NREL
NATIONAL RENEWABLE ENERGY LABORATORY

CAE Tool Overview

NREL Wind Turbine Modeling Workshop

August 9, 2013

CU – Boulder, CO (USA)

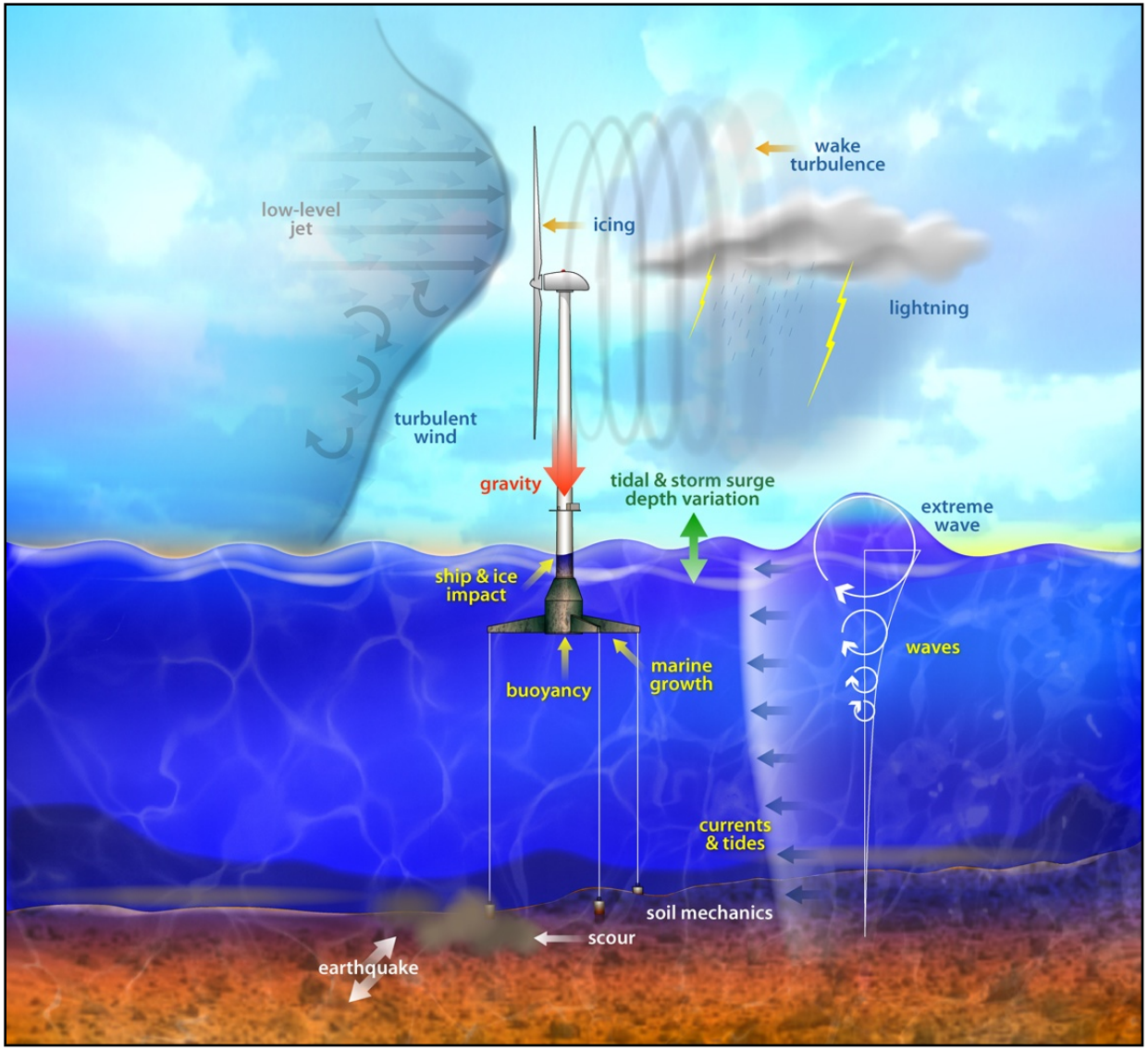
Jason Jonkman, Ph.D.
Senior Engineer, NREL

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
  - FAST-AeroDyn-HydroDyn Coupling
  - Main Focus: New FAST Modularization Framework
  - Model Verification
  - Model Validation
- Users & Support:
  - Users of NREL-Developed Tools
  - Successful Applications
  - Website & Forum

Introduction & Background

Modeling Requirements

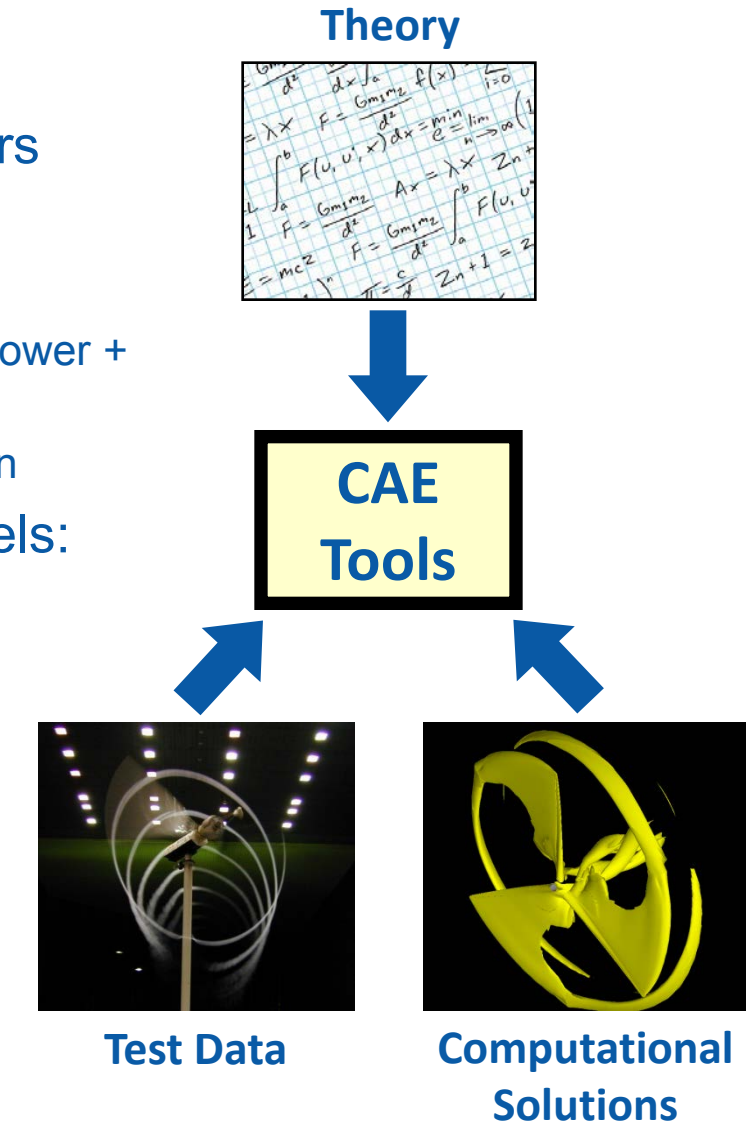


- Coupled aero-hydro-servo-elastic interaction
- Wind-inflow:
  - –Discrete events
  - –Turbulence
- Waves:
  - –Regular
  - –Irregular
- Aerodynamics:
  - –Induction
  - –Rotational augmentation
  - –Skewed wake
  - –Dynamic stall
- Hydrodynamics:
  - –Diffraction
  - –Radiation
  - –Hydrostatics
-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

Introduction & Background

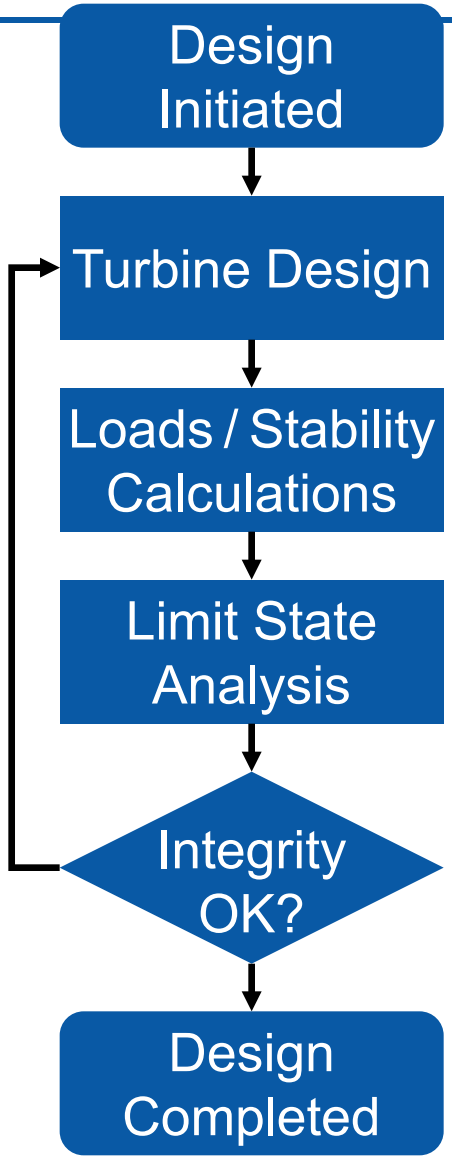
What Kind of Tools Are We Talking About?

- 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 for the wind system application
- Tools based on advanced engineering models:
  - 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”)

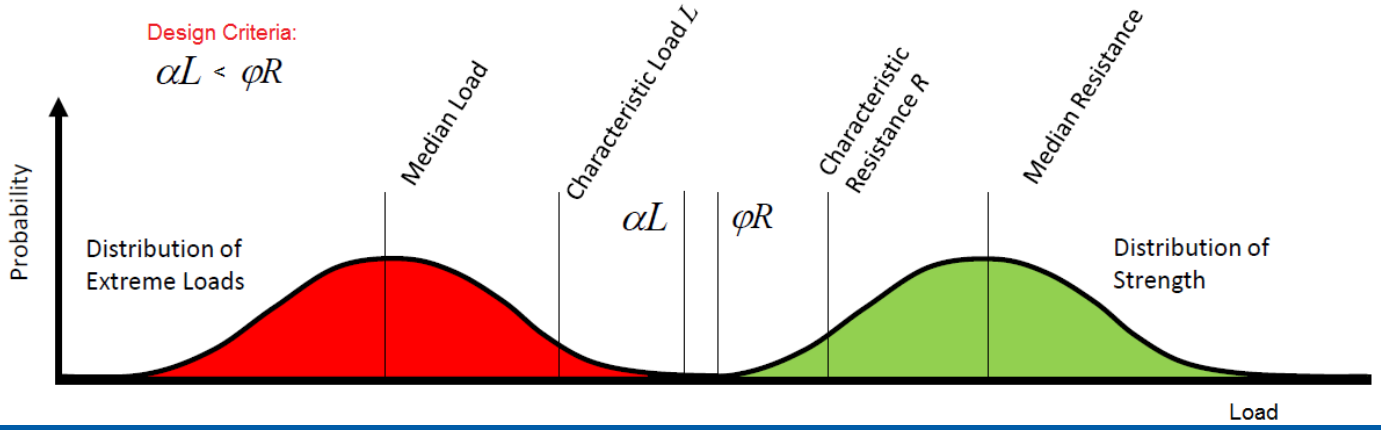


Introduction & Background

Wind Turbine Design Process

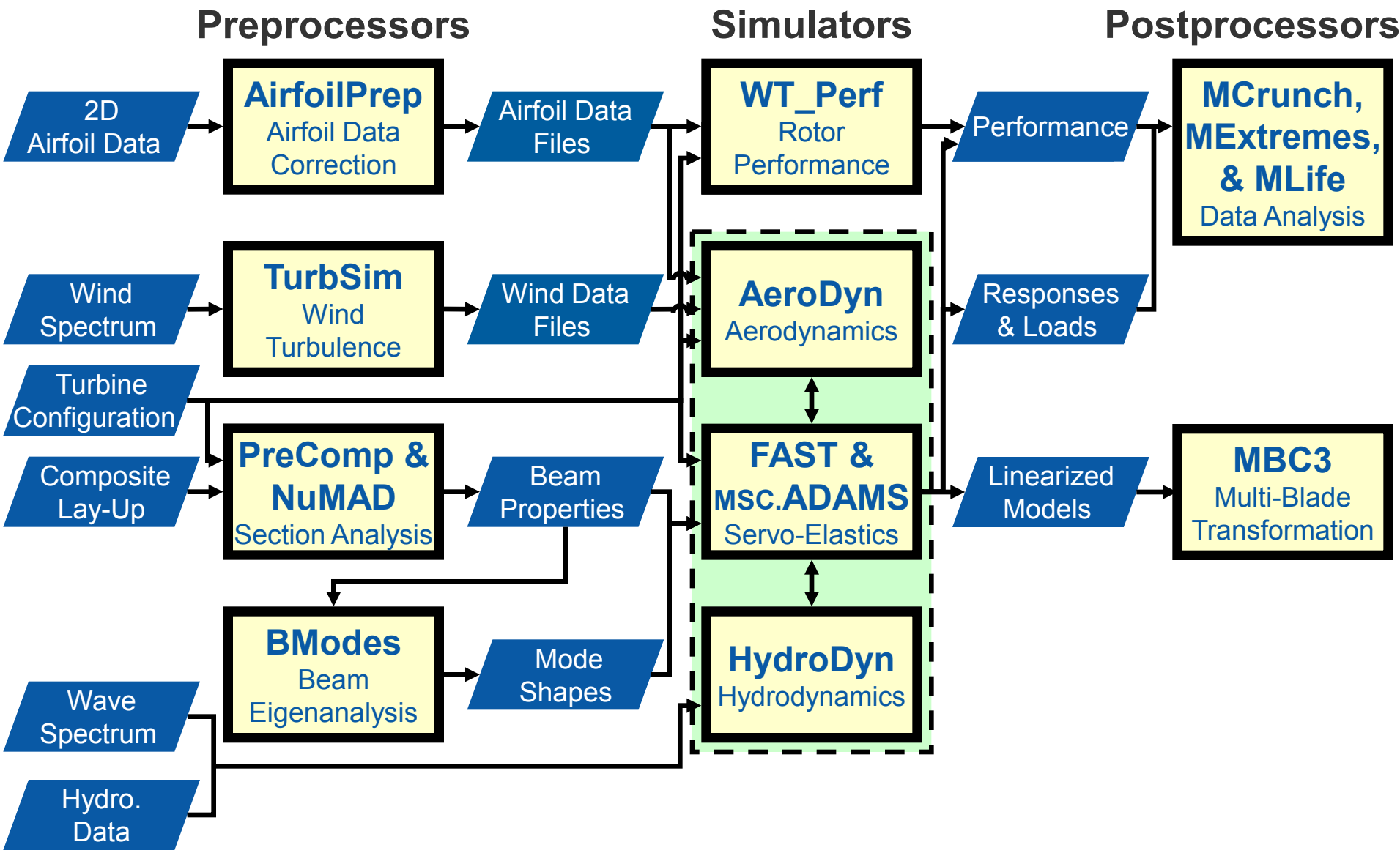


- A design is derived from a design basis, consisting of:
  - Design objectives
  - Environmental conditions
  - Analysis methods
  - Design standards
- Coupled aero-hydro-servo-elastic models of the full system are used to calculate loads / stability
- The loads are used within component models (e.g.,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



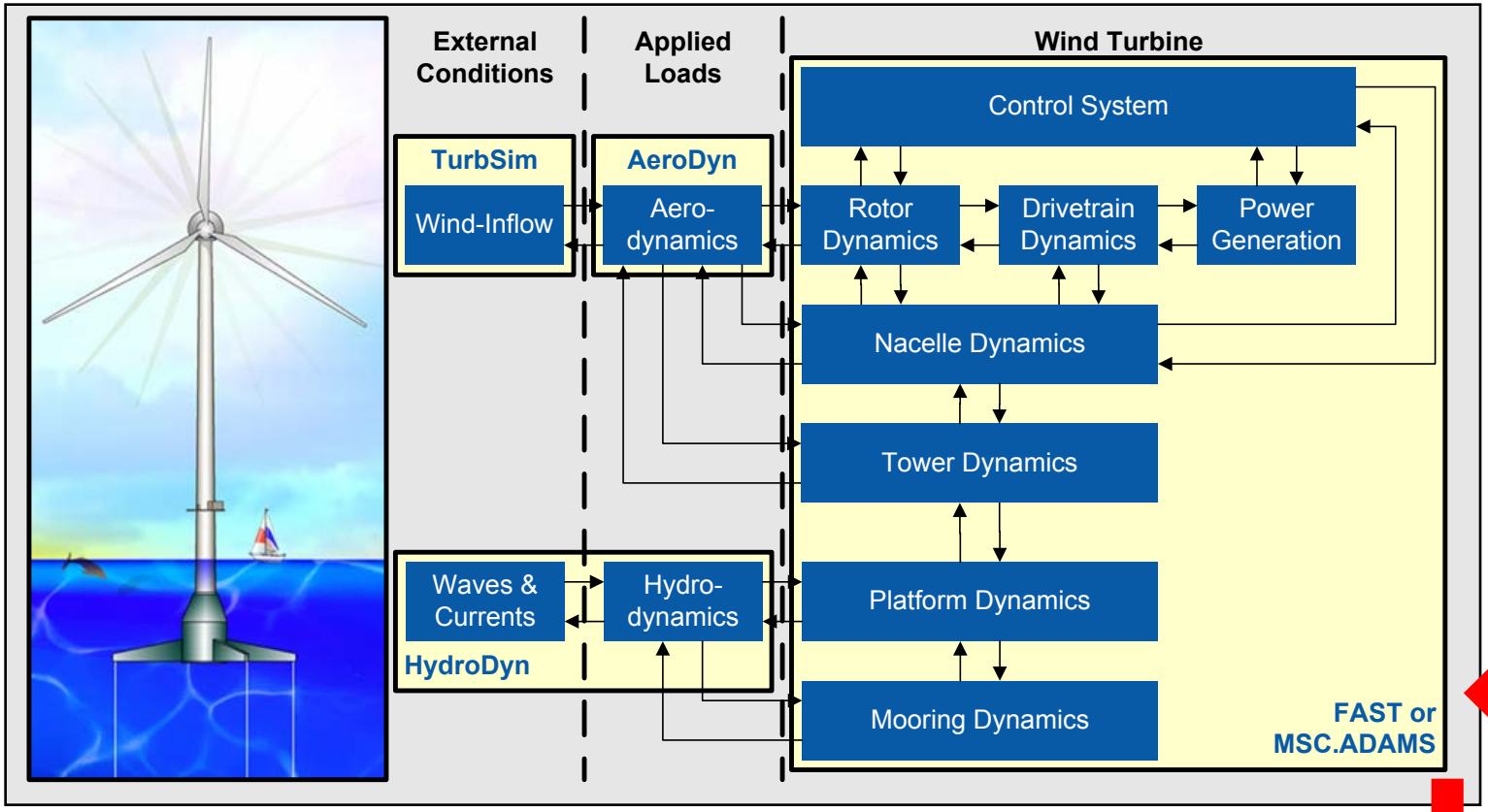
CAE Tools

Key NREL Tools in the Design Process



CAE Tools

FAST-AeroDyn-HydroDyn Coupling

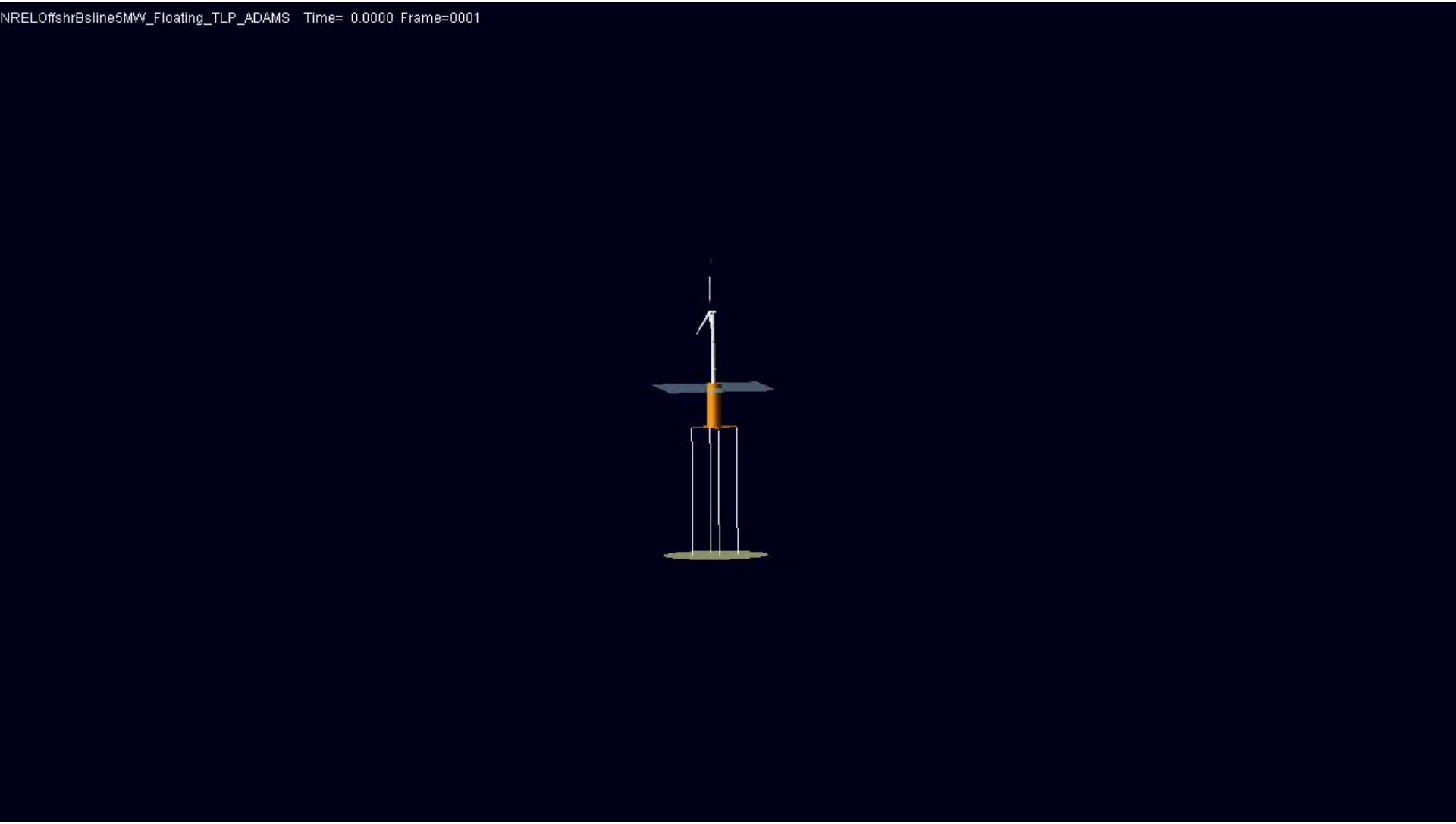


Full-System Level

Component Level

CAE Tools

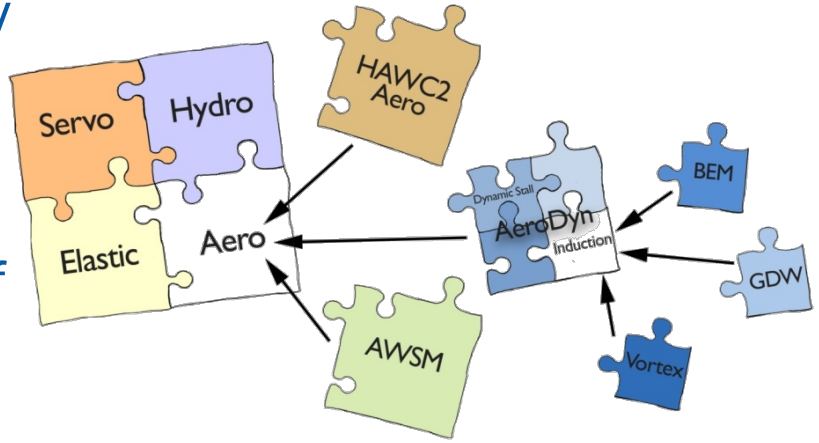
Sample MIT/NREL TLP Response

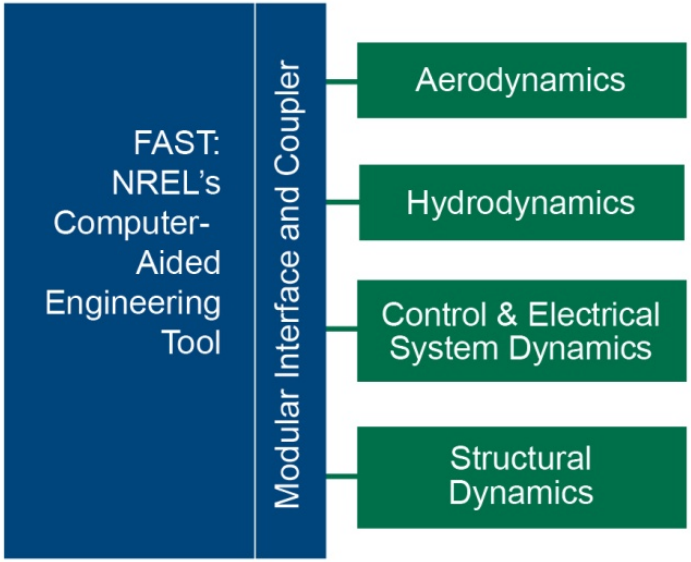


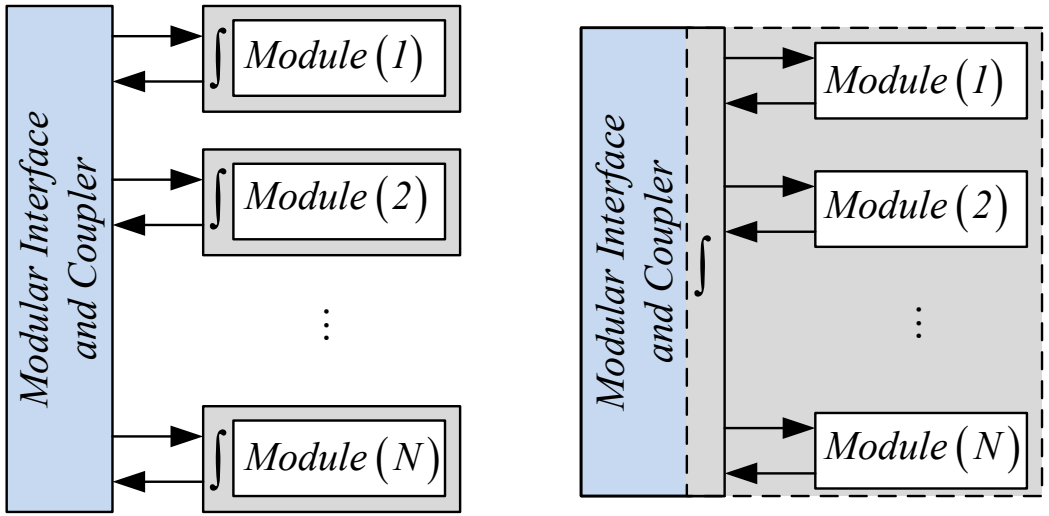
CAE Tools

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





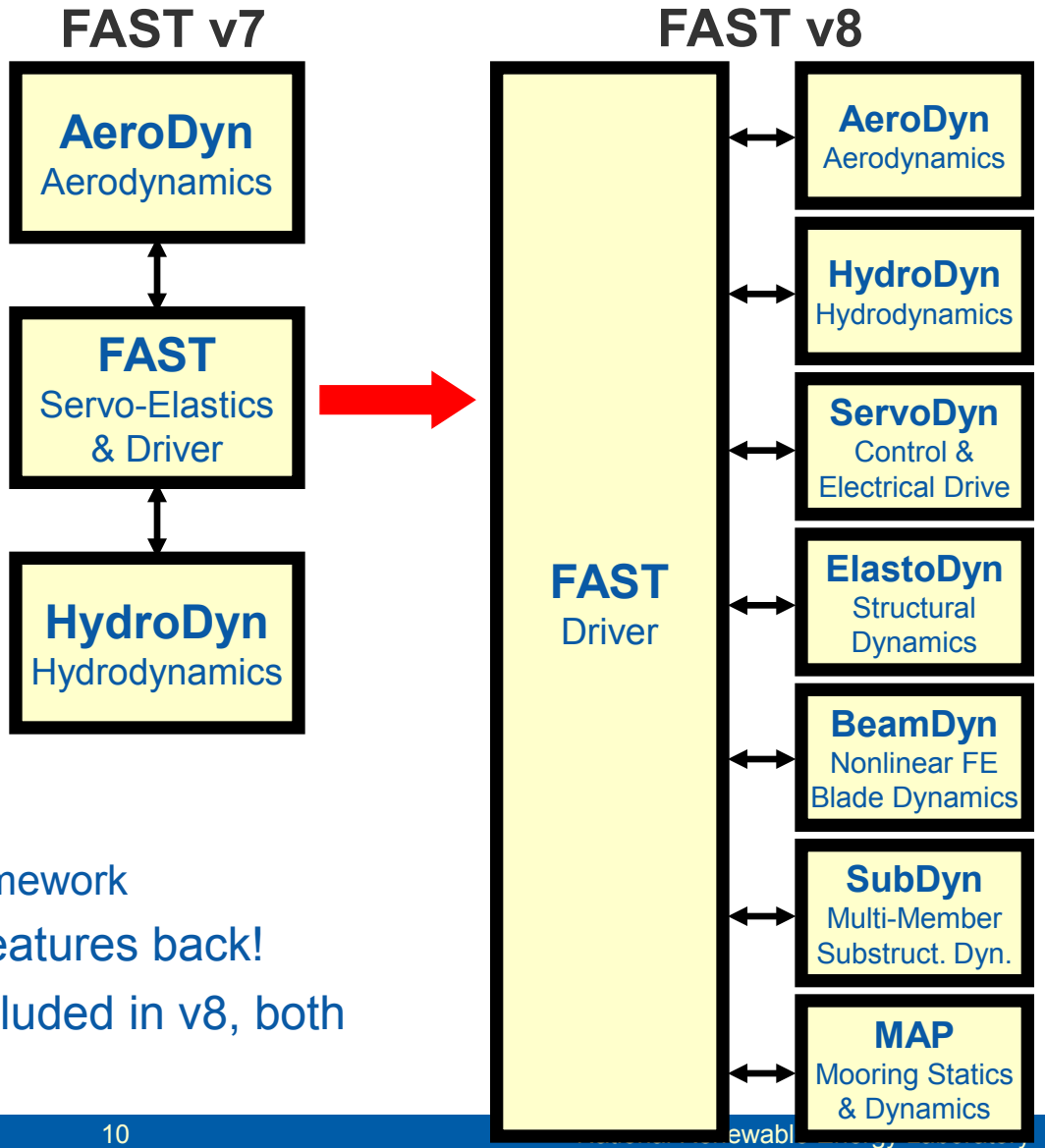


Loose- (left) and tight- (right) coupling schemes

CAE Tools

Main Focus: FAST Modularization (cont)

- This workshop will apply **FAST** v7, which is pre-framework
- All new features are being added to **FAST** v8, which is in the new modularization framework
- Current limitations of **FAST** v8:
  - 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
- Don't worry, we plan to add these features back!
- Until all features of **FAST** v7 are included in v8, both versions will be supported



CAE Tools

Main Focus (cont)

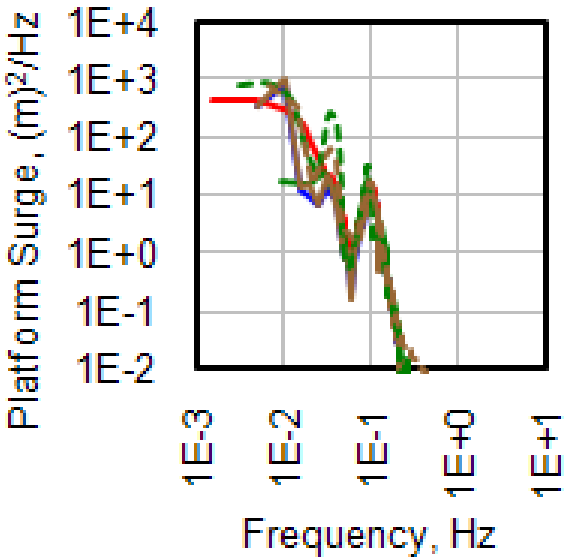
- Distinguishing features of **FAST** v8:
  - Module-independent inputs, outputs, states, & parameters
  - States in continuous-time, discrete-time, & in constraint form
  - Loose & tight coupling
  - Independent time & spatial discretizations
  - Time marching, operating-point determination, & linearization
  - 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	✓	✓

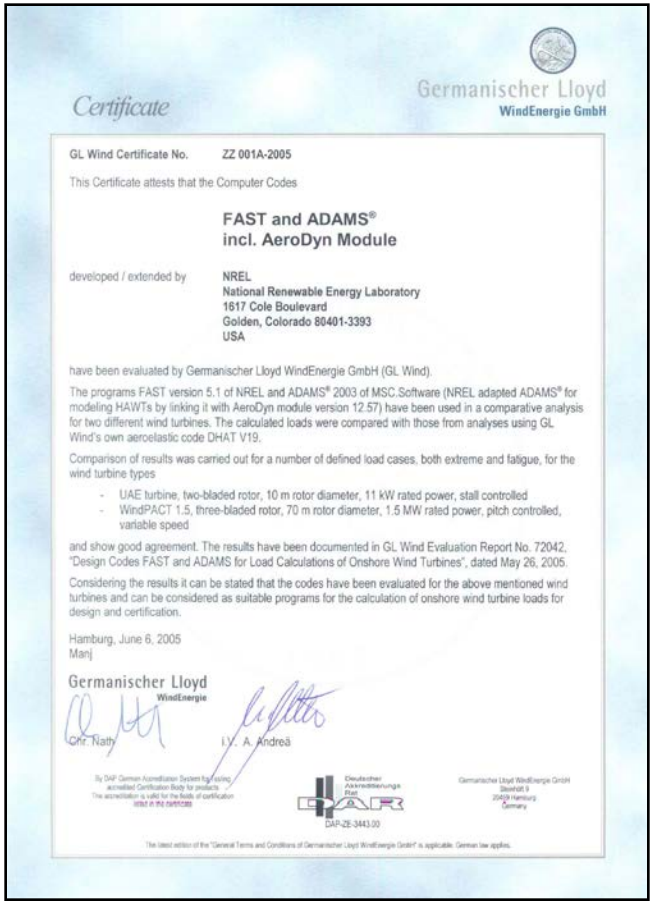
CAE Tools

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**



OC3 Full-System Test



Germanischer Lloyd
WindEnergie GmbH

Certificate

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

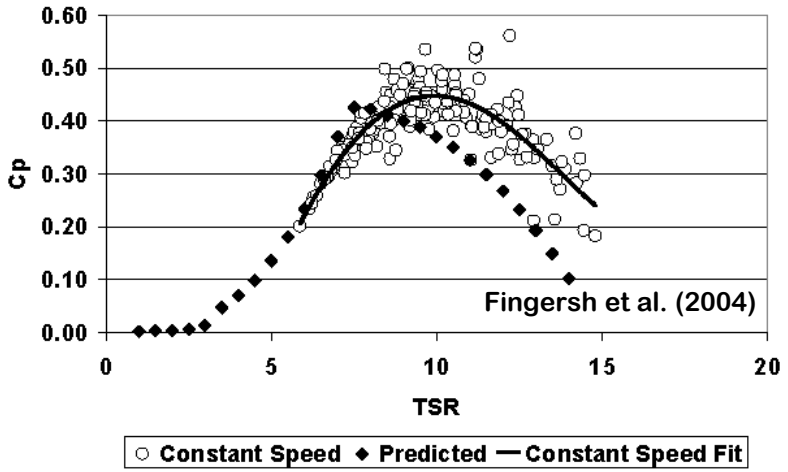
DAP-ZE-3443.00

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

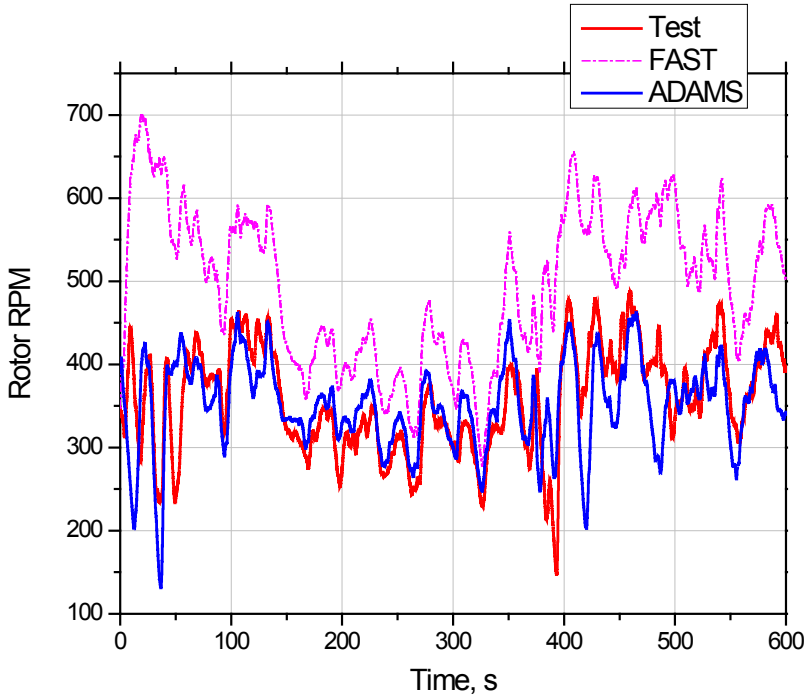
CAE Tools

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*

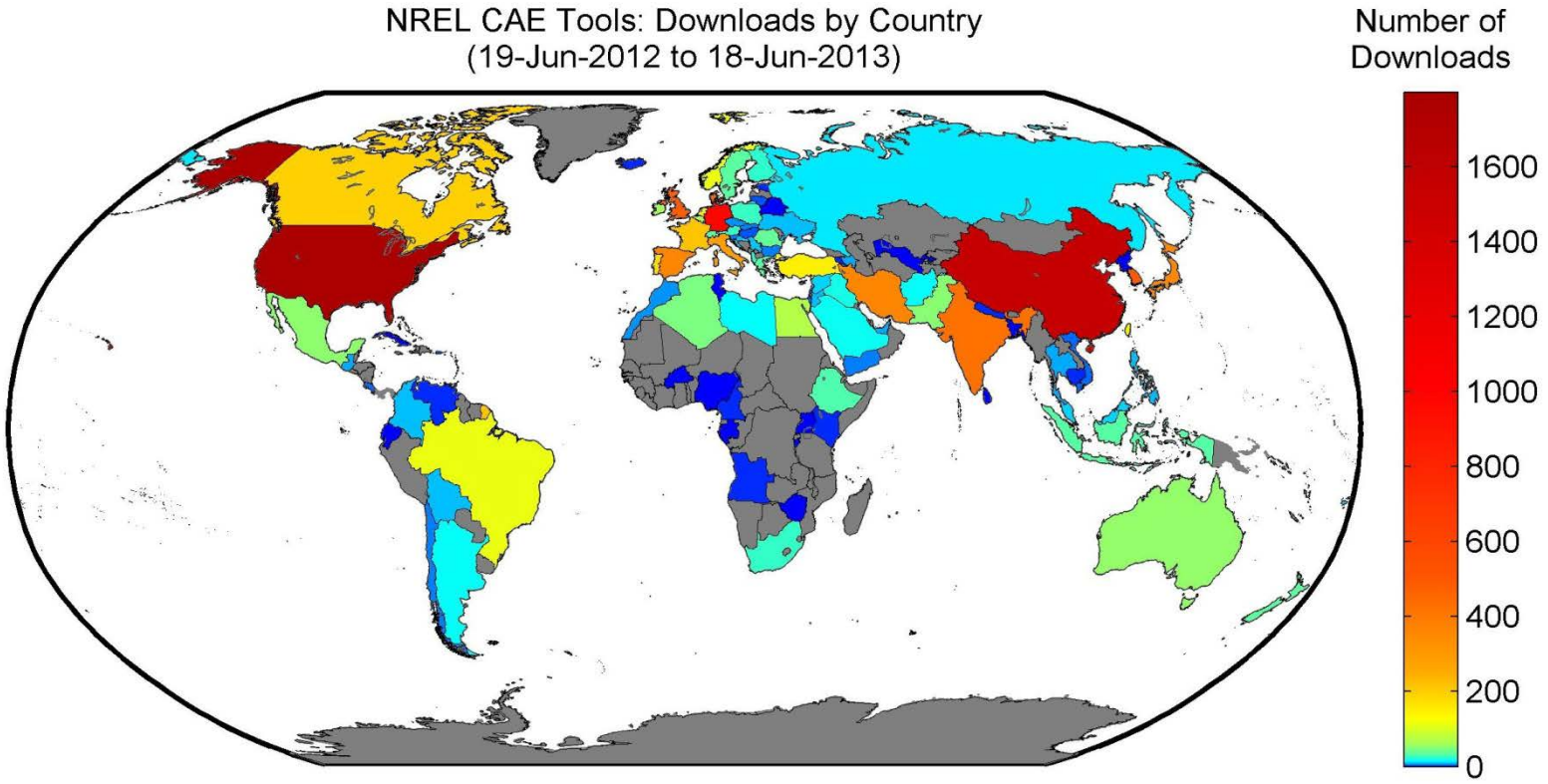


*SWRT in high winds – **ADAMS** has Blade Torsion, **FAST** doesn't*

Users & Support

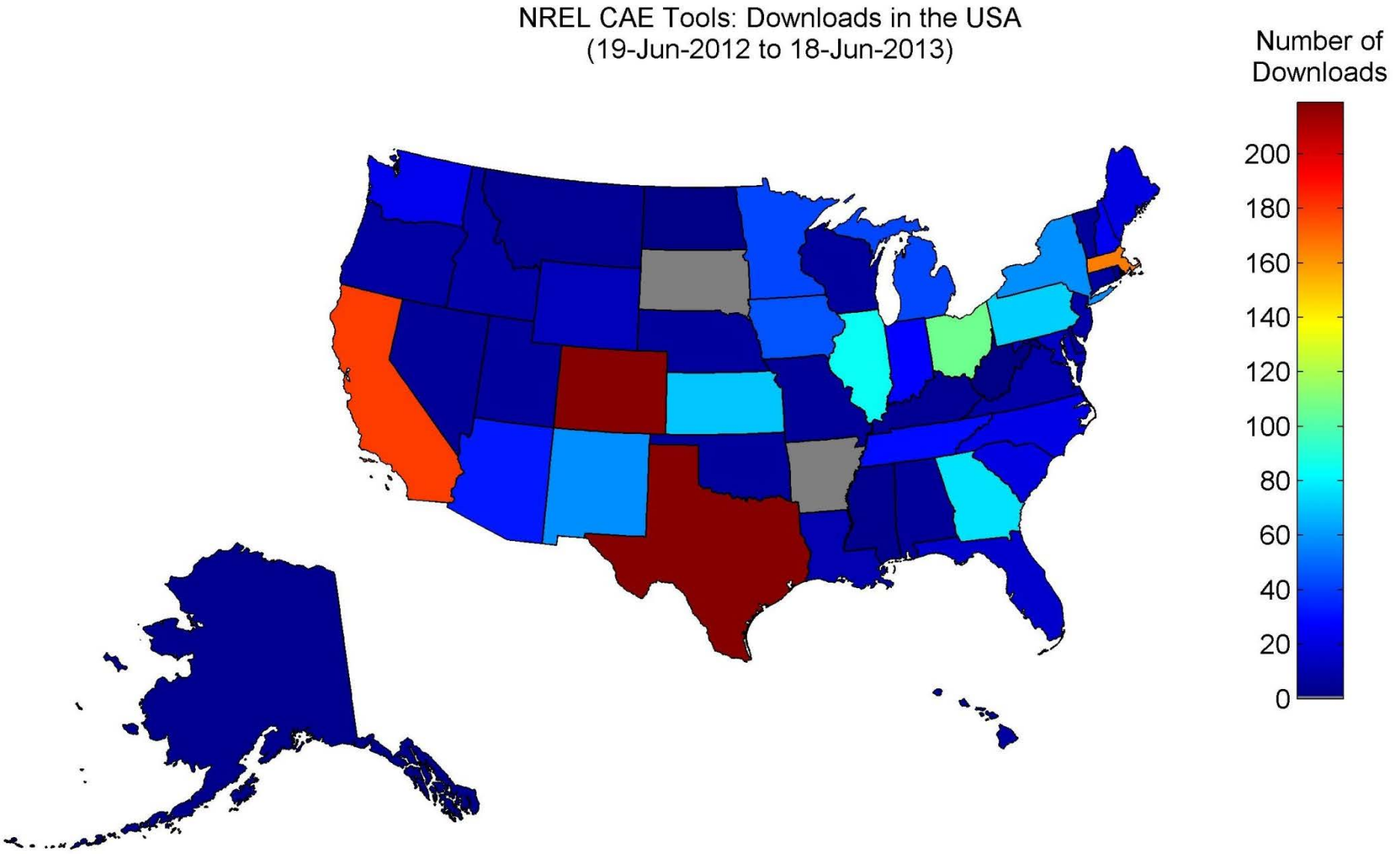
Users of NREL-Developed Tools

- Used worldwide by wind turbine manufacturers, consultants, certifiers, researchers, educators, & students
- In last 12 months, there have been 10,610 unique downloads by 3,764 users from 1,398 organizations in 109 countries



Users & Support

Users of NREL-Developed Tools (cont)



Users & Support

Successful Applications (Only Subset Shown)

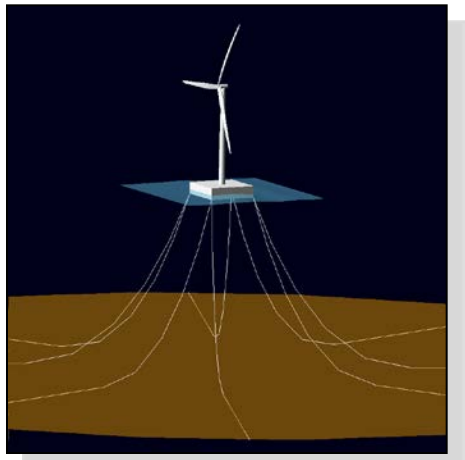
Southwest Windpower Skystream

CART2

Clipper 2.5-MW Liberty

NorthWind 100

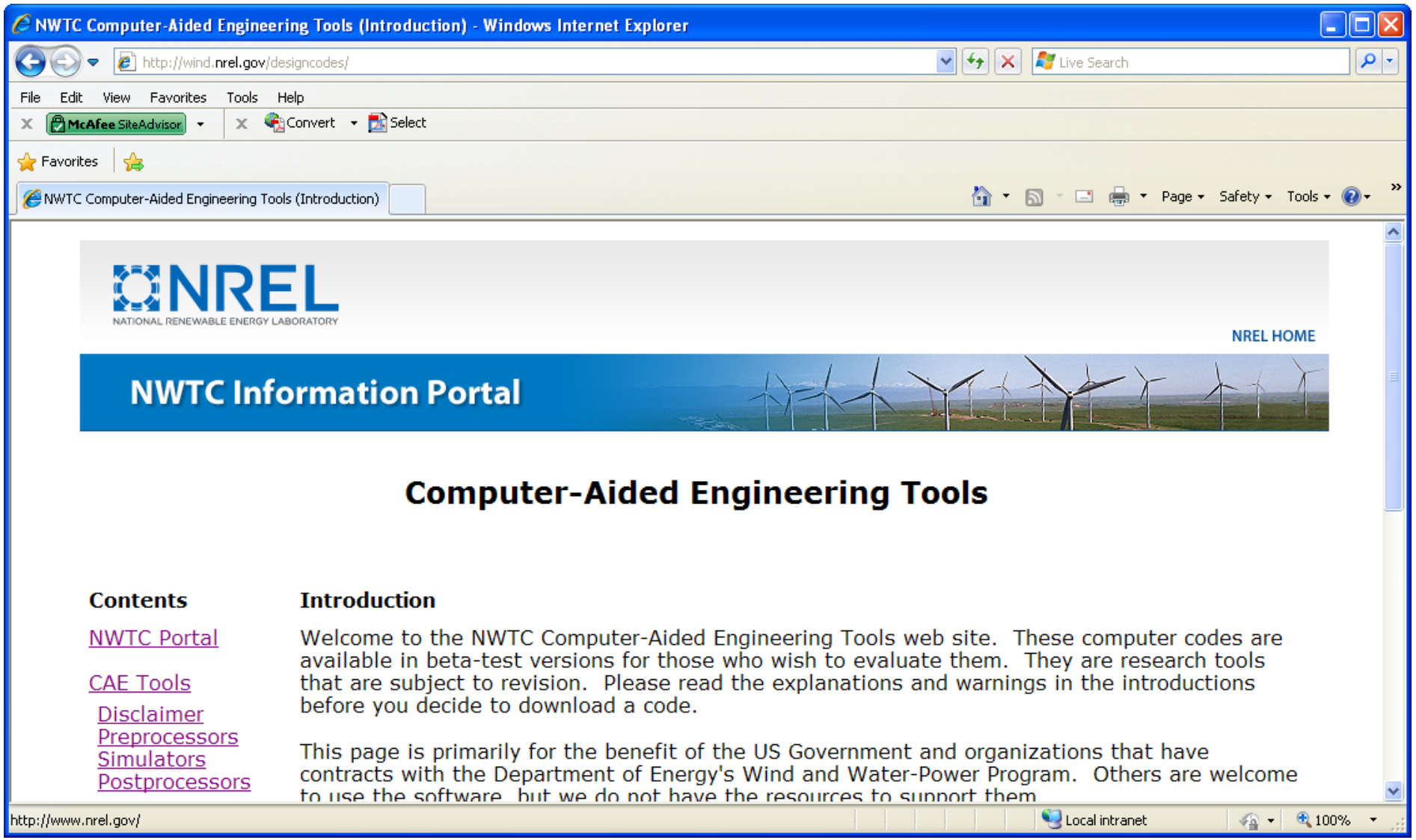
GE 1.5 MW



NREL 5-MW Turbine on ITI Energy Barge

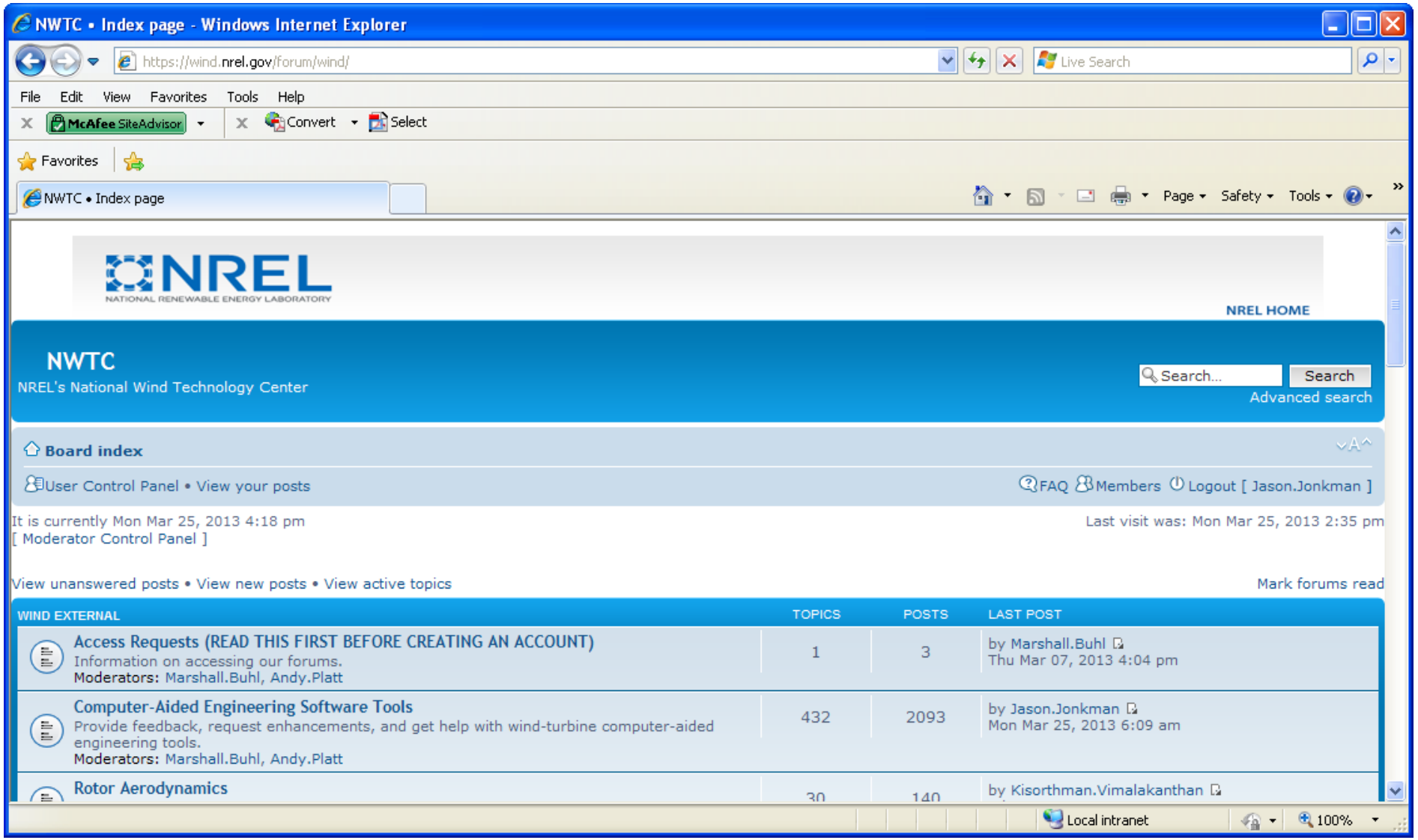
Users & Support

NWTC CAE Tools Website



Users & Support

NWTC Forum



NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Questions?

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