NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Summary of Ancillary Tools & Pre- & Post-Processors

NREL Wind Turbine Modeling Workshop

March 2, 2012

NREL – Golden, CO

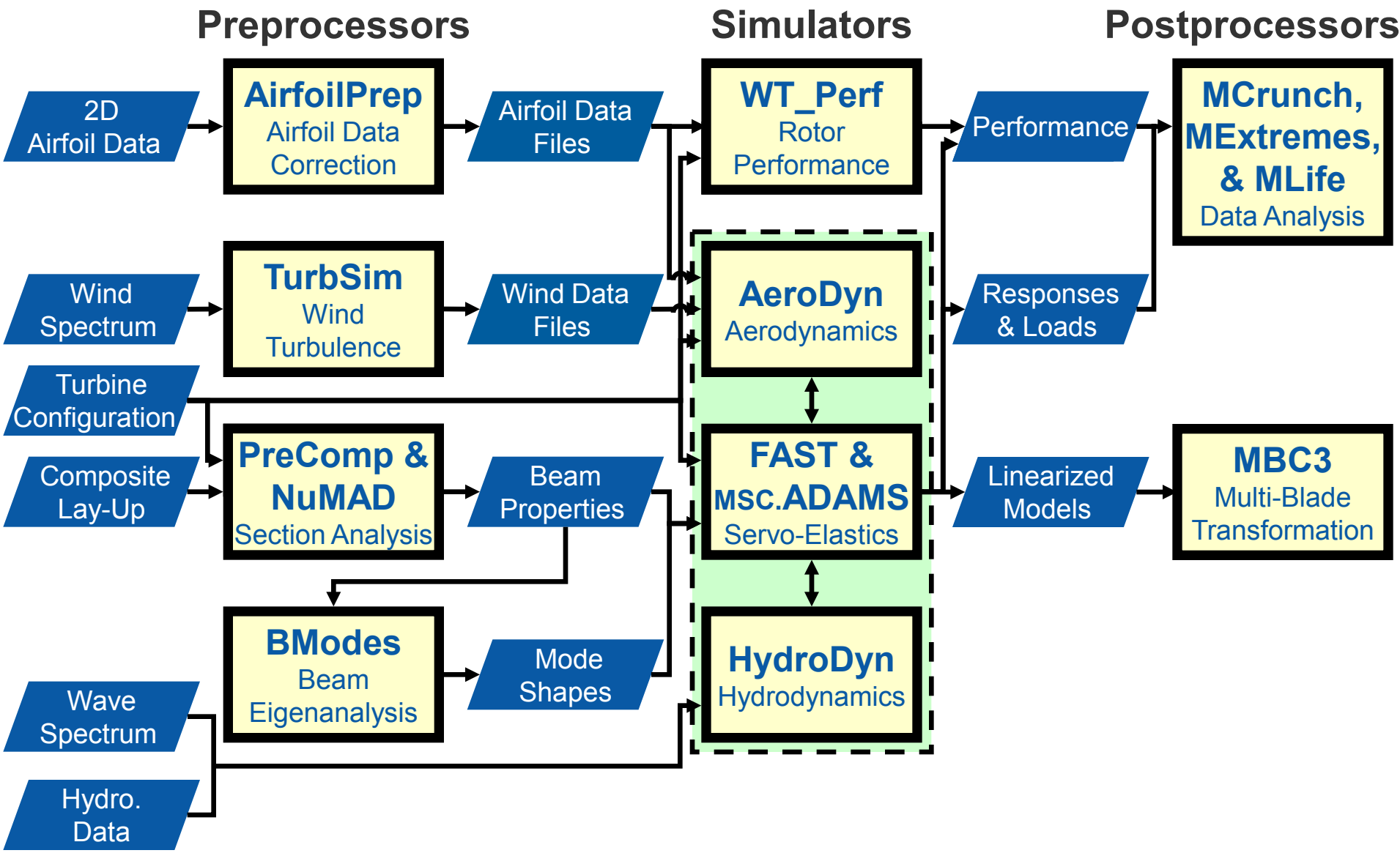
Jason Jonkman, Ph.D.
Senior Engineer, NREL

Outline

- Key NREL Codes in the Design Process
- AirfoilPrep
- TurbSim
- PreComp
- NuMAD
- BModes
- WT_Perf & HARP_Opt
- MSC.ADAMS, A2AD, & FAST-to-ADAMS
- MCrunch, MExtremes, & MLife
- MBC3
- NWTC Subroutine Library
- Automation Scripts

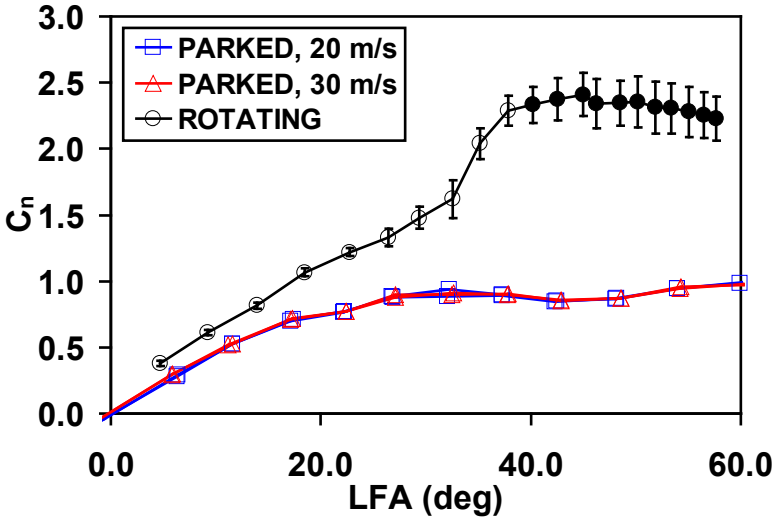
Design Codes

Key NREL Codes in the Design Process



Design Codes
AirfoilPrep

- Generates airfoil data files from 2D data:
  - Adjusts 2D data for rotational augmentation (3D effects):
    - Selig/Du for lift (stall delay)
    - Eggers for drag
  - Extrapolates to high AoA:
    - Uses Viterna method or flat-plate theory for -180º < AoA < 180º data
  - Computes dynamic stall parameters
  - Blends aerodynamic coefficients

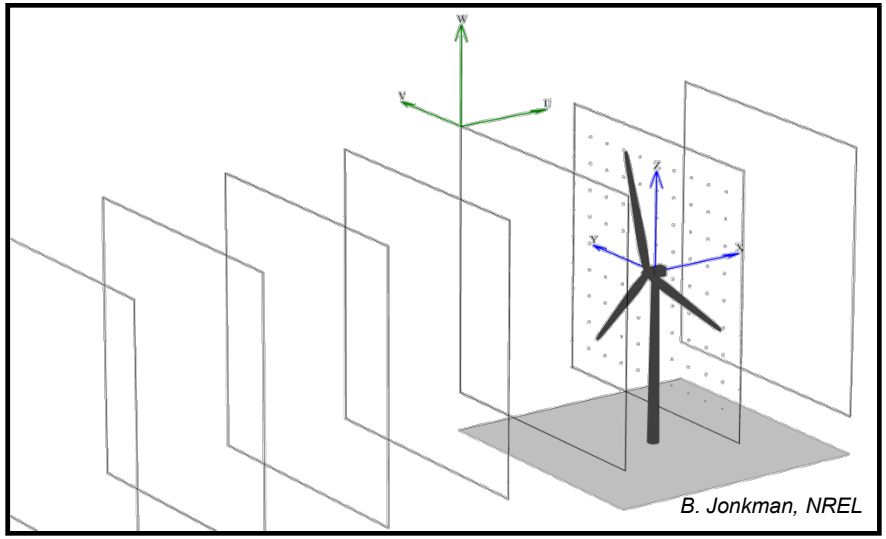


Data from NASA Ames Wind Tunnel: Unsteady Aerodynamics Experiment

- Current & planned work – Build functionality into **WT_Perf** & **AeroDyn**
- Future opportunity – Include new stall-delay models

Design Codes
TurbSim

- Computes full-field stochastic wind realizations:
  - Inputs are desired wind profile & turbulence characteristics
  - Includes IEC- & site-specific turbulence models
  - Option to generate coherent structures from LES & DNS output
- Future opportunities:
  - Apply code to determine impact of non-IEC turbulence on turbine response
  - Include additional site-specific turbulence models
  - Add Mann model

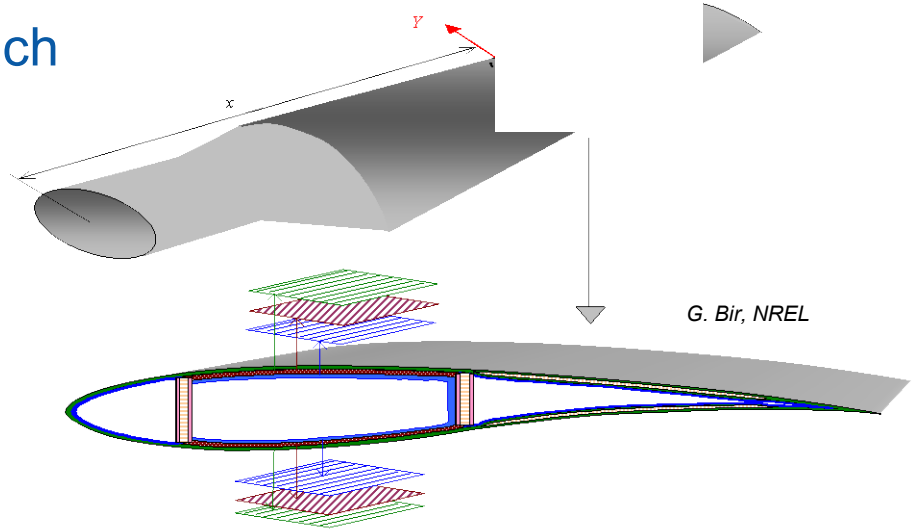


Full-Field Turbulence Grids

Design Codes
PreComp

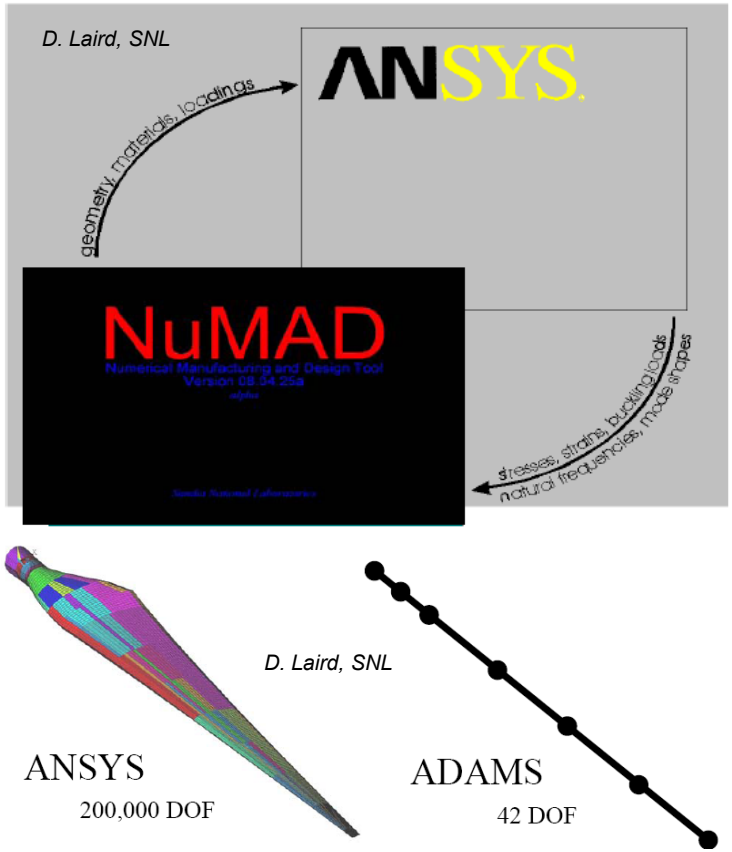
- Computes coupled section properties of composite blades for beam-type models:
  - Inputs are the airfoil shape & internal lay-up of composite laminas
  - Uses a combined laminate theory (modified) with shear flow approach
- Future opportunities:
  - Further verification against **NuMAD** & **VABS**
  - Add stress analysis
  - Add inverse design algorithm

$$\begin{Bmatrix} F_X \\ M_Y \\ M_Z \\ T_X \end{Bmatrix} = \begin{bmatrix} \overline{EA} & S_{af} & S_{al} & S_{at} \\ S_{af} & \overline{EI}_{flap} & S_{fl} & S_{ft} \\ S_{al} & S_{fl} & \overline{EI}_{lag} & S_{lt} \\ S_{at} & S_{ft} & S_{lt} & \overline{GJ} \end{bmatrix} \begin{Bmatrix} u_e' \\ w'' \\ v'' \\ \theta' \end{Bmatrix}$$



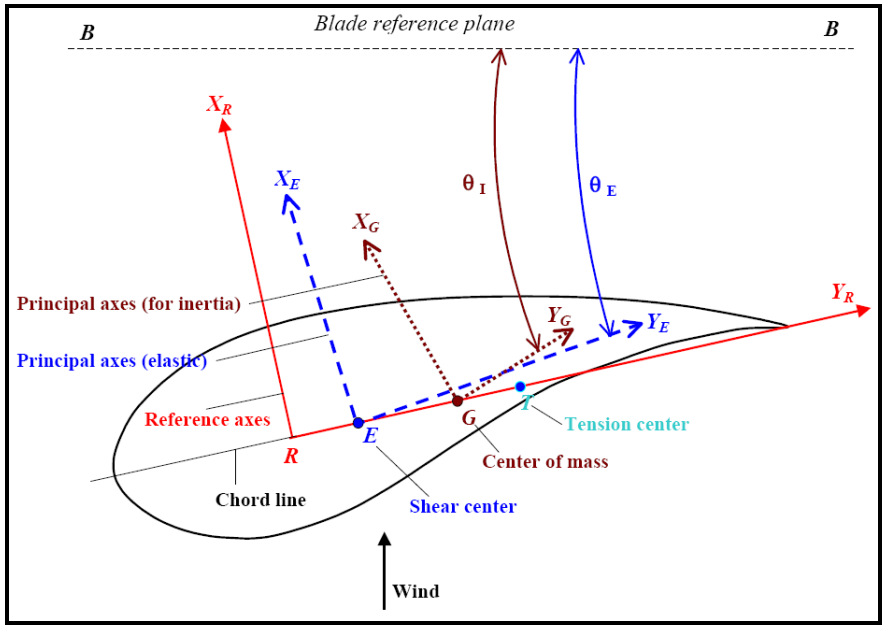
Design Codes
NuMAD

- A GUI pre- & post-processor for **ANSYS**-based FEA analysis:
  - Tailored to wind turbine blades
  - Enables one to create a 3D FEA model & perform structural analysis
  - "Beam property extraction" feature to produce section properties for beam-type models
- Current & planned work:
  - Verify against **PreComp** & **VABS**
  - Output more section properties from "beam property extractor"
- Future opportunities:
  - Compute centrifugally stiffened mode shapes & frequencies
  - Allow for built-in curvature & sweep



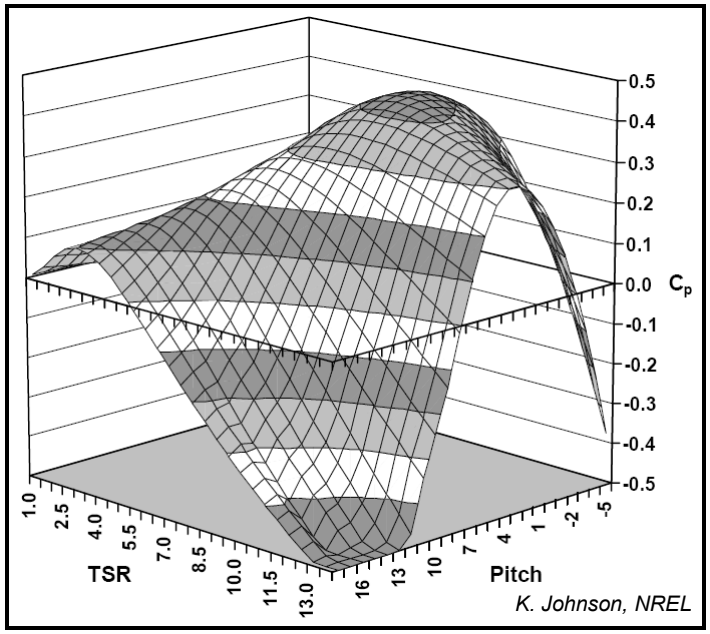
Design Codes
BModes

- Computes coupled mode shapes & frequencies of blades & towers:
  - Inputs are the boundary conditions & distributed isotropic beam properties
  - Considers axial-flap-lag-torsion coupling
  - Uses a 15-DOF FE specially developed to handle rotation-related terms
  - Boundary conditions include towers with flexible foundations or floating bases
- Current & planned work:
  - Replace with FE formulation in **FAST**
- Future opportunities:
  - Add gravitational destiffening to tower model
  - Compute mode shapes about loaded deflection
  - Allow for anisotropic material (from **PreComp**, **NuMAD**, or **VABS**)
  - Allow for built-in curvature & sweep



Design Codes
WT_Perf & HARP_Opt

- **WT_Perf** calculates steady-state rotor performance:
  - Inputs are rotor geometry, airfoil data, wind, pitch, & rotor speed
  - Uses BEM theory
- **HARP_Opt** optimizes rotor performance:
  - **MATLAB**-based wrapper of **WT_Perf**
  - Uses GA to design rotor geometry for optimal aerodynamic efficiency (AEP)
- Current & planned work:
  - Improve solution algorithm
- Future opportunities:
  - Import **AirfoilPrep** features
  - Add algorithm for tuning airfoil data to match measured performance
  - Incorporate new aerodynamic models (e.g., vortex wake)

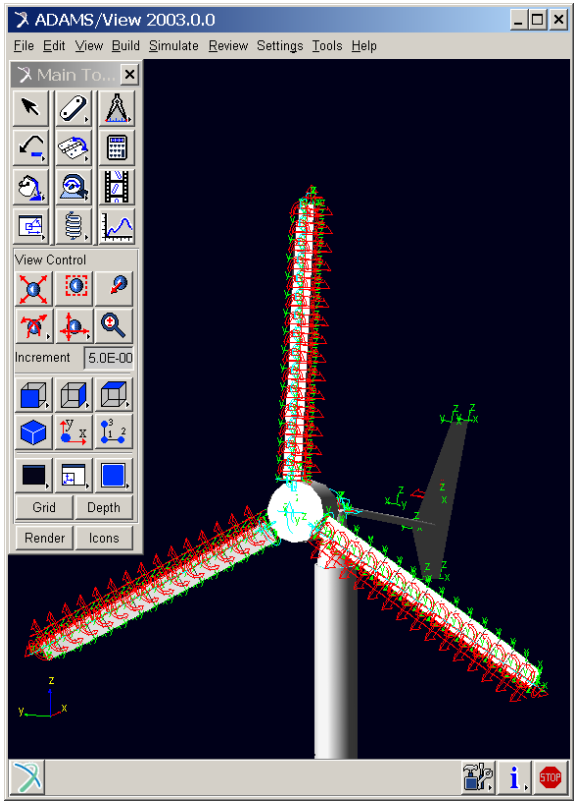


Power Coefficient for the CART2

Design Codes

MSC.ADAMS, A2AD, & FAST-to-ADAMS

- Computes structural-dynamic & control-system responses as part of the aero-hydro-servo-elastic solution:
  - Commercial product from MSC Software
  - Uses a multi-body representation with virtually unlimited DOFs
  - Controls through subroutines or DLLs
  - Nonlinear time-domain solution for loads analysis
  - Linearization of nonrotating system
  - Coupled to **AeroDyn** & **HydroDyn** through **A2AD**
  - Datasets can be created by **FAST**
  - Bypasses some limitations of **FAST**
  - Evaluated by Germanischer Lloyd WindEnergie
- Current & planned work:
  - Enable compatibility with the **ADAMS** C++ solver
  - Restructure **A2AD** for improved numerical processing of fluid-structure interaction
  - Improve modeling pre-curved & pre-swept blades
- Future opportunities:
  - Replace rigid with flex bodies (imported from FEA)
  - Utilize linearization in a rotating frame
  - Model gearboxes in detail

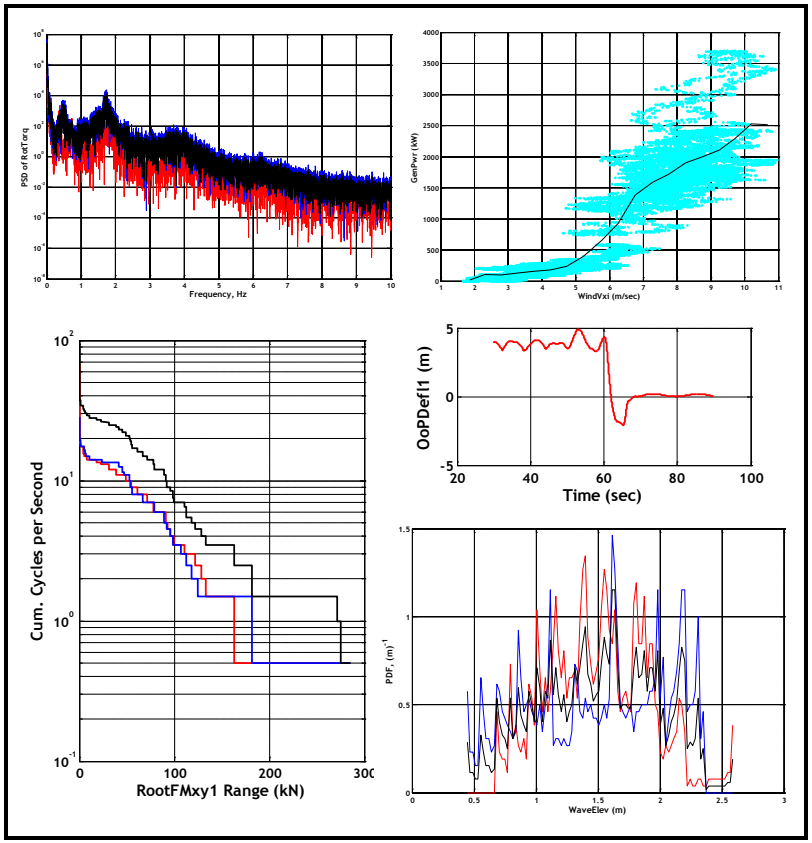


ADAMS Model Created by FAST

Design Codes

MCrunch, MExtremes, & MLife

- **MATLAB**-based postprocessors
- **MCrunch** for general data analysis:
  - Merges features from legacy codes (**Crunch**, **GPP**, **GenStats**, & **Fatigue**):
    - Scales, offsets, & calculated channels
    - Statistics
    - Probability density functions
    - Power spectral density
    - Extreme event tables
    - Rainflow counting, DELs, & lifetime damage
    - Plotting
  - Processes all data files together

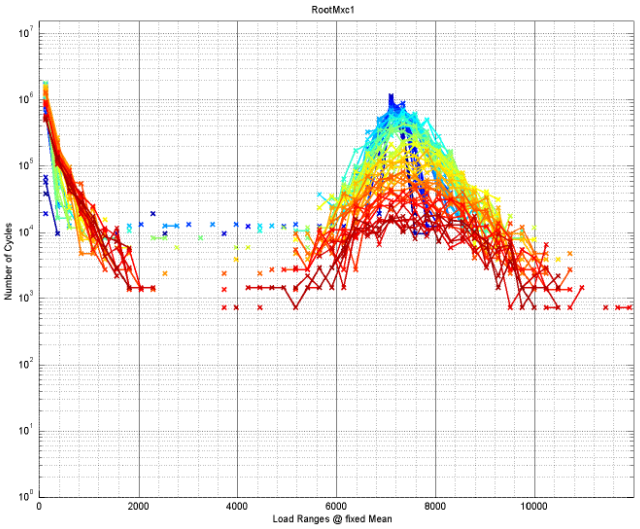


Example Outputs from MCrunch

Design Codes

MCrunch, MExtremes, & MLife (cont)

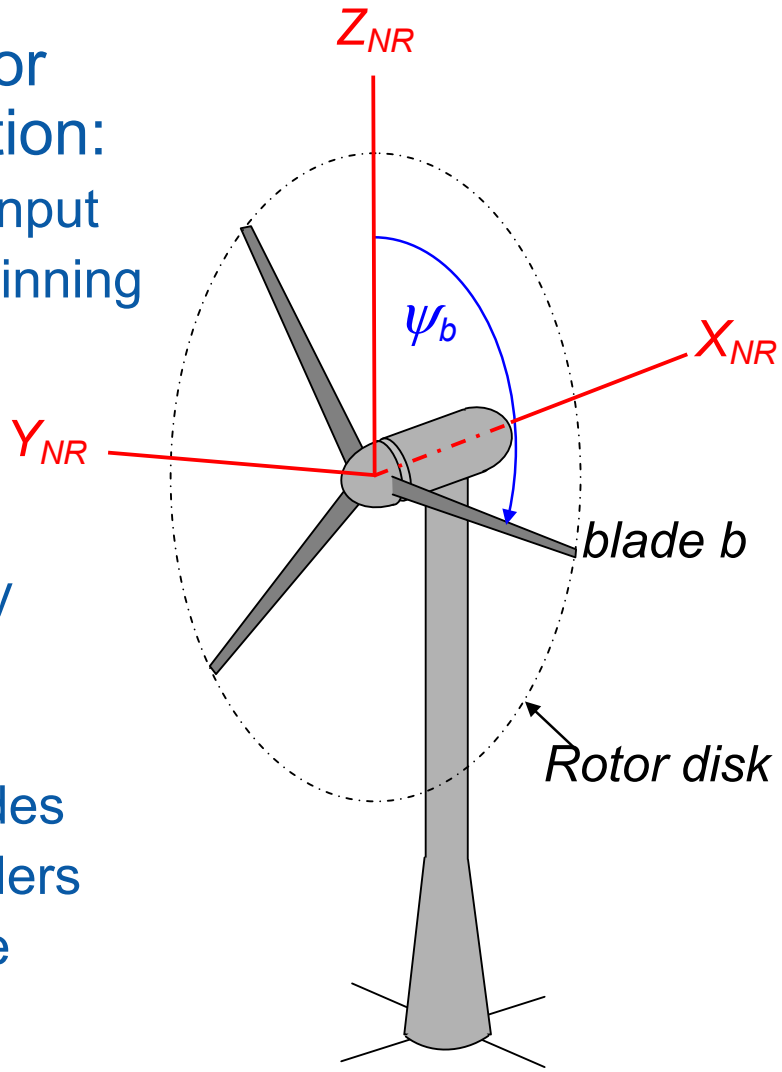
- **MExtremes** for extreme-event tables:
  - Processes data files independently
  - Scales, offsets, PSFs, & calculated channels
  - Statistics
  - Peak finding
- **MLife** for fatigue-life analysis:
  - Processes data files independently
  - Scales, offsets, PSFs, & calculated channels
  - Statistics
  - Rainflow counting, DELs, & lifetime
- Current & planned work:
  - Develop consistency across tools & release beta versions
- Future opportunities:
  - Filtering, load roses, azimuth averages, statistical extrapolation, etc.



Lifetime Cycles of In-Plane Blade-Root Bending Moment Per Simulation

Design Codes
MBC3

- A **MATLAB**-based postprocessor for Multi-Blade-Coordinate transformation:
  - Accepts **FAST** linearization output as input
  - Transforms cumulative dynamics of spinning rotor blades into the nonrotating frame
  - Handles system, controls, & disturbance matrices for states & outputs
  - Applicable to controls design & stability analysis for 3-bladed rotors
- Future opportunities:
  - Extend formulation to more than 3 blades
  - Develop Floquet-based tools for 2 bladers
  - Establish stability guidelines for turbine designers



Design Codes
NWTC Subroutine Library

- Contains general-purpose routines for use by all codes:
  - I/O, math, aerodynamic, & compiler-specific routines
  - Used by most of the NWTC codes
  - Reduces development & maintenance time
- Current & planned work:
  - Update as needed to support codes development
- Future opportunities:
  - Develop new libraries for numerical methods:
    - Newton-Raphson iteration root solvers
    - ODE & DAE time-integrators
    - FFT routines
    - Linear equation solvers
    - Eigensolvers

Design Codes
Automation Scripts

- Three scripts available on the web site:
  - **RunIEC**: Runs **IECWind**, **FAST**, & **Crunch** for IEC discrete load cases
  - **RunNTM**: Runs **TurbSim**, **FAST**, & **Crunch** for multiple turbulence cases
  - **CondorNTM**: Same as **RunNTM**, but uses Condor
  - All written in Perl; must know a little Perl to modify
  - No further development planned
- Have an in-house script also called **RunIEC**:
  - Combined features from all three of the above scripts
  - Tailored to IEC-style load cases
  - Runs jobs serially, on Condor pool, or on HPC (multi-processor server)
  - Currently requires significant customization to use
- Current & planned work:
  - Make in-house **RunIEC** user friendly, write manual, & distribute
  - Add option for customizable load cases (parametric or combined-case analyses)
  - Use for loads analysis & uncertainty quantification (UQ)

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Questions?

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