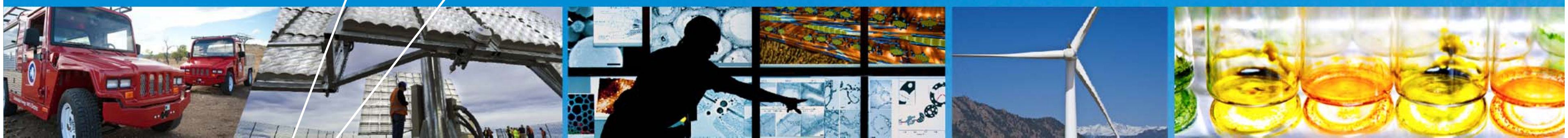
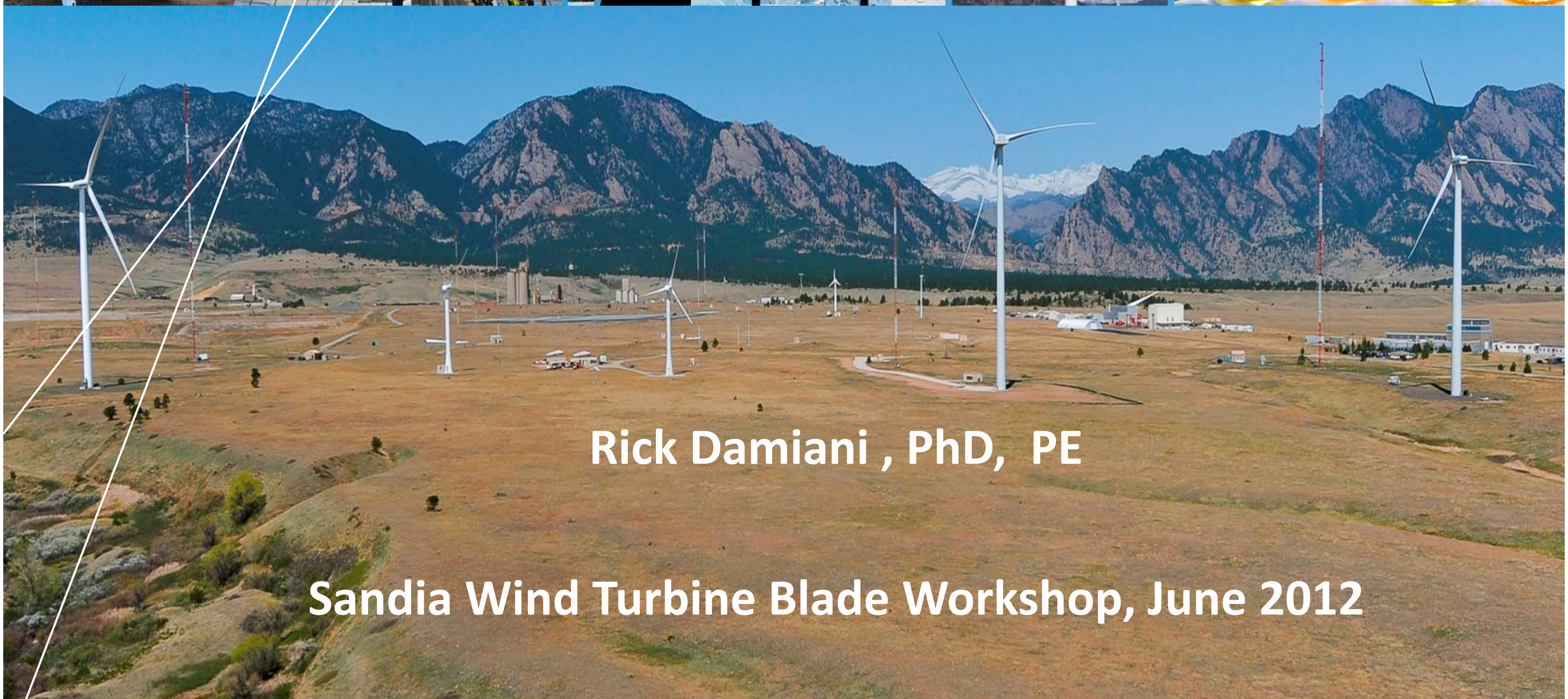
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Current and Planned DWT R&D at the NWTC





Rick Damiani , PhD, PE

Sandia Wind Turbine Blade Workshop, June 2012

Presentation Outline

- **Definition of the DWT field**
- **DOE Goals**

- **Current Technical Program**
  - Independent Testing, NWTC Accredited organization
  - Regional Test Centers (AWEA standards, SWCC)
  - Mid-Size Turbine Development (TTU +NPS, Design Guidance and Review)
    - Mid-Size System Modeling (COE first, SE later)
  - Examples of NWTC support for turbine R&D

- **DWT Program and Planned Activities**
  - Multi-pronged approach for small wind turbines
  - Modeling and Blade Codes,
  - International Standards Development

Distributed Wind Technology

- **Small and Mid-Sized Turbines up to 1 MW**
  - Generally interconnected at distribution level
  - Residential, Farm/Ranch, Off-Grid, Wind-Diesel, Telecom

DOE DWT GOAL

GOAL #1: Increase the number of small wind turbine models certified to performance and safety standards from the 2010 baseline of zero to forty models by 2020.

GOAL #2: Retain US Leadership in Small Wind, Foster Mid-Size

GOAL #3: Address Built-Environment Wind – Safety/Performance/Best Practices/Standards

(CURRENT STATUS: 2 turbines certified, 4 with conditional certification)

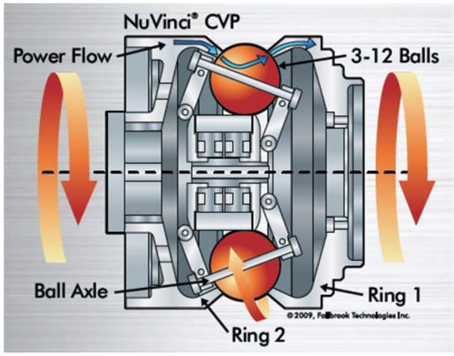
Certification and R&D Testing

- **NWTC is accredited (by A2LA) to test against full suite of IEC tests:**
  - Acoustics (pressure/power level 61400-11)
  - Duration(61400-2:reliability, dynamic characteristics, 2500 hrs)
  - Power Quality(61400-21; flicker, harmonics)
  - Power Performance(61400-12-1, AEP)
  - Safety and Function(61400-2; safety and fault/emergency handling)
- **American Association of Laboratory Accreditation (A2LA)**

NREL PIX #13311 – Jacobs 20kW

On-Going Certification Tests

- **Viryd**
  - Initially developed through CRADA CRD-03-130 (Mechanical Continuously Variable Transmission)

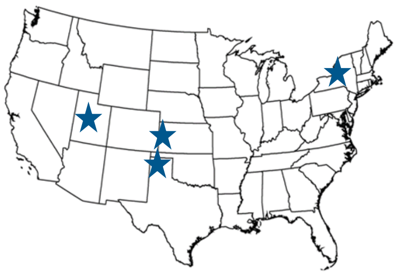


- **SWIFT**

- **Completed: ARE442,EW50,Gaia 11KW, Ventera VT10)**

Regional Test Centers

- **Establishment of 4 RTCs supported and awarded with DOE funds**



Potencia Hummingbird (10 kW) wind turbine installed at RTC (West Texas A&M/Alternative Energy Institute). NREL PIX #19571.

Mid-Size Design Review

- **Texas-Tech/General Dynamics- WindFlow 500 kW ReDesign**
  - New composite blades, 2 vs. 3 trade-off

- **NPS-450 kW- Class III, AEP improvement w.r.t. NPS100**
  - **Hub, Blade, Tower Design/Reviews**

Active NDA agreements in place

Examples of Recent NWTC Support

Northern Power NW100A/B

- 10 units deployed in Alaskan Wind Diesel applications
- Farm applications seen as a real market
- Prototype testing at NWTC April ’07

AOC 15/50 50 kW

- – Tested overall system
- **Installed at several communities**

Bergey 10 kW

- – Tested overall system
- – Structural tests of blades

Southwest Windpower Storm 1.8 kW

- – Tested control settings
- – Tested to IEC standards
- **Production started fall ’06**

Multi-pronged approach for small-mid-sized wind

- **To support the growth of the small wind industry in the U.S.:**

- 1 - Develop a process for certifying small wind turbines (currently managed by the SWCC)

  www.smallwindcertificationcouncil.org

Photo from Northwest Seed, Bergey 10kW, NREL/PIX 13162

Multi-pronged approach (cont.)

- 2 - Develop Open-Source Engineering Tools
  - Aeroelastic models
  - Multi-body dynamics
  - FEA
  - *Blade and component design*
  - Fatigue Damage Estimators
- 3 - Support Standard Development and Approach Validation
- 4 - Support Structural Component Testing

Photo from INL, Blackhawk tilt-rotor, NREL/PIX 17303

Table II: Ratio of measurements/simple design equations

	LMW1003 CRES	Inventus 6 DEWI	Proven 2200 NEL	AOC 15/50 NREL
Load case A Normal operation (equivalent ranges)				
Blade root edge bending	-	**1.3**	**1.06**	0.96
Blade root flap bending	**3.31**	**1.01**	-	**1.20**
Thrust force				0.19
Shaft torsion	-	0.8	**1.12**	0.25
Shaft bending	-	-	-	**1.56**
Loadcase B : Yawing				
Blade root flap bending	**1.2**	0.55	-	0.99
Shaft bending	-	-	-	0.85
Load case C: Loss of load (max rotational speed)				
Centrifugal force	-	[illegible]	[illegible]	-
Shaft bending	-	-	-	**12.47**
Loadcase E: Shut down				
Shaft torsion	-	-	-	**2.78**
Blade root edge bending	-	0.7	-	**1.95**

61400-2 (1999)

>>> Competitiveness Improvement Program Upcoming Solicitation

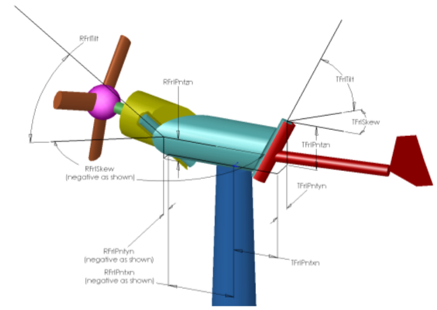
Multi-pronged approach (cont.)

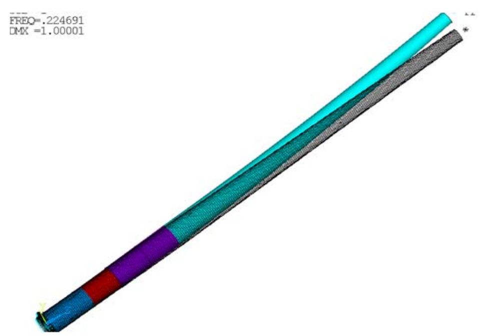
- 5 - Develop a small wind turbine **installer** certification program (supported by NABCEP)
- 6 - Develop a small wind **site assessor** certification program (host TBD)

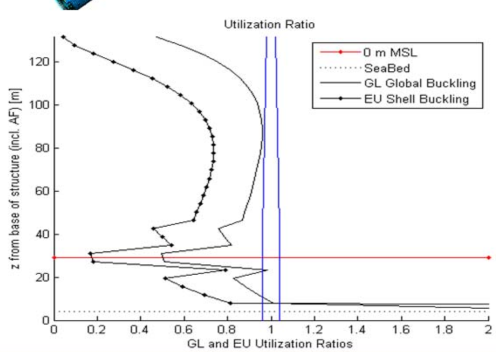
Photo from Southwest Windpower, Skystream, NREL/PIX 15337

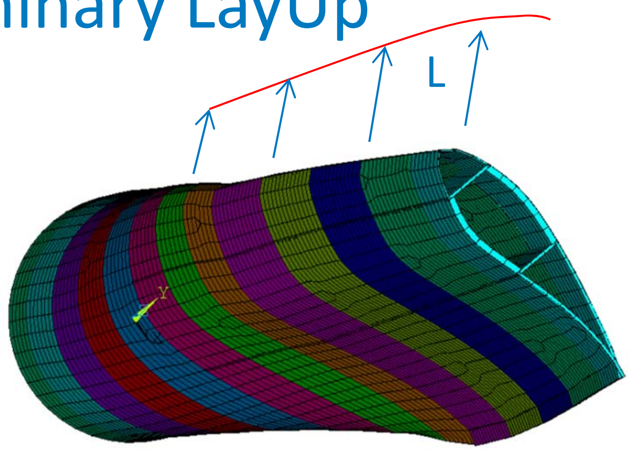
R&D: Code Development and Value Engineering

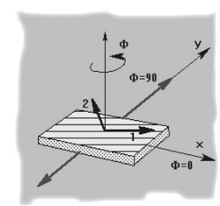
- **Multi-body: Improve FAST Furling Dynamics**
- **Tower Design**
- **Inverse Blade-Design:**
  - o Loads-> Preliminary LayUp

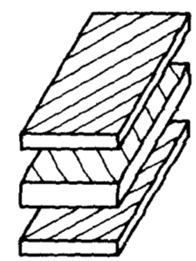










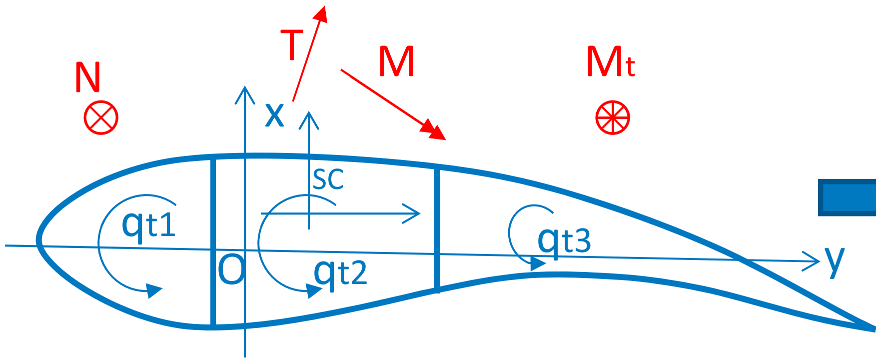


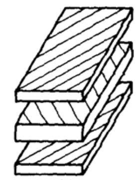
ABD_composite.m→A,B, D matrices
XSecComposite.m →axial and shear stresses

R&D: Code Development and Value Engineering

- **Inverse Blade-Design:**

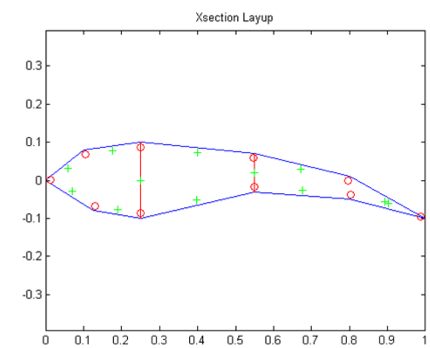
Discretize Section, Sectional Properties, Loads





Layup & material definition

Discretization



layer.E,G,nu(3),t,Θ ➔Q➔ assemble laminates & A,B, D matrices

XSectionComposite.m➔EA, EJ_{xx}, EJ_{yy}, ES_x, ES_y, GJ_{0q} (smeared properties within laminates)

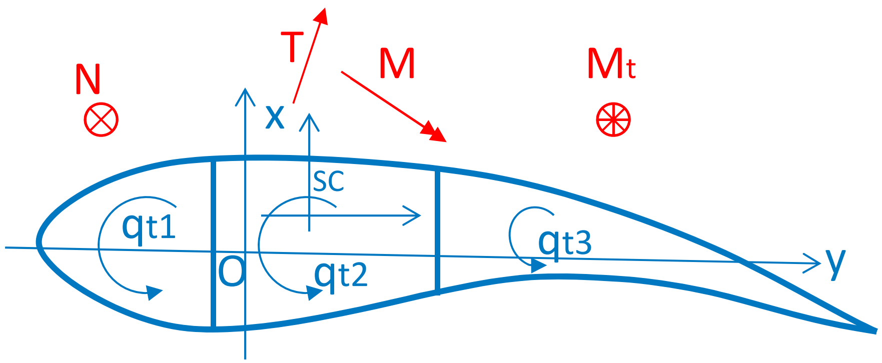
load.Tx,Ty,Mxx,Myy,MT➔S_{zz}, qt+qs

R&D: Code Development and Value Engineering

- **Inverse Blade-Design:**

  Strain, Stress

XCompEuler.m ➔ strain



$$\begin{bmatrix}\varepsilon_0\\ \phi \\ \psi\end{bmatrix} = \begin{bmatrix} EA & ESy & ESx \\ ESx & EJxy & EJxx \\ -ESy & -EJyy & -EJxy \end{bmatrix}^{-1} \begin{bmatrix} N \\ Mxx \\ Myy \end{bmatrix}$$

load.MT➔ qt

load.Tx, Ty, Mxx, Myy➔qss=qs0+qs

$$\sigma_{zz} = E_{zz}(x,y)[\varepsilon_0(z)+\phi(z)x+\psi(z)y]$$

$$matA(i+1,\max(i-1,1):\min(i+2,ncells)) = \left[-\frac{fweb_{i-1}}{2A_{i+1}};\frac{f_i}{2A_i}+\frac{fweb_i}{2A_{i+1}};-\frac{f_{i+1}}{2A_{i+1}}+\frac{fweb_i}{2A_{i+1}};+\frac{fweb_{i+1}}{2A_{i+1}}\right]$$

$$\begin{bmatrix} q_{t1} \\ q_{t2} \\ \vdots \\ q_{tn}\end{bmatrix} = matA^{-1}\begin{bmatrix} MT \\ 0 \\ \vdots \\ 0\end{bmatrix}$$

$$f_i = \sum_j \frac{w_j}{G_{xy,j}t_j}$$

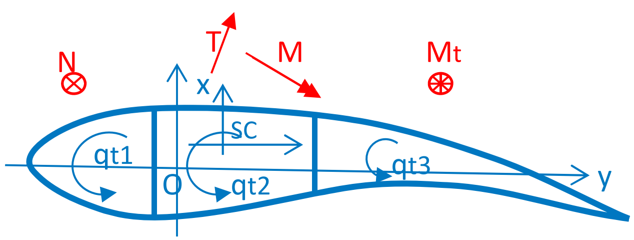
$$\frac{\partial \sigma_{zz}}{\partial z}$$

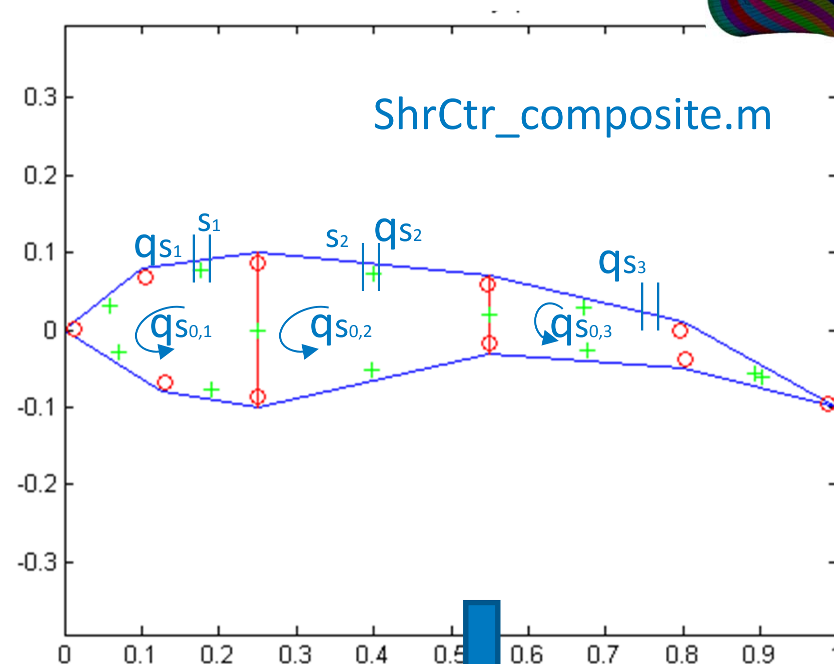
XSecStress_composite.m➔stress

R&D: Code Development and Value Engineering

- **Inverse Blade- Design:**

  Shear Stress, Shear Center





load.Tx, Ty, ➔qss

$$q_{s,i}(s) = \int_0^s \frac{\partial \sigma_{zz}}{\partial z} t\, ds$$

+ compatibility equation(s)

$$\oint_i \frac{q_{s0,i}}{Gt} ds - \oint_{i,i-1} \frac{q_{s0,i-1}}{Gt} ds - \oint_{i+1} \frac{q_{s0,i+1}}{Gt} ds = -\oint_i \frac{q_{s,i}}{Gt} ds$$

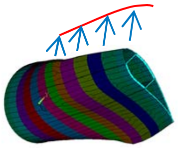
$$q_{ss,i} = q_{s,i} + q_{s0,i}$$

$$\begin{bmatrix} q_{ss,1} \\ q_{ss,2} \\ \vdots \\ q_{ss,n} \end{bmatrix}$$

XSecStress_composite.m

R&D: Code Development and Value Engineering

- **Inverse Blade-Design:**
  - Strain check, stress check vs. allowable
  - Buckling (approximate treatment)
  - Additional Failure Criteria (Tsai Wu etc) Checks
  - Combine with Beam-Model→ deflection checks



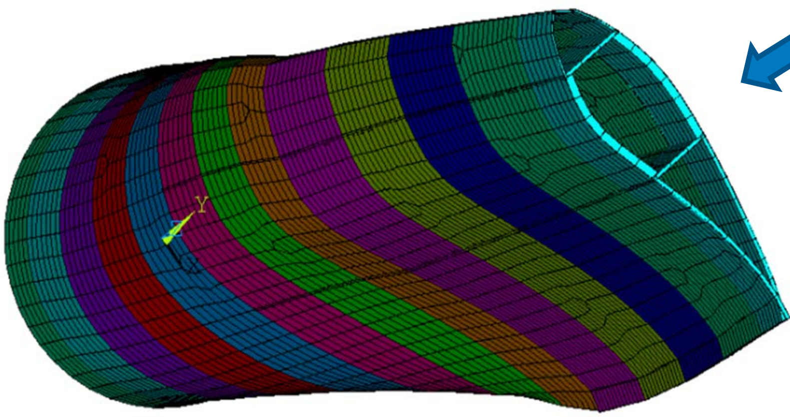
$$\sigma_{zz} \leq \sigma_{zz}^{*}\, PSF$$

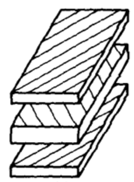
$$\frac{N_{zz}}{LF} \leq \min\left[t\sigma_{zz,y},\, \frac{4\pi^2 D_{11}}{w^2}\, \frac{\sqrt{D_{22}/D_{11}} + \left(D_{12} + 2D_{66}\right)/D_{11}}{2} \right]$$

$$\left(\frac{1}{X_t} - \frac{1}{X_c}\right)\sigma_{zz} + \frac{\sigma_{zz}^2}{X_t X_c} + \frac{\tau_{zs}^2}{S_{zs}^2} \leq 1 PSF$$

R&D: Code Development and Value Engineering

- **Inverse Blade- Design, in progress and planned:**
  - Verification
  - Structural Optimization (leverage upon SysEng.→ Dakota)
  - Graph Theory-> automatic generation of ‘circuits’ (cells, shear calculation, any geometry)
  - Towers





R&D: Code Development and Value Engineering

- **Support Manufacturers with High-Value Engineering**
- **Let tools and know-how trickle down from Large Wind**

R&D: Component Testing

100 ft-kip Portable Test Stand

- **Used for 20-kW and smaller static and fatigue blade testing**
- **100 ft-kip moment rating**

110-kip Load Frame

- 6” stroke, 110-kip load capacity
- Typical use is for subcomponent testing (double ended root studs, panel testing, beam testing)
- Setup shown has cold temperature chamber for testing root studs

225 kW Dynamometer

22-kip Load Frame

- Typical use is for material coupon testing
- 10” Stroke, 22,000-lb capacity
- Used for resonant base-excitation testing of small wind turbines

International Standards

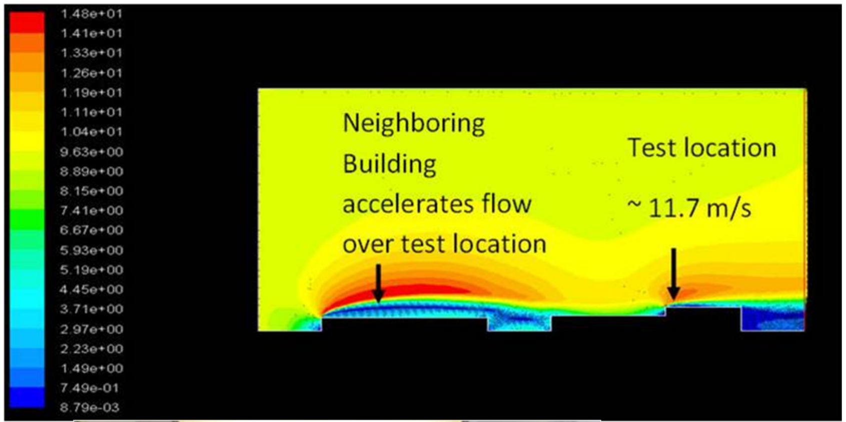
NREL PIX #17523 – Gaia 11kW

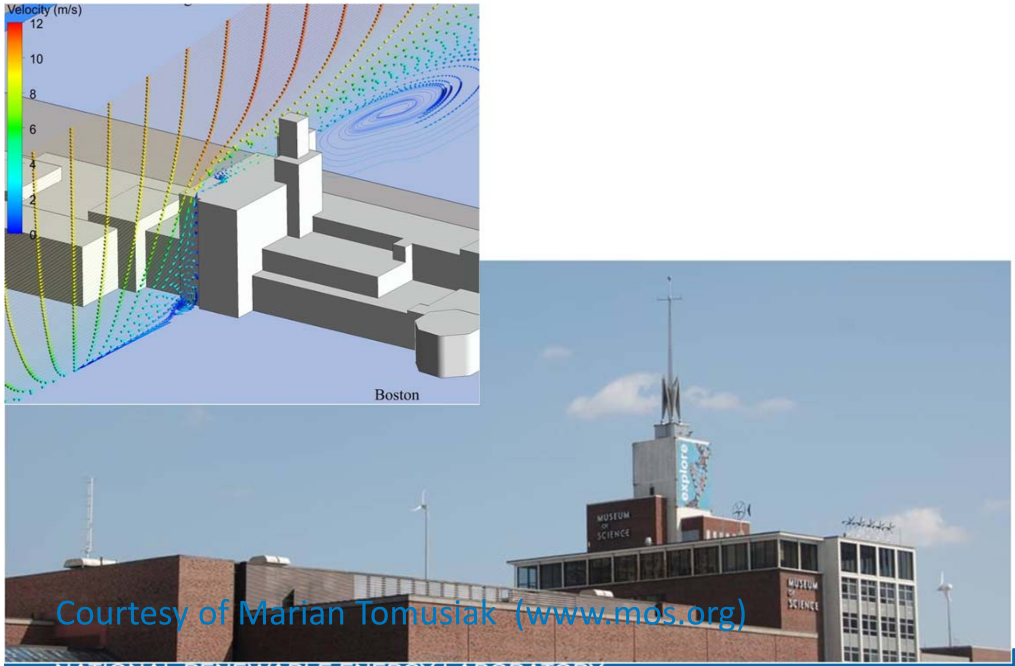
- **IEC 61400, UL, IEEE, Measnet**
  - Turbine design requirements, blades, generators, measurements
- **IEA Task 27**
  - Recently completed: Consumer Label for Small Wind Turbines (up to 200m2 rotor swept area)
  - Developing Recommended Practice for Design of Small Wind Turbines in the **Built Environment**

BEWT (Built-Environment)

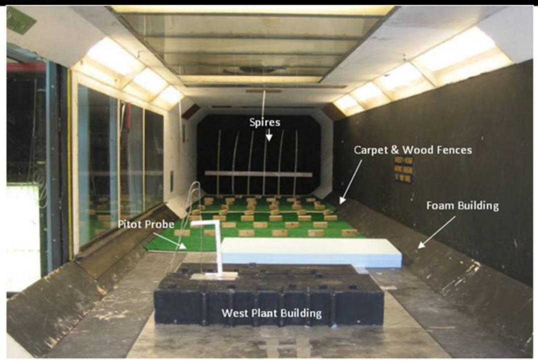
- Literature Survey
- Field Campaign- Structural Loading/Vibration and Noise
- Modeling
- Standard Development
- IEA Task 27

Courtesy of Cascade Engineering

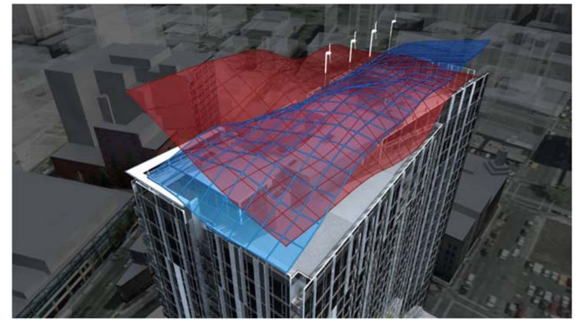


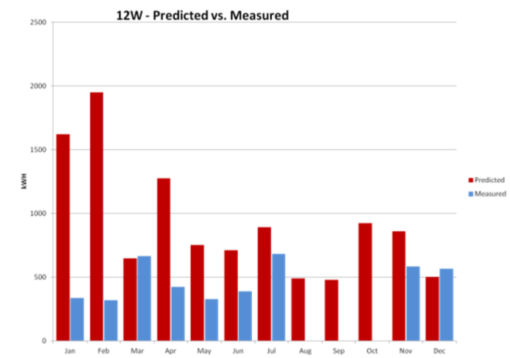


Courtesy of Marian Tomusiak (www.mos.org)



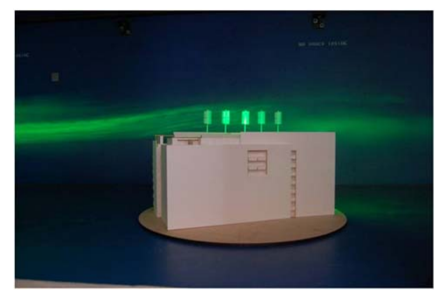
BEWT (Built-Environment)





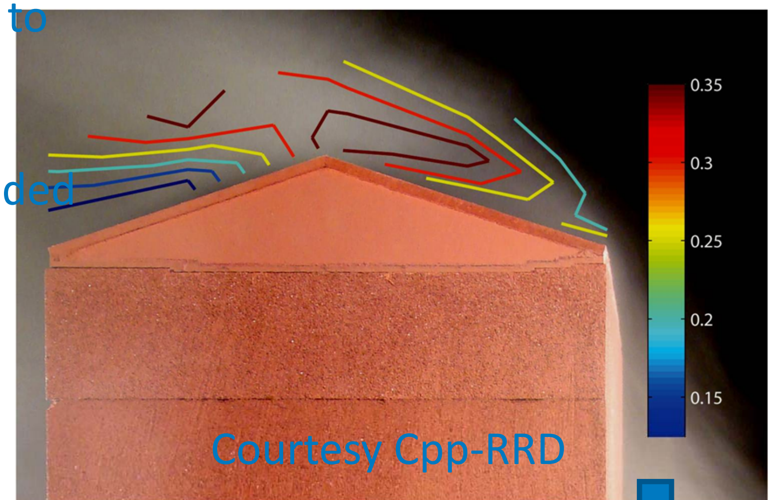
- Safety – proximity to population
- Vibrations and Structural interfaces
- ASCE / IEC

Courtesy of ZGF



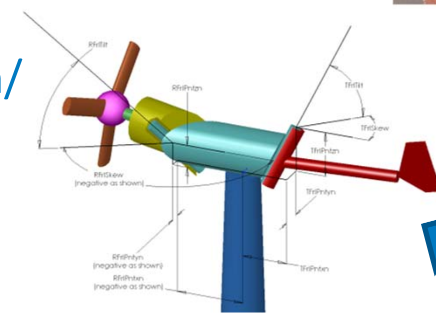
BEWT (Built-Environment)

- Identify Flow and Turbulence Characteristics necessary to define loading behavior
- Improve Modeling Capabilities
- Expand Standards to cover built- guidelines/recommended practice

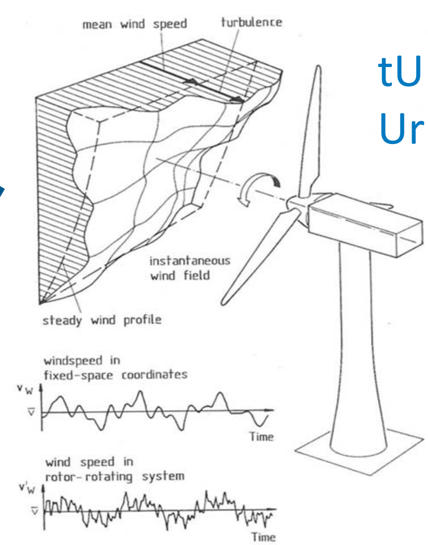


Courtesy Cpp-RRD

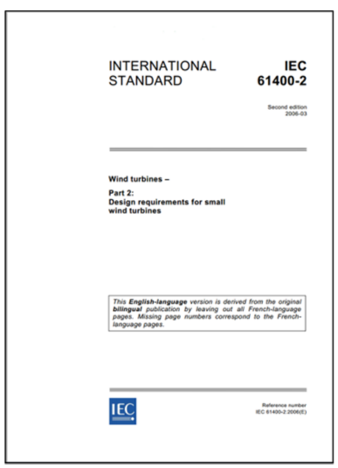
Field Data Comparison/ Verification



FAST Simulations



tURBsym- Urban Inflow


INTERNATIONAL STANDARD

IEC 61400-2

Second edition 2006-03

Wind turbines –

Part 2: Design requirements for small wind turbines

This English-language version is derived from the original bilingual publication by leaving out all French-language pages. Missing page numbers correspond to the French-language pages.

IEC

Reference number IEC 61400-2:2006(E)

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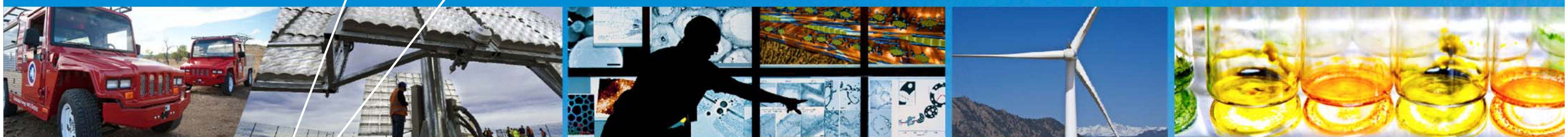
For More Information



Go to: www.nrel.gov/wind/smallwind/