

CAE Tool Overview



NREL Wind Turbine Modeling Workshop

April 17, 2013

JEMA – Tokyo, Japan

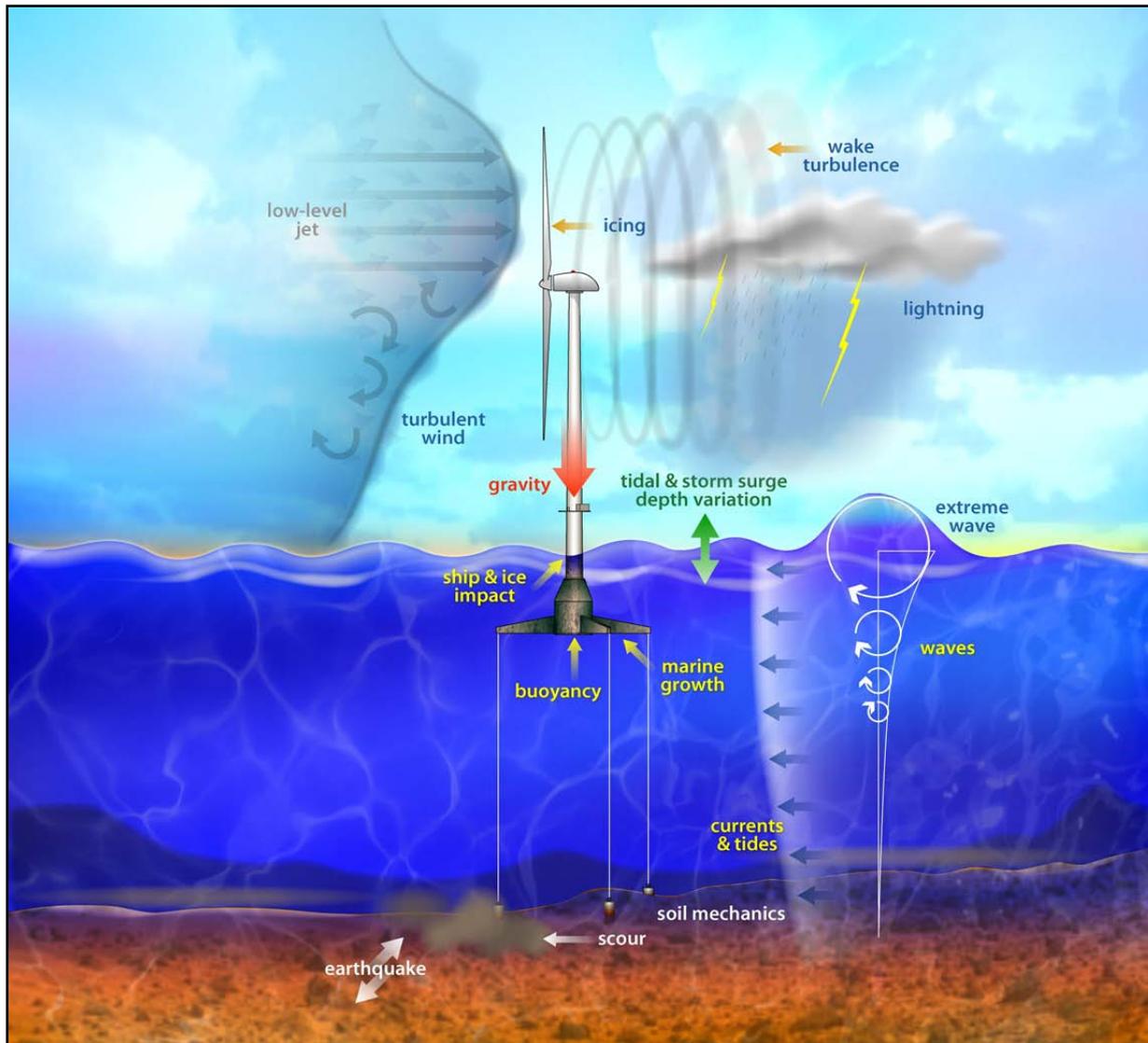
**Jason Jonkman, Ph.D.
Senior Engineer, NREL**

Outline

- Introduction & Background:
 - Modeling Requirements
 - What Kind of Tools Are We Talking About?
 - Wind Turbine Design Process
- CAE Tools:
 - Key NREL Tools in the Design Process
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 - Main Focus: New FAST Modularization Framework
 - Model Verification
 - Model Validation
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 - Users of NREL-Developed Tools
 - Successful Applications
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Introduction & Background

Modeling Requirements

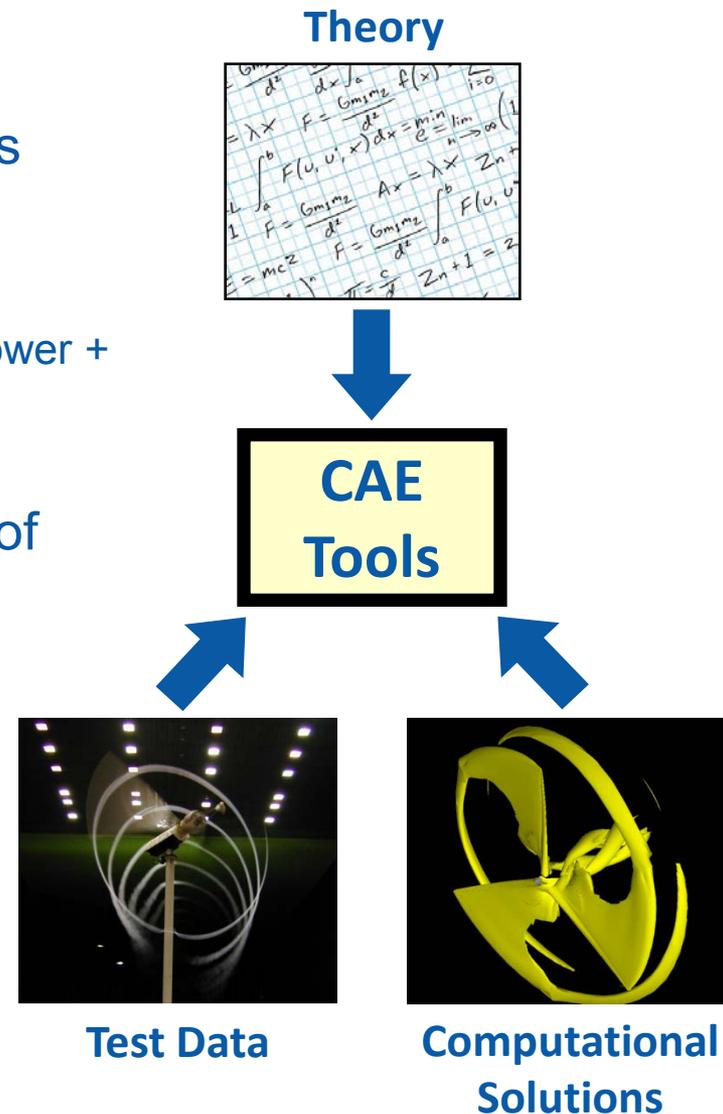


- Coupled aero-hydro-servo-elastic interaction
- Wind-inflow:
 - Discrete events
 - Turbulence
- Waves:
 - Regular
 - Irregular
- Aerodynamics:
 - Induction
 - Rotational augmentation
 - Skewed wake
 - Dynamic stall
- Hydrodynamics:
 - Diffraction
 - Radiation
 - Hydrostatics
- Structural dynamics:
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

Introduction & Background

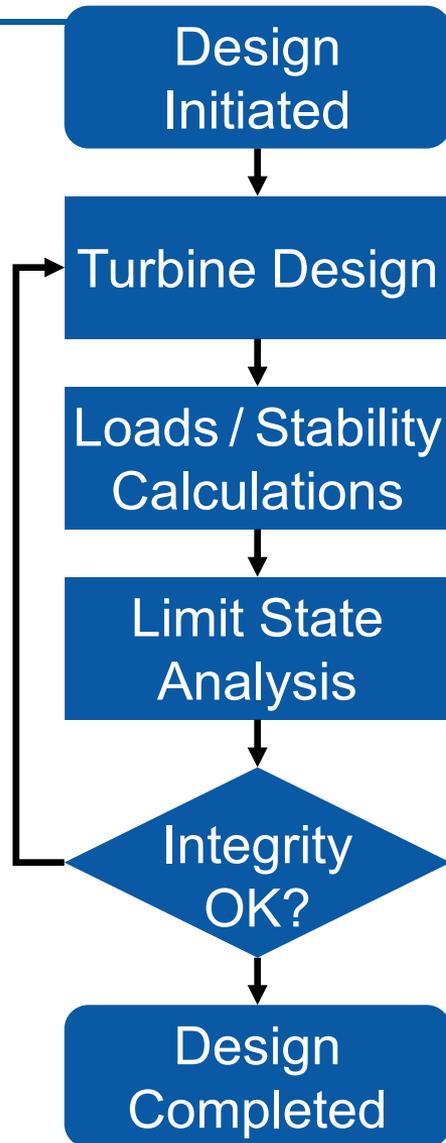
What Kind of Tools Are We Talking About?

- Tools applied in the design process
- Preprocessors, simulators, & post-processors
- The primary (simulation) tools are:
 - Multi-physics models (aero-hydro-servo-elastic)
 - Full-system models (rotor + drivetrain + nacelle + tower + substructure + foundation)
 - Developed uniquely to the wind turbine application
- Tools derived from theory/fundamental laws of physics with appropriate simplifications & assumptions:
 - Supplemented with computational solutions & test data
- Tools developed to run on standard PCs (not supercomputers)
- Tools whose accuracy is only as good as their inputs (often need “calibrating”)



Introduction & Background

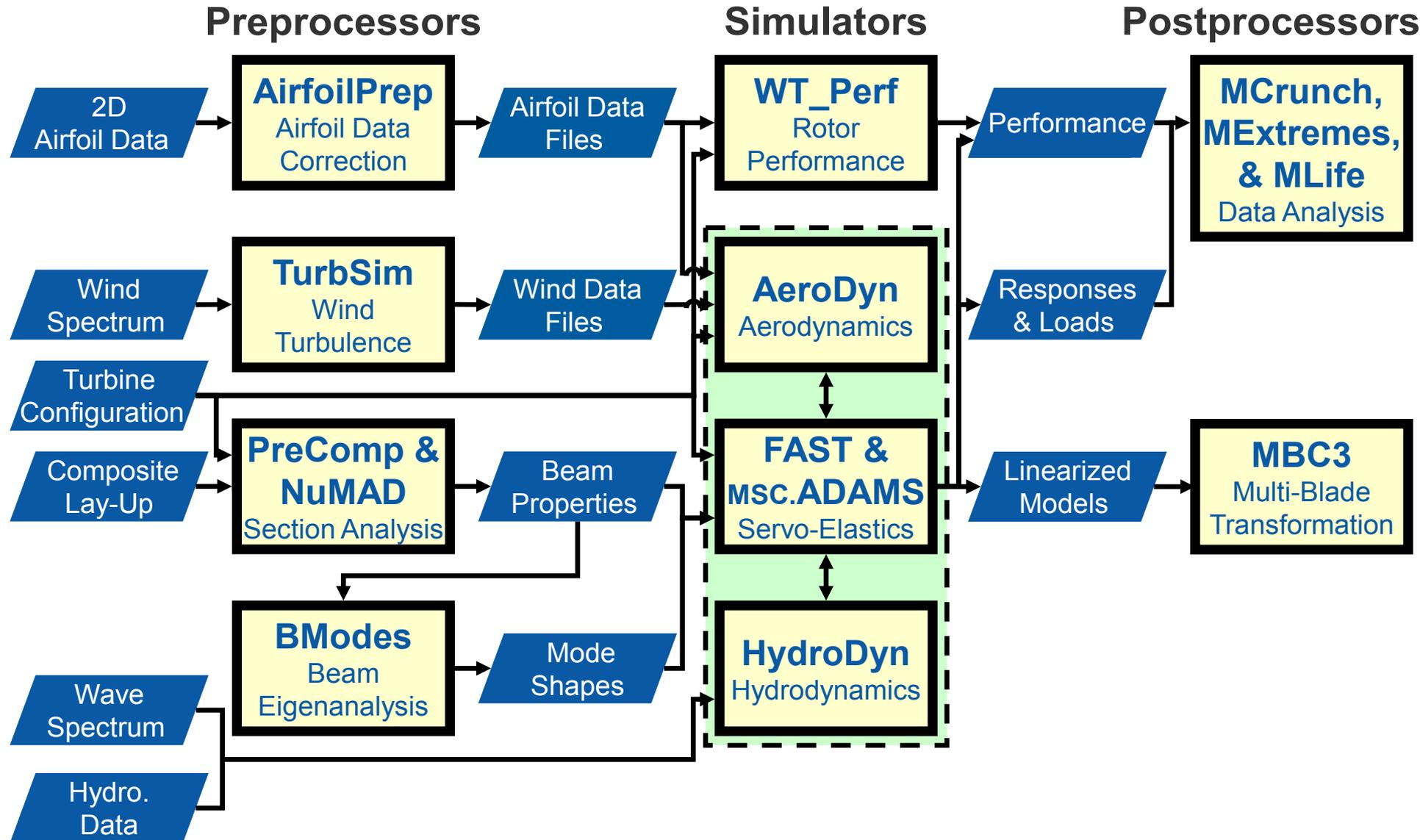
Wind Turbine Design Process



- A design is derived from a design basis, consisting of:
 - Design objectives
 - Environmental conditions
 - Analysis methods
 - Design standards
- Coupled aero-hydro-servo-elastic models of the full system are used to calculate loads / stability
- The loads are used within component models (e.g., FEA) to perform limit state analysis
- The design is iterated until structural integrity is achieved
- Structural integrity achieved when:
 $\text{Design Load} \leq \text{Design Resistance}$

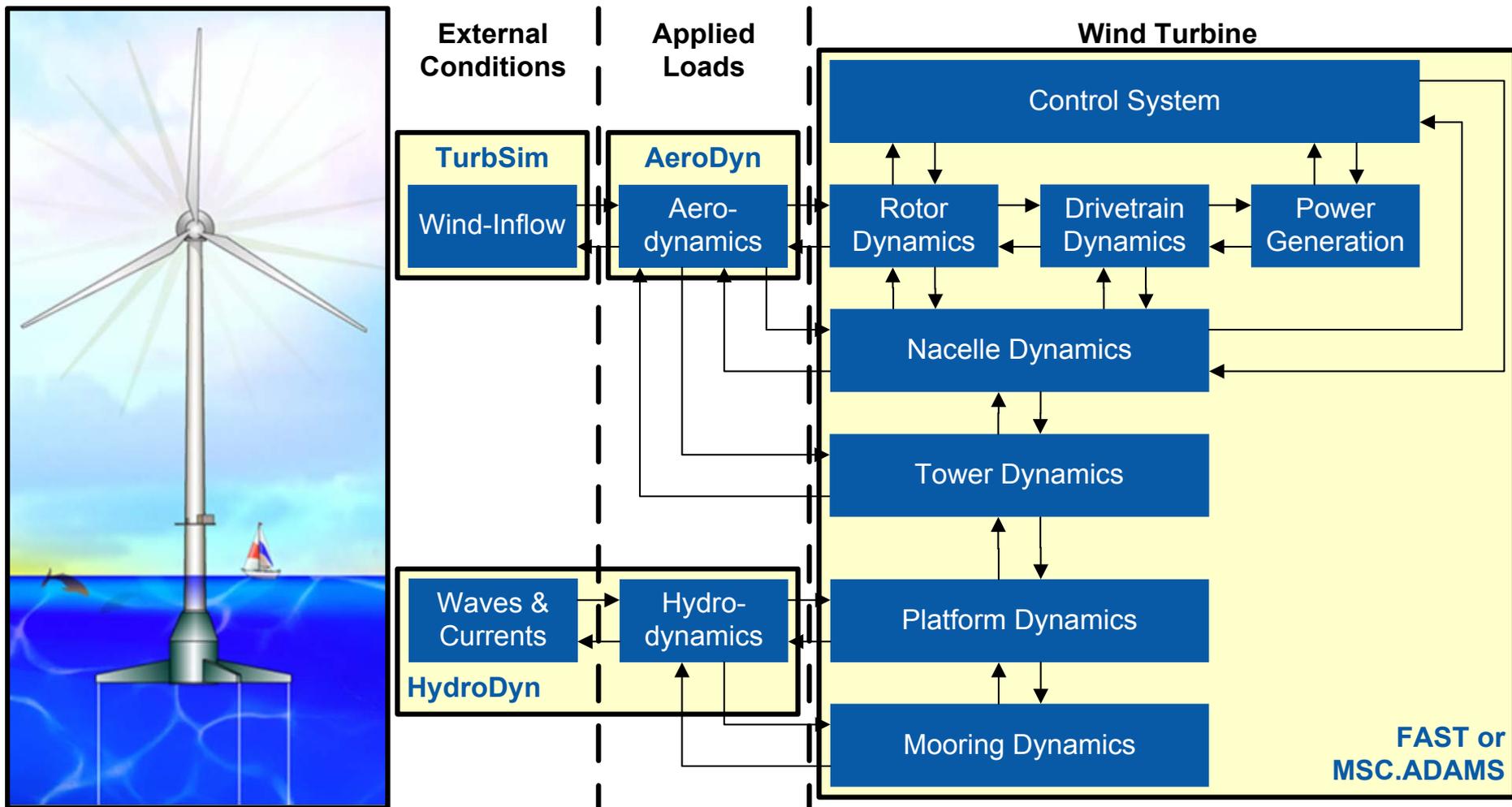
CAE Tools

Key NREL Tools in the Design Process



CAE Tools

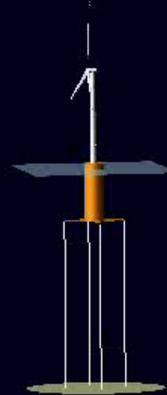
FAST-AeroDyn-HydroDyn Coupling



CAE Tools

Sample MIT/NREL TLP Response

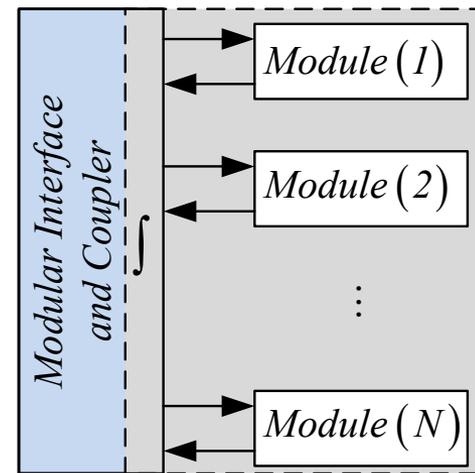
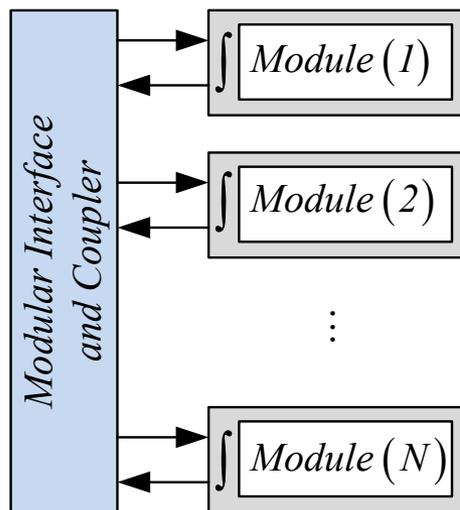
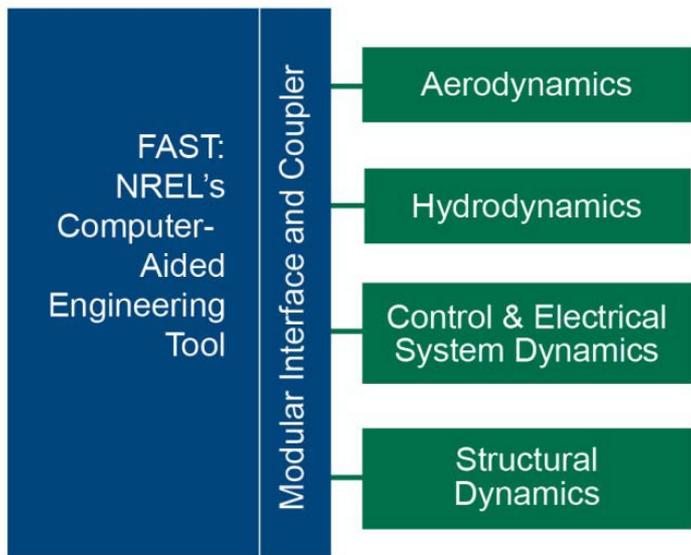
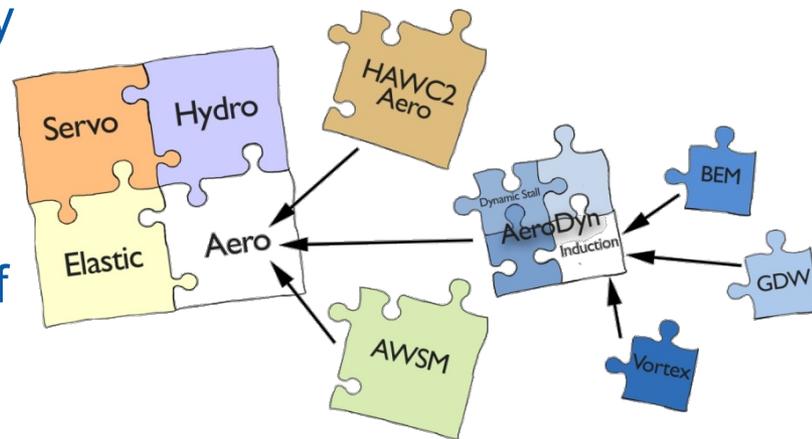
NRELOffshrBslne5MW_Floating_TLP_ADAMS Time= 0.0000 Frame=0001



CAE Tools

Main Focus: New FAST Modularization Framework

- Motivation – Increasing system complexity requires coupled analysis
- Benefits – Enables shared code development, increases maintainability, improves numerics, & eases integration of science advances
- Challenges – Establishing standardized interfaces & coupling schemes

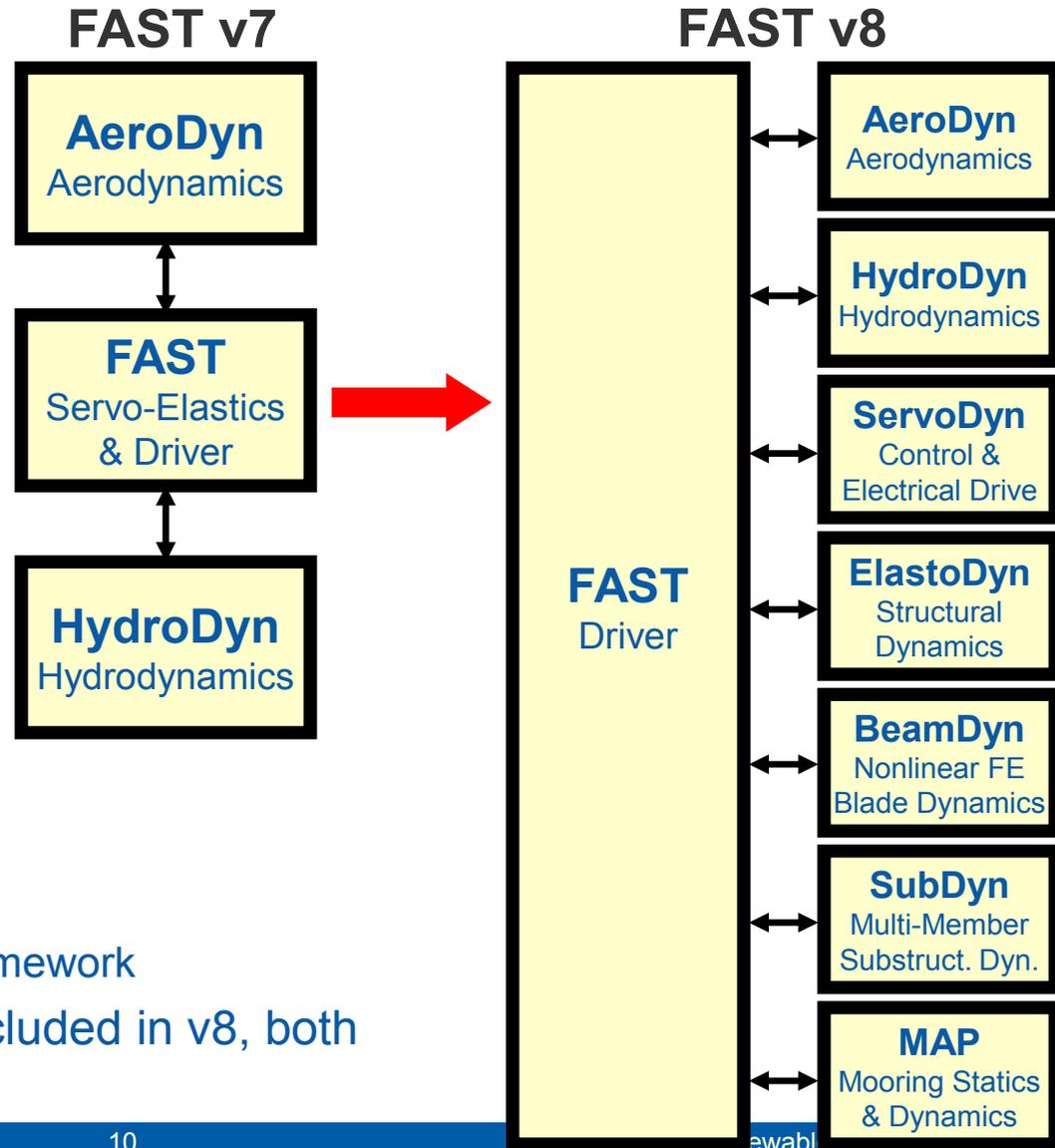


Loose- (left) and tight- (right) coupling schemes

CAE Tools

Main Focus: FAST Modularization (cont)

- This workshop will apply **FAST v7**, which is in the old framework
- All new features are being added to **FAST v8**, which is in the new modularization framework
- Current limitations of **FAST v8**:
 - No hydrodynamics
 - No earthquake excitation
 - No furling
 - No gearbox friction
 - No tip or HSS brakes
 - No noise
 - No linearization
 - No FAST-to-ADAMS preprocessor
 - No **Simulink** or **LabVIEW** interface
 - User-defined routines not yet in framework
- Until all features of **FAST v7** are included in v8, both versions will be supported



CAE Tools

Main Focus (cont)

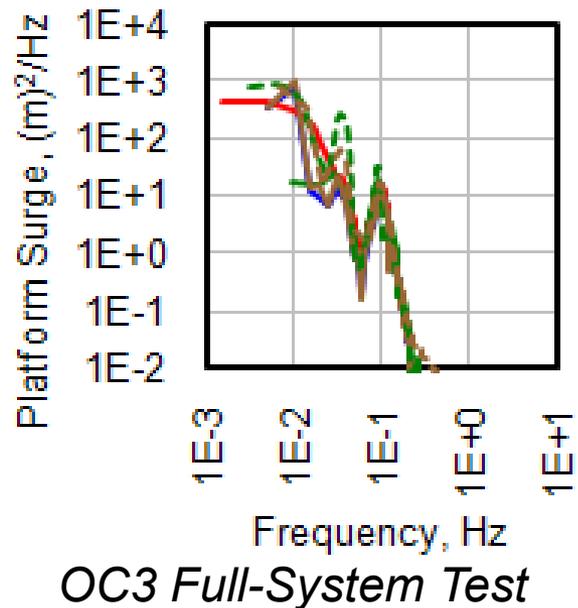
- Distinguishing features of **FAST v8**:
 - Module-independent inputs, outputs, states, & parameters
 - States in continuous-time, discrete-time, & in constraint form
 - Loose & tight coupling
 - Independent time & spatial discretizations
 - Time marching, operating-point determination, & linearization
 - Data encapsulation & dynamic allocation
 - Save/retrieve capability
 - Modules with new functionality

Features	Loose	Tight
Module-Independent Variables		
• Inputs	✓	✓
• Outputs	✓	✓
• Parameters	✓	✓
• Continuous states	✓	✓
• Discrete states	✓	✓
• Constraint states	✓	✓
System Formulation		
• Explicit continuous-time ODEs	✓	✓
• Explicit discrete-time updates	✓	✓
• Constraint equations of index 1	✓	✓
• Output equations with direct feedthrough	✓	✓
• Semi-explicit DAEs of index 1	✓	✓
• Systems of any form	✓	
Independent Spatial Discretizations		
• Available	✓	✓
Operating-Point Determination		
• Static equilibrium		✓
• Steady state		✓
• Periodic steady state		✓
• With trim of inputs		✓
Linearization		
• About given initial conditions		✓
• About given time		✓
• About operating point		✓
Time Marching		
• From given initial conditions	✓	✓
• From operating point		✓
• Independent time steps for continuous states between modules	✓	
• Independent time steps for discrete states between modules	✓	✓
Solution		
• Solver implementation is up to the module developer	✓	
• Solver is selectable from those available in the glue		✓
• Overall solvability, numerical stability, and convergence verifiable		✓
Data Encapsulation and No Global Data		
• Required	✓	✓
Dynamic Allocation of Instances of Modules		
• Available	✓	✓
Save/Retrieve Capability		
• Available	✓	✓

CAE Tools

Model Verification (Code-to-Code)

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

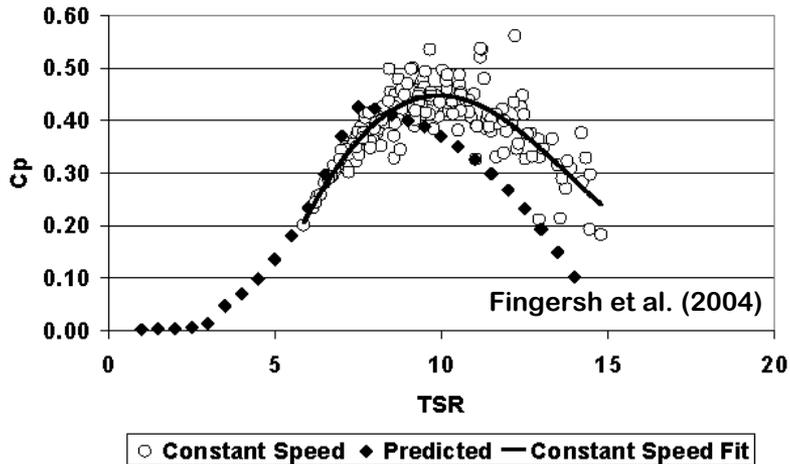


**GL Certificate Approving
FAST & ADAMS with AeroDyn**

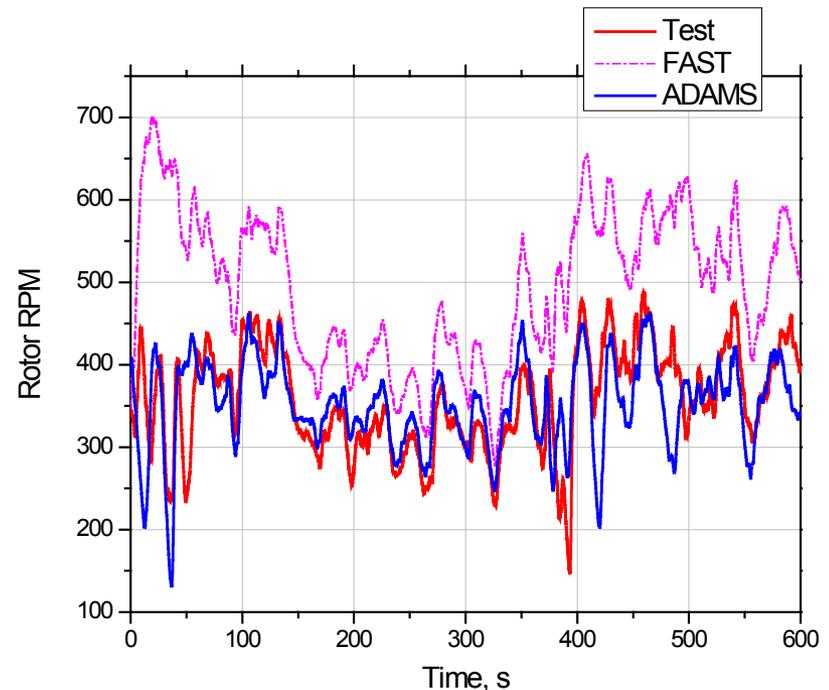
CAE Tools

Model Validation (Code-to-Data)

- UAE Phase VI
- SWRT
- CART2 & CART3
- Many industry wind turbines (confidential)
- Floating validation in progress



Comparison of Uncalibrated WT_Perf Prediction to CART2 Data



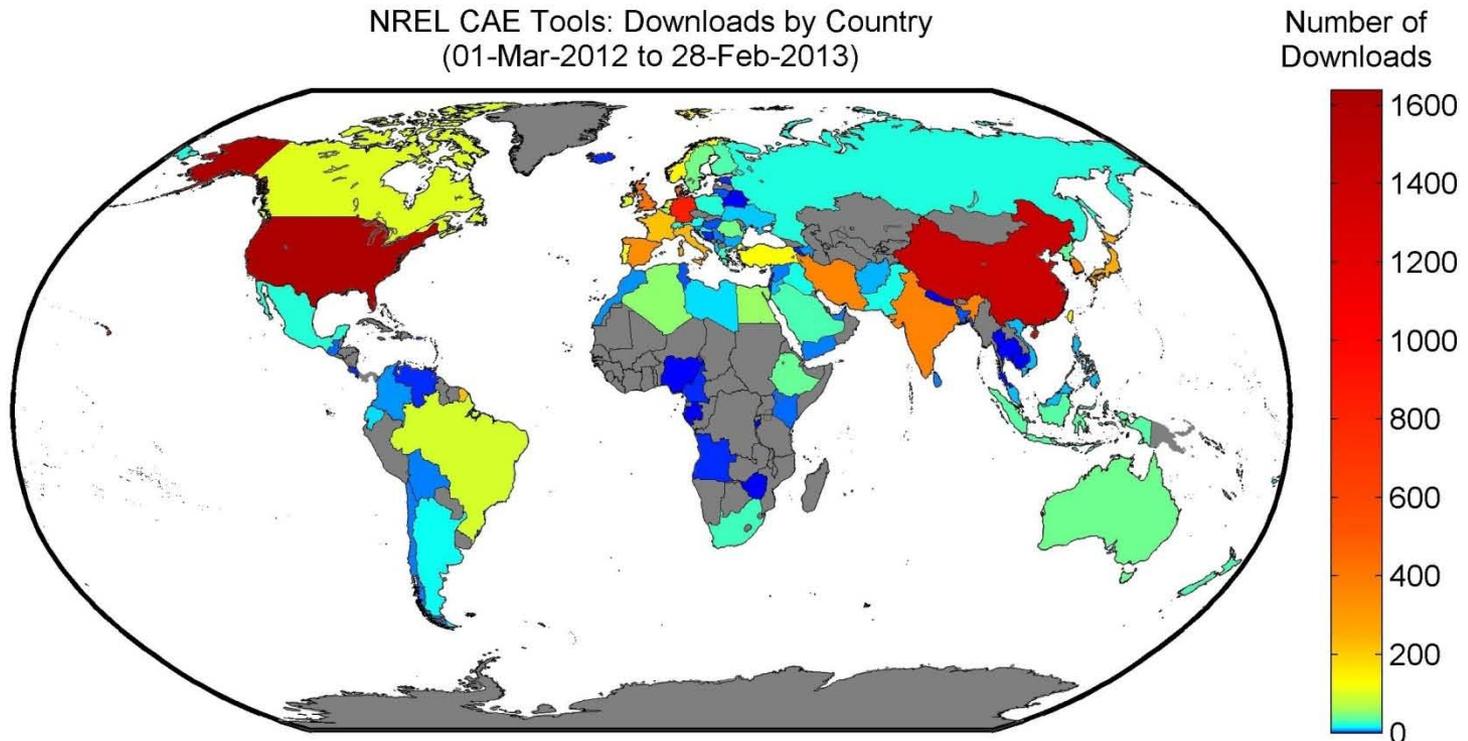
*SWRT in high winds – **ADAMS** has Blade Torsion, **FAST** doesn't*

Users & Support

Users of NREL-Developed Tools

- Used worldwide by wind turbine manufacturers, consultants, certifiers, researchers, educators, & students
- In last 12 months, there have been 9,506 unique downloads by 3,596 users from 1,257 organizations in 102 countries

NREL CAE Tools: Downloads by Country
(01-Mar-2012 to 28-Feb-2013)



Users & Support

Successful Applications (Only Subset Shown)



*Southwest
Windpower
Skystream*



CART2



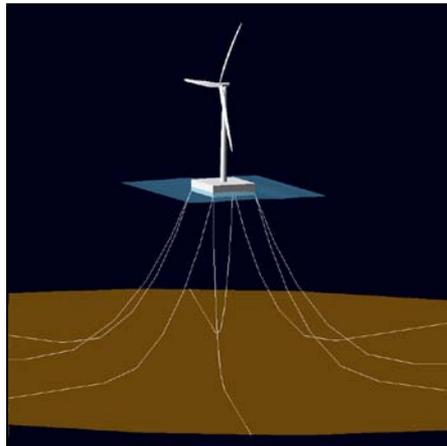
*Clipper 2.5-MW
Liberty*



NorthWind 100



GE 1.5 MW



NREL 5-MW Turbine on ITI Energy Barge

Users & Support

NWTC CAE Tools Website

The screenshot shows a Windows Internet Explorer browser window displaying the NWTC Computer-Aided Engineering Tools website. The browser's address bar shows the URL <http://wind.nrel.gov/designcodes/>. The website features the NREL logo (National Renewable Energy Laboratory) and a banner for the NWTC Information Portal. The main heading is "Computer-Aided Engineering Tools". On the left, there is a "Contents" section with links to "NWTC Portal", "CAE Tools", "Disclaimer", "Preprocessors", "Simulators", and "Postprocessors". The "Introduction" section contains the following text:

Introduction

Welcome to the NWTC Computer-Aided Engineering Tools web site. These computer codes are available in beta-test versions for those who wish to evaluate them. They are research tools that are subject to revision. Please read the explanations and warnings in the introductions before you decide to download a code.

This page is primarily for the benefit of the US Government and organizations that have contracts with the Department of Energy's Wind and Water-Power Program. Others are welcome to use the software, but we do not have the resources to support them.

The browser's status bar at the bottom shows the address <http://www.nrel.gov/>, a "Local intranet" icon, and a 100% zoom level.

Users & Support

NWTC Forum

NWTC • Index page - Windows Internet Explorer

https://wind.nrel.gov/forum/wind/

File Edit View Favorites Tools Help

McAfee SiteAdvisor Convert Select

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NREL HOME

NWTC
NREL's National Wind Technology Center

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FAQ Members Logout [Jason.Jonkman]

It is currently Mon Mar 25, 2013 4:18 pm
[Moderator Control Panel]

Last visit was: Mon Mar 25, 2013 2:35 pm

View unanswered posts • View new posts • View active topics

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WIND EXTERNAL	TOPICS	POSTS	LAST POST
 Access Requests (READ THIS FIRST BEFORE CREATING AN ACCOUNT) Information on accessing our forums. Moderators: Marshall.Buhl, Andy.Platt	1	3	by Marshall.Buhl Thu Mar 07, 2013 4:04 pm
 Computer-Aided Engineering Software Tools Provide feedback, request enhancements, and get help with wind-turbine computer-aided engineering tools. Moderators: Marshall.Buhl, Andy.Platt	432	2093	by Jason.Jonkman Mon Mar 25, 2013 6:09 am
 Rotor Aerodynamics	30	140	by Kisorthman.Vimalakanthan

Local intranet 100%

Questions?



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