Overview of Sandia Wind Turbine Blade Analysis

May 31, 2012
Sandia Blade Workshop

Brian Resor
Blade Design Tools and System Analysis Lead
Wind Energy Technologies Department
Sandia National Laboratories
brresor@sandia.gov

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Problem and Strategy

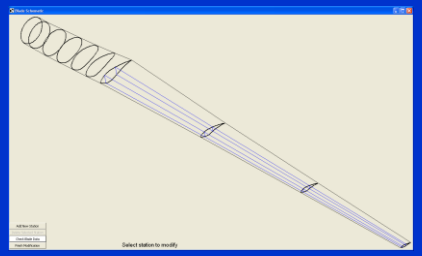
- **Simulation and analysis demands associated with aggressive Sandia wind energy technology projects constantly push the limits of the state of the art in wind turbine blade structural and full system aeroelastic simulation**
- **Strategy:**
  - Utilize a hybrid of existing design codes and in-house developments to meet Sandia needs
  - Complement the NREL NWTC Design Codes and commercially available codes
  - Create new capabilities only when capabilities do not exist

Blade Design with NuMAD

NuMAD

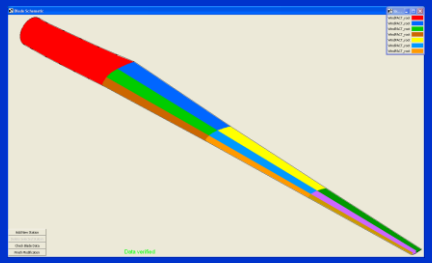
NuMAD:
Numerical Manufacturing
And Design Tool

Blade Geometry

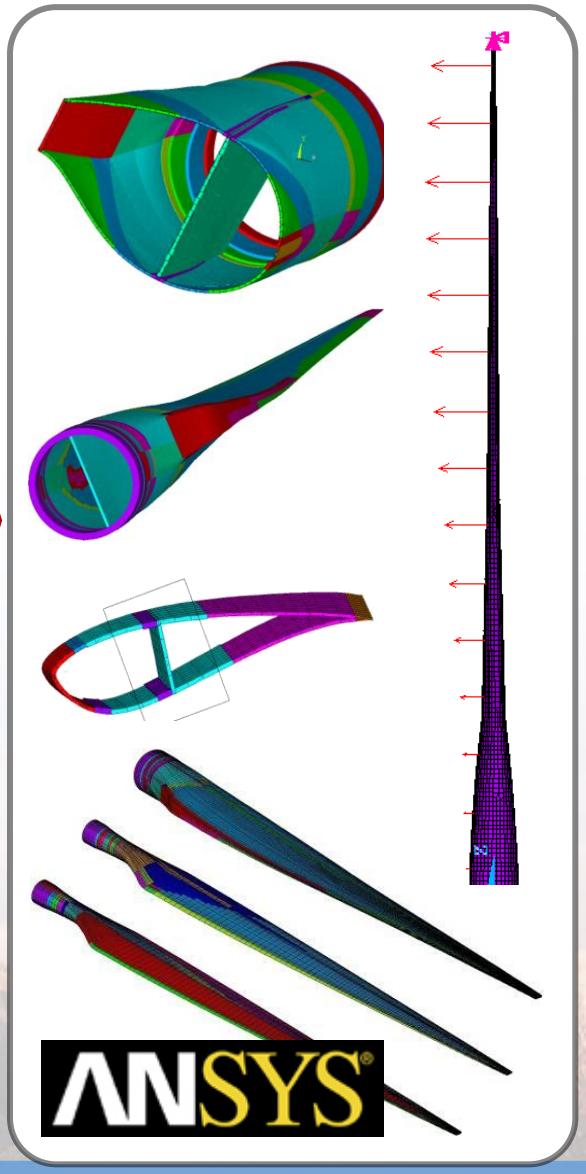


Materials & Layups

Stack Placement

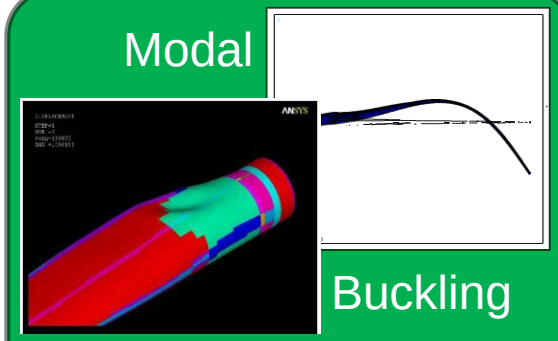


ANSYS FE Model



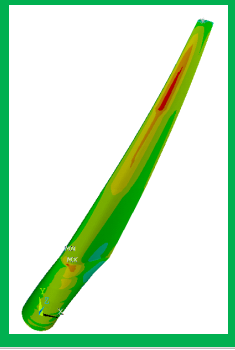
ANSYS Analysis

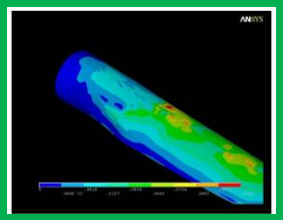
Modal

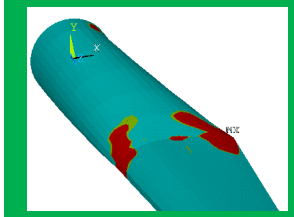


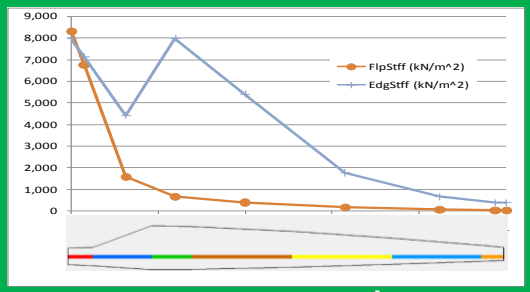
Buckling

Stress & Strain





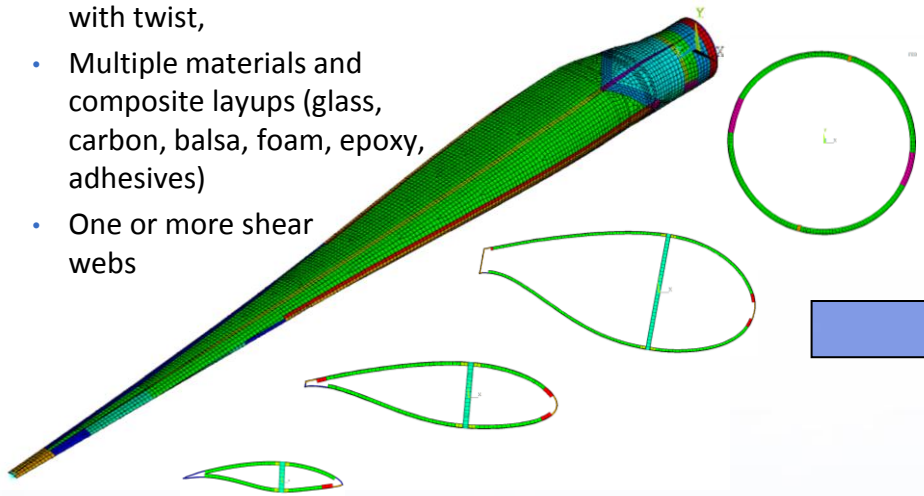


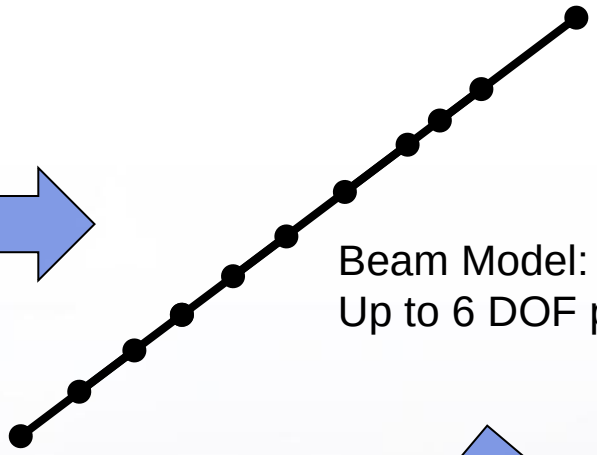


Beam Properties

Aeroelasticity: The Structural Design & Analysis Cycle

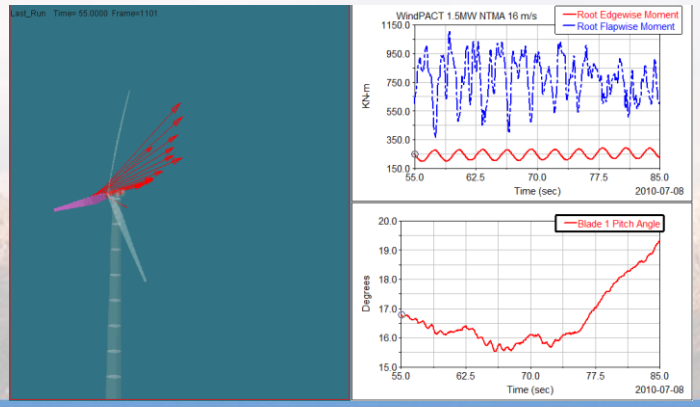
- **Wind turbine blades include**
  - Variable section shapes with twist,
  - Multiple materials and composite layups (glass, carbon, balsa, foam, epoxy, adhesives)
  - One or more shear webs





Beam Model:
Up to 6 DOF per node

Full system aeroelastic simulation
FAST or ADAMS & AeroDyn



Aerodynamic and structural dynamic loads applied to the model

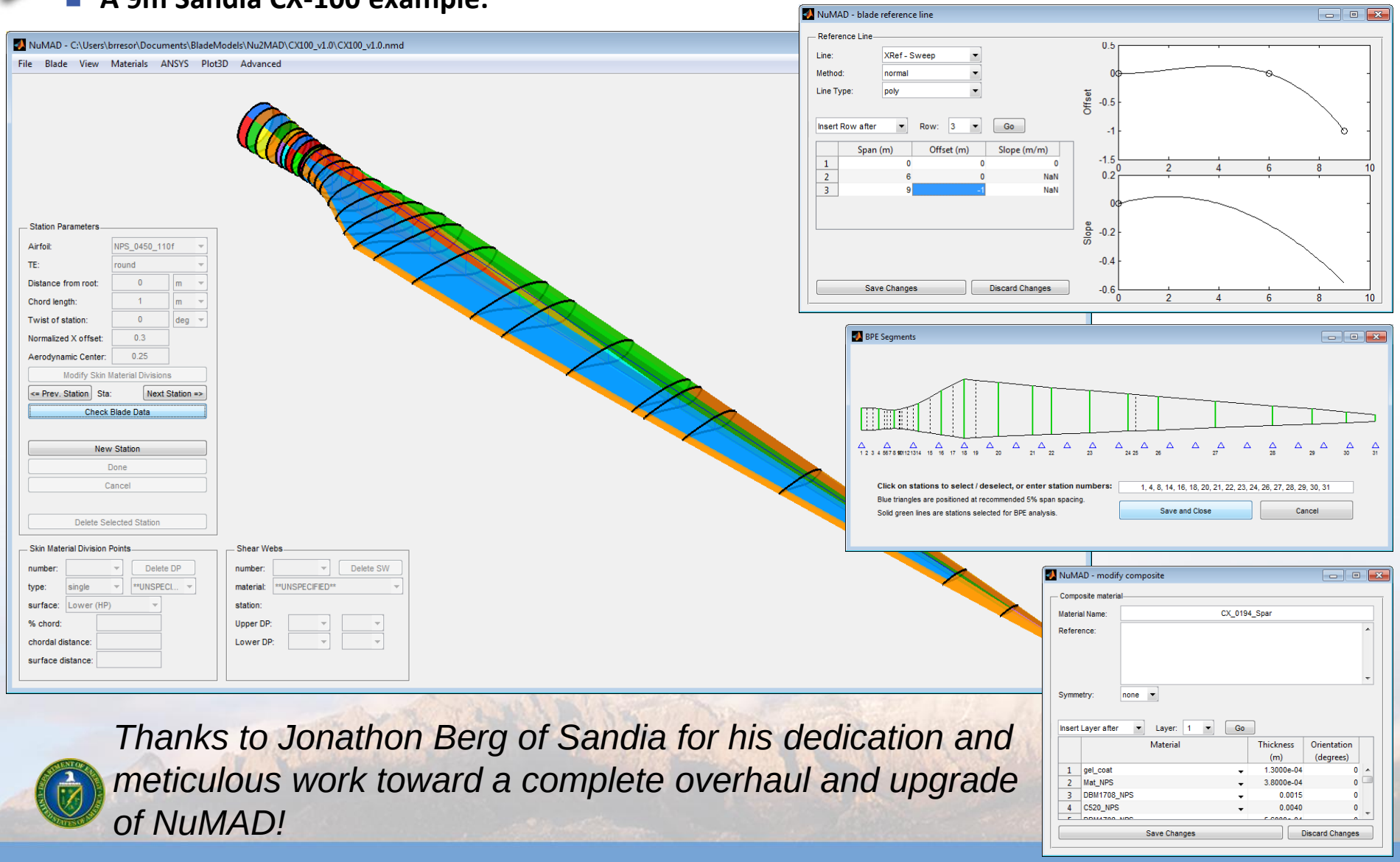
Sandia National Laboratories

NuMAD History

- **(Nu)merical (M)anufacturing (A)nd (D)esign tool for wind turbine blades**
- **Released initially ~2001 at Sandia; written in Tcl**
- **Experienced a few hurdles along the way:**
  - Concerns regarding offset node shell element formulations
    - Created motivation for development of tools such as PreVABS/VABS as well as 2D sectional analysis approaches; some pursued blade models made of brick elements
  - Concerns regarding amount of time required to build and solve models
  - Concerns about an increasing number of bugs in NuMAD, likely associated with more recent operating systems
- **A NuMAD tutorial was held at this workshop 2 years ago where it was decided to pursue a major update of the NuMAD tool for the benefit of Sandia users, as well as users in the research community at large**
- **The beginnings of a Matlab-based NuMAD was born in late 2010**
- **Public release of new version planned for end of summer 2012**

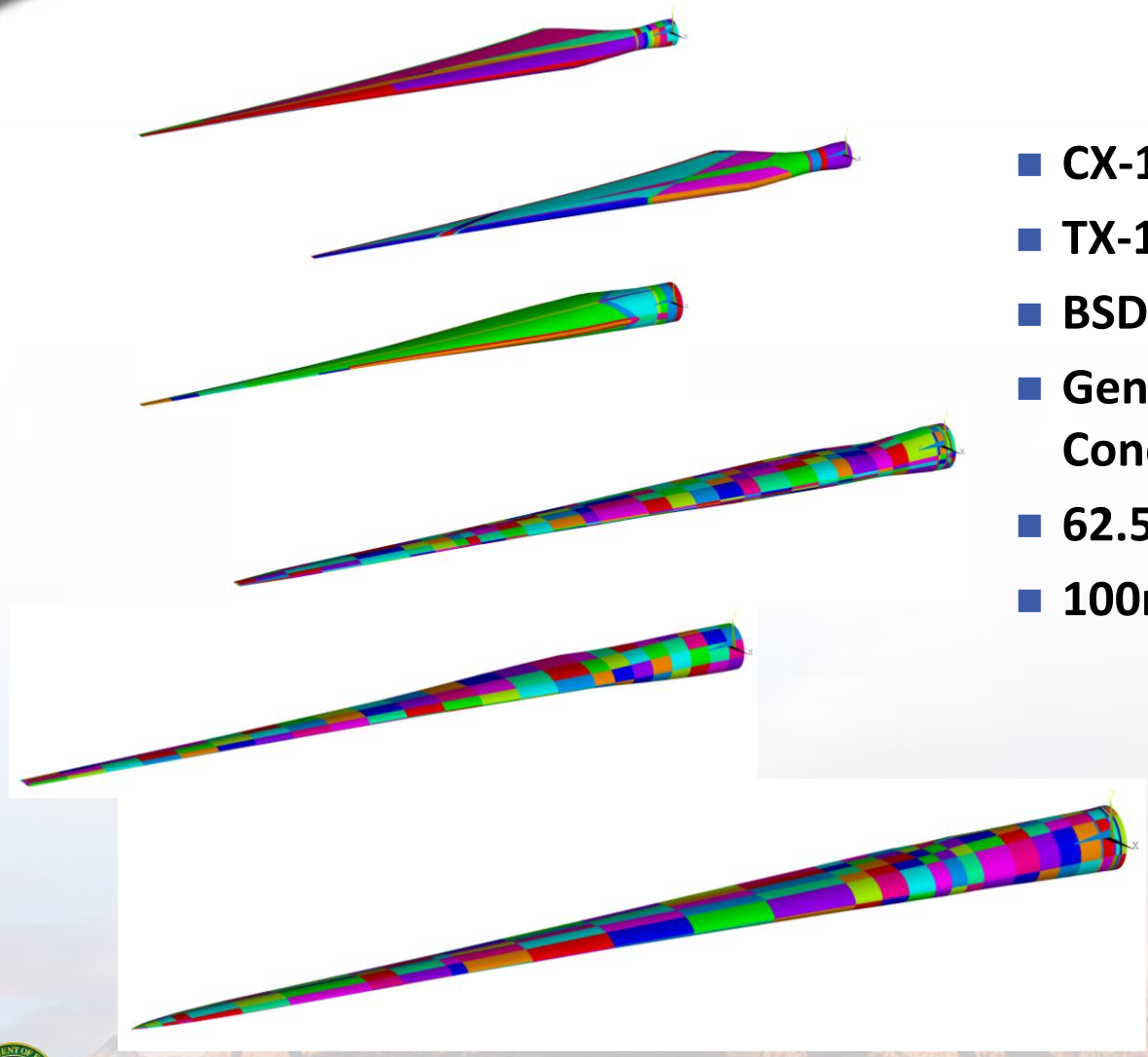
NuMAD Interface

- **A 9m Sandia CX-100 example:**



Thanks to Jonathon Berg of Sandia for his dedication and meticulous work toward a complete overhaul and upgrade of NuMAD!

Sandia Blade Models



- CX-100 9m
- TX-100 9m
- BSDS 9m
- Generic WindPACT 33.25m Concept
- 62.5m Concept
- 100m Concept

Sandia Supported Projects

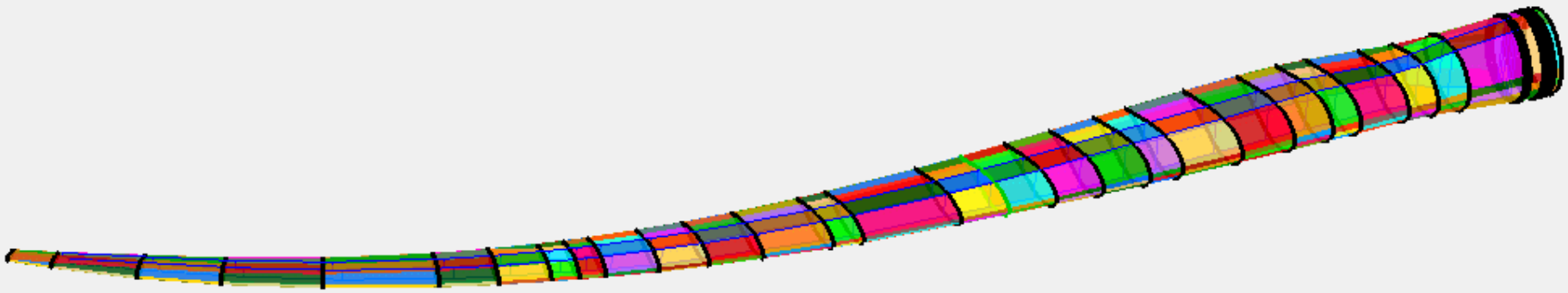
- SNL 100m blade
- Offshore SHM studies
- Active aero load control
- Blade reliability collaborative
- Radar blade investigations
- Sensor blade 1 & 2
- Hydro blade acoustics
- Scaled underwater turbine

New Features of NuMAD 2012

- **Matlab-based user interface**
  - Fast
  - Bug free
  - Easy to customize and develop
- **Sweep and/or prebend**
- **Excel input**
- **Output for CFD geometry**
- **NREL FAST Blade file output**
  - 2D method: NREL PreComp
  - 3D method: Beam Property Extraction (BPE)
- **Classical flutter analysis**

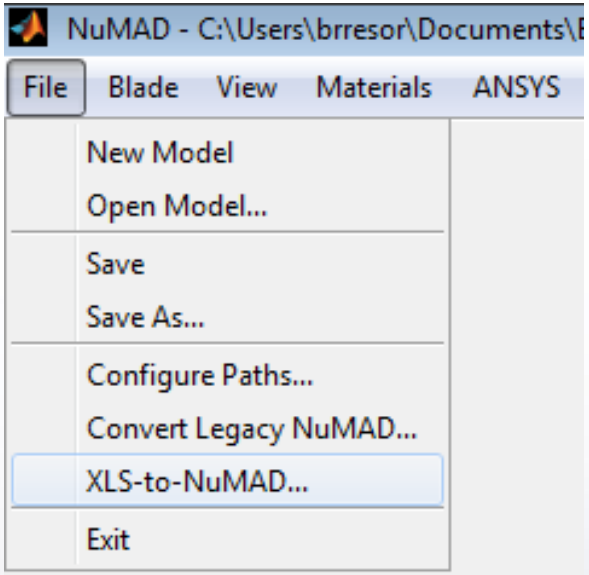
Blade Sweep/Prebend

- **Arbitrary blade reference axis can be defined**



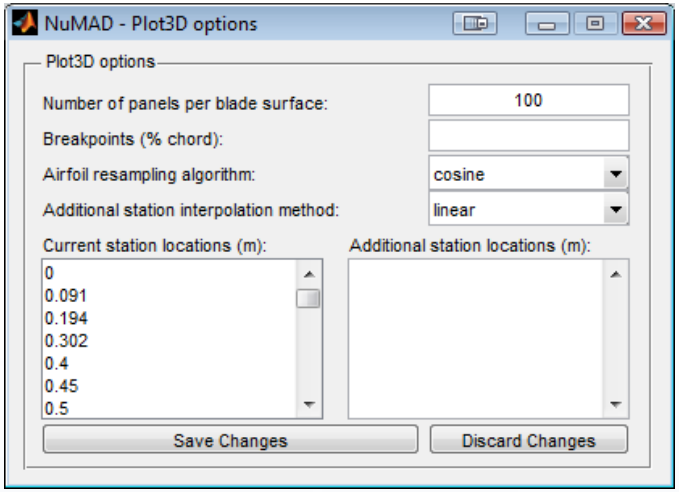
Excel Input

- An advanced user feature
- Enables easy parametric inputs
- Automatic computation of intermediate airfoil shapes
- Easy definition of numerous ply drops
- Easy definition of layup stacks; similar to manufacturing drawings
- Easy sharing of blade model information

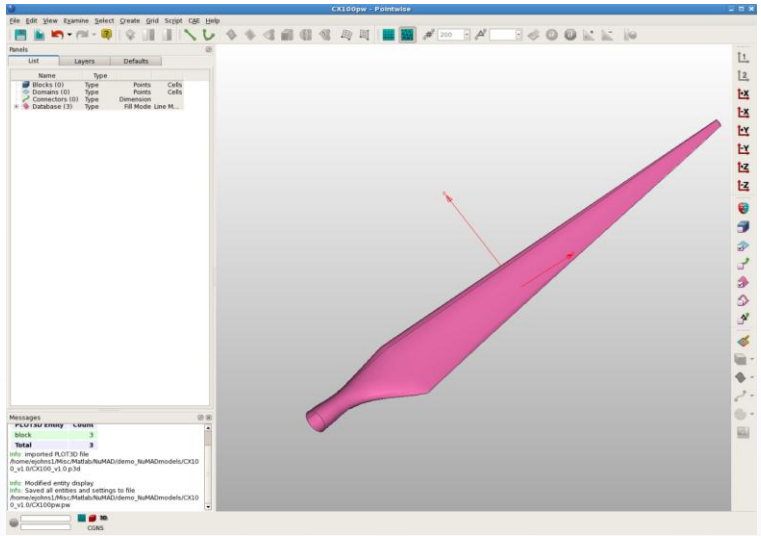


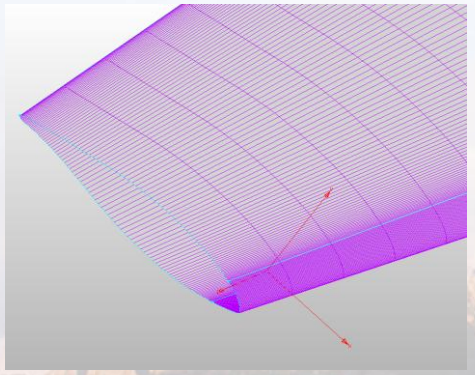
Output for CFD Geometry

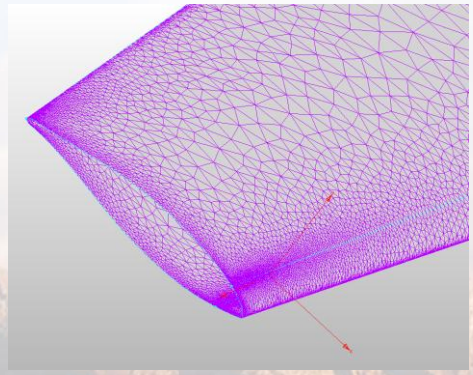
- **NuMAD -> Plot3D data format**

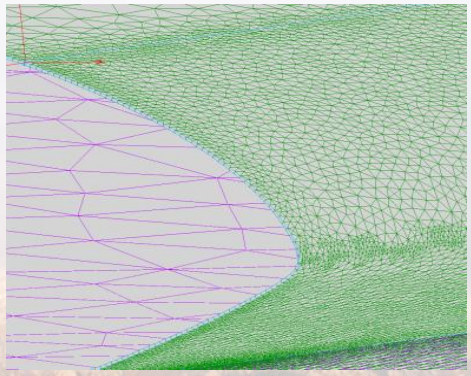


CX-100 Blade Surface in Pointwise®



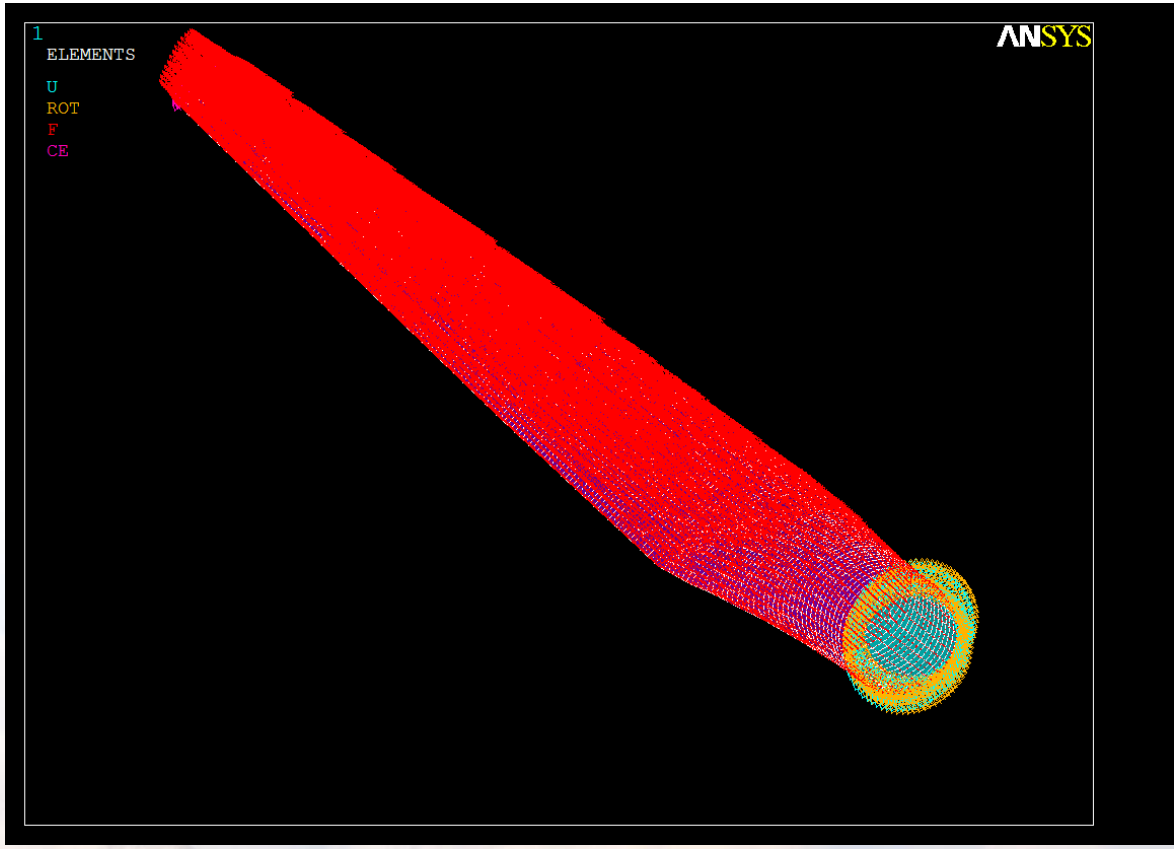






Loads application to the FE Model

- Normal, tangential and pitching forces can be mapped from BEM simulation (AeroDyn) to all skin nodes in the blade model



Beam Properties Computation

Two-Dimensional Approach

- **Pros**
  - *Readily and freely available*
  - *Computationally efficient*
- **Cons**
  - *Limited to 2D analysis*
  - *Simple examples below:*

$$EI_flap = \iint E(x,y)x^2 dxdy\ ,$$

$$EI_edge = \iint E(x,y)y^2 dxdy\ ,$$

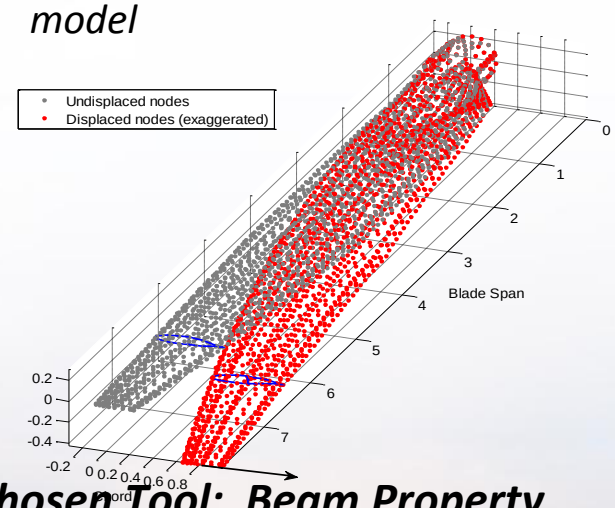
$$GJ = \iint G(x,y)(x^2+y^2)dxdy \text{ and}$$

$$EA = \iint E(x,y)dxdy$$

- **Chosen Tool: PreComp**
  - *Available from NREL NWTC*

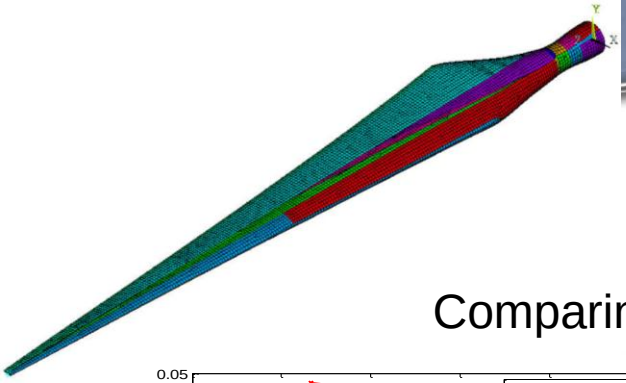
Three-Dimensional Approach

- **Pros**
  - *Includes three dimensional effects: Boundary conditions and warping*
- **Cons**
  - *Requires creation of the finite element model*



- **Chosen Tool: Beam Property Extraction (BPE)**
  - *Created by David Malcolm, GEC/DNV*
  - *See Malcolm, 2007 Wind Energy for more info*

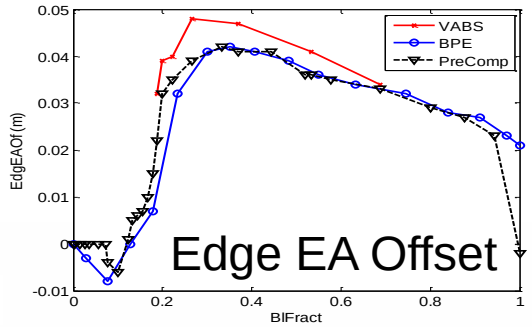
Sandia National Laboratories

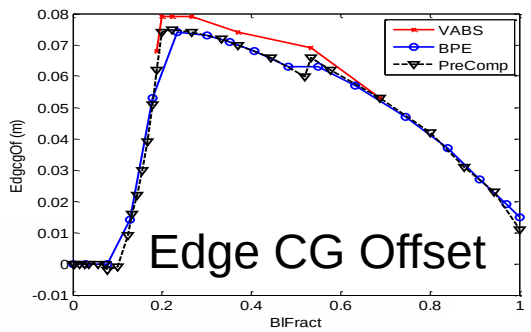


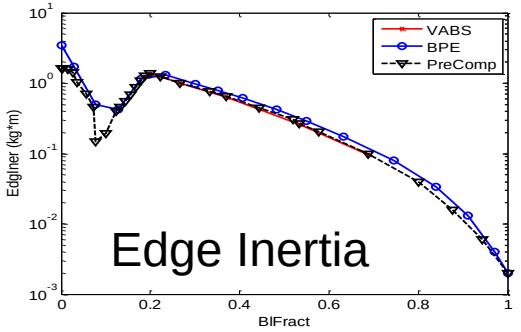
Calculate Beam Properties

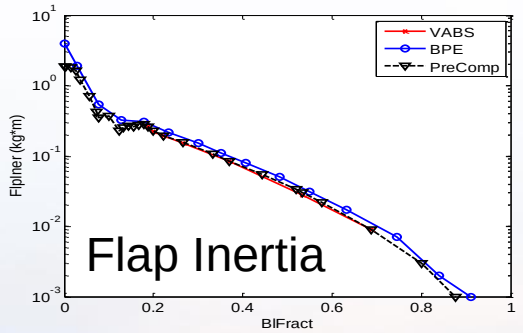
Resor,B. "Uncertainties in Prediction of Wind Turbine Blade Flutter." AIAA SDM 2011
Resor,B. "An Evaluation of Wind Turbine Blade Cross Section Analysis Techniques." AIAA SDM 2010

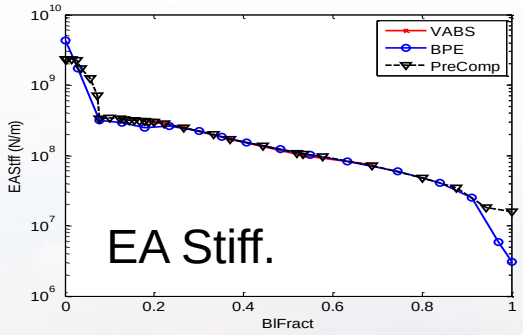
Comparing three techniques: BPE, 2D Section & VABS

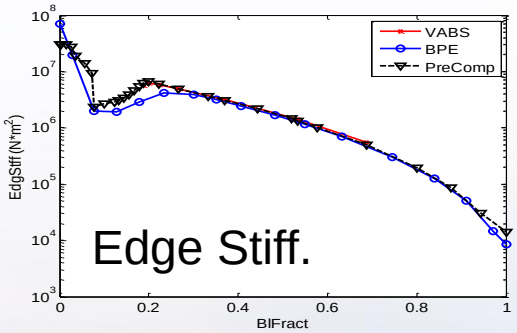


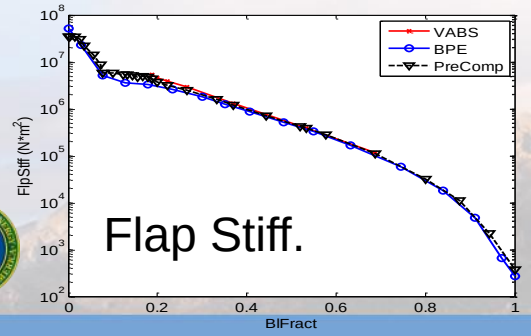


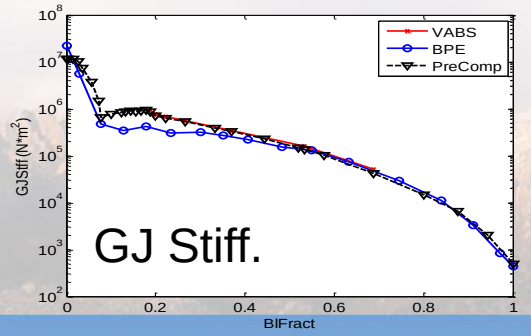


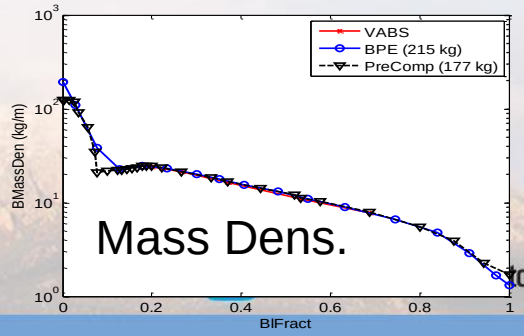












Sandia Classical Flutter Capability

- **SNL legacy capability (Lobitz, Wind Energy 2007) utilized MSC.Nastran and Fortran to set up and solve the classical flutter problem.**

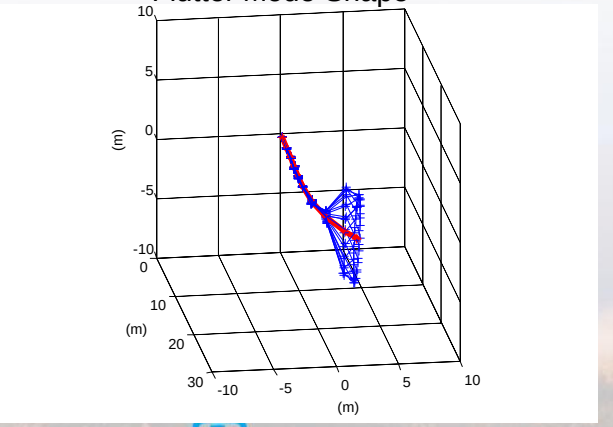
$$[M + M_a(\Omega)]\{\ddot{u}\} + [C_C(\Omega) + C_a(\omega,\Omega)]\{\dot{u}\} + [K(u_0,\Omega) + K_{tc} + K_{cs}(\Omega) + K_a(\omega,\Omega)]\{u\} = 0$$

  - Requires numerous manual iterations to find the flutter speed

- **A new Matlab based tool has been developed in 2012 by Brian Owens, Texas A&M**
  - Starting point: Emulate all assumptions of the legacy Lobitz tool
  - Continued development and verification: automated iterations, higher fidelity modeling assumptions

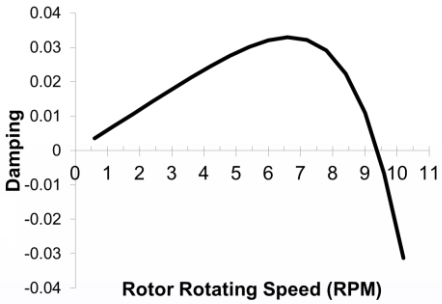
Matrix	Description
M, C, K	Conventional matrices (with centrifugal stiffening)
$M_a(\Omega)$, $C_a(\omega, \Omega)$, $K_a(\omega, \Omega)$	Aeroelastic matrices
$C_C(\Omega)$	Coriolis
$K_{cs}(\Omega)$	Centrifugal softening
K_{tc}	Bend-twist coupling

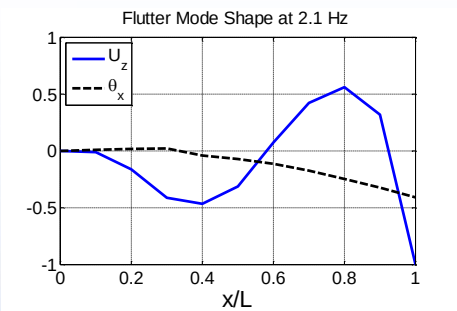
Flutter Mode Shape



100m Blade Flutter Parameter Study

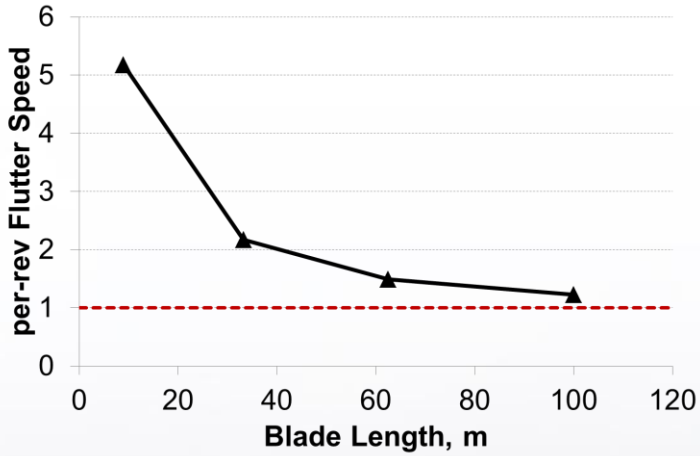
- **Resor and Griffith. "Aeroelastic Instability of Very Large Wind Turbine Blades." Scientific Poster. EWEA Copenhagen, 2012.**

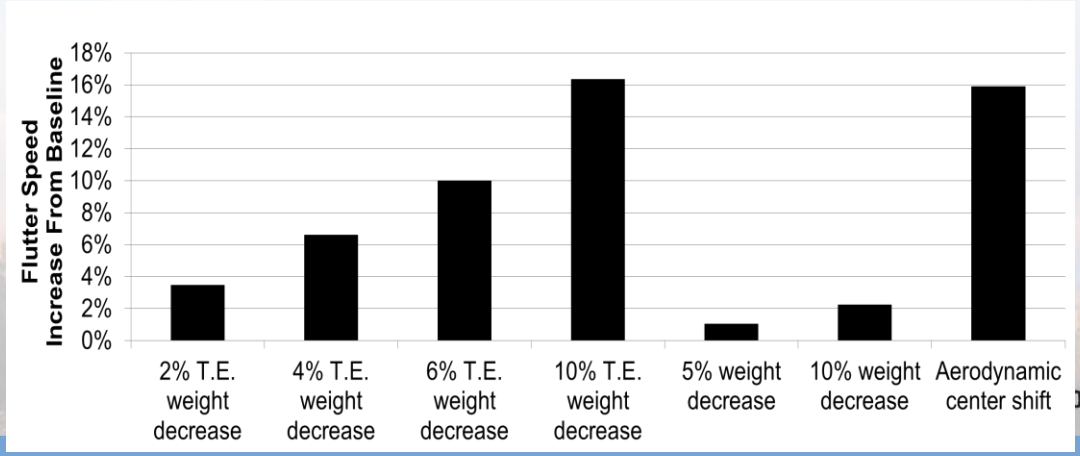




Data shown are from classical flutter analyses of various wind blade sizes:

- SNL 9-meter CX-100 experimental blade [Resor, 2011]
- WindPact 33.25-meter 1.5MW concept blade [Lobitz, 2007]
- SNL 62.5-meter blade (preliminary design)
- SNL 100-meter blade concept

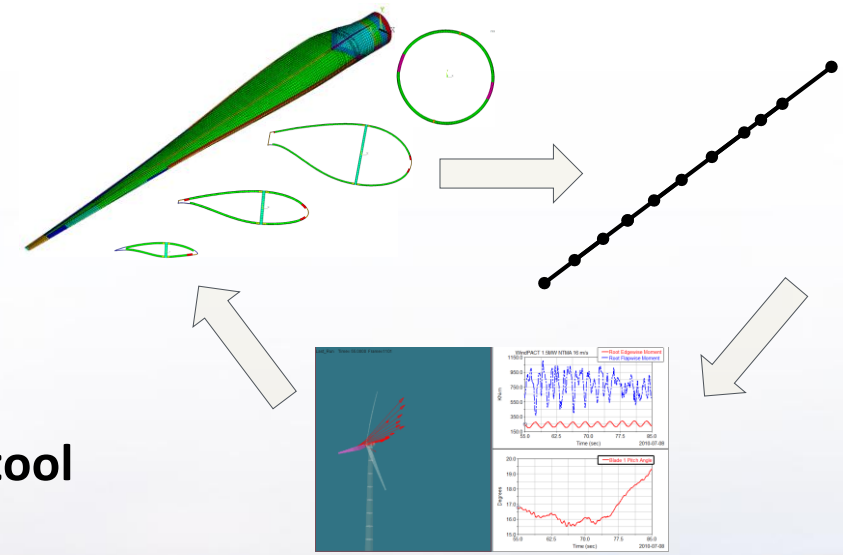




Future Work in Aeroelasticity

Areas for future research:

- **Perform blade beam property validations**
  - Torsion matters: Passive load alleviation via bend twist coupling or blade geometry
    - Flexible, nonlinear blades
    - Large deflection blades
- **Blade materials response characterization**
- **Accurate determination of blade loads**
  - Especially extreme loads
- **Continued aeroelastic instability (flutter) tool development and validation**
  - Will be required for very large blade concepts



Our Goals

- **Provide Sandia and its partners with a state of the art blade modeling capability and also**
- **Enable the entire research community to benefit from these developments to do cutting edge research**
- **Remainder of 2012 …**
  - Package and release NuMAD (source and compiled), supporting tools and example blade models
  - Software will be available by end of the summer on the Sandia Wind Energy Technologies website
- **And beyond …**
  - Some time available for maintenance and integration of externally generated ideas
  - There are extensive plans for internal use at Sandia and among partners, which will drive future developments