



Increased Strength in Wind Turbine Blades through Innovative Structural Design

Joshua Paquette Paul Veers

Wind Energy Technology Department

Sandia National Laboratories

Albuquerque, NM, USA

EWEC 2007

Milan, Italy



Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Overview

- **Blade Research at Sandia National Laboratories**
- **CX-100 and BSDS 9 m Blade Designs**
 - **Carbon in Blades**
 - **Flatback Airfoils**
- **Blade Testing**
- **Acoustic Emissions Monitoring**
- **Finite Element Modeling**



Blade Research at Sandia National Laboratories

Increased Strength in Wind Turbine Blades through Innovative Structural Design
EWEC 2007
May 8th, 2007



Blade Research at Sandia National Labs

- SNL initiated a blade research program in 2002 to investigate the use of carbon in blades along with other advanced structural concepts
- Objective: stronger, lighter blades
- Three 9 m blade designs were produced
 - CX-100 (Carbon Experimental 100 kW)
 - TX-100 (Twist-Bend Coupled Experimental 100 kW)
 - BSDS (Blade System Design Study)
- Laboratory and field tests conducted to evaluate the designs and to validate modeling tools

CX-100

- **Manufactured using existing 9 m molds**
- **Based on ERS-100 blade with NW-100 root**
- **Glass-Epoxy blade with full length carbon spar cap**
- **Conventional design methodology**

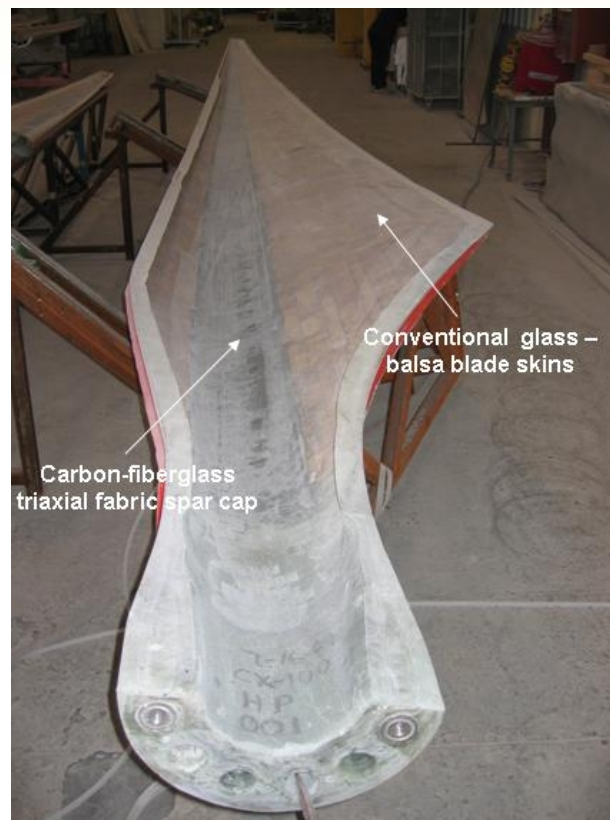
Aerodynamic



Structural



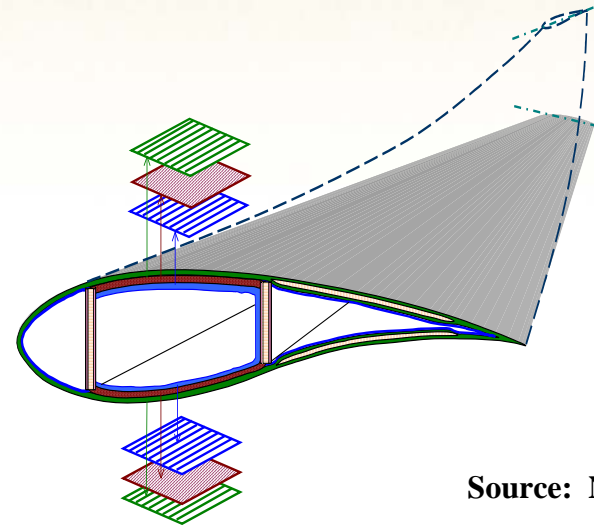
Manufacturing



CX-100 Blade Skin

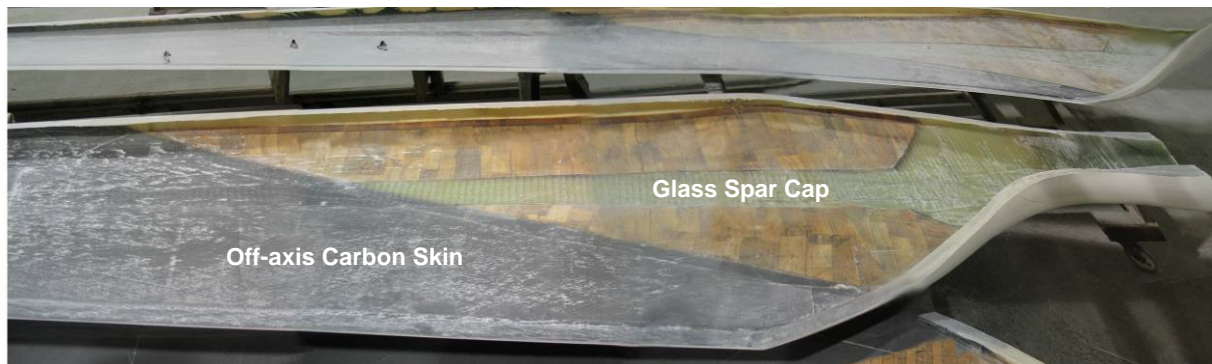
TX-100

- Identical geometry to CX-100
- Partial length glass spar cap
- 20° off-axis carbon in outboard (~>3.5 m) skins to produce material-induced, passive aerodynamic load alleviation



Source: NREL

Material Induced Twist-Bend Coupling



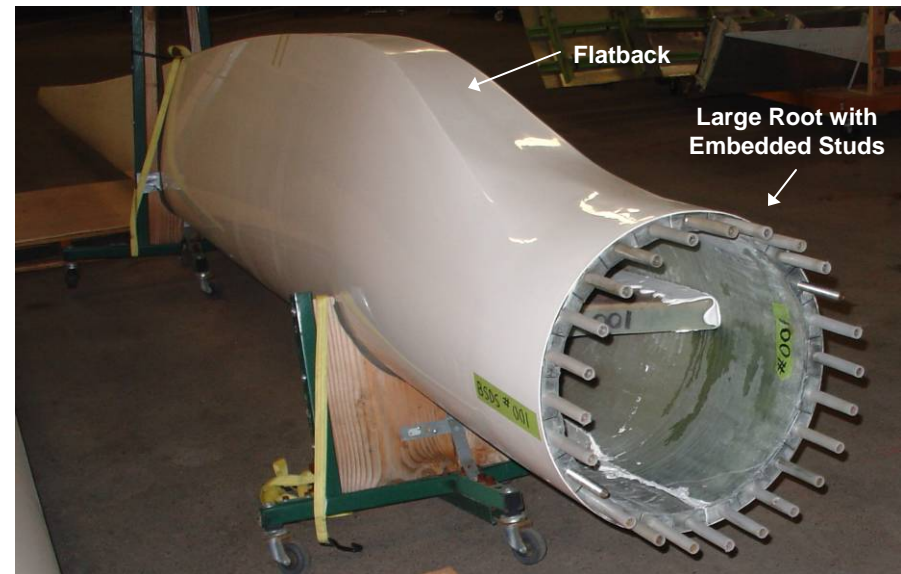
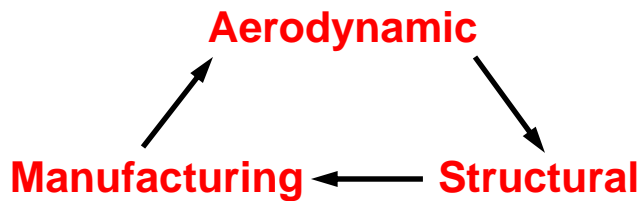
TX-100 Blade Skin

Increased Strength in Wind Turbine Blades through Innovative Structural Design
EWEC 2007
May 8th, 2007



BSDS

- **Advanced design**
 - Flatback airfoils
 - Full-length constant thickness
 - Carbon spar cap
 - Embedded root studs
 - High performance airfoils
 - Large, thin root
- **8.325 m in length**
- **Arrived at through system design approach**



BSDS Blade

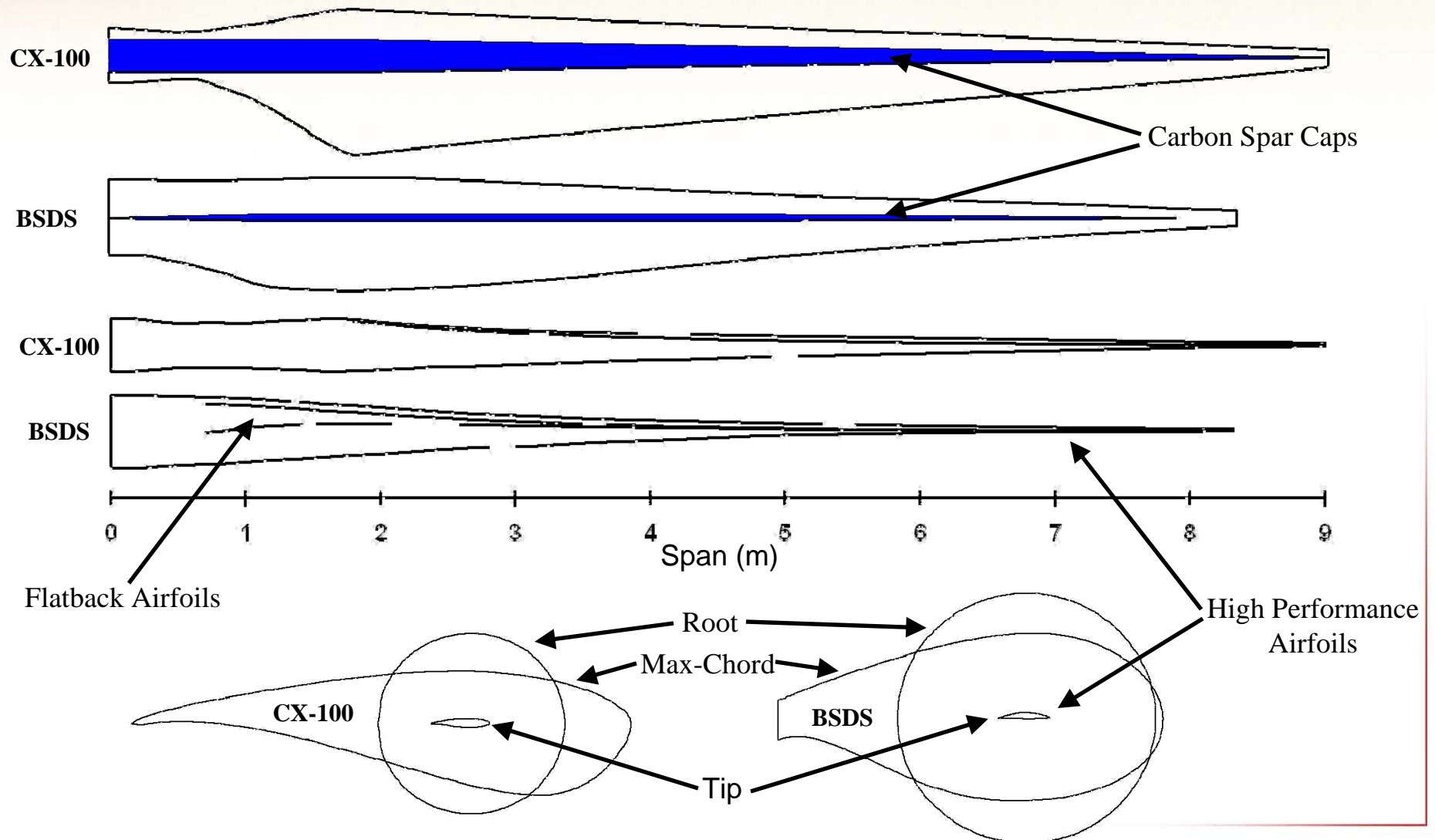


CX-100 and BSDS 9 m Blade Designs

Increased Strength in Wind Turbine Blades through Innovative Structural Design
EWEC 2007
May 8th, 2007



CX-100 and BSDS Blade Designs

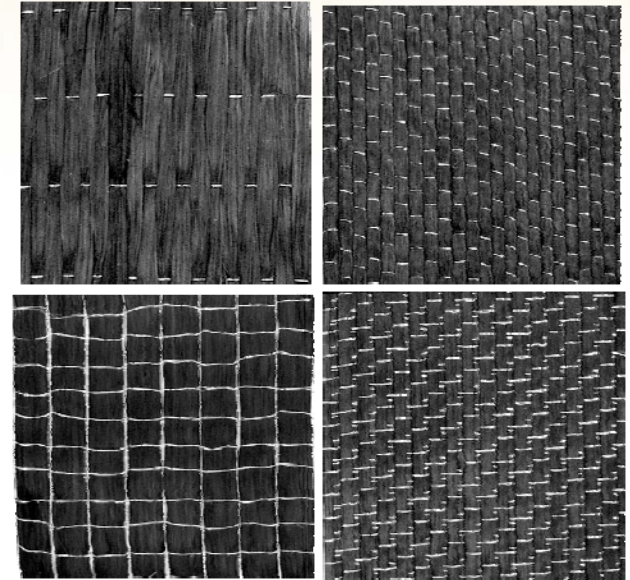


Increased Strength in Wind Turbine Blades through Innovative Structural Design
EWEC 2007
May 8th, 2007

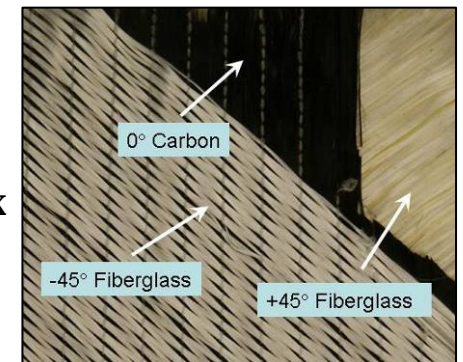
Carbon in Blades

- **Advantages:**
 - High stiffness/weight ratio
 - Excellent properties with straight fibers
- **Disadvantages:**
 - Higher cost
 - Limited availability
 - Difficult to infuse
 - Poor properties with wavy fibers
- **Potential solution: SAERTEX glass/carbon triax fabric**
 - Relatively inexpensive
 - Permeable
 - Dry fabric for conventional infusion techniques
 - Maintains excellent fiber straightness

Common Dry
Carbon Fabrics



SAERTEX
Glass/Carbon Triax
used in SNL 9 m
Blades

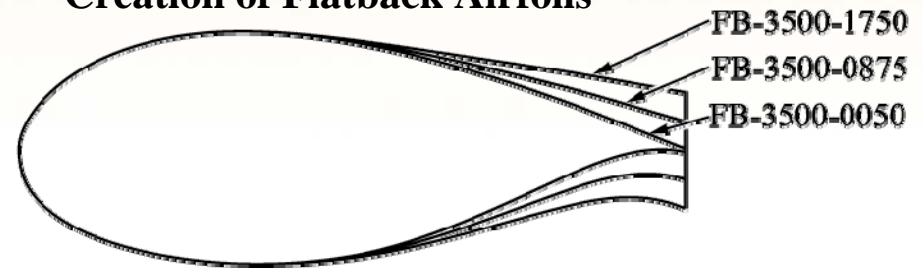


*Study of carbon materials performed in collaboration with GEC and MSU

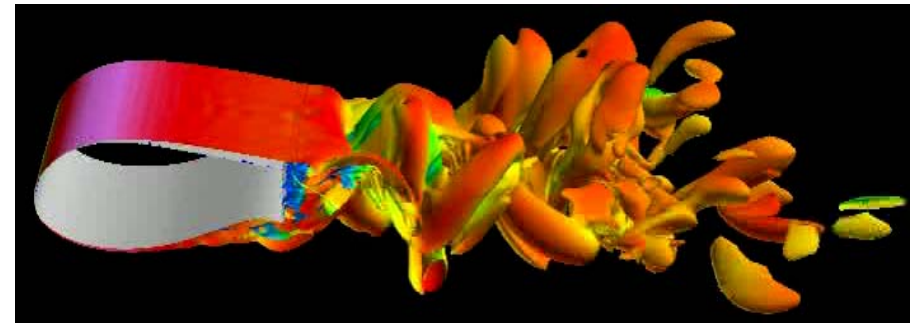
Flatback Airfoils

- Flatback airfoils created by the symmetric addition of thickness about the camber line
- Different from truncated airfoils which “chop” the trailing edge off and thus lose camber
- Advantages
 - Structural:
 - Increased sectional area
 - Increased sectional moment of inertia
 - Aerodynamic:
 - Increased maximum lift coefficient
 - Reduced sensitivity to surface soiling
- Disadvantages
 - Increased drag
 - Unknown and complex 3D flow
 - Greater aero-acoustic emissions
- One solution for increasing thickness, others exist such as thick airfoil families

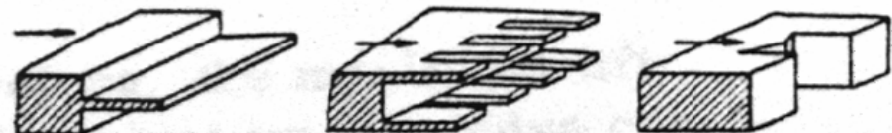
Creation of Flatback Airfoils



Flatback Flow Field

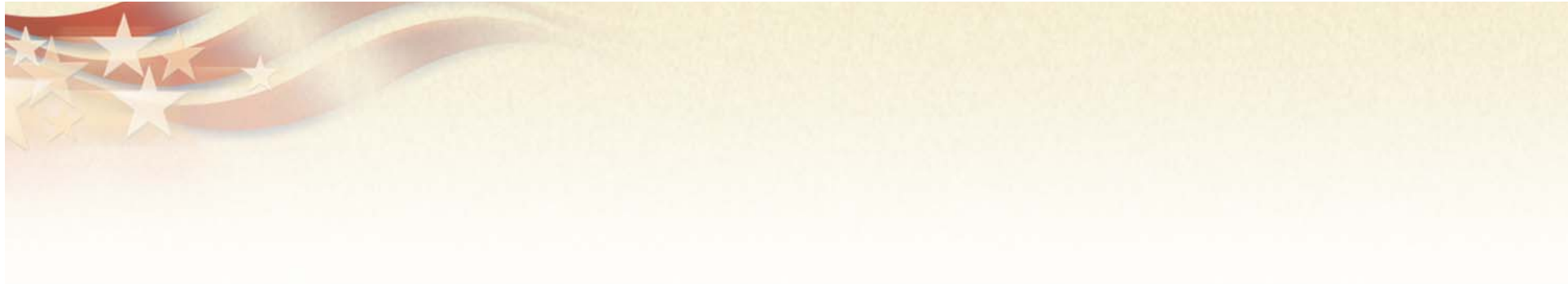


Possible Trailing Edge Treatments to Reduce Drag



*Study of flatback airfoils performed in collaboration with UC Davis

Source: Tanner (1973)

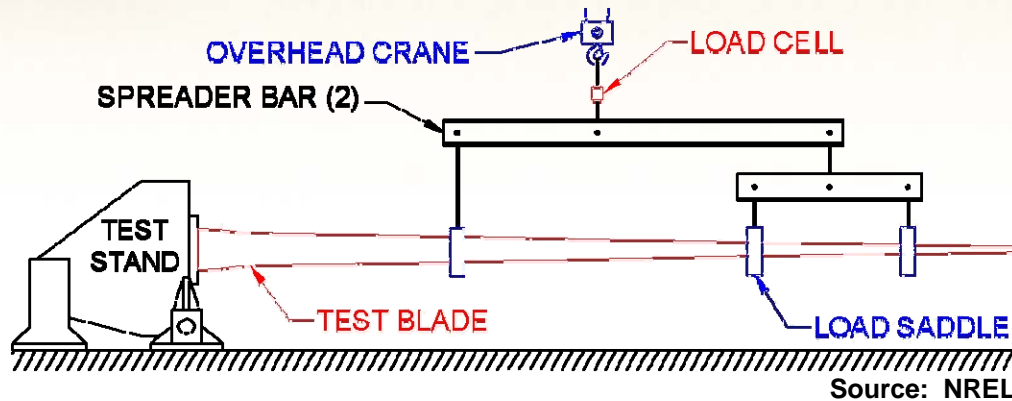


Blade Testing

Increased Strength in Wind Turbine Blades through Innovative Structural Design
EWEC 2007
May 8th, 2007



Testing: Setup



Whiffle-Tree Loading Arrangement

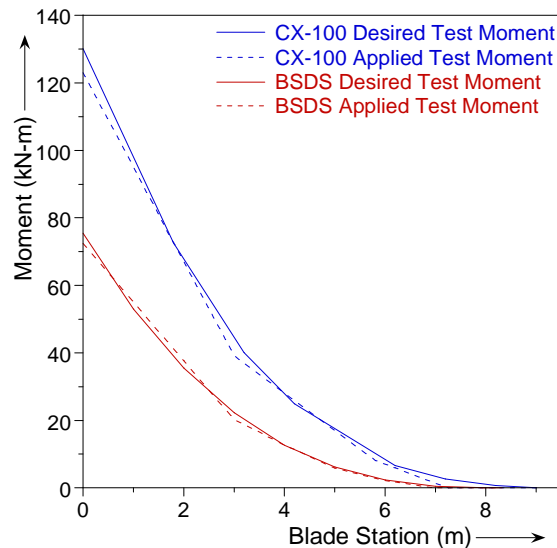
CX-100 and BSDS Test Loads

Saddle #	CX-100		BSDS	
	Position (m)	Load (kN)	Position (m)	Load (kN)
1	3.00	16.91	3.00	9.79
2	5.81	5.47	4.80	3.96
3	7.26	5.59	6.60	3.65

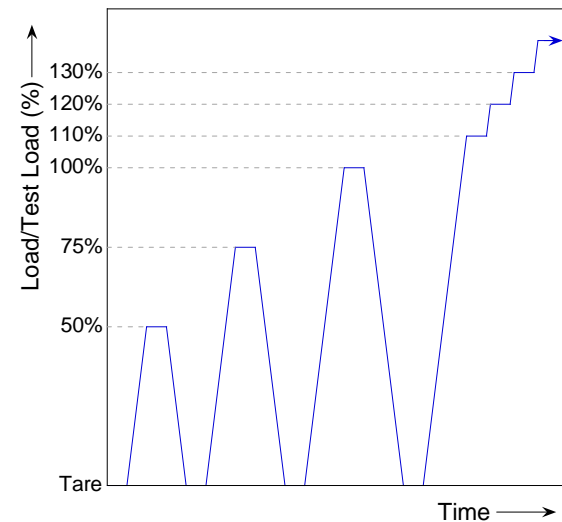
Blade Extreme Root Moments

CX-100: 86.4 kN-m

BSDS: 53.8 kN-m



Test Loading Distribution



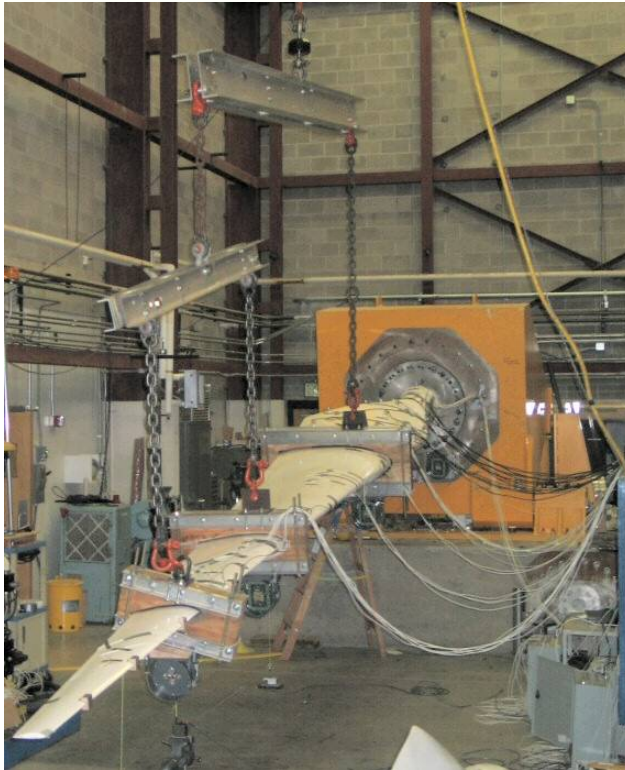
Test Loading Sequence

Increased Strength in Wind Turbine Blades through Innovative Structural Design

EWEC 2007
May 8th, 2007

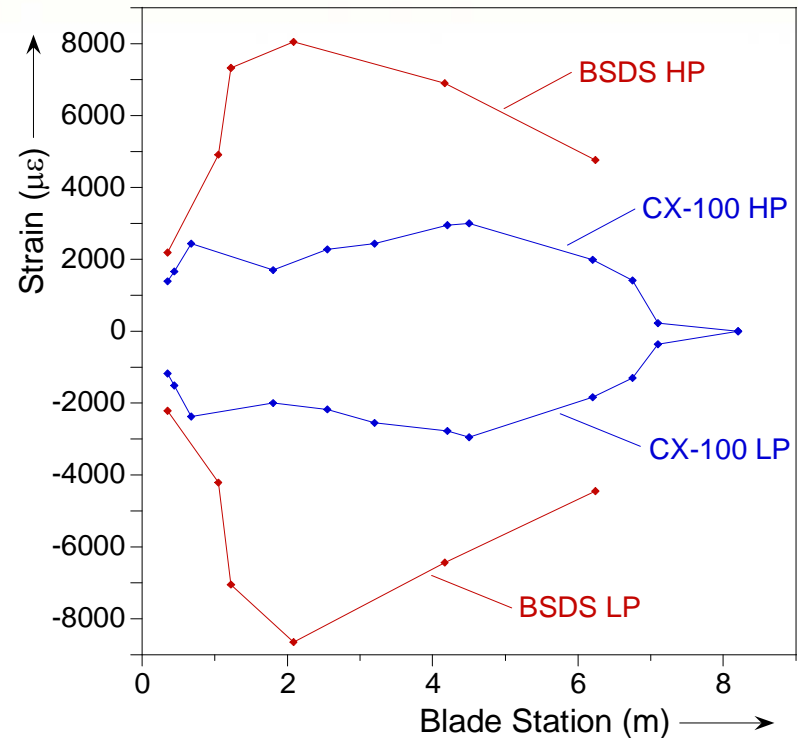
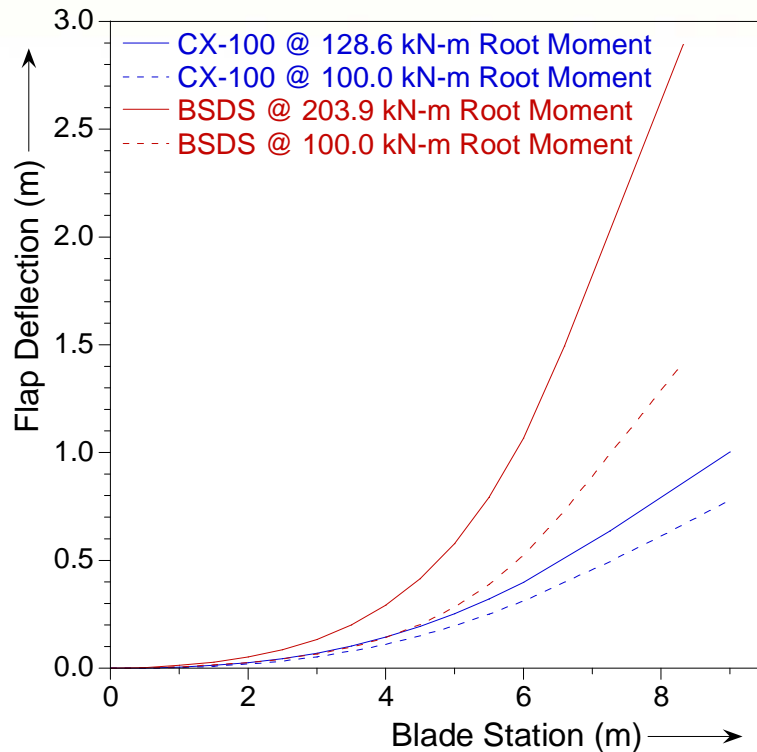


Testing: Setup



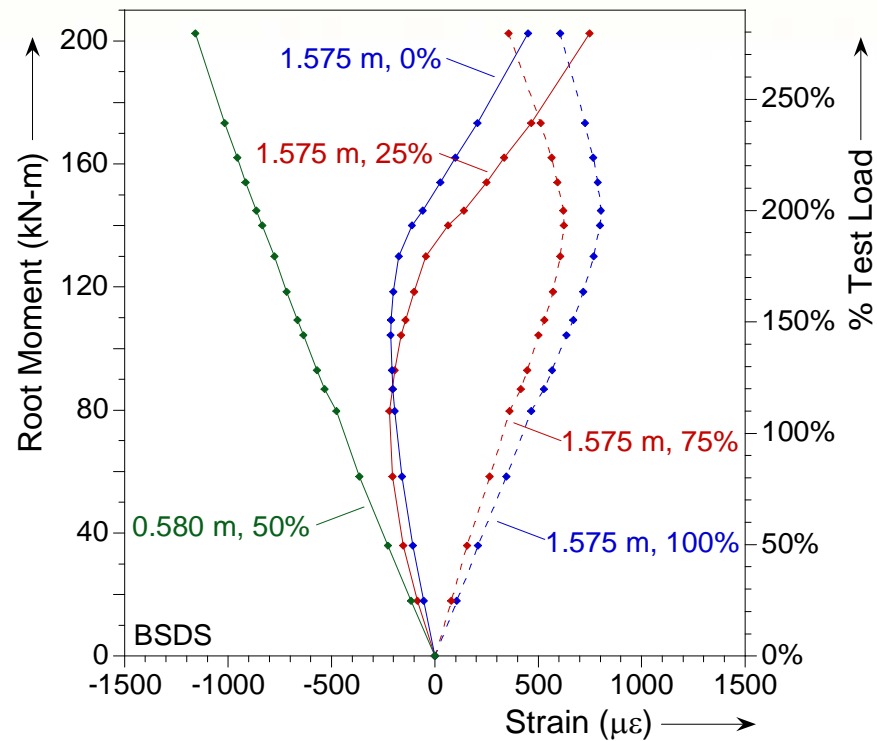
Static Blade Tests for CX-100 (left) and BSDS (right) at the NWTC

Testing: Results



Blade Deflections (left) and Spar Cap Strains (right) under Test Loading

Testing: Results



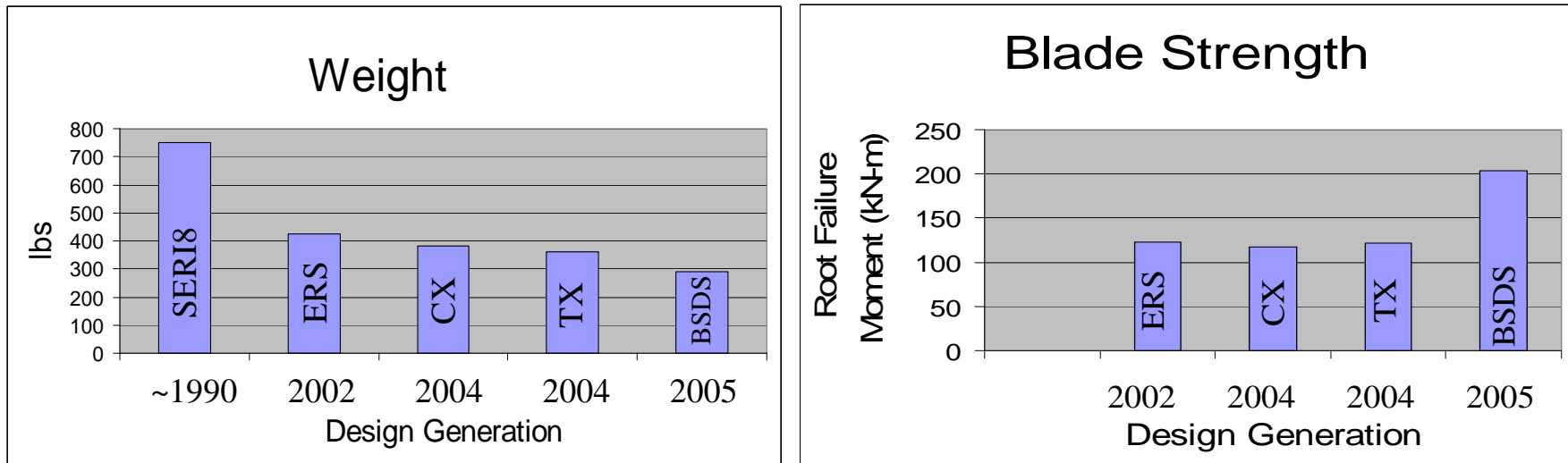
BSDS Flatback Strains under Test Loading

Testing: Results

Comparison of CX-100 and BSDS Blade Properties and Testing Results

Property	CX-100	BSDS
Weight (lb)	383	289
% of Design Load at Failure	115%	310%
Root Failure Moment (kN-m)	128.6	203.9
Max. Carbon Tensile Strain at Failure (%)	0.31%	0.81%
Max. Carbon Compressive Strain at Failure (%)	0.30%	0.87%
Maximum Tip Displacement (m)	1.05	2.79

Historical Comparison of 9 m Blade Weights and Strengths



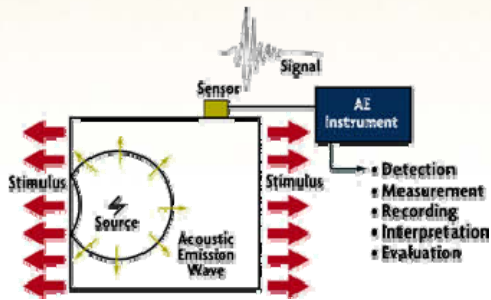


Acoustic Emissions Monitoring

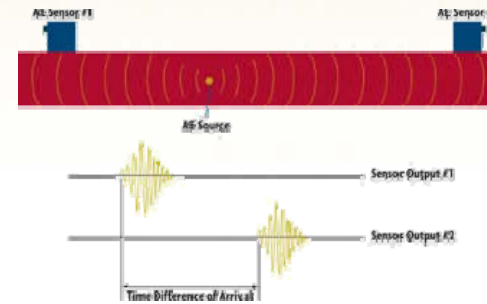
Increased Strength in Wind Turbine Blades through Innovative Structural Design
EWEC 2007
May 8th, 2007



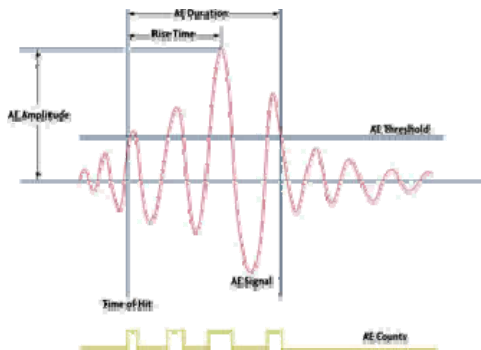
Acoustic Emissions Monitoring: Background



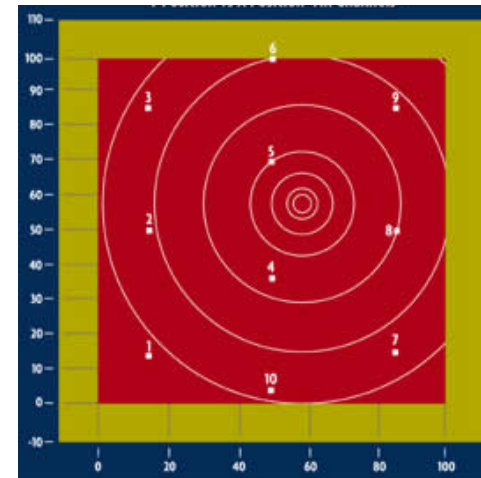
Initiation of Acoustic Waves from Source



Arrival Times of Acoustic Wave for Two Separated Sensors



Typical Acoustic Wave Signature

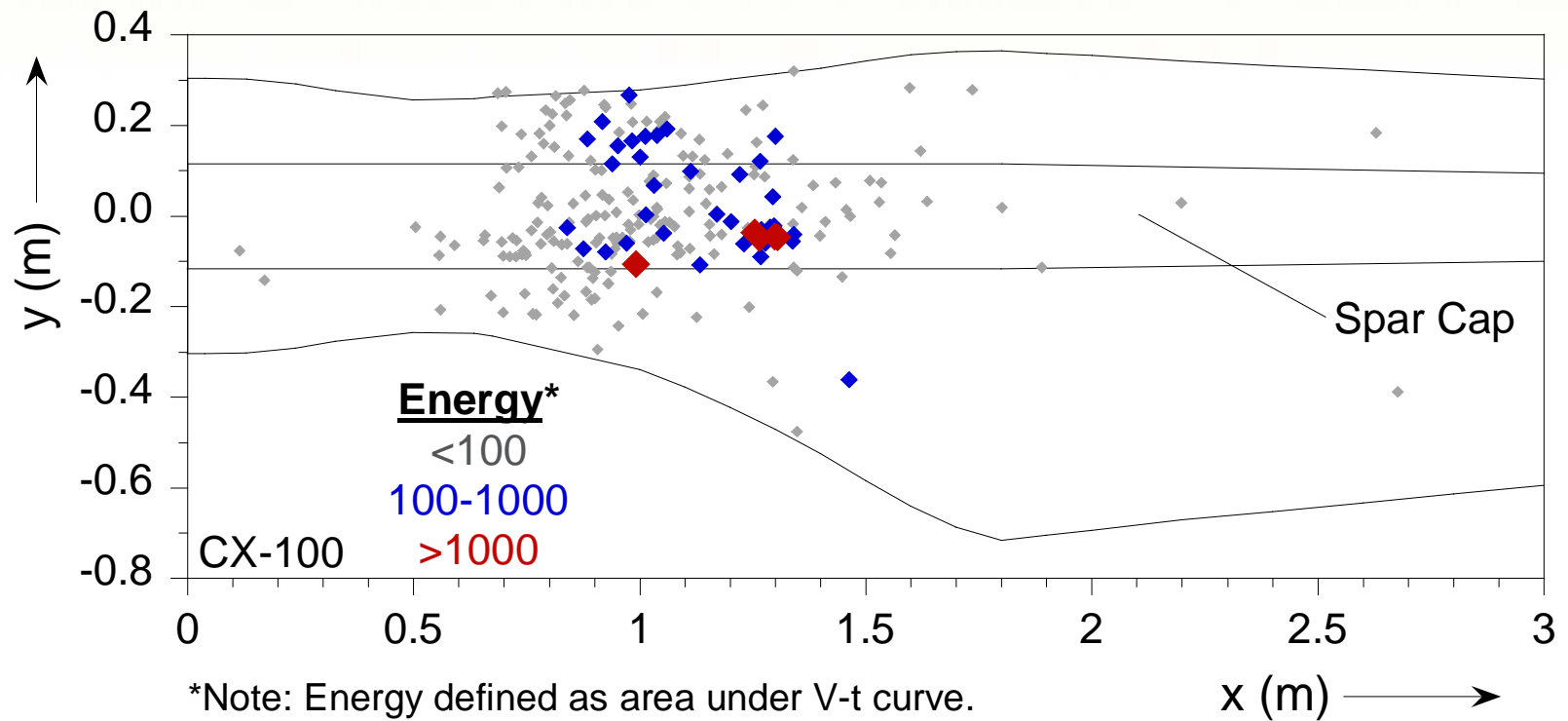


Acoustic Wave Hitting Sensor Field

Source: ASTM (2003)

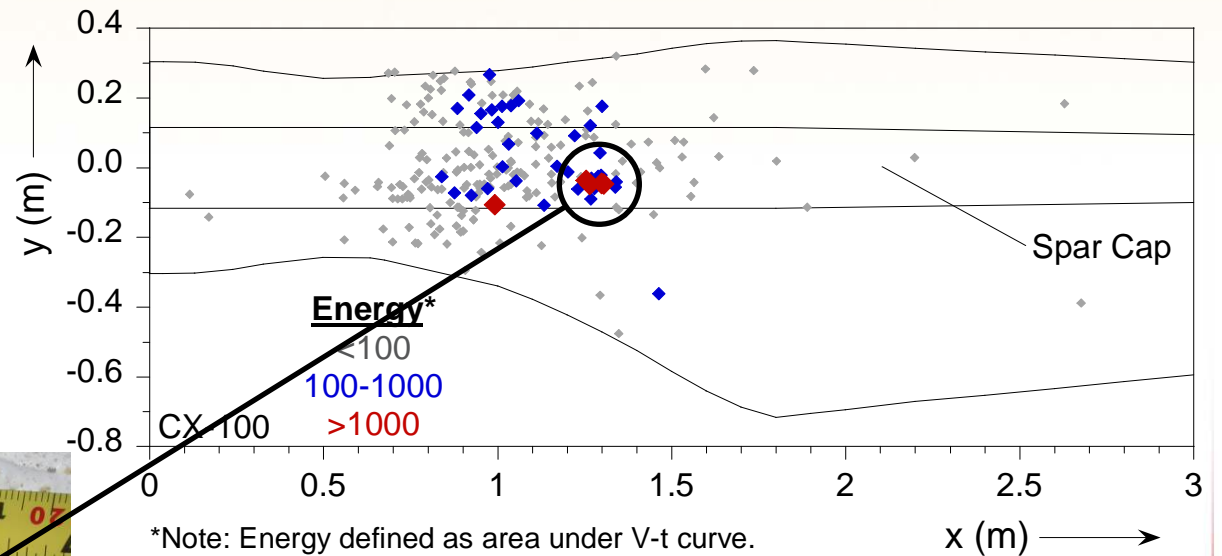
Increased Strength in Wind Turbine Blades through Innovative Structural Design
 EWEC 2007
 May 8th, 2007

Acoustic Emissions Monitoring



Locations and Intensities of Detected CX-100 Acoustic Events

Acoustic Emissions Monitoring

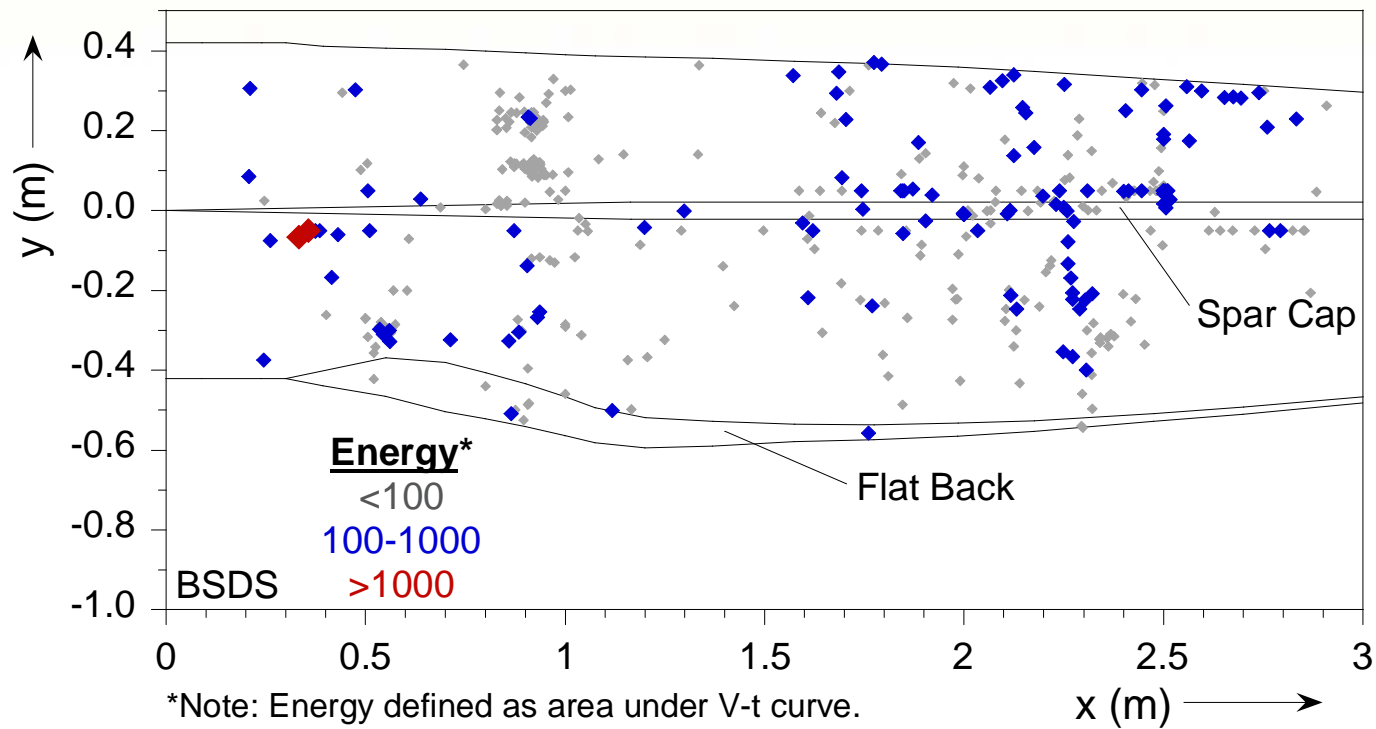


Locations and Intensities of Detected CX-100 Acoustic Events



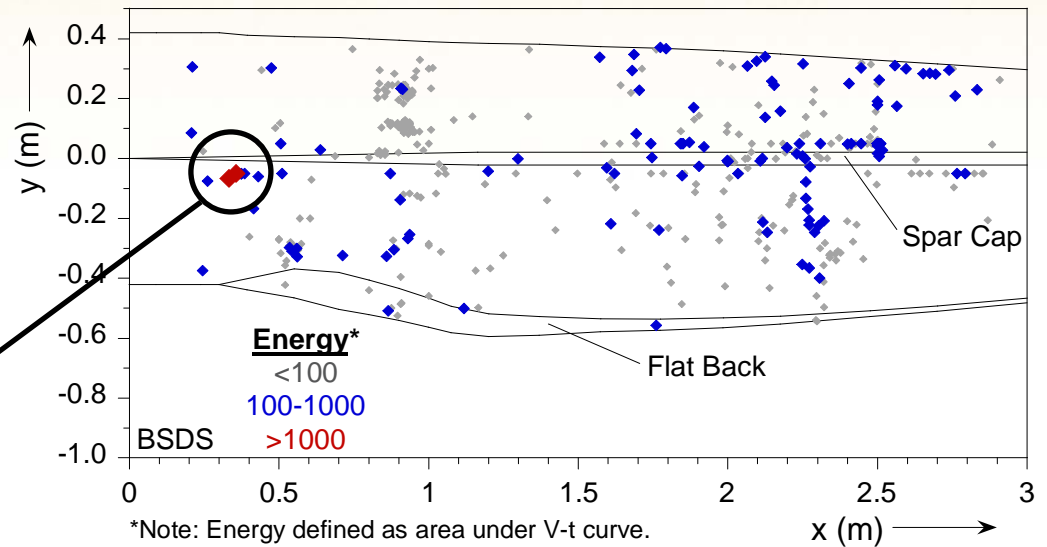
**Post-test Photo of CX-100 Shear Web
Bond Line at 1200-1300 mm**

Acoustic Emissions Monitoring

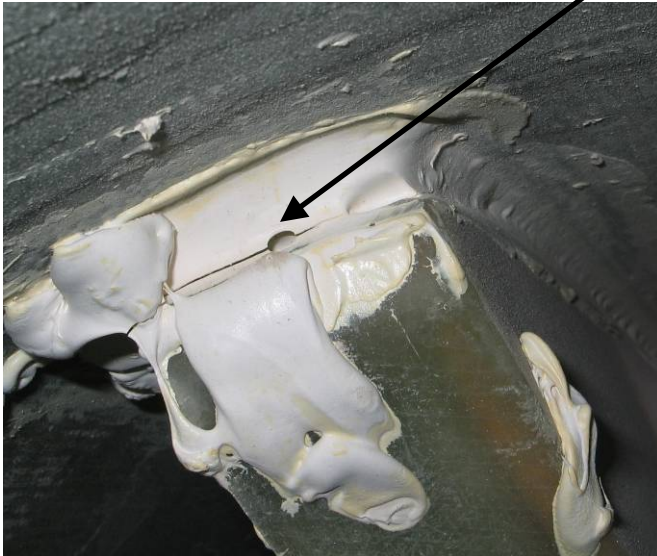


Locations and Intensities of Detected BSDS Acoustic Events

Acoustic Emissions Monitoring

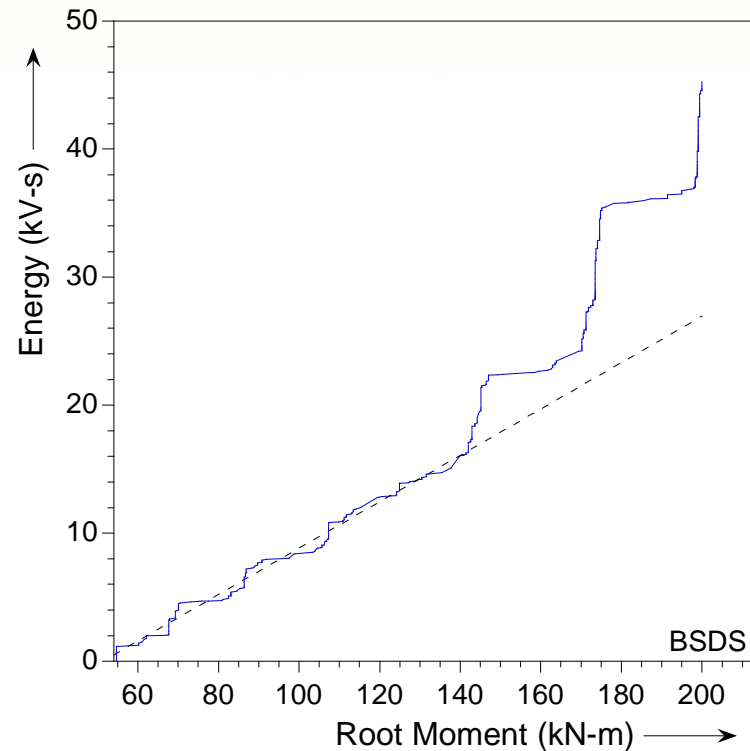
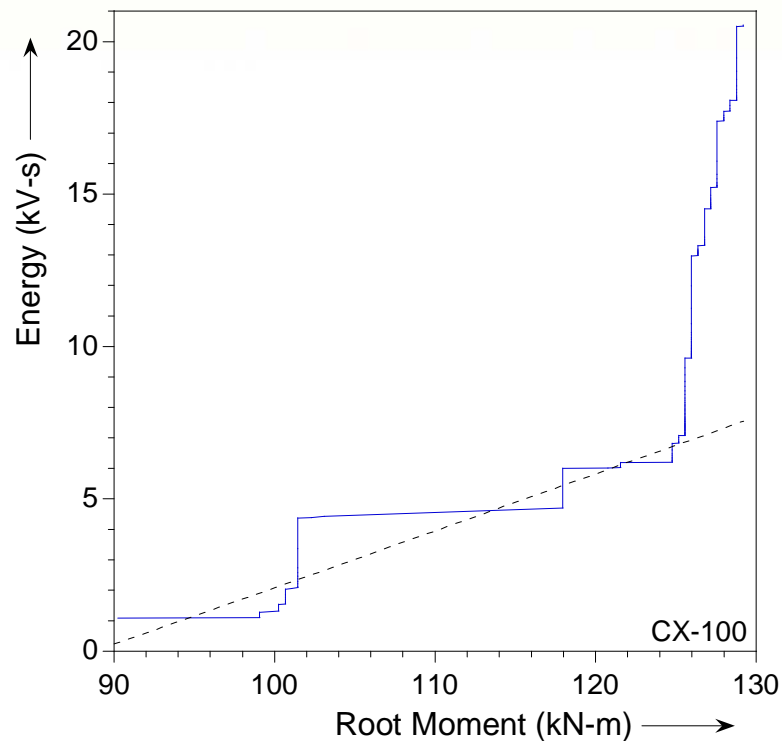


Locations and Intensities of Detected BSDS Acoustic Events

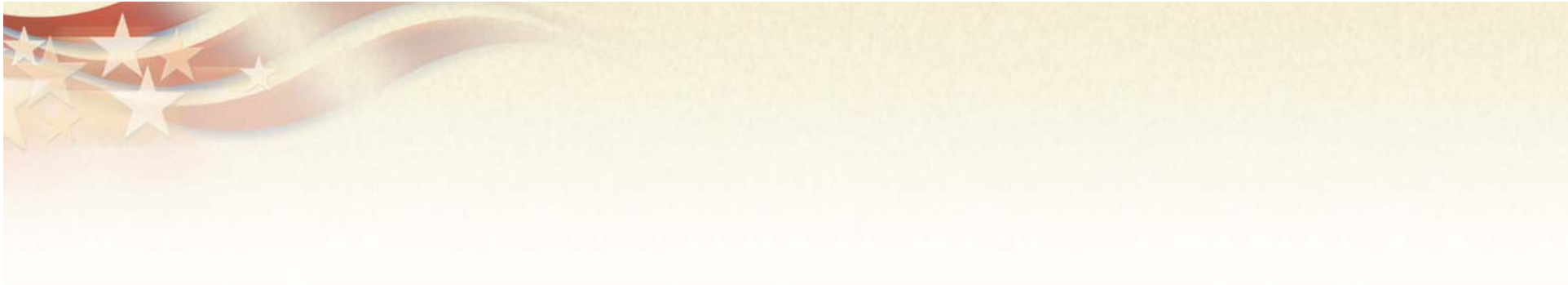


Post-test Photo of BSDS Shear Web Termination at 350 mm

Acoustic Emissions Monitoring



Acoustic Energy Accumulation for CX-100 (left) and BSDS (right) Tests



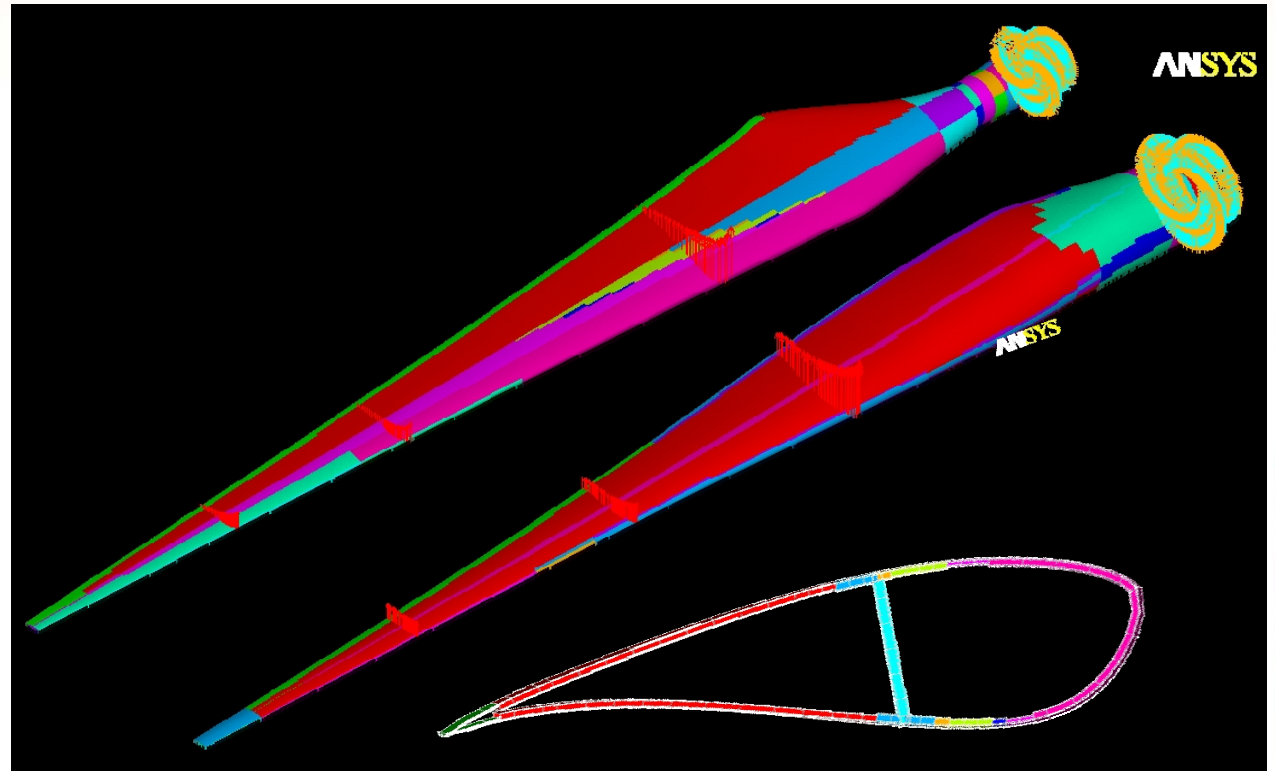
Finite Element Modeling

Increased Strength in Wind Turbine Blades through Innovative Structural Design
EWEC 2007
May 8th, 2007



Finite Element Modeling

- **CX-100 and BSDS finite element models created with NuMAD ANSYS pre and postprocessor developed at Sandia National Laboratories**
- **Models created using offset and mid-node shell elements**
- **Loads applied to simulate test loading**



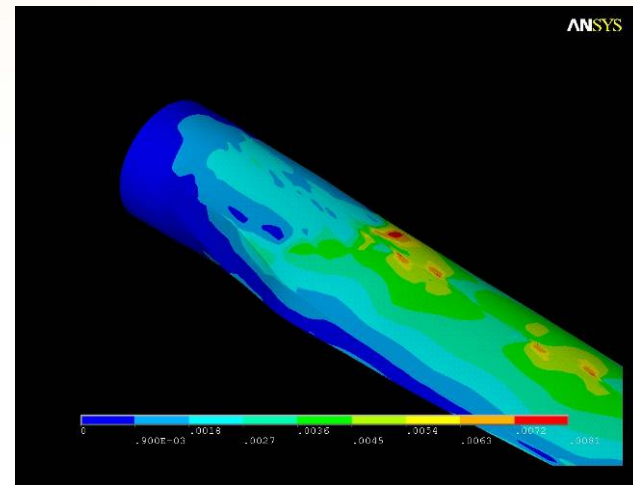
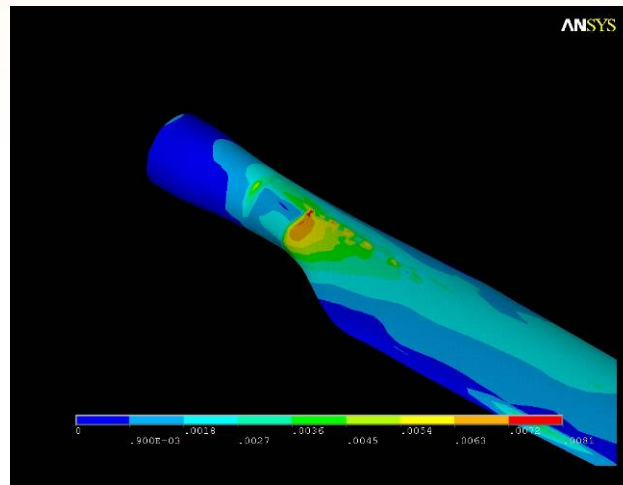
CX-100 and BSDS Finite Element Models

Finite Element Modeling: Results

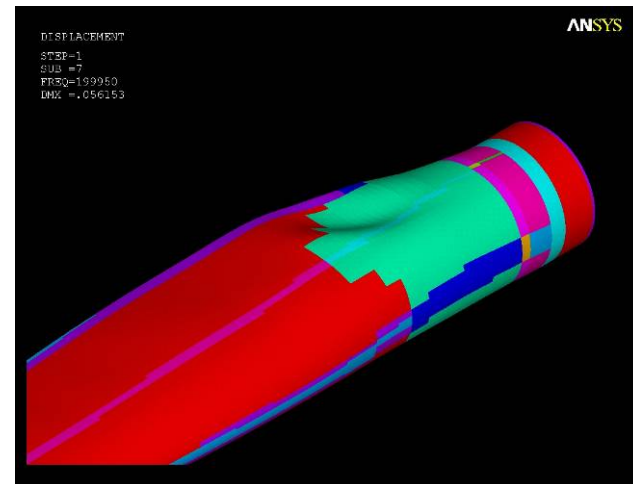
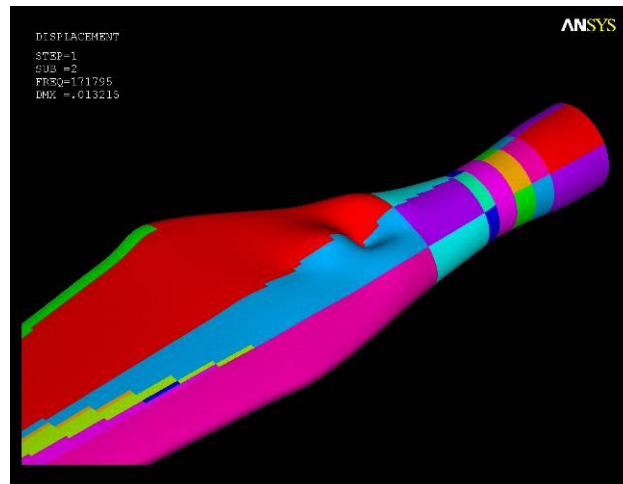
CX-100

BSDS

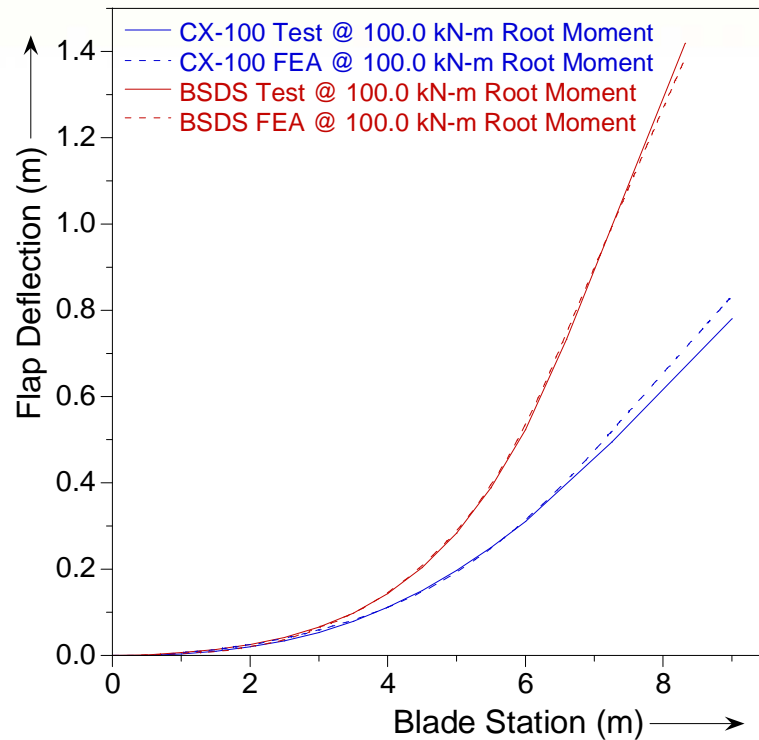
Strain Field



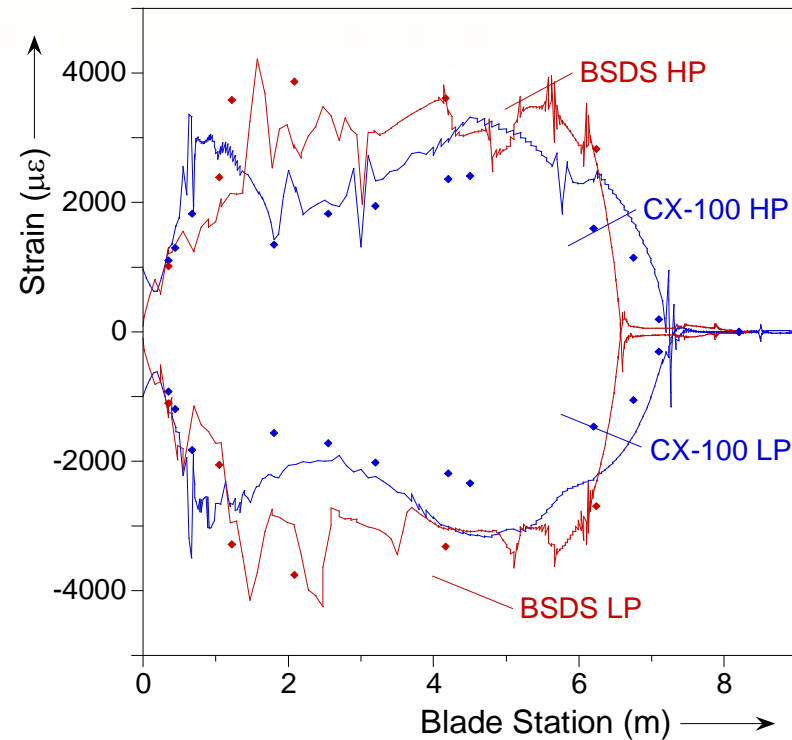
Linear Buckling



Finite Element Modeling: Results



FEA and Measured Blade Deflections under Test Loading



FEA and Measured Blade Spar Cap Strains under Test Loading

Conclusions

- **Lighter, stronger blades can be improved through a system design approach where aerodynamic, structural, and manufacturing constraints are met in unison**
- **Acoustic emissions monitoring is a valuable tool for determining when and where a blade is incurring damage in laboratory environment**
- **FEA tools can be used to accurately predict strains, displacements, and buckling**