

# *CAE Tool Overview*



## **NREL Wind Turbine Modeling Workshop**

November 20, 2013

EWEA Offshore

Frankfurt, Germany

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

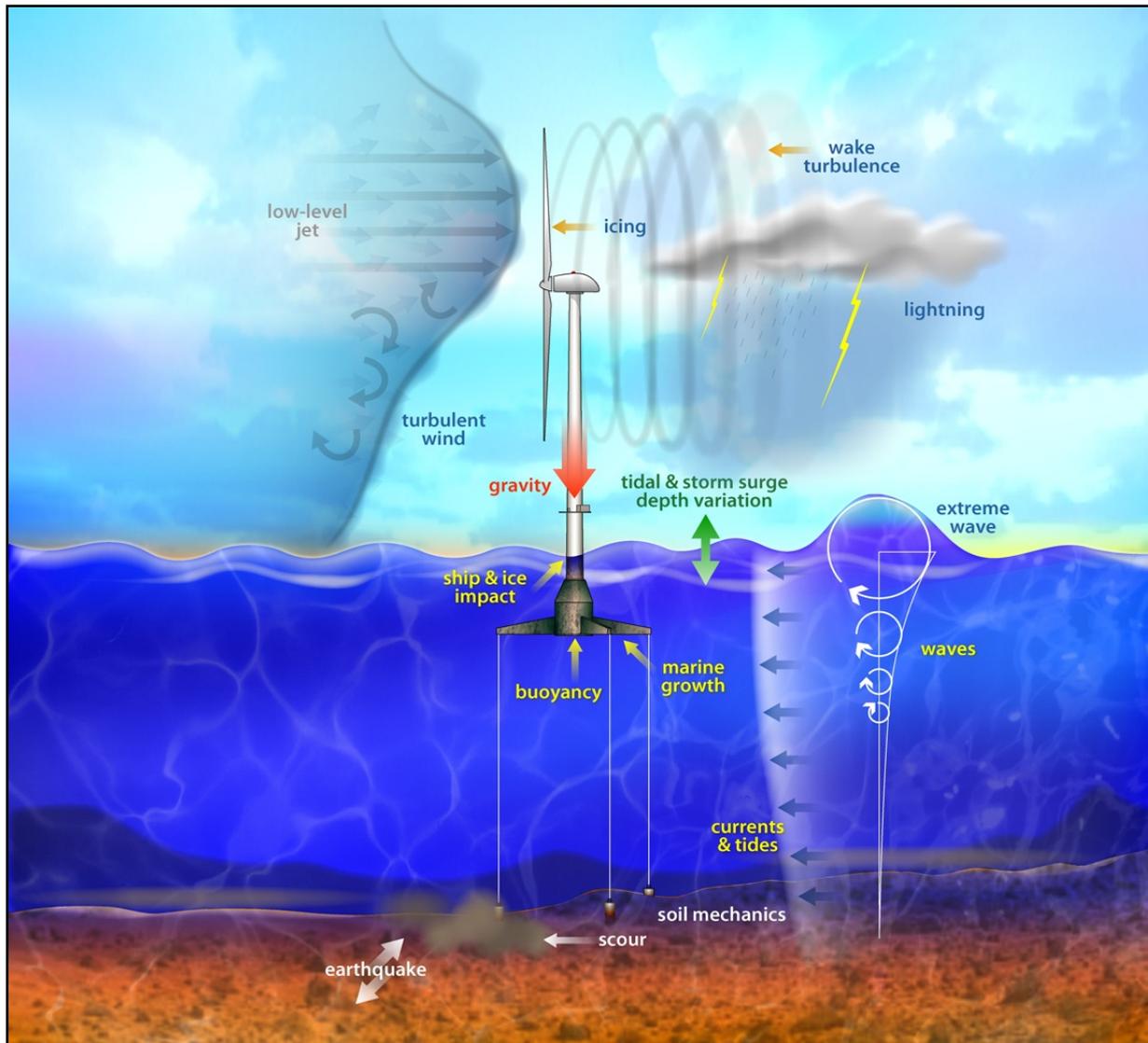
# Outline

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  - What Kind of Tools Are We Talking About?
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# Introduction & Background

## Modeling Requirements

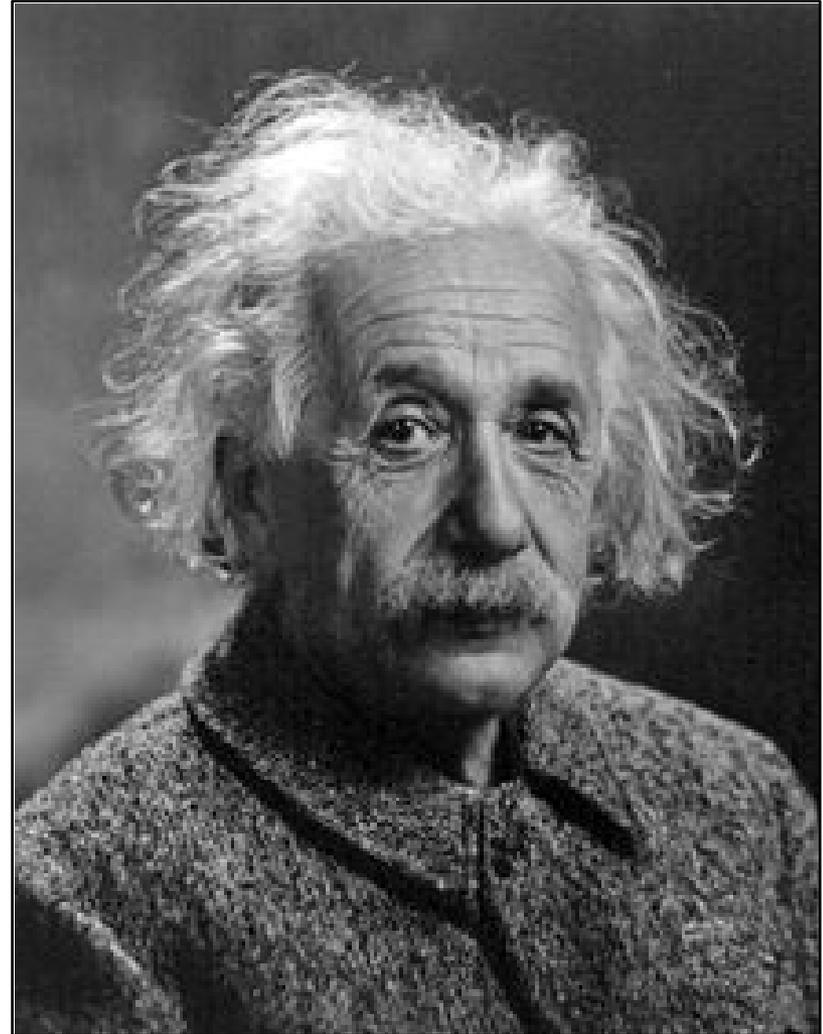


- Coupled aero-hydro-servo-elastic interaction
- Wind-inflow:
  - Discrete events
  - Turbulence
- Waves:
  - Regular
  - Irregular
- Aerodynamics:
  - Induction
  - Rotational augmentation
  - Skewed wake
  - Dynamic stall
- Hydrodynamics:
  - Diffraction
  - Radiation
  - Hydrostatics
- Structural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

# Modeling Requirements & Challenges

## Einstein Principle

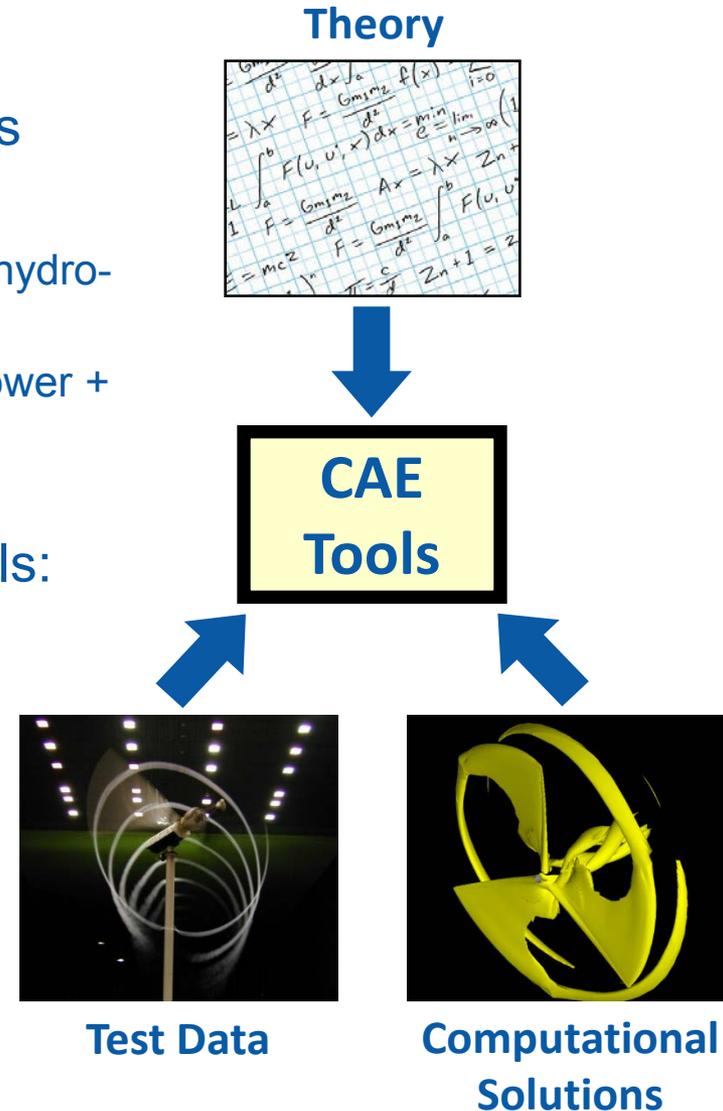
***“A model should be as simple as possible, but no simpler.”***



# Introduction & Background

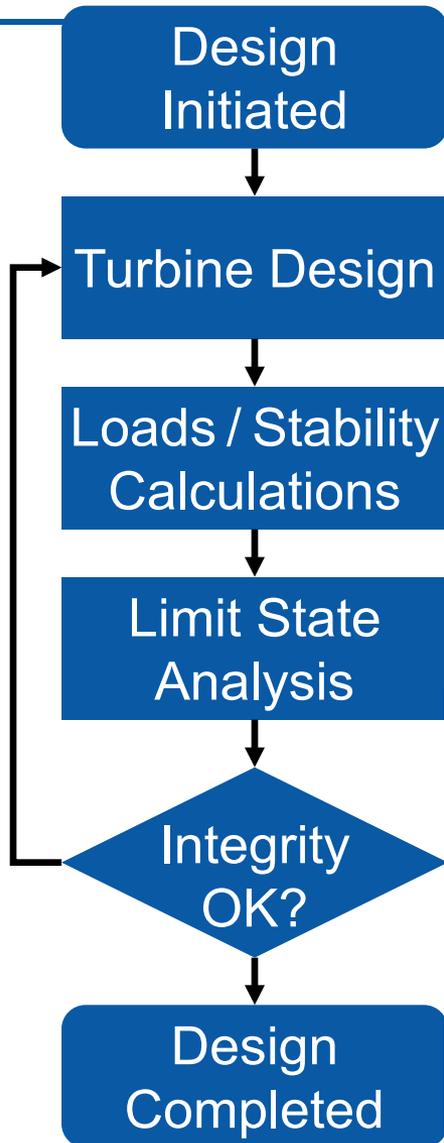
## What Kind of Tools Are We Talking About?

- Tools applied in the design process
- Preprocessors, simulators, & post-processors
- The primary (simulation) tools are:
  - Nonlinear time-domain 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”)

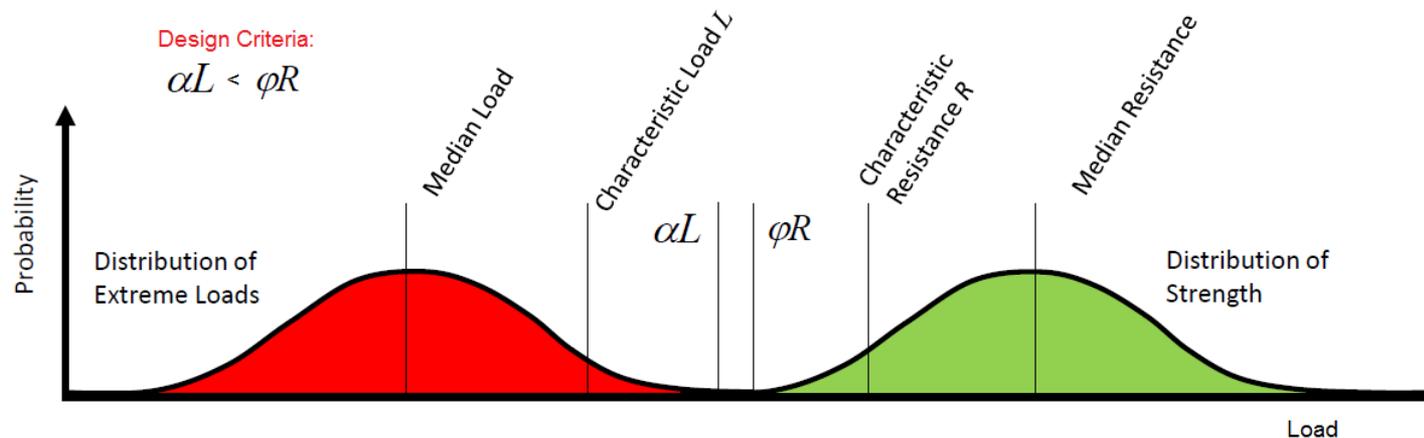


# Introduction & Background

## Wind Turbine Design Process



- Wind turbine design requires evaluation of response:
  - Ultimate loads for 50-yr extreme
  - Fatigue loads for 20-yr life
  - Aero-hydro-servo-elastic stability
- 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



# Introduction & Background

## Wind Turbine Design Process – Loads

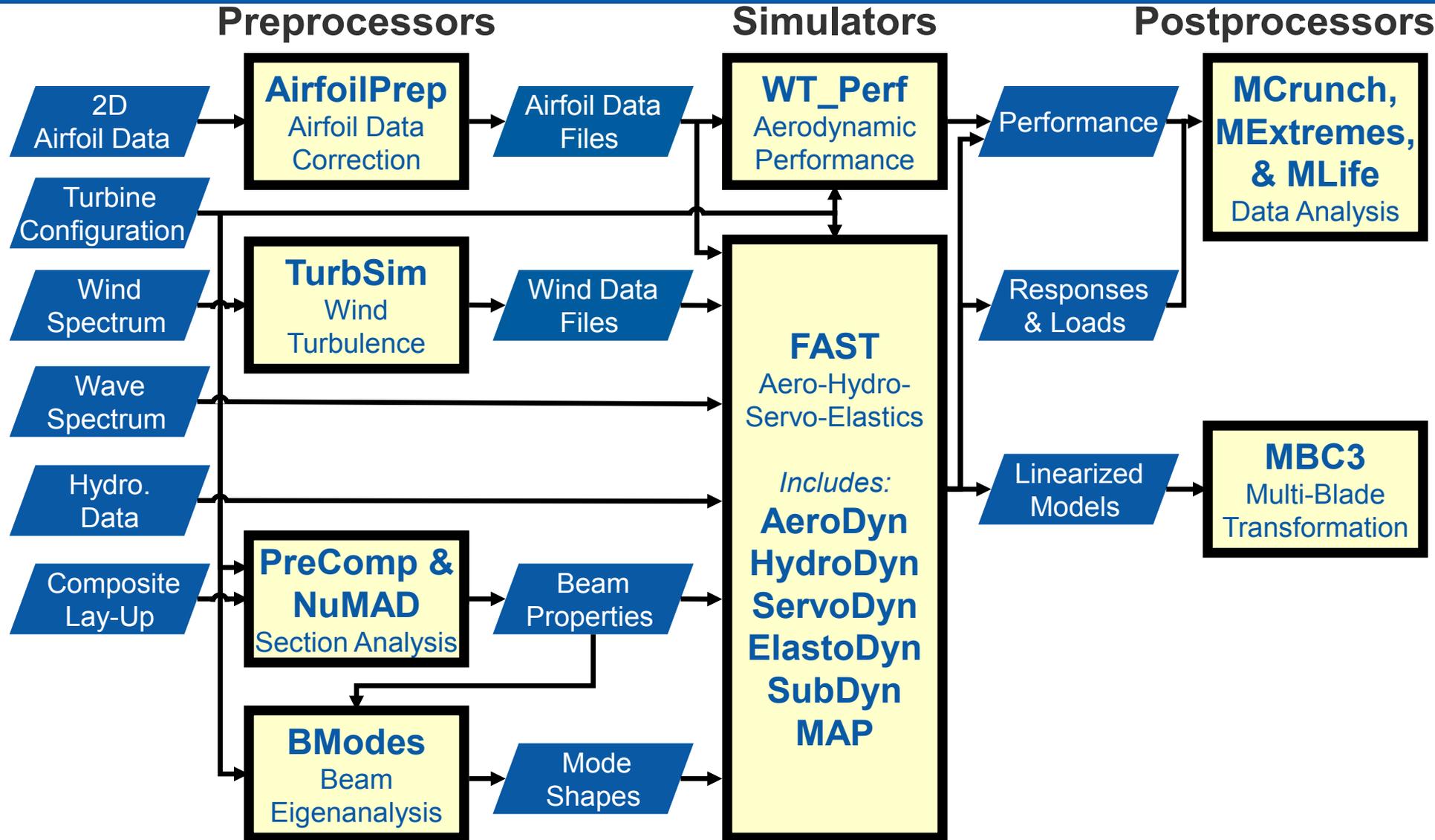
- Loads analysis involves running a large set of nonlinear time-domain simulations
- Design situations & conditions:
  - Turbulent & deterministic winds
  - Regular & irregular waves
  - Power production with control
  - Start-up & shut-down maneuvers
  - Idling & parked conditions
  - Control system faults
  - Earthquake excitation

| Design Situation                          | DLC | Wind Condition | Wave Condition | Directionality | Other Conditions | Type of Analysis |
|---|-----|----------------|----------------|----------------|------------------|------------------|
| Power production                          | 1.x |                |                |                |                  |                  |
| Power production plus occurrence of fault | 2.x |                |                |                |                  |                  |
| Start up                                  | 3.x |                |                |                |                  |                  |
| Normal shut down                          | 4.x |                |                |                |                  |                  |
| Emergency shut down                       | 5.x |                |                |                |                  |                  |
| Parked                                    | 6.x |                |                |                |                  |                  |
| Parked with fault                         | 7.x |                |                |                |                  |                  |
| Transport, assembly, and maintenance      | 8.x |                |                |                |                  |                  |

*Load Case Matrix*

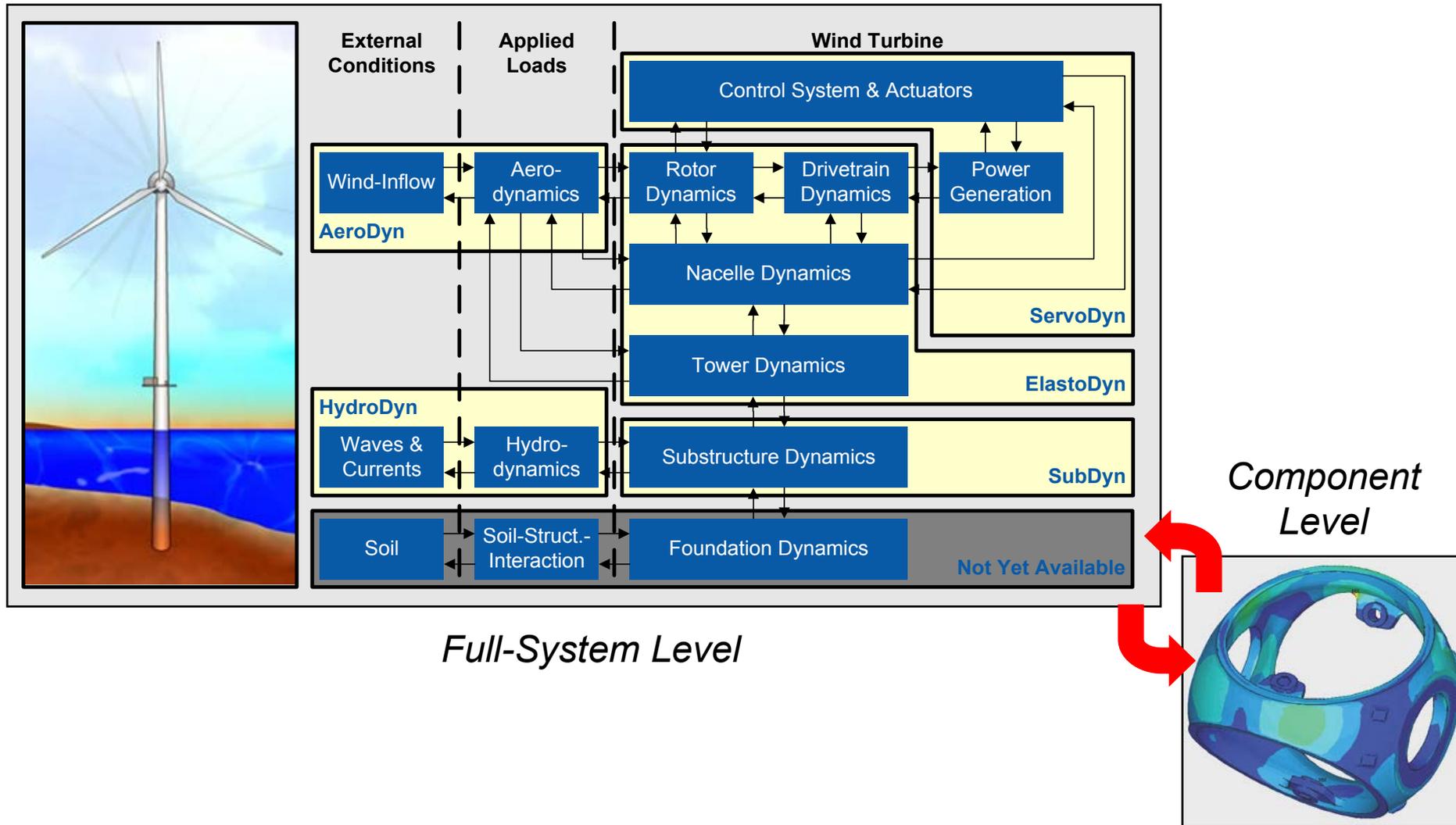
# CAE Tools

## Key NREL Tools in the Design Process



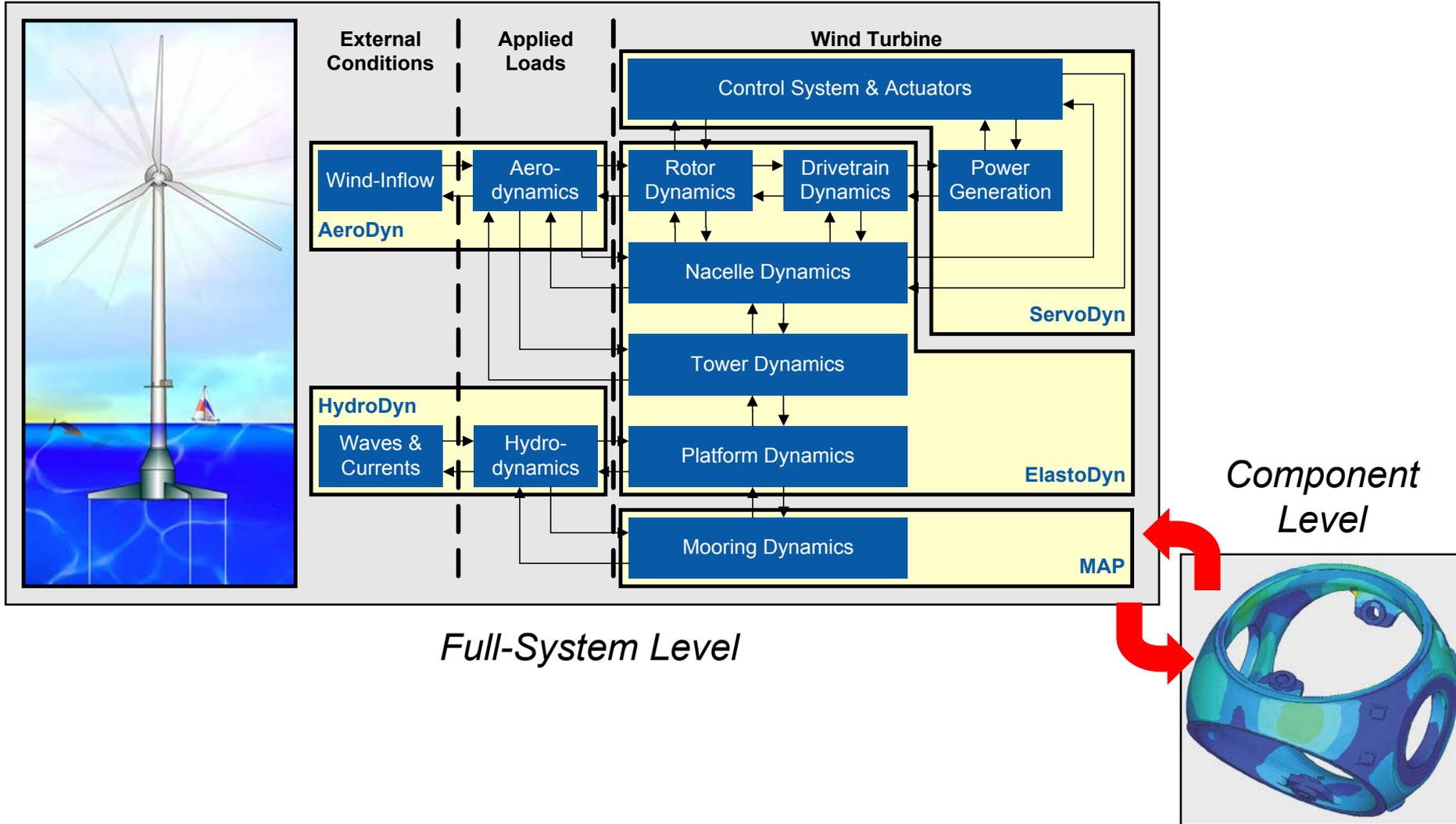
# CAE Tools

## FAST Module Control Volumes – Fixed-Bottom



# CAE Tools

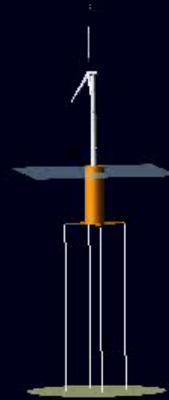
## FAST Module Control Volumes – Floating



# CAE Tools

## Sample MIT/NREL TLP Response

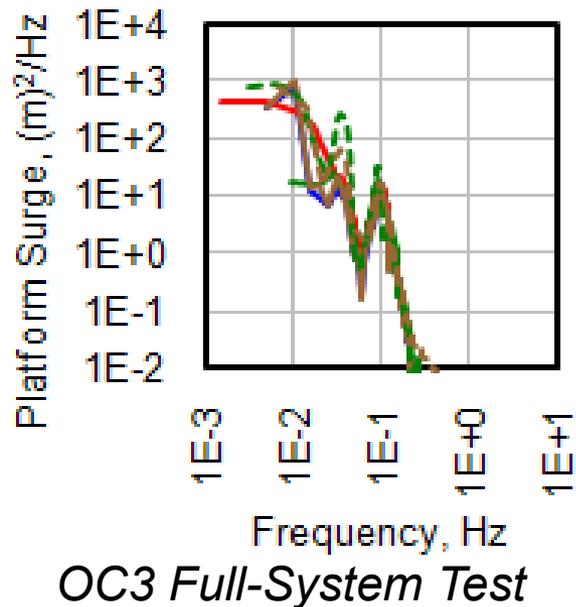
NRELOffshrBslne5MW\_Floating\_TLP\_ADAMS Time= 0.0000 Frame=0001



# 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**

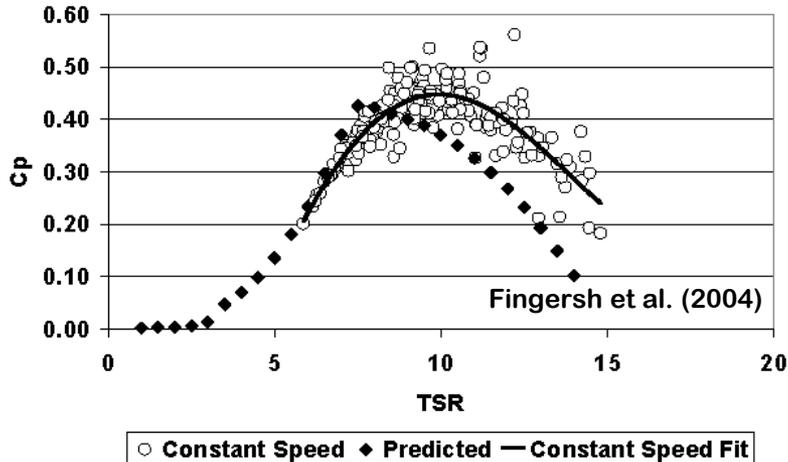


**GL Certificate Approving  
FAST & ADAMS with AeroDyn**

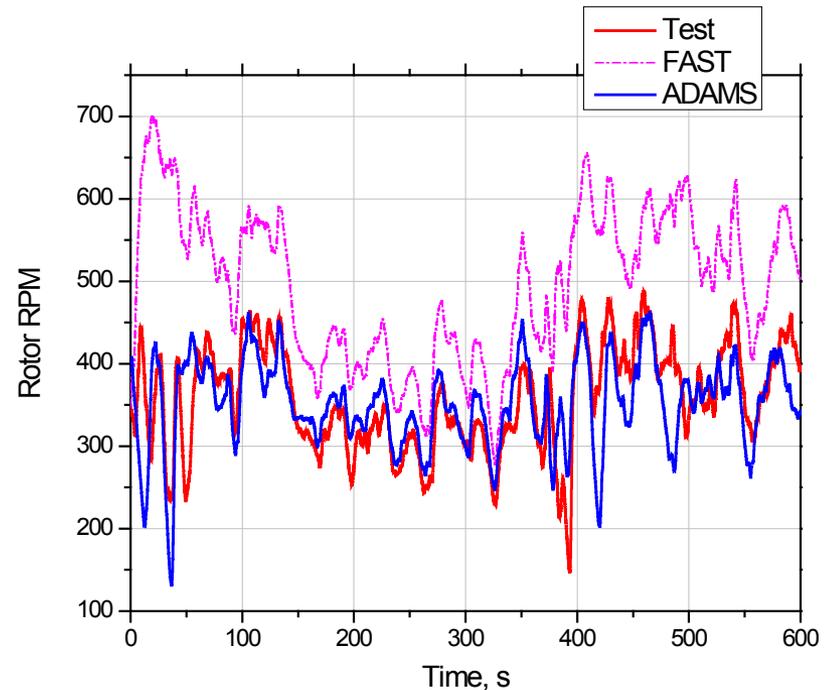
# CAE Tools

## 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

## Disclaimer, Copyright, & Licensing

- NREL's CAE tool development is sponsored by the U.S. Department of Energy (DOE) Wind & Water Power Technologies Office
- The CAE tools are developed as free, publicly available, open-source, professional-grade products as a resource for the wind industry
- User's of the CAE tools must agree to NREL's disclaimer & licensing agreement:
  - Disclaimer: <http://wind.nrel.gov/designcodes/disclaimer.html>
  - New dual licensing arrangement:
    - Most CAE tools are being released under the Apache 2.0 open-source license: <http://www.apache.org/licenses/LICENSE-2.0>
    - When tied to some 3<sup>rd</sup> party code, some CAE tools are offered under the more restrictive GPL v3.0 open-source license: <http://www.gnu.org/copyleft/gpl.html>
    - Details are still being discussed by our legal team

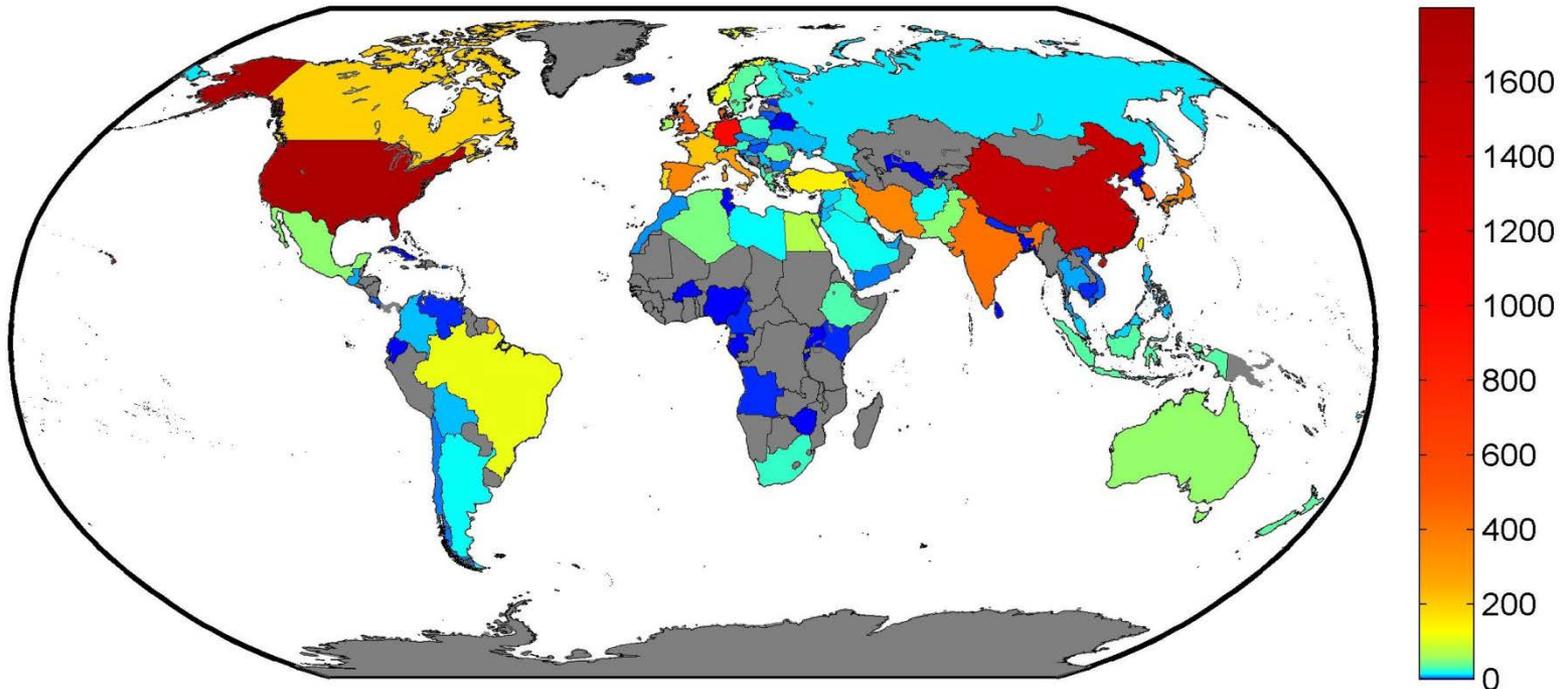
# Users & Support

## 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

NREL CAE Tools: Downloads by Country  
(19-Jun-2012 to 18-Jun-2013)

Number of Downloads



# Users & Support

## Successful Applications (Only Subset Shown)



*Southwest  
Windpower  
Skystream*



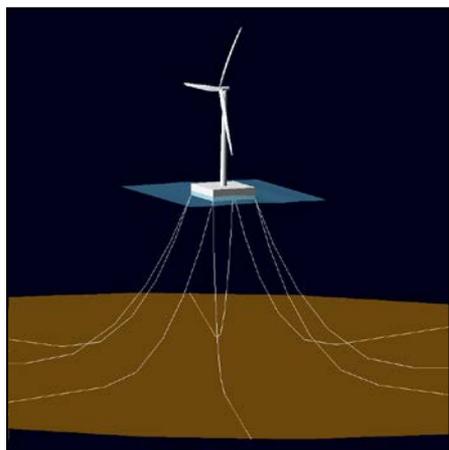
*CART2*



*Clipper 2.5-MW  
Liberty*



*NorthWind 100*



*NREL 5-MW Turbine on ITI Energy Barge*



*GE 1.5 MW*

# 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 header features the NREL logo (National Renewable Energy Laboratory) and a "NREL HOME" link. Below the header is a blue banner with the text "NWTC Information Portal" and a background image of wind turbines. The main content area is titled "Computer-Aided Engineering Tools" and is divided into two columns. The left column, titled "Contents", lists several links: [NWTC Portal](#), [CAE Tools](#), [Disclaimer](#), [Preprocessors](#), [Simulators](#), and [Postprocessors](#). The right column, titled "Introduction", contains two paragraphs of text. The first paragraph welcomes visitors to the website, stating that the computer codes are available in beta-test versions for evaluation and are subject to revision. The second paragraph explains that the page is primarily for the benefit of the US Government and organizations with contracts with the Department of Energy's Wind and Water-Power Program, and that while others are welcome to use the software, support is not provided. The browser's status bar at the bottom shows the address <http://www.nrel.gov/> and a "Local intranet" icon.

NWTC Computer-Aided Engineering Tools (Introduction) - Windows Internet Explorer

<http://wind.nrel.gov/designcodes/>

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NWTC Information Portal

### Computer-Aided Engineering Tools

#### Contents

- [NWTC Portal](#)
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- [Disclaimer](#)
- [Preprocessors](#)
- [Simulators](#)
- [Postprocessors](#)

#### 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.

<http://www.nrel.gov/> Local intranet 100%

# Users & Support

## NWTC Forum

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[ Moderator Control Panel ]

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

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# *Questions?*



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