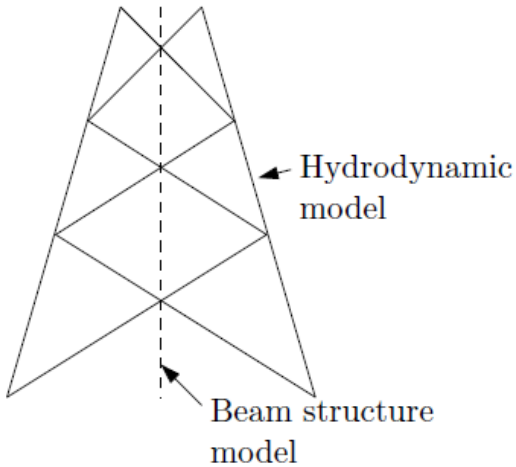


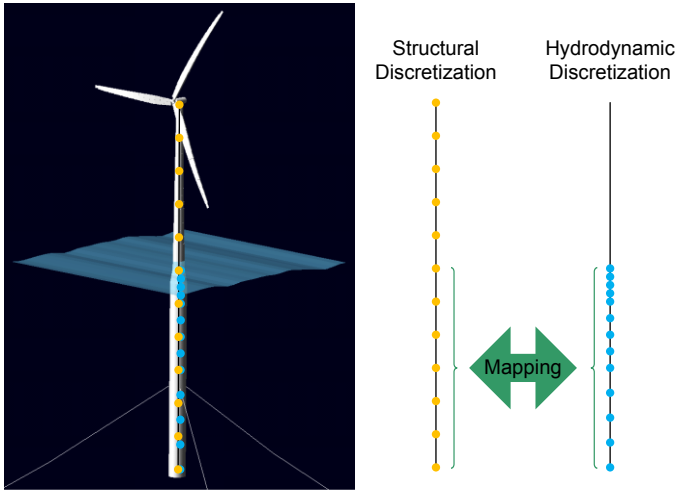
Coupling of Modules

FAST Modularization Framework

Independent Spatial Discretizations & Mapping

- Module inputs & outputs residing on a spatial boundary use a mesh, consisting of:
  - Nodes & elements (nodal connectivity)
  - Nodal reference locations (position & orientation)
  - One or more nodal fields, including motion, load, &/or scalar quantities
- Mesh-to-mesh mapping supports:
  - Extremely disparate meshes
  - Large motion/deformation
  - Relative motion or follower meshes
- Mapping guiding principles:
  - Load transfer maintains force & moment balance
  - Motion transfer maintains rigid-body motion
  - Load & motion mappings are conjugate
  - Identical meshes lead to 1-to-1 mapping of fields





Mapping Independent Discretizations

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Structural Dynamics (ElastoDyn)

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Structural Dynamics (ElastoDyn)

Inputs, Outputs, States, & Parameters

Inputs:
- Aerodynamic loads
- Hydrodynamic loads
- Controller commands
- Substructure reactions @ transition piece

→

ElastoDyn

Continuous States:
- Displacements
- Velocities

Parameters:
- Geometry
- Mass/inertia
- Stiffness coefficients
- Damping coefficients
- Gravity

→

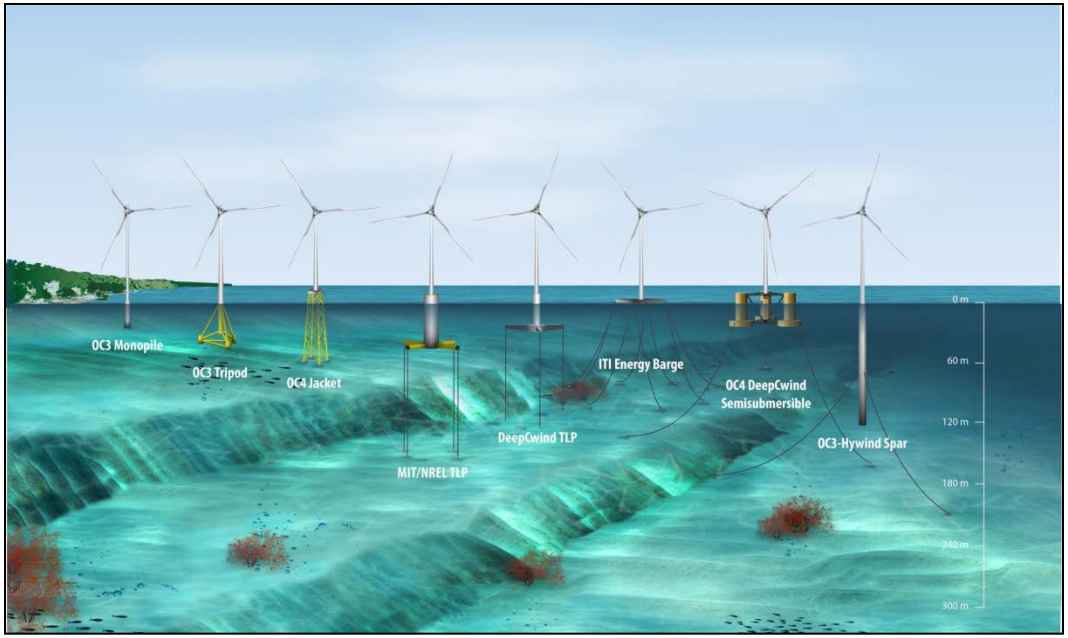
Outputs:
- Displacements
- Velocities
- Accelerations
- Reaction loads

Structural Dynamics (ElastoDyn)

Turbine Configurations

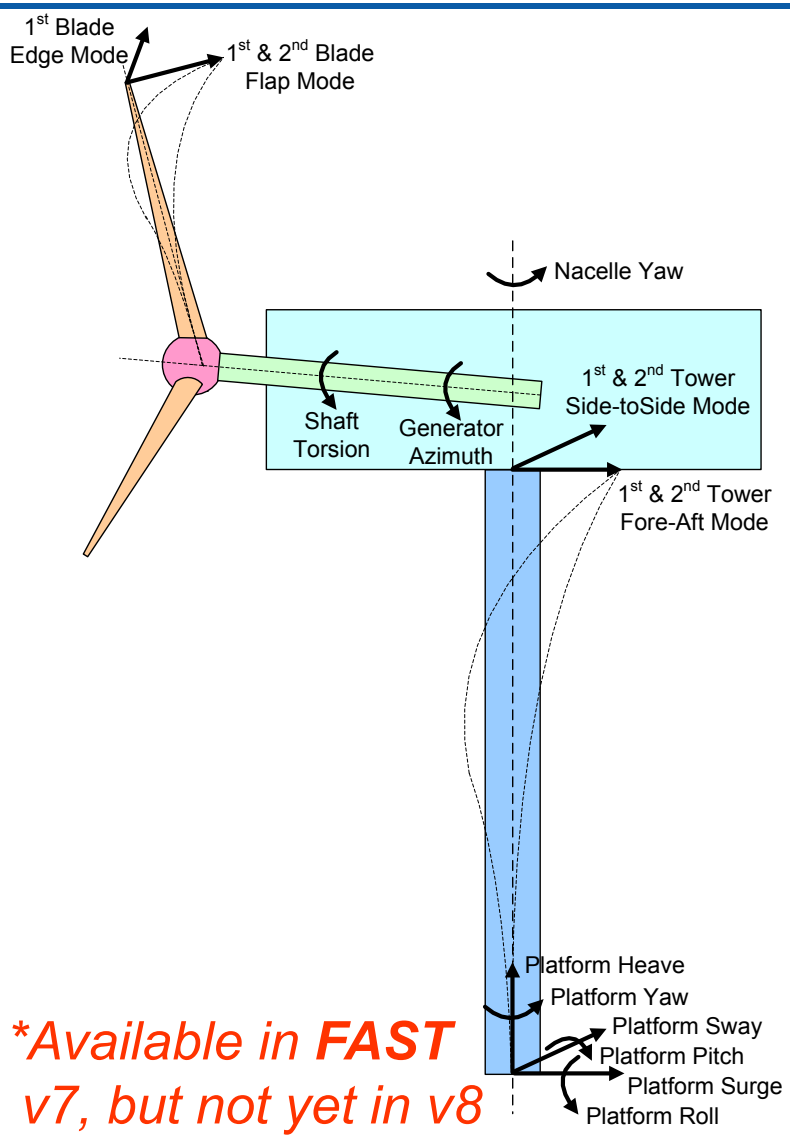
- Horizontal-axis (HAWT)
- 2- or 3-bladed rotor
- Upwind or downwind rotor
- Rigid or teetering hub
- Conventional configuration or inclusion of rotor- &/or tail-furling*
- Support structure that includes a tower atop a platform
- Land- or offshore-based (via **HydroDyn**)
- Offshore fixed-bottom (via **SubDyn**) or floating (via **MAP**)

Available in **FAST v7, but not yet in v8*



Structural Dynamics (ElastoDyn)

Degrees of Freedom



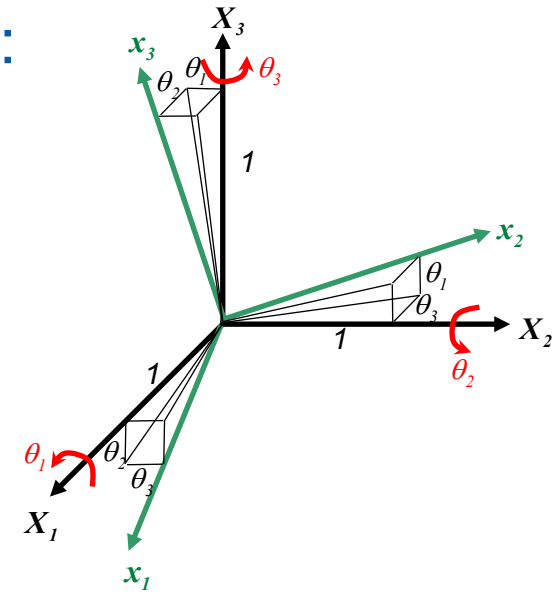
Available in **FAST v7, but not yet in v8*

Blades:	2 flap modes per blade 1 edge mode per blade
Teeter:	1 rotor teeter hinge with optional δ_3 (2-blader only)
Drivetrain:	1 generator azimuth 1 shaft torsion
Furl*:	1 rotor-furl hinge of *arbitrary orientation & location* between the nacelle & rotor 1 tail-furl hinge of *arbitrary orientation & location* between the nacelle & tail
Nacelle:	1 yaw bearing
Tower:	2 fore-aft modes 2 side-to-side modes
Platform:	3 translation (surge, sway, heave) 3 rotation (roll, pitch, yaw)
Total:	24 DOFs available for 3-blader 22 DOFs available for 2-blader

Structural Dynamics (ElastoDyn)

Theory Basis Overview

- Combined multi-body- & modal-dynamics:
  - Modal: blades, tower
  - Multi-body: platform, nacelle, generator, gears, hub, tail
- Utilizes relative DOFs:
  - No constraint equations
  - ODEs instead of DAEs
  - Platform rotations & 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



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

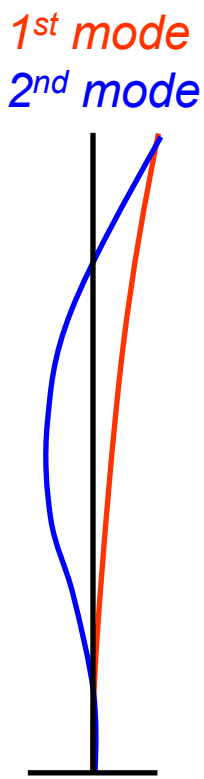
$$\begin{Bmatrix} x_1 \\ x_2 \\ x_3 \end{Bmatrix} = \frac{\begin{bmatrix} \theta_1^2\sqrt{1+\theta_1^2+\theta_2^2+\theta_3^2}+\theta_2^2+\theta_3^2 & \theta_3\left(\theta_1^2+\theta_2^2+\theta_3^2\right)+\theta_1\theta_2\left(\sqrt{1+\theta_1^2+\theta_2^2+\theta_3^2}-1\right) & -\theta_2\left(\theta_1^2+\theta_2^2+\theta_3^2\right)+\theta_1\theta_3\left(\sqrt{1+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

Correction for Orthogonality

Structural Dynamics (ElastoDyn)

Blade & Tower Modeling Assumptions

- Bernoulli-Euler beams under bending:
  - No axial or torsional DOFs
  - No shear deformation
- Straight beams with isotropic material & no mass/elastic offsets:
  - Blade pretwist induces flap/edge coupling
- Motions consider small to moderate deflections:
  - Superposition of lowest modes:
    - Mode shapes specified as polynomial coefficients
    - Mode shapes not calculated internally (found from e.g. **BModes** or modal test)
    - Shapes should represent modes, but **FAST** doesn't require orthogonality (no diagonalization employed)
  - Bending assumes small strains: $\theta \approx \frac{\partial u}{\partial h} \quad \kappa \approx \frac{\partial^2 u}{\partial h^2}$
    - Employs small angle approximations with nonlinear corrections for coordinate system orthogonality
- Otherwise, all terms include full nonlinearity:
  - Mode shapes used as shape functions in a nonlinear beam model (Rayleigh-Ritz method)
  - Motions include radial shortening terms (geometric nonlinearity)
  - Inertial loads include nonlinear centrifugal, Coriolis, & gyroscopic terms



Modal Representation

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Aerodynamics (AeroDyn)

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Aerodynamics (AeroDyn)

Inputs, Outputs, States, & Parameters

Inputs:
- Turbine disp.
- Turbine velocities

→

AeroDyn

Continuous States:
- Induction in GDW

Discrete States:
- States in B-L dynamic stall

Constraint States:
- Induction in BEM

Parameters:
- Geometry
- Airfoil data
- Undisturbed wind inflow
- Air Density

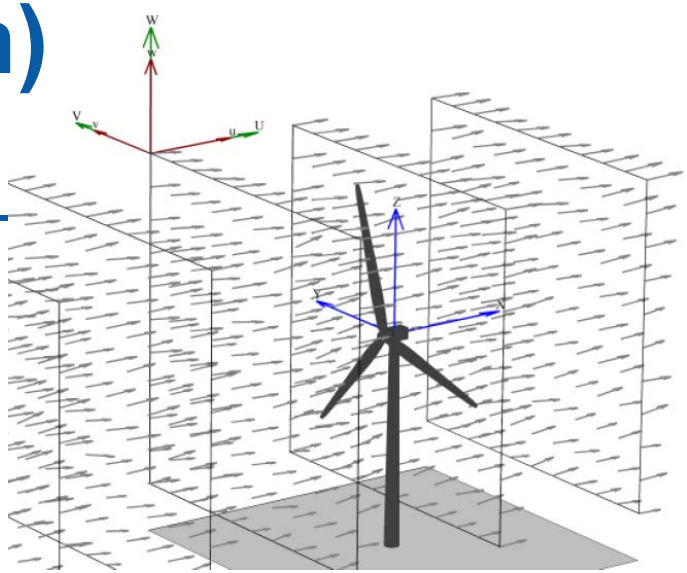
→

Outputs:
- Aero. loads
- Wind

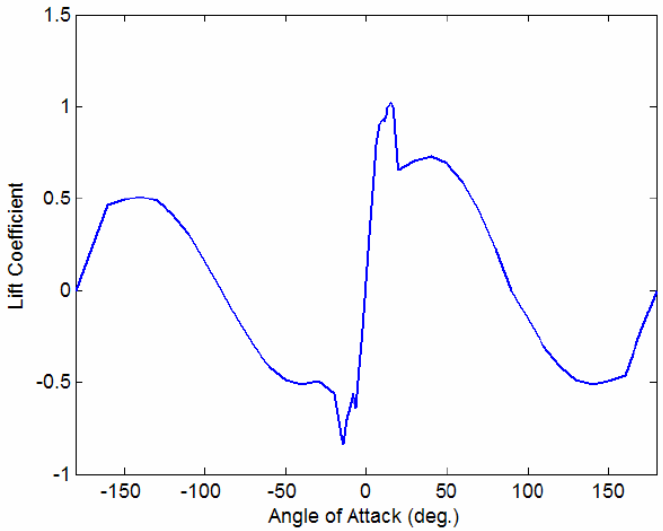
Aerodynamics (AeroDyn)

User Inputs

- Undisturbed wind inflow from **InflowWind** submodule:
  - Uniform, but time-varying
  - Full-field (FF) turbulence
  - User-defined
- Aerodynamic submodel selection:
  - Quasi-steady, dynamic, or no wake
  - Steady or unsteady airfoil aerodynamics, including dynamic stall
- 2-D/3-D airfoil properties:
  - C_L, C_D, C_M (vs. AoA & Re) & dynamic-stall parameters
  - **AirfoilPrep**
- Tower influence & drag properties



FF Wind Treated with Taylor's Frozen Turbulence Hypothesis

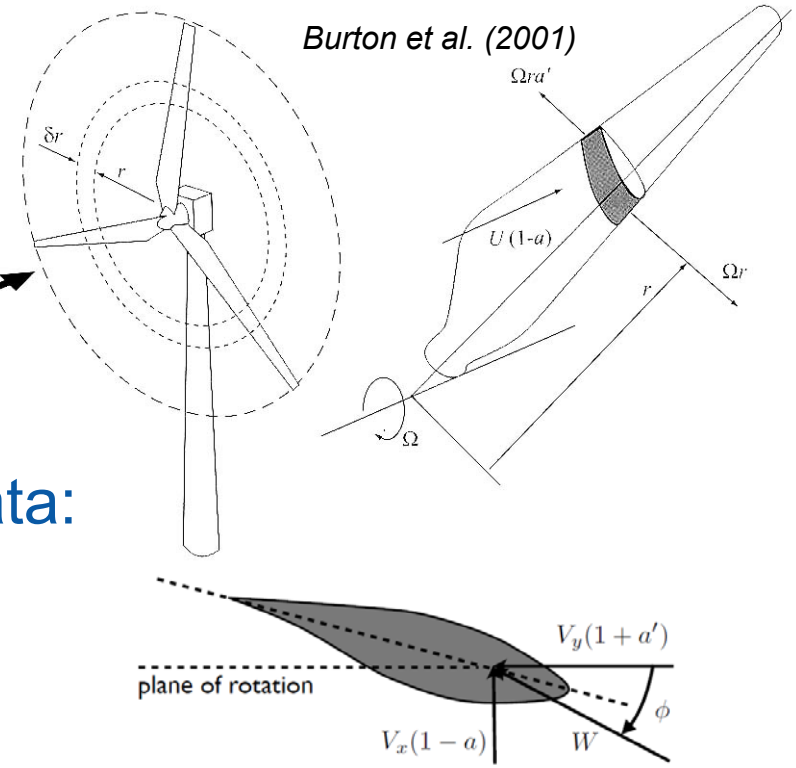


S809 Airfoil Data @ Re=750M

Aerodynamics (AeroDyn)

Wake – Blade-Element / Momentum (BEM)

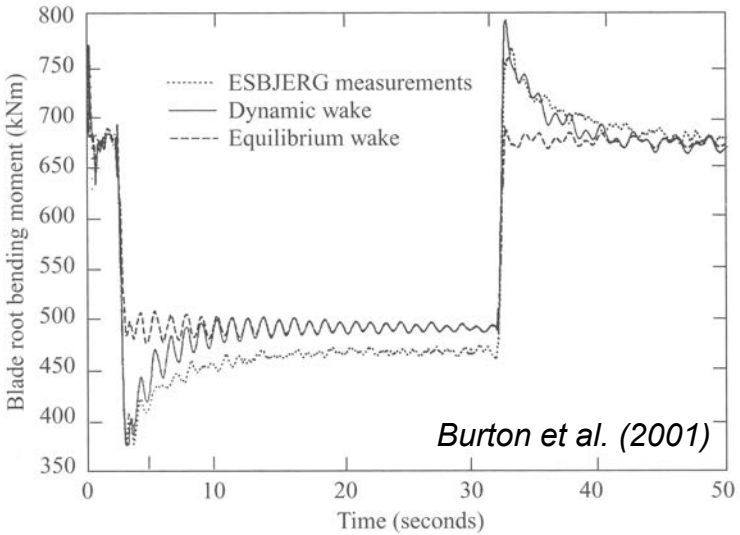
- Blades discretized into elements
- Momentum balance in annuli:
  - Linear → axial induction (*a*)
  - Angular → tangential induction (*a'*)
  - Implemented per element per blade
  - Nonlinear solve requires iteration
- Blade-element loads from airfoil data:
  - Drag terms can optionally be used in induction calculation
- Limitations to theory:
  - No interaction between annuli (2-D only) (3D effects from **AirfoilPrep**)
  - Instantaneous reaction of wake to loading changes
  - Needs corrections for high induction, tip & hub losses, & skewed flow
  - Despite these, BEM is applied in many conditions



Aerodynamics (AeroDyn)

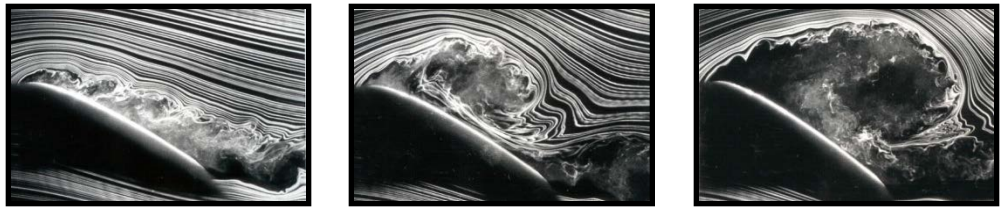
Wake – Generalized Dynamic Wake (GDW)

- Transient loading leads to a dynamic wake:
  - Turbulence/gusts
  - Skewed flow
  - Pitch control
- GDW models the time- & spatial-varying induction across the rotor
- Based on Peters, Boyd, & He:
  - Induced flow at the rotor expressed as modes in the radial & azimuthal directions (10 flow states considered)
  - ODEs relating induced flow to rotor loading in state-space form
  - Time-integration using ABM4 scheme
- Limitations:
  - Unstable for heavily loaded rotors (below rated)
  - Proper tip loss requires many more flow states

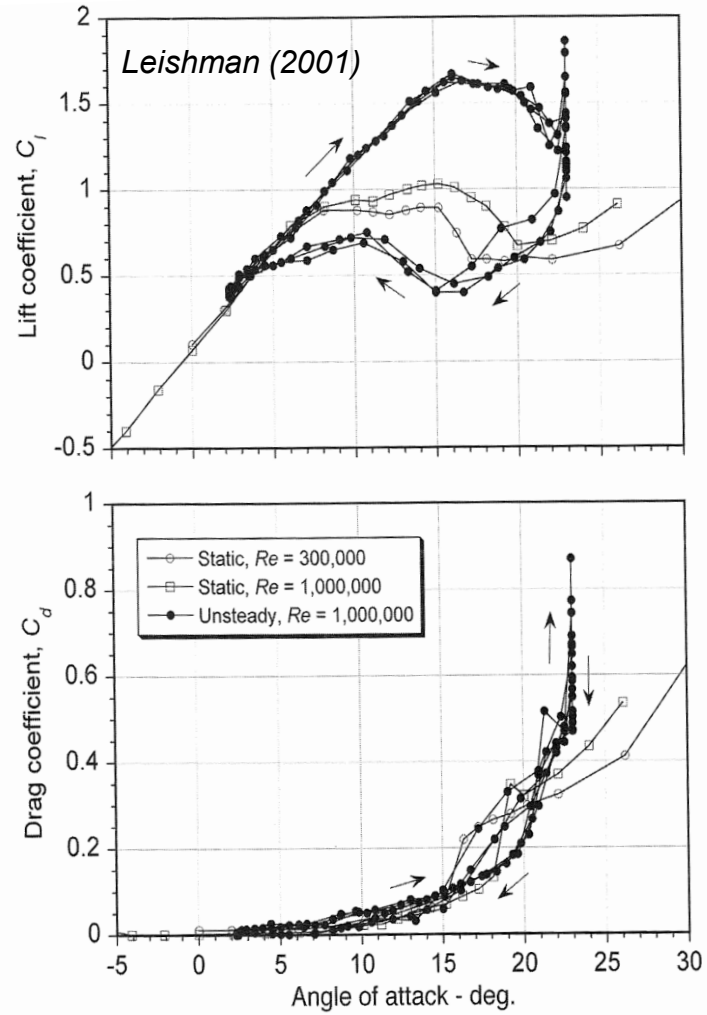


Blade Loading During Rapid Pitch Events

Aerodynamics
Unsteady Airfoil Aero



- Dynamically stalled flow field:
  - Static stall dynamically exceeded
  - C_N, C_T, C_M transiently amplified
  - Flow hysteresis
  - Produced by even slight skew & turbulence
- Beddoes-Leishman model:
  - A semi-empirical model
  - 3 submodels:
    - Unsteady attached flow
    - Trailing-edge flow separation
    - Dynamic stall & vorticity advection
  - Semi-empirical airfoil-dependent parameters derived from static data
  - Applicable for operational conditions, not in deep stall
- **AeroDyn** adds after induction calculations

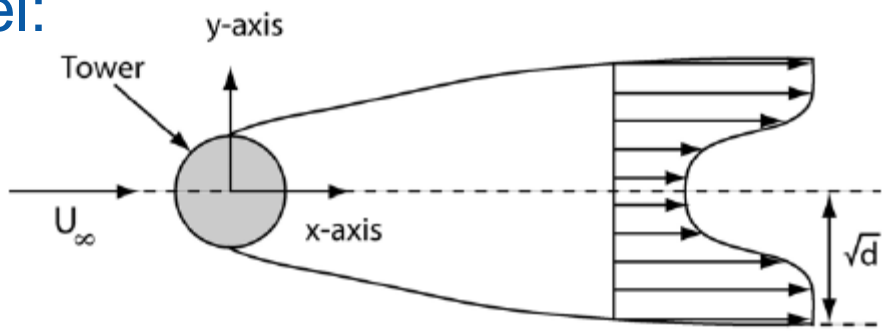


Dynamic Stall of S809 Airfoil

Aerodynamics (AeroDyn)

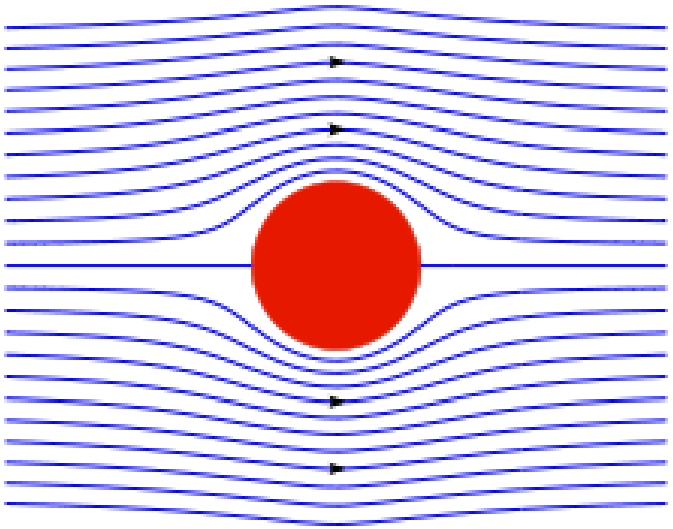
Tower Influence & Drag Load

- Downwind tower-shadow model:
  - Augments undisturbed wind
  - Simple user-tailored shape



Tower Shadow

- Upwind tower-influence model:
  - Augments undisturbed wind
  - Based on potential-flow solution around a cylinder
  - Optional Bak correction



Potential Flow Around a Cylinder

- Tower drag model:
  - Drag load @ each tower node proportional to square of undisturbed relative wind speed

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Control & Electrical-Drive Dynamics (ServoDyn)

NAWEA 2015 Symposium

June 8, 2015

Blacksburg, VA (USA)

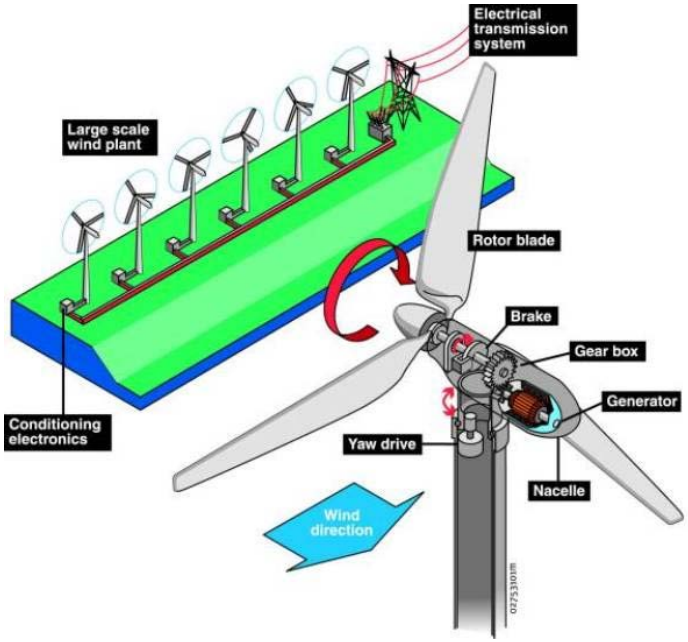
Jason Jonkman, Ph.D.
Senior Engineer, NREL

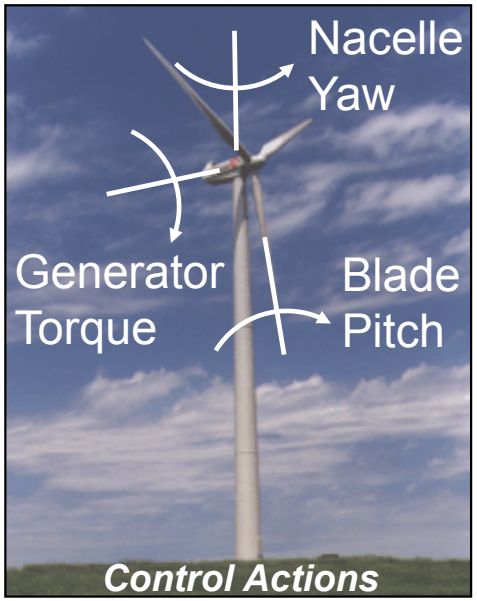
NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

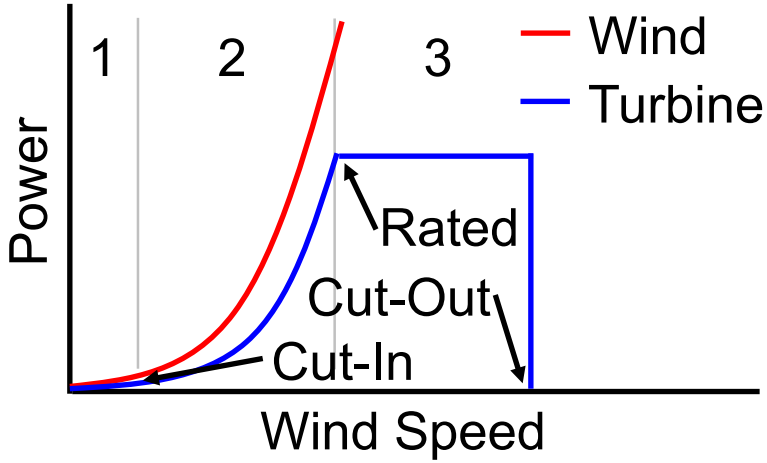
Control & Electrical Drive (ServoDyn)

Control & Electrical-Drive Functions

- Controls:
  - Operation
  - Start-up & shut-down
  - Safety & protection
- Sensors & actuators:
  - Sensors
  - Servo motors
  - Hydraulics
- Electrical drive:
  - Generator
  - Power electronics
  - Grid
- Faults







Control & Electrical-Drive (ServoDyn)

Inputs, Outputs, States, & Parameters

Inputs:
- Structural motions
- Reaction loads
- Wind measurements

ServoDyn

Continuous States:
- Analog control signals

Discrete States:
- Digital control signals

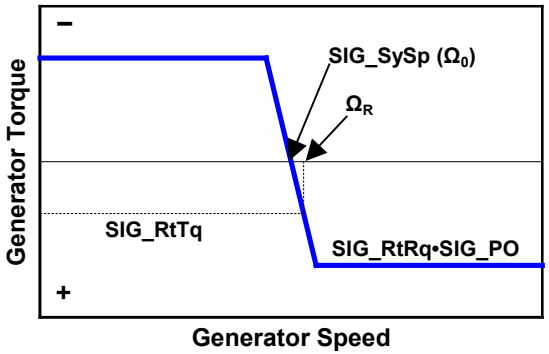
Parameters:
- Controller gains
- Control limits

Outputs:
- Controller commands

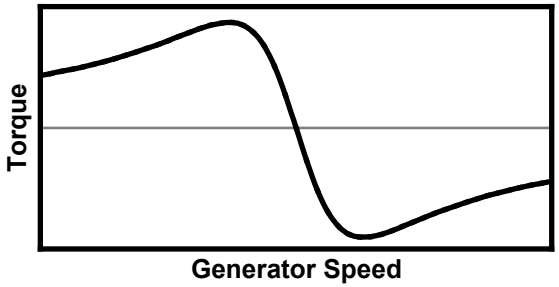
Control & Electrical-Drive (ServoDyn)

Control Methods

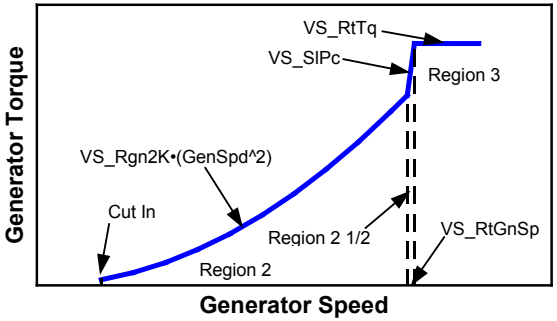
- Blade pitch:
  - Collective or independent
  - To feather or to stall
  - Command the angle
  - No actuator dynamics
  - Override maneuvers available
- Generator torque:
  - Fixed (w/ or w/o slip) or variable speed
  - Command the torque
  - Indirect electrical power
  - Default models built in
- HSS brake:
  - Command the deployment



Simple Induction Generator (SIG)



Thevenin-Equivalent Circuit (TEC) Generator



Simple Variable-Speed Controller

Control & Electrical-Drive (ServoDyn)

Control Methods (cont)

- Nacelle yaw:
  - Command the angle &/or rate
  - 2nd-order actuator determines the torque
  - Override maneuvers available
- Blade-tip brake*:
  - Command the deployment
- Passive control methods:
  - Aerodynamic stall
  - Rotor teeter (w/ or w/o soft & hard stops)
  - Nacelle yaw (free or restrained)
  - Nacelle-based tuned-mass-dampers:
    - Fore-aft & side-to-side
    - Optional stops
  - Rotor &/or tail furl*

Wind Turbine with Blade-Tip Brakes

Available in **FAST v7, but not yet in v8*

Control & Electrical-Drive (ServoDyn)

Interfacing Active Controllers – 5 Options

1) Select from one of the built-in routines
2) Fortran subroutine:
   - Separate routines for each controller (i.e.: separate routines for blade pitch, generator torque, nacelle yaw, & brake)
   - Requires recompile with each change to controller source code
   - Sample variable-speed torque controller based on table look-up provided with **FAST** archive
   - Sample PID blade-pitch controller provided with **FAST** archive
3) **Bladed**-style dynamic link library (DLL):
   - DLL compiled separately from **FAST**:
     - Mixed languages possible – Can be Fortran, C++, etc.
   - DLL is a master controller (i.e.: pitch, torque, yaw, & brake controlled with same DLL)
   - Sample NREL 5-MW baseline controllers provided with **FAST** archive

Control & Electrical-Drive (ServoDyn)

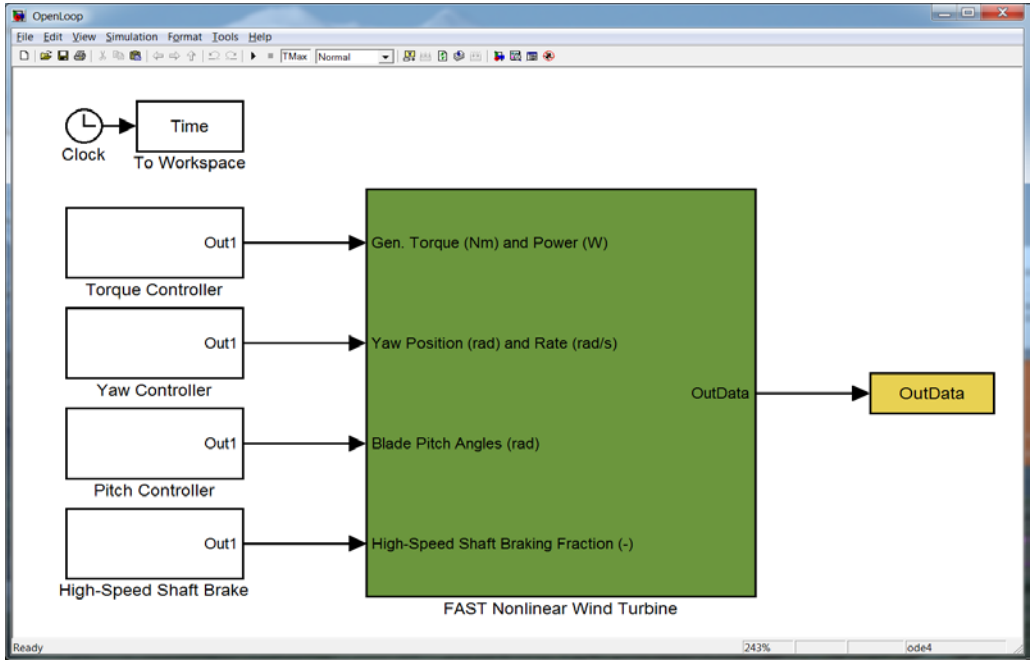
Interfacing Active Controllers – 5 Options (cont)

4) **MATLAB/Simulink**:

- **FAST** implemented as S-Function block
- Controls implemented in block-diagram form
- **SimPowerSystems** toolbox for detailed electrical drive

5) **LabVIEW***:

- **FAST** implemented as DLL callable by **LabVIEW**
- Hardware-in-the-loop (HIL) possible



*Open-Loop **Simulink** Model*

Available in **FAST v7, but not yet in v8*

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Hydrodynamics & Offshore Features (HydroDyn, SubDyn, & MAP)

NAWEA 2015 Symposium

June 8, 2015

Blacksburg, VA (USA)

Jason Jonkman, Ph.D.
Senior Engineer, NREL

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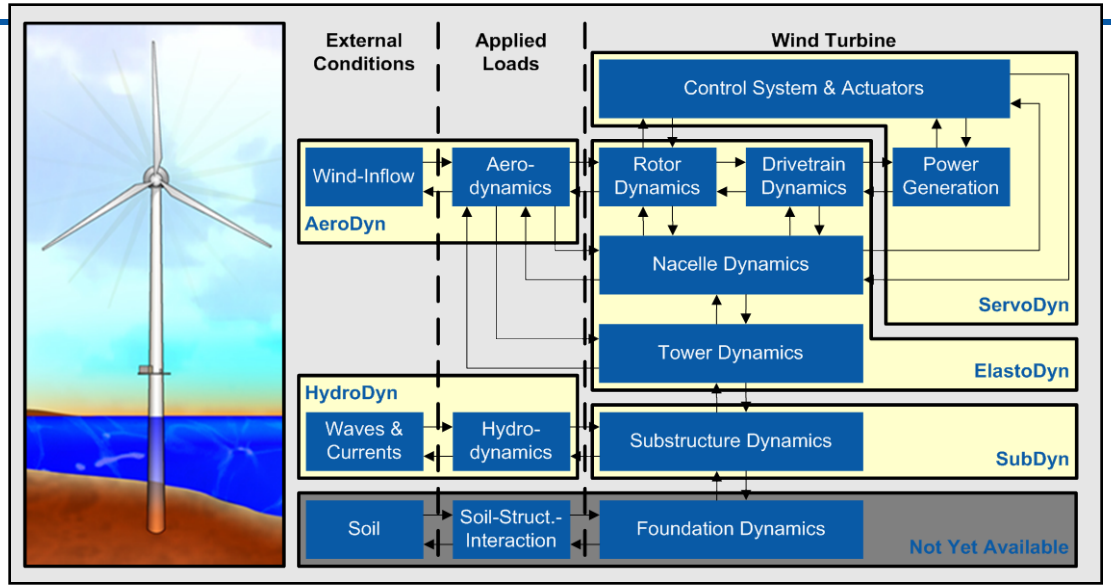
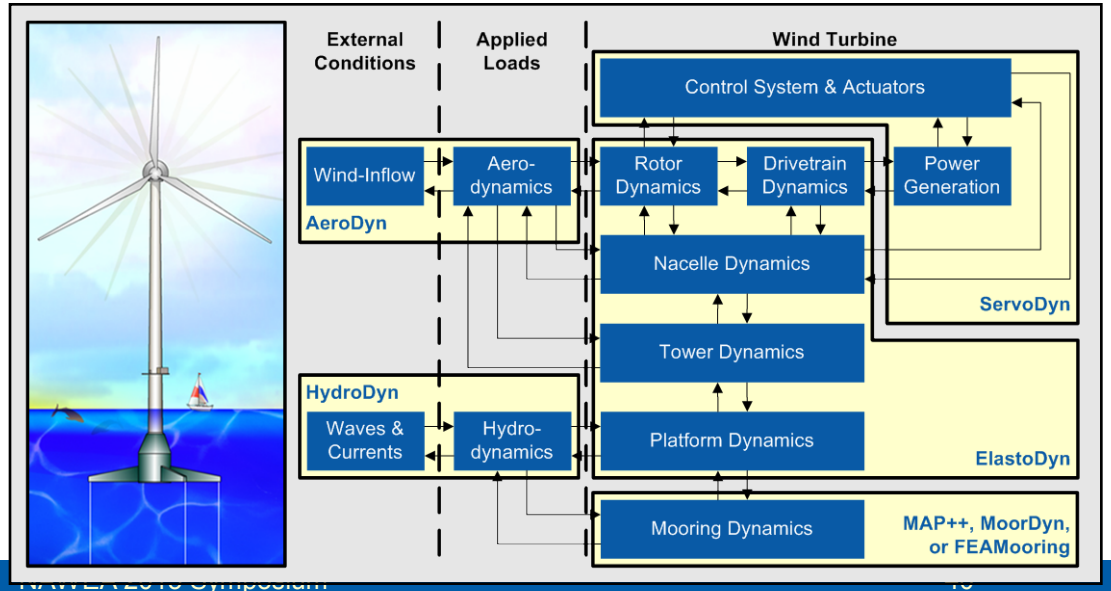
Hydrodynamics & Offshore Features

Offshore Modules of FAST





- **HydroDyn** – Hydrodynamics for fixed & floating
- **SubDyn** – Fixed substructure structural dynamics
- **MAP** – Mooring quasi-statics
- Not presented:
  - **MoorDyn** – Lumped-mass mooring dynamics (incomplete)
  - **FEAMooring** – FE mooring dynamics
  - **IceFloe** – Sea ice dynamics from DNV-GL
  - **IceDyn** – Sea ice dynamics from UMich (incomplete)
  - **OrcaFlex-FAST** v7 coupling for mooring dynamics

Hydrodynamics & Offshore Features

HydroDyn – Inputs, Outputs, States, & Parameters

Inputs:
- Substructure disp.
- Substructure vel.
- Substructure accel.

→

HydroDyn

Continuous States:
- State-space-based radiation "memory"

Discrete States:
- Convolution-based radiation "memory"

Parameters:
- Geometry
- Hydrodynamic coefficients
- Undisturbed incident waves
- Water Density
- Gravity

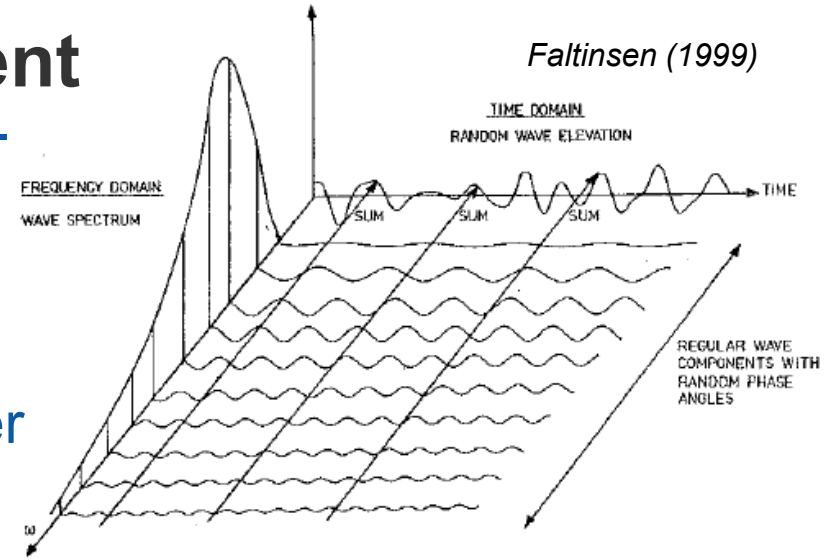
→

Outputs:
- Hydro. loads

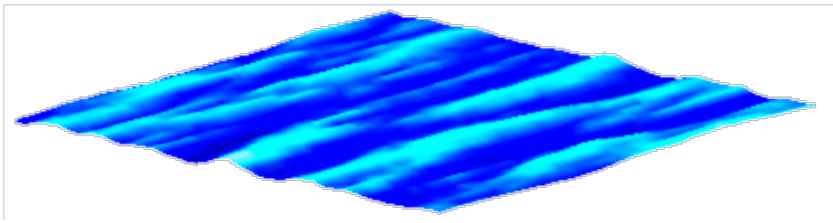
Hydrodynamics & Offshore Features

HydroDyn – Waves & Current

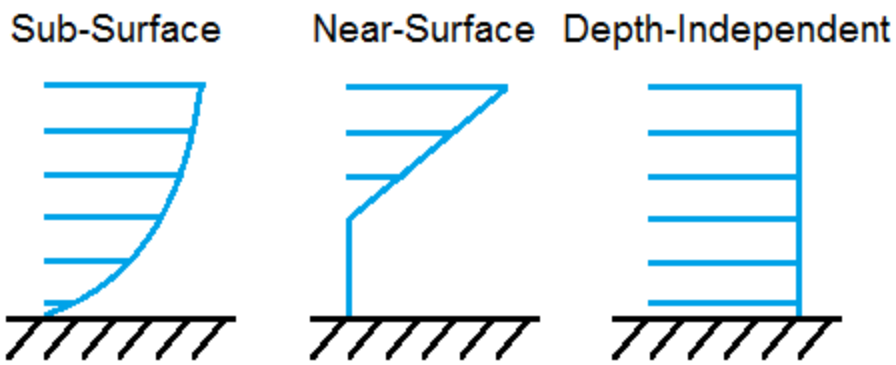
- Regular, irregular, or white noise waves
- Wave directional spreading
- 1st- (Airy) & 2nd- (Sharma/Dean) order



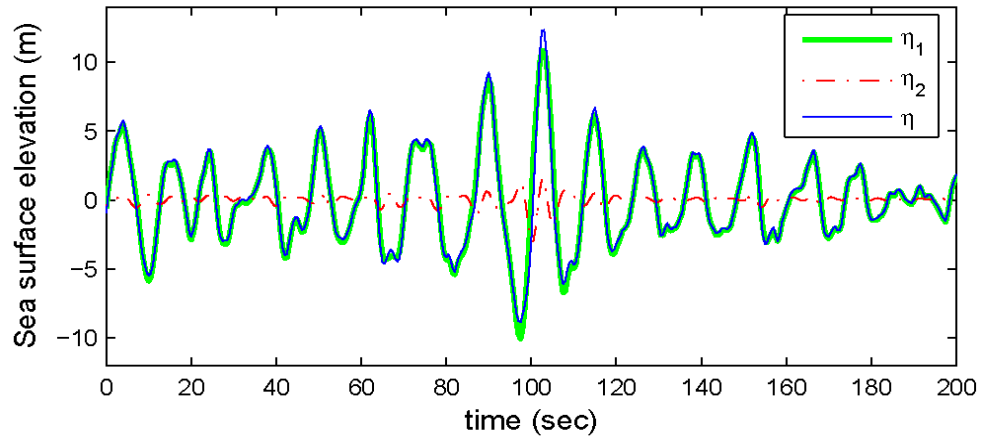
Frequency-to-Time Domain Transform of Wave Elevation



Multi-Directional Sea State



IEC Sea Currents

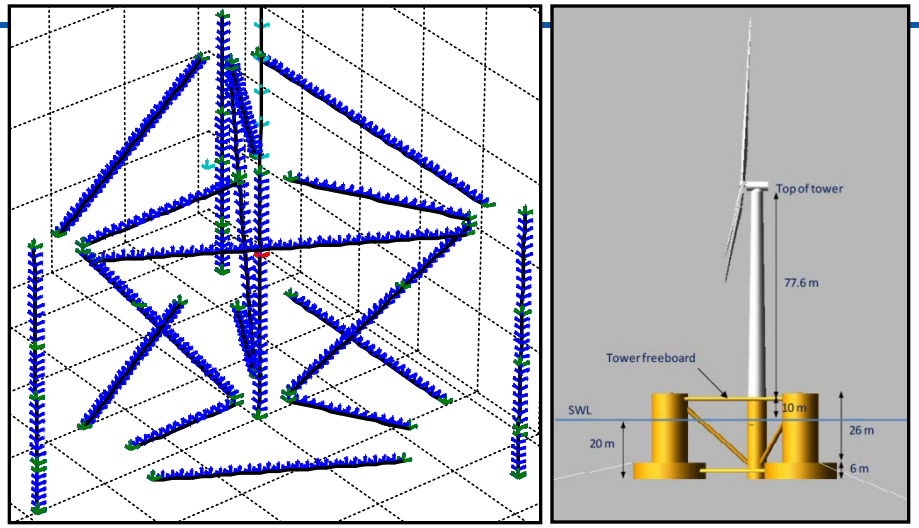


Sea-Surface Elevation (η) from the Summing of 1st- (η_1) & 2nd- (η_2) Order Waves

Hydrodynamics & Offshore Features

HydroDyn – Hydrodynamic Loading

- 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- (QTF) order
- Combination of these two



Strip-Theory Nodes for the OC4-DeepCwind Semisubmersible

$$u \longrightarrow \boxed{y(t) = \int_0^t K(t-\tau)u(\tau)\,d\tau} \longrightarrow y$$

$$u \longrightarrow \boxed{\begin{aligned} \dot{x} &= Ax + Bu \\ y &= Cx \end{aligned}} \longrightarrow y$$

Reformulation of Radiation Convolution to Linear SS Form

Hydrodynamics & Offshore Features

SubDyn – Inputs, Outputs, States, & Parameters

Inputs:
- Hydrodynamic loads
- TP* displacements
- TP* velocities
- TP* accelerations

→

SubDyn

Continuous States:
- Displacements
- Velocities

Parameters:
- Geometry
- Mass/inertia
- Stiffness coefficients
- Damping coefficients
- Gravity

→

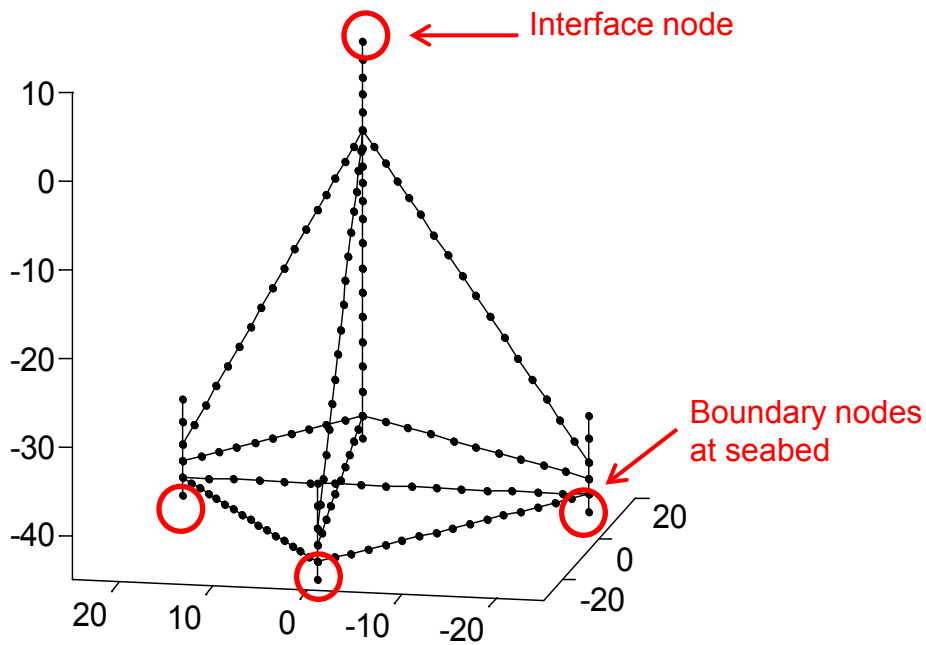
Outputs:
- Displacements
- Velocities
- Accelerations
- Reaction loads

**TP = Transition piece*

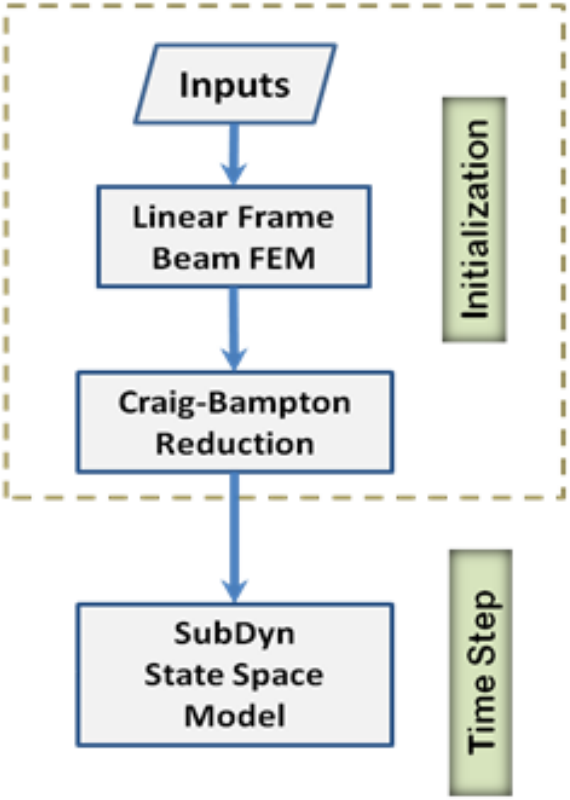
Hydrodynamics & Offshore Features

SubDyn – Key Features

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



Finite-Element Discretization of the OC3-Tripod



***SubDyn** Flow Chart*

Hydrodynamics & Offshore Features

MAP – Key Features

MAP

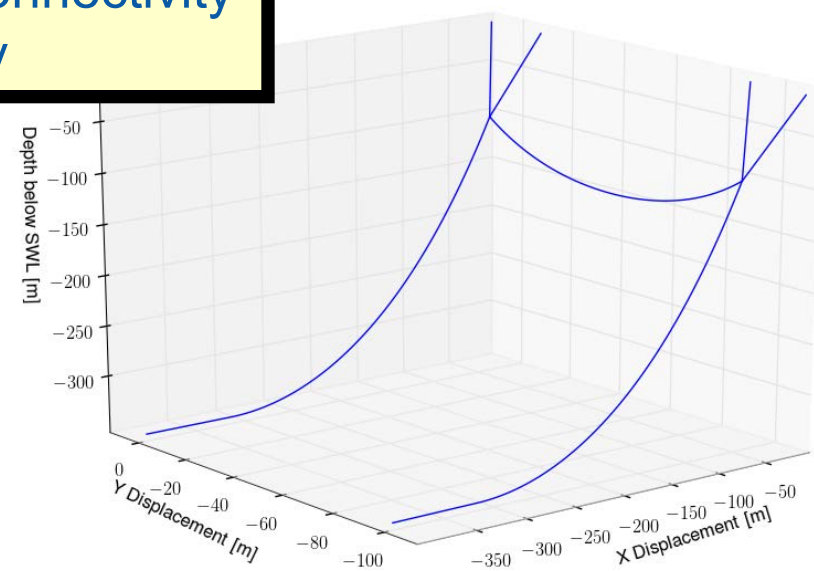
Inputs:
- Platform disp.

Constraint States:
- Line tensions
- Joint locations

Parameters:
- Line properties
- Line connectivity
- Gravity

Outputs:
- Line tensions
- Line disp.

- 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***

NATIONAL RENEWABLE ENERGY LABORATORY

Transition to a Developer Community

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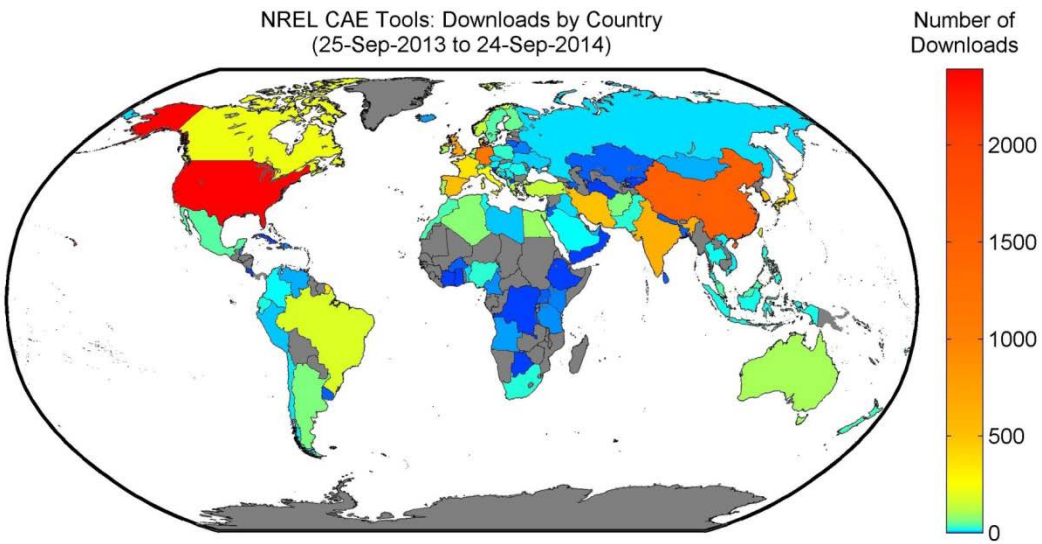
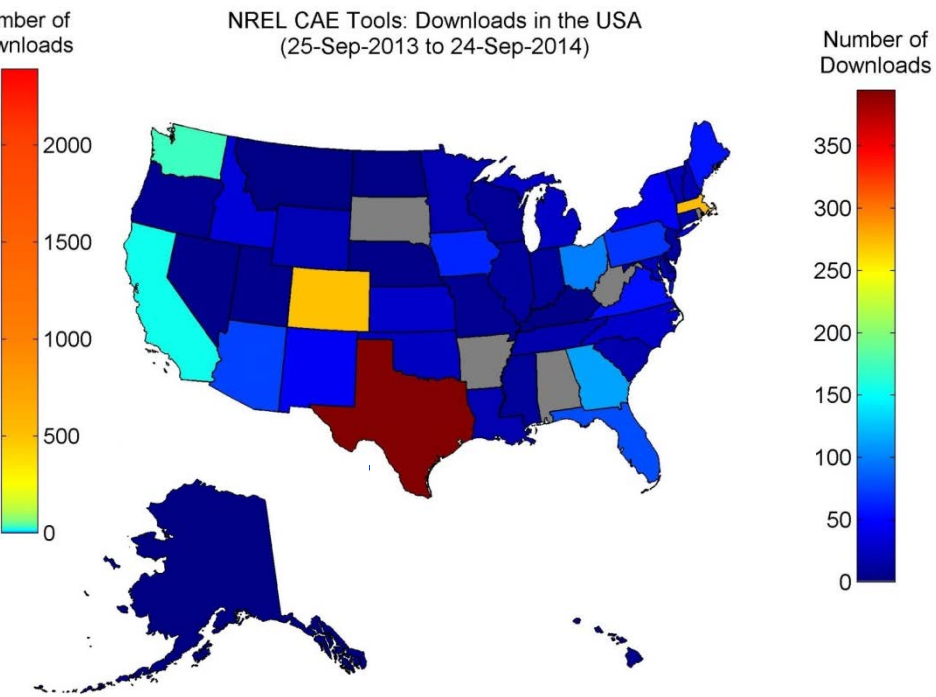
Transition to a Developer Community

Users of DOE/NREL-Developed Tools

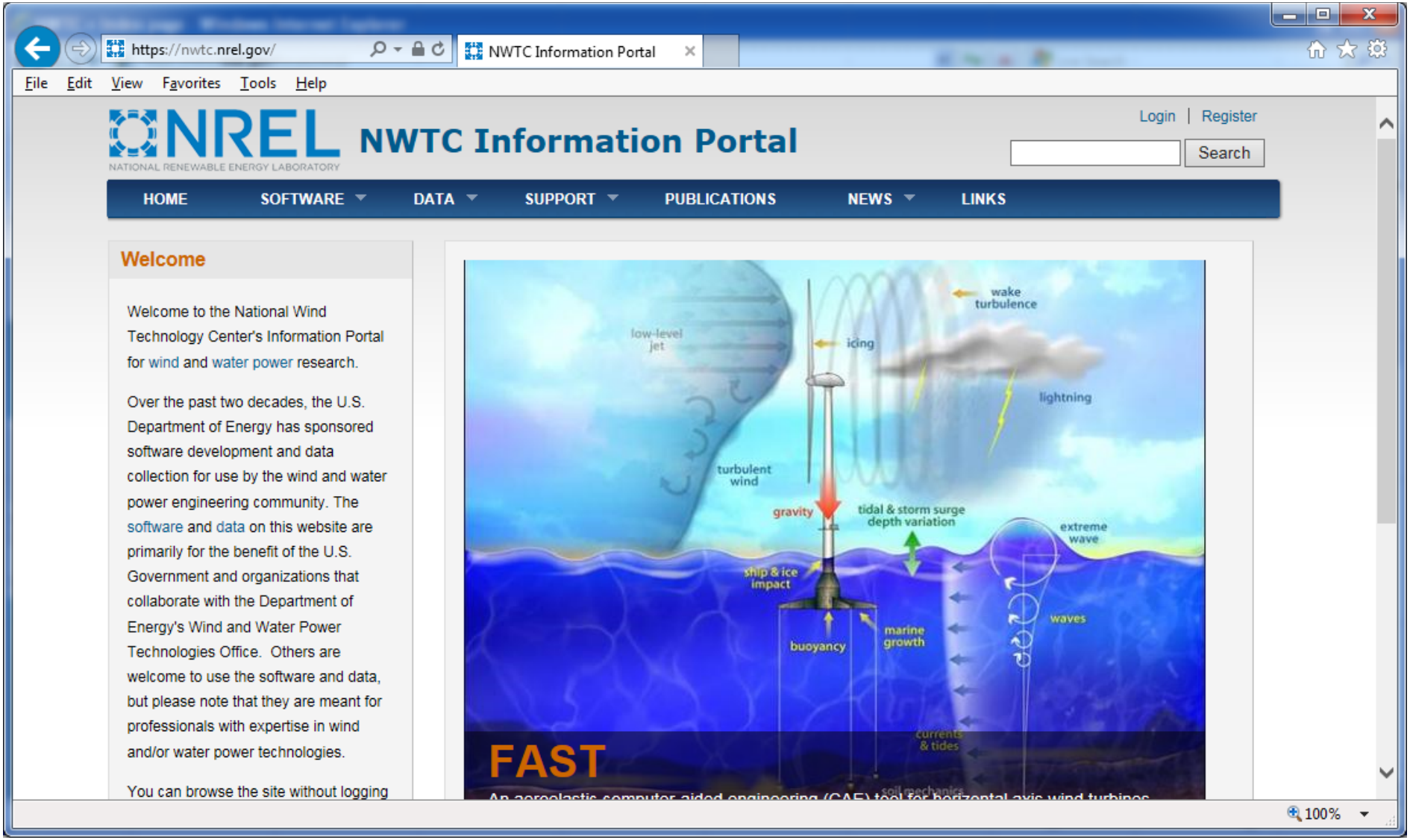
- Used worldwide by designers/manufacturers, consultants, certifiers, researchers, educators, & students:
  - In last 12 months, there have been 12,995 unique downloads by 4,374 users from 1,917 organizations in 114 countries
- Transitioning from an NREL-centric development to a development community





Transition to a Developer Community

NWTC Information Portal



Transition to a Developer Community

NWTC Forum

https://wind.nrel.gov/forum/wind/ | NWTC • Index page

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NWTC

NREL's National Wind Technology Center

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FAQ Members Logout [Jason.Jonkman]

It is currently Thu Jun 04, 2015 4:10 pm

[Moderator Control Panel]

Last visit was: Thu Jun 04, 2015 2:13 pm

View unanswered posts • View new posts • View active topics

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INFORMATION AND ANNOUNCEMENTS	TOPICS	POSTS	LAST POST
Forum Access Requests (READ THIS FIRST BEFORE CREATING AN ACCOUNT) Information on accessing our forums. **Moderator:** Bonnie.Jonkman	2	8	by Bonnie.Jonkman Tue Sep 23, 2014 10:42 am
Answers to Frequently Asked Questions (FAQ) - Read this first before posting Answers to some of the most frequently asked questions can be found here. **Moderator:** Bonnie.Jonkman	1	1	by Marshall.Buhl Tue Jul 02, 2013 9:03 am
News and Announcements Announcements of new or updated CAE and systems engineering software tools, upcoming and past modeling workshops, and other news. **Moderators:** Bonnie.Jonkman, Jason.Jonkman, Katherine.Dykes	3	31	by Bonnie.Jonkman Thu Apr 02, 2015 11:11 am

WIND EXTERNAL	TOPICS	POSTS	LAST POST
Computer-Aided Engineering Software Tools Provide feedback, request enhancements, and get help with wind-turbine computer-aided	710	3665	by Jason.Jonkman Thu Jun 04, 2015 2:12 pm

100%

Transition to a Developer Community

Vision for a FAST Development Community

DOE Program Management
- Establish/maintain board & maint. team
- Manage program

Strategic Board (Labs, Universities, Industry)
- Identify strategic directions
- Engage research community

Maintenance Team (Labs & Key Developers)
- General code & website maintenance
- Support users
- Train developers
- Advise development projects
- Review/correct/approve code
- Integrate modules
- Distribute code
- Independent test & V&V

Developers (Labs, Universities, & Industry)
- Engage boards
- Develop code within the context of the FAST modularization framework
- Test & V&V
- Documentation
- Demonstration

Users (Anyone)
- Apply software to engineering problems
- Report software issues to maintenance team
- Request new features

Transition to a Developer Community

Development Process in a Developer Community

Step	Responsibility
1) Identify new development	Strategic Board, Maintenance Team, & Developers
2) Establish collaboration	Maintenance Team & Developers
3) Develop plan	Developers
4) Code within framework	Developers
5) Local test & V&V	Developers
6) Documentation	Developers
7) Demonstrate improvement	Developers
8) Submit to repository	Developers
9) Review/correct/approve	Maintenance Team
10) Global test & V&V	Maintenance Team
11) Distribute software	Maintenance Team

Transition to a Developer Community

Where Community Stands & Tasks Remaining

Progress Towards Establishing a FAST Development Community:

- Developed modularization framework to be used as code backbone
- Established regression tests for code checking
- Documented theoretical basis, coding requirements, & recommended practices
- Developed a source-code-control repository
- Collaborated with several external contributors:
  - Many others across the research community have customized **FAST** without collaboration
- Supported large user base through forums & workshops

Tasks Remaining to Establish a Development Community:

- Complete **FAST** documentation
- Build an online web presence & software infrastructure for:
  - Downloading, uploading, & controlling source code, including public contribution
  - Compiling **FAST** with different compilers on various platforms
  - Automating regression testing
- Establish strategic board & maintenance team
- Advertise new development community paradigm
- Establish development community training workshops
- Initiate development community collaborations

NATIONAL RENEWABLE ENERGY LABORATORY

Outlook

NAWEA 2015 Symposium

June 8, 2015

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Senior Engineer, NREL

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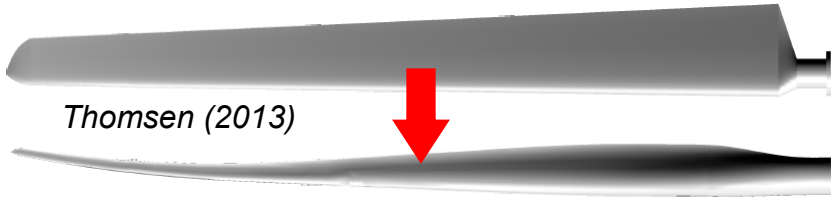
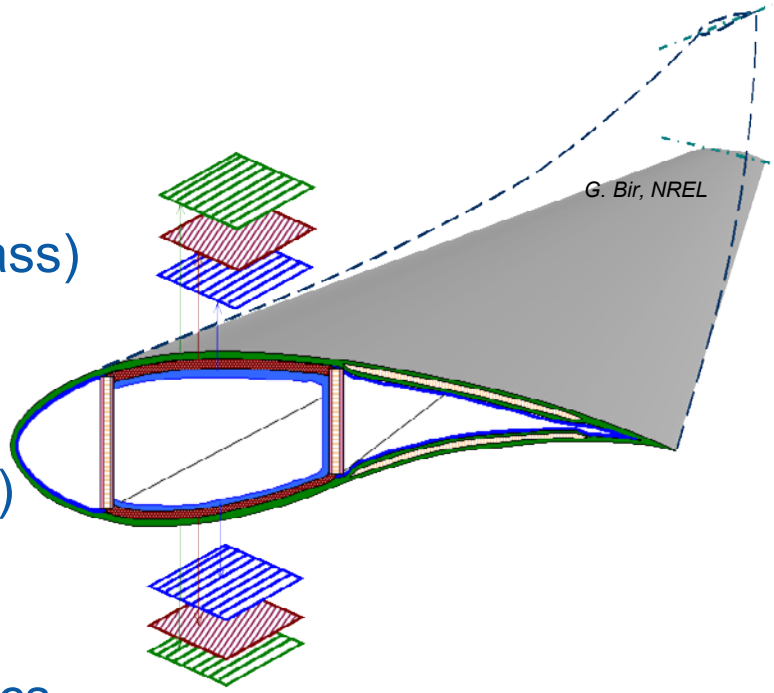
Outlook

Ongoing Developments

- Structural dynamics:
  - **BeamDyn** nonlinear (geometrically exact) beam spectral FE blade dynamics
- Aerodynamics:
  - **AeroDyn** overhaul
  - **OpenFOAM** coupling (**SOWFA**)
  - **DWM** dynamic wake meandering (UMass)
- Hydrodynamics & offshore:
  - User-defined wave input
  - **FIT** nonlinear fluid-impulse theory (MIT)
  - **MoorDyn** lumped-mass mooring dynamics (UMaine)
  - **OrcaFlex** interface for mooring dynamics
- V&V collaboration with Siemens



Advancement in Blade Design



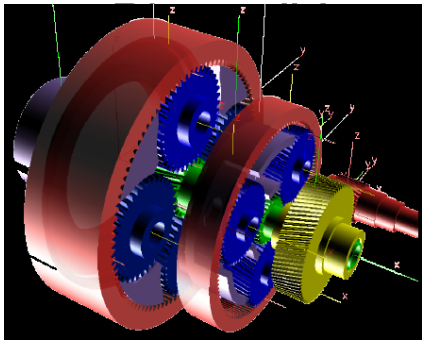
Blade Twist Induced By Anisotropic Layup

Outlook

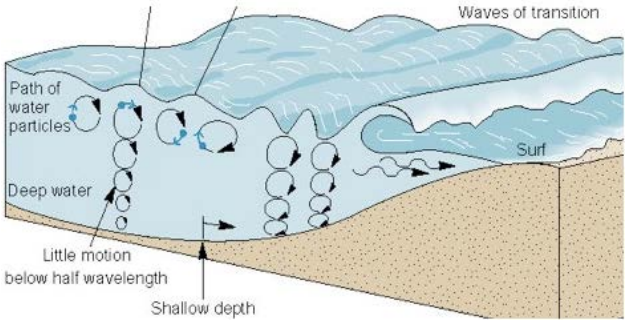
Future Needs

- OP determination & linearization
- Visualization
- Improved wind-plant aerodynamics
- Vortex methods
- Modal-reduced form of **BeamDyn**
- Drivetrain dynamics
- Foundation models (esp. for offshore)
- Structural flexibility of members that have previously been considered rigid (esp. for floating platforms)
- High-order wave models with kinematics up to the free surface
- Further verification & validation

NASA-Ames Test of UAE



***SIMPACK** Gearbox*



Wave Propagation from Deep to Shallow

Outlook

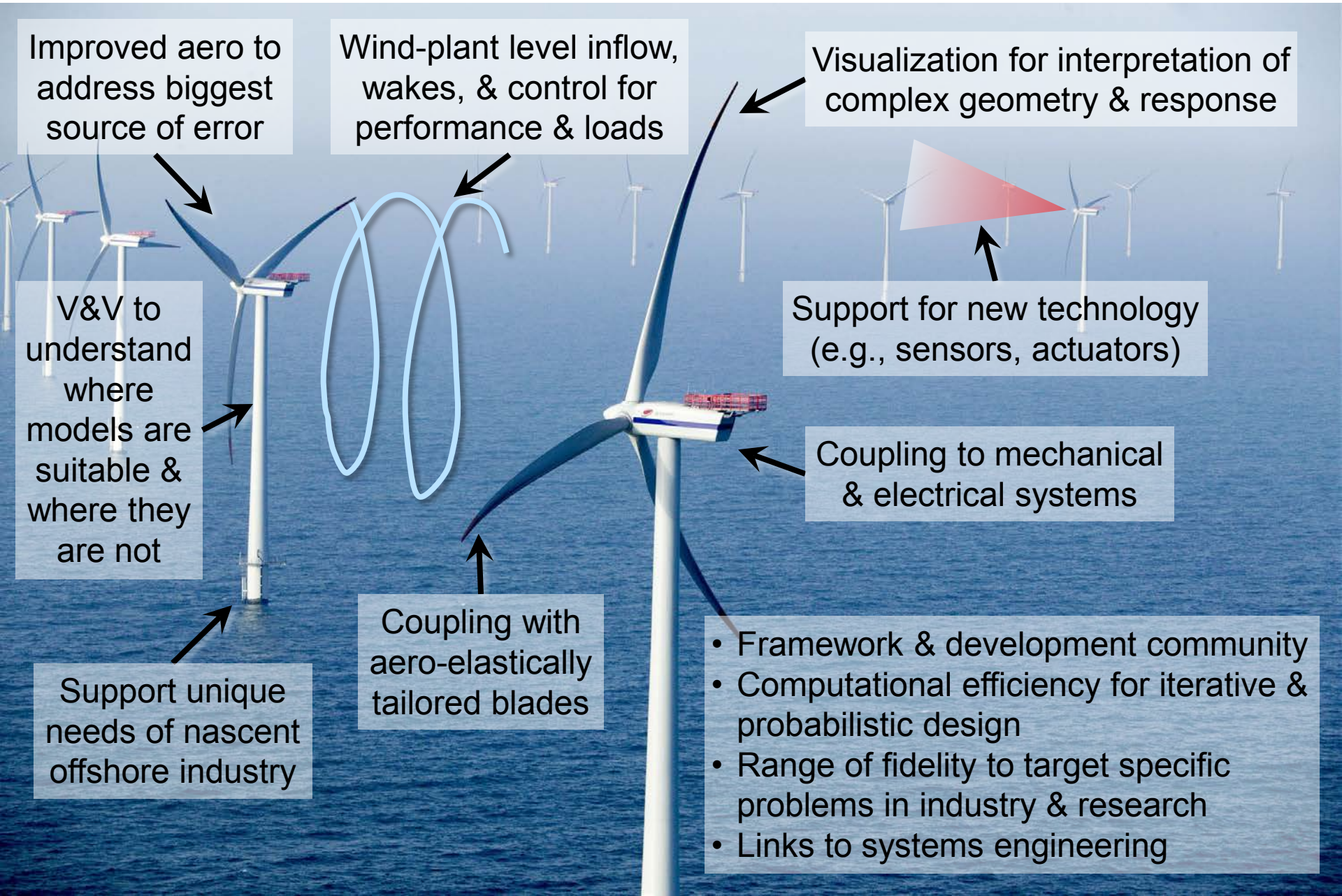
Conclusions

- Engineering models required to address design challenges, so that 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

Outlook – Vision for Future Engineering Models



Outlook

A Final Thought – Quoting George E. P. Box

"Essentially, all models are wrong, but some are useful."

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Carpe Ventum!

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

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