Modeling the Structural Dynamic Response of Wind Turbines

March 2nd, 2011

Mid-Project Review
Intelligent Wind Turbine
Laboratory Directed R&D
Los Alamos National Laboratory

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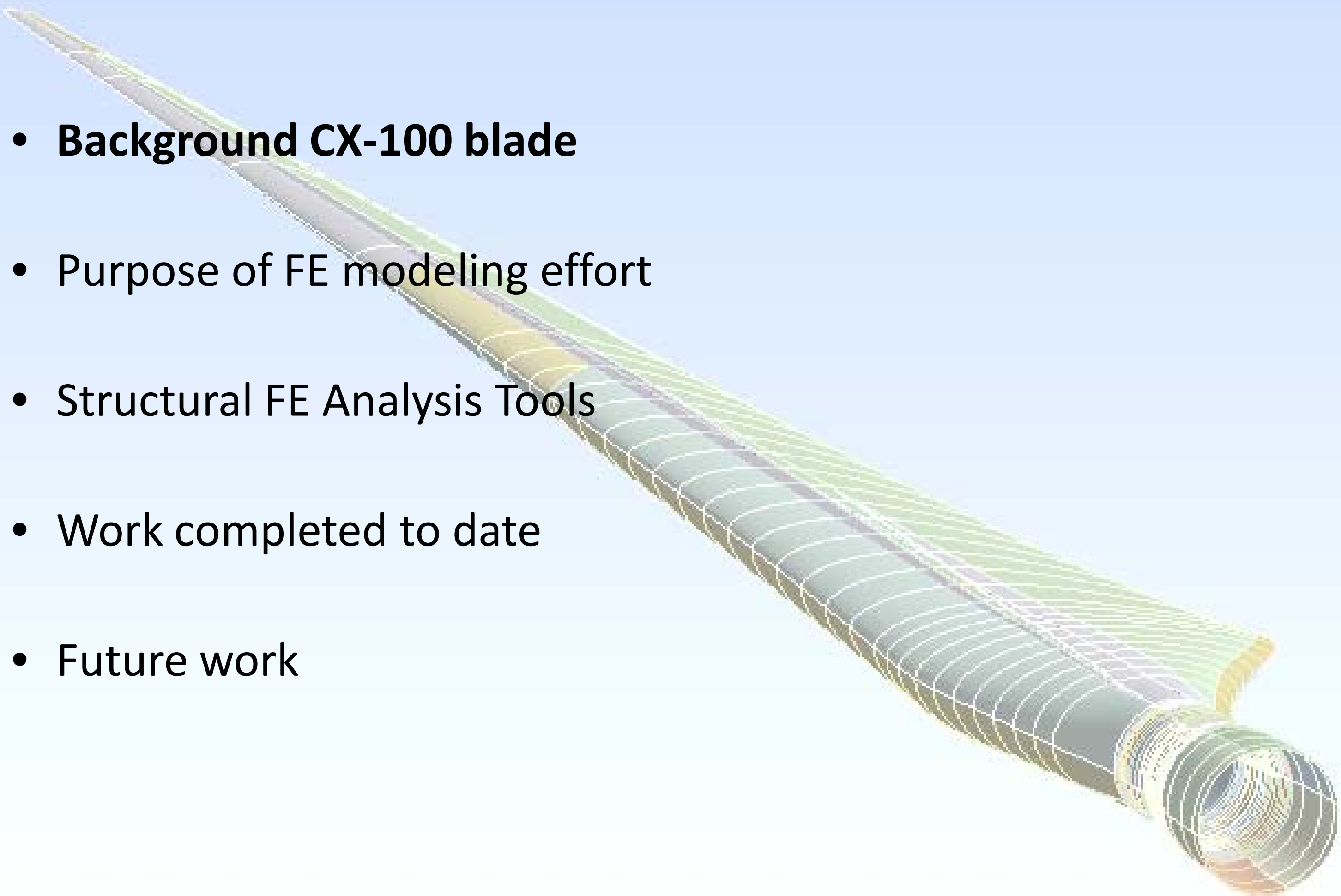
Modeling the Structural Dynamic Response of Wind Turbines

Part 1: Detailed finite element modeling of the CX-100 Blade

Part 2: Plant-scale aeroelastically-coupled wind turbine response from geometrically exact beam theory

Detailed Finite Element Modeling of the CX-100 Blade

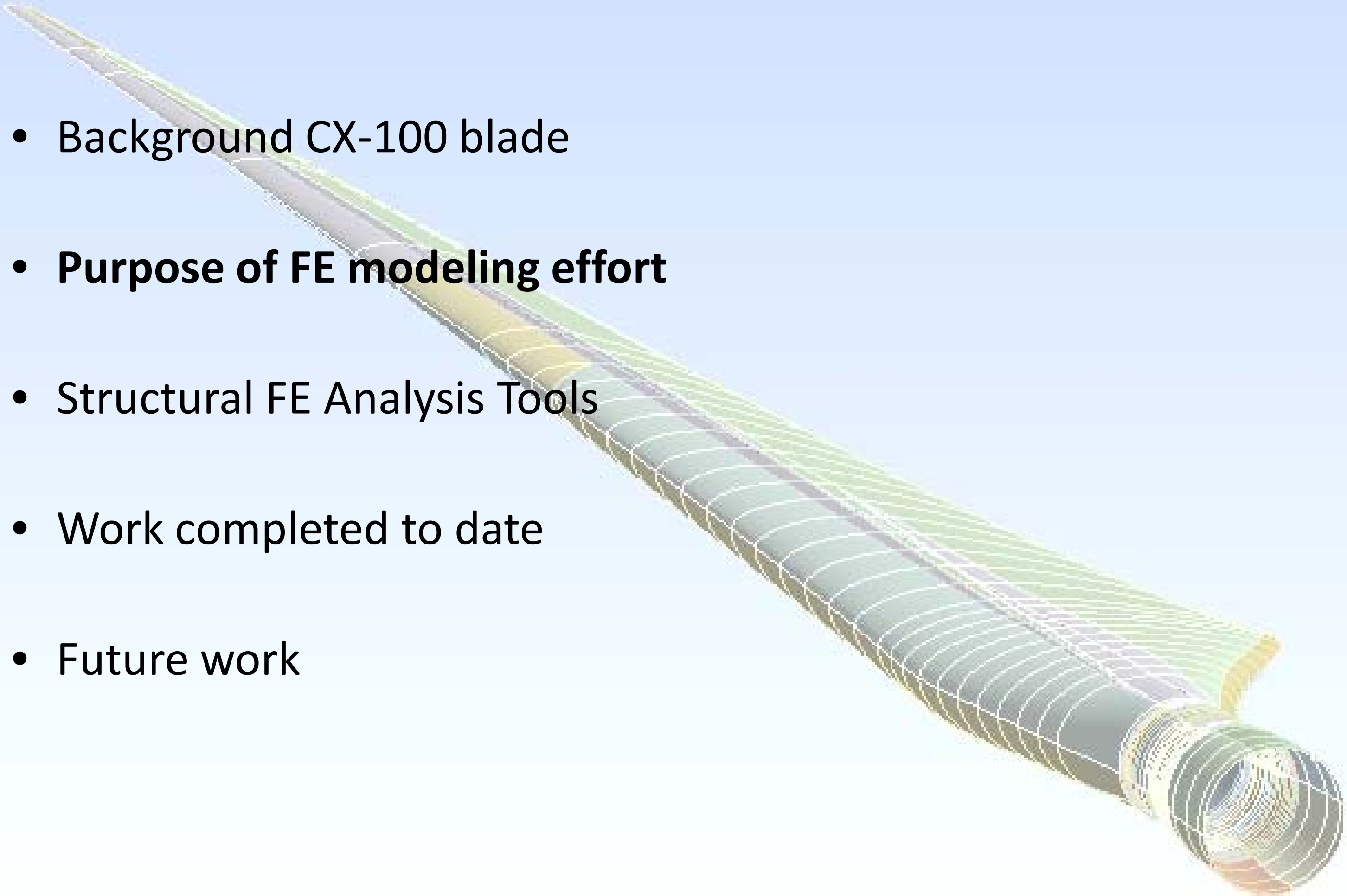


- **Background CX-100 blade**
- Purpose of FE modeling effort
- Structural FE Analysis Tools
- Work completed to date
- Future work

CX-100 Blade – Why are we using it? What is its history?

- **Sandia National Laboratories (SNL) initiated a blade research program in 2002 to investigate the use of carbon in subscale 9 m blade** *D. Berry et al., SNL* **:**
  - CX-100 (Carbon Experimental – 100 (kW turbine)) wind turbine blade
  - Collaboration of SNL, TPI Composites, Inc., Global Energy Concepts, LLC (GEC), and MDZ Consulting (MDZ)
- **CX-100 blade is a 9 m blade, designed for a 20-year life per International Electrotechnical Commission (IEC) Class II loads with turbulence level "B"** *D. Berry et al., SNL*
- **This blade has been structurally well-characterized by SNL and NREL through modal, static, and fatigue testing** *J. Paquette, Todd Griffith, Brian Resor, Daniel Laird, et al. SNL; J. van Dam, S. Hughes, et al., NREL*
- **We have chosen to use the CX-100 blade because it is affordable and of suitable size that its scale and materials are relevant to present day wind turbine industry practice**

Detailed Finite Element Modeling of the CX-100 Blade



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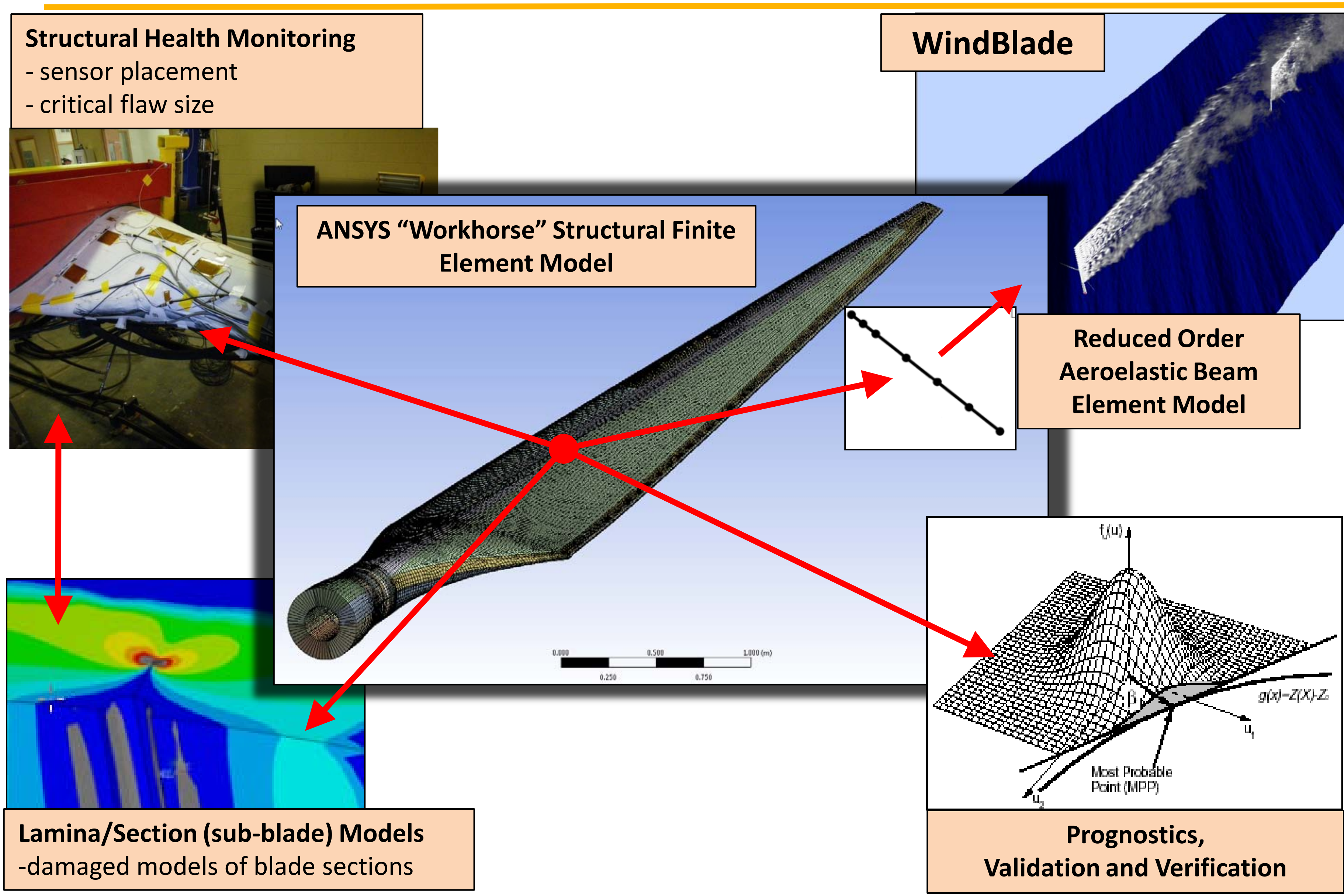
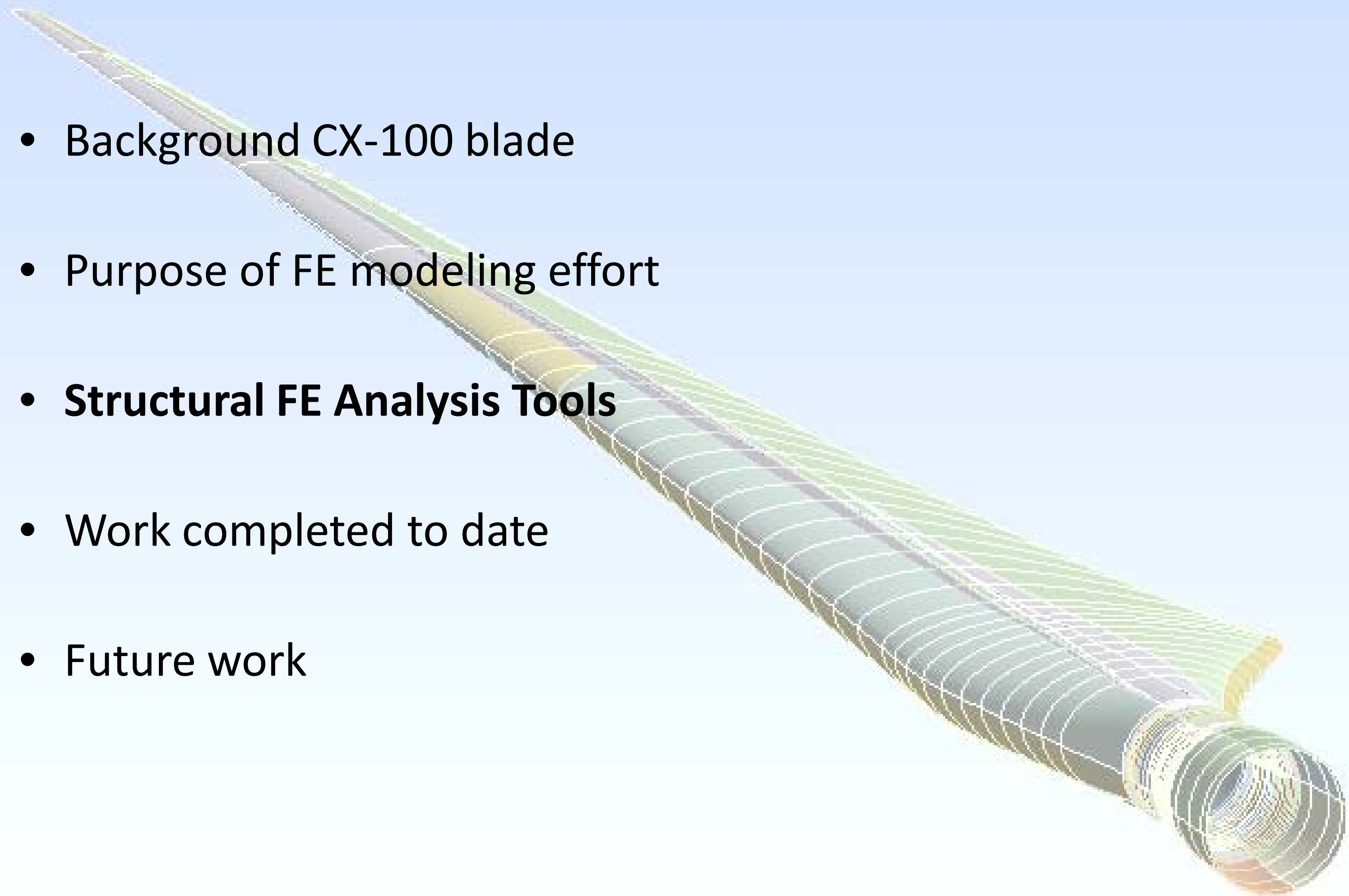
Purpose of Detailed Structural Finite Element Model



Detailed Finite Element Modeling of the CX-100 Blade



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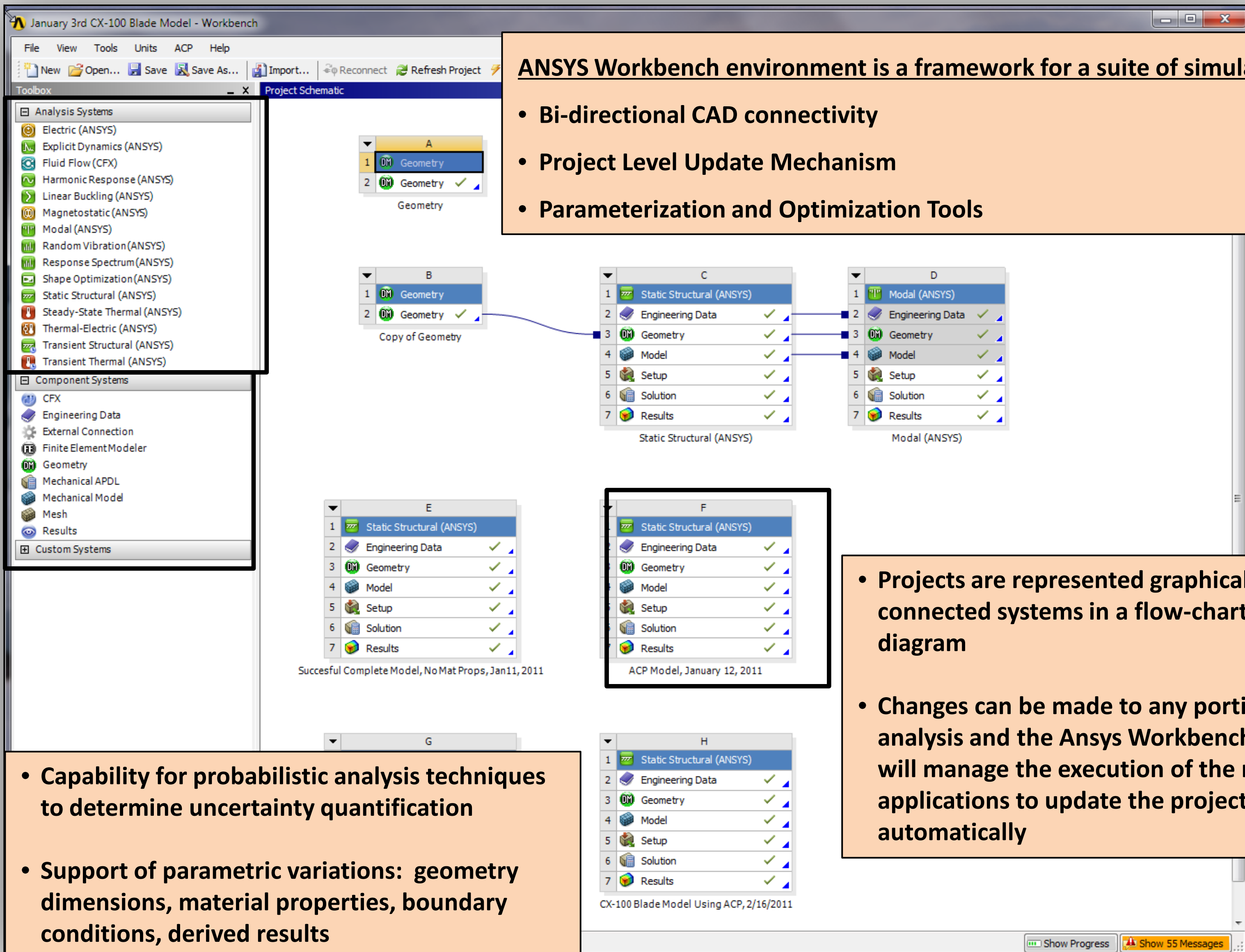
Software Tools for Structural Finite Element Analysis



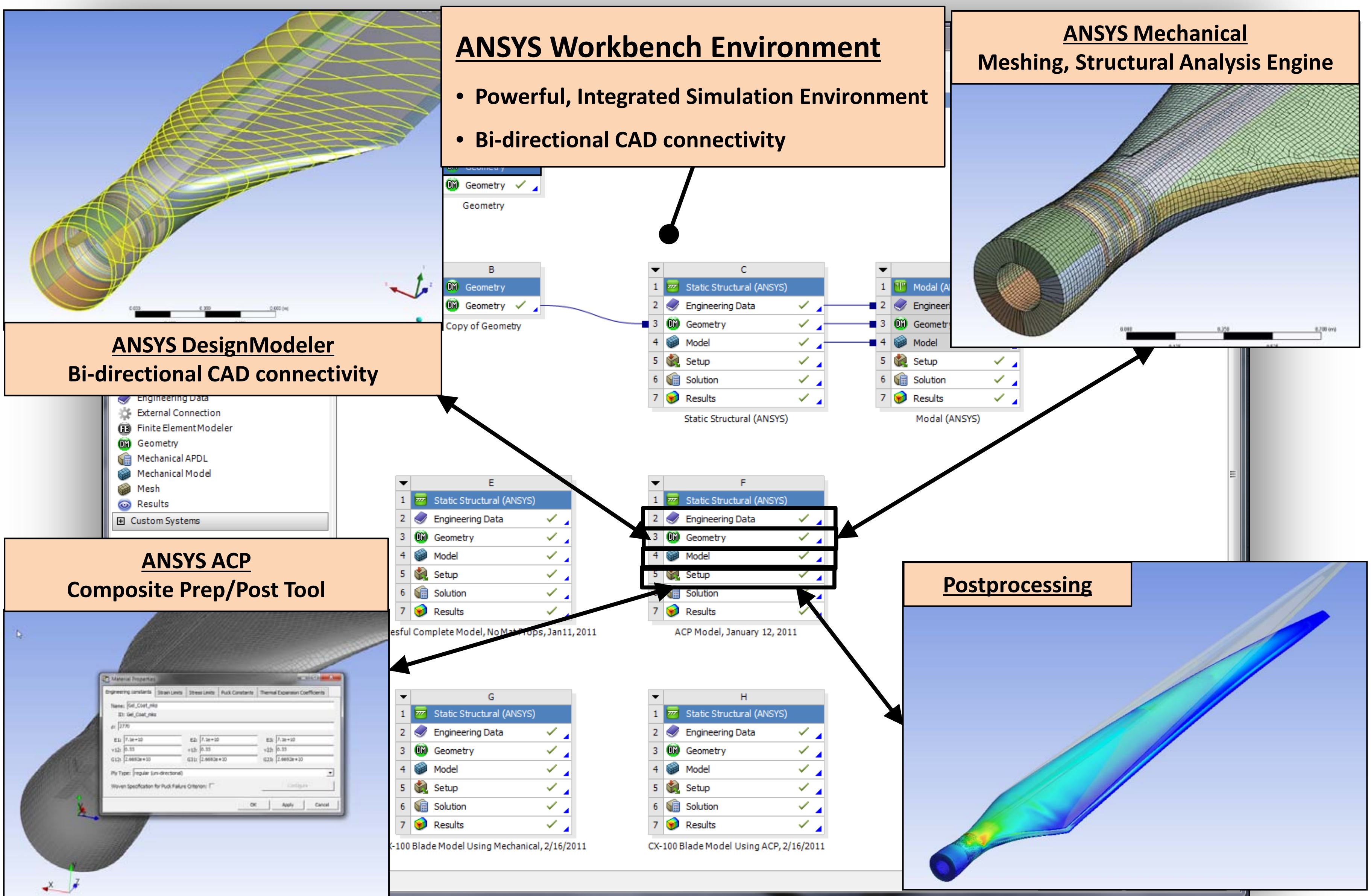
<u>ANSYS Workbench environment is a framework for a suite of simulation tools</u>:

- **Bi-directional CAD connectivity**
- **Project Level Update Mechanism**
- **Parameterization and Optimization Tools**

- **Projects are represented graphically as connected systems in a flow-chart like diagram**
- **Changes can be made to any portion of the analysis and the Ansys Workbench platform will manage the execution of the required applications to update the project automatically**

- **Capability for probabilistic analysis techniques to determine uncertainty quantification**
- **Support of parametric variations: geometry dimensions, material properties, boundary conditions, derived results**

Software Tools for Structural Finite Element Analysis



CX-100 Blade Structural Finite Element Modeling Effort

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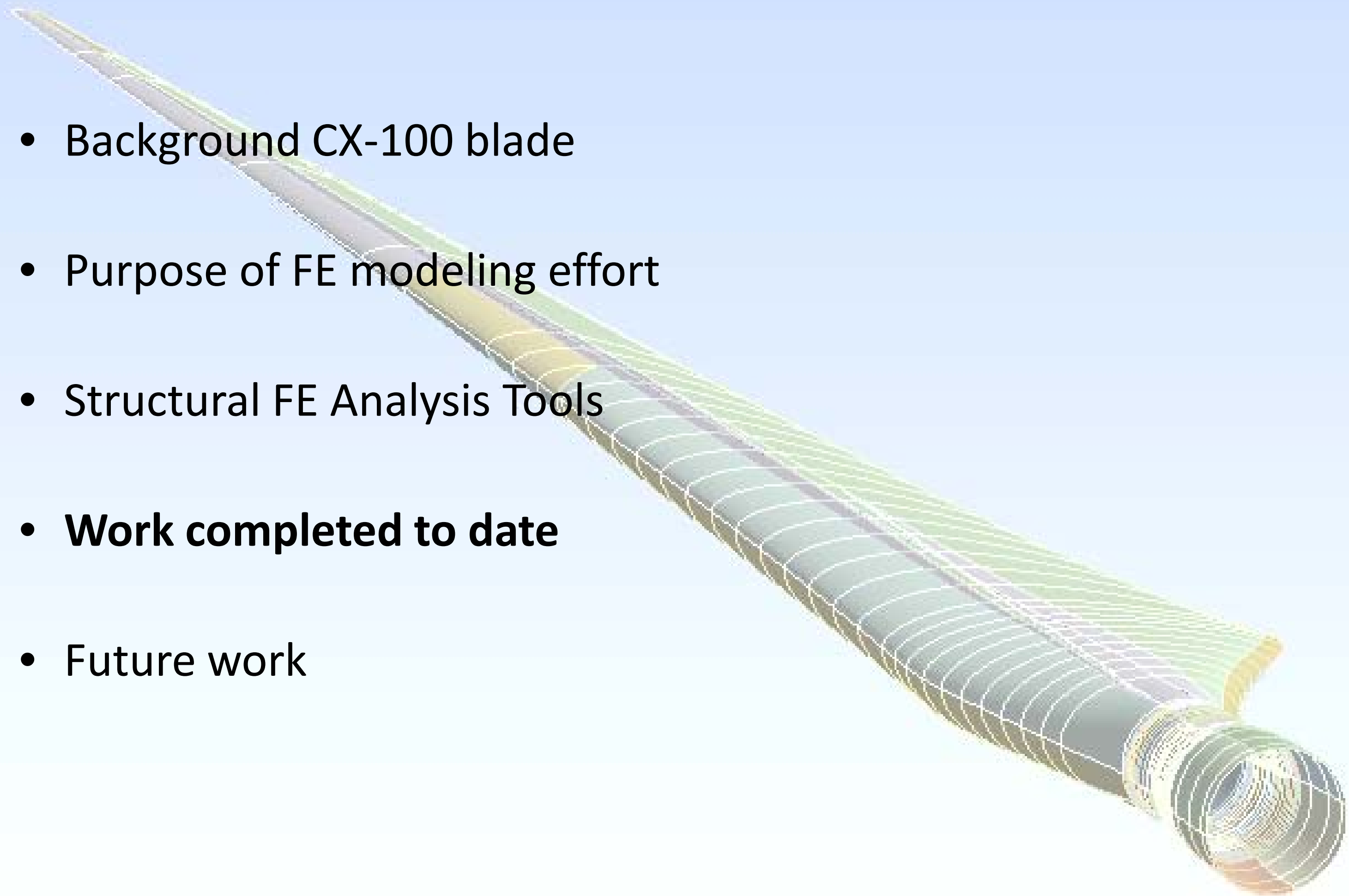
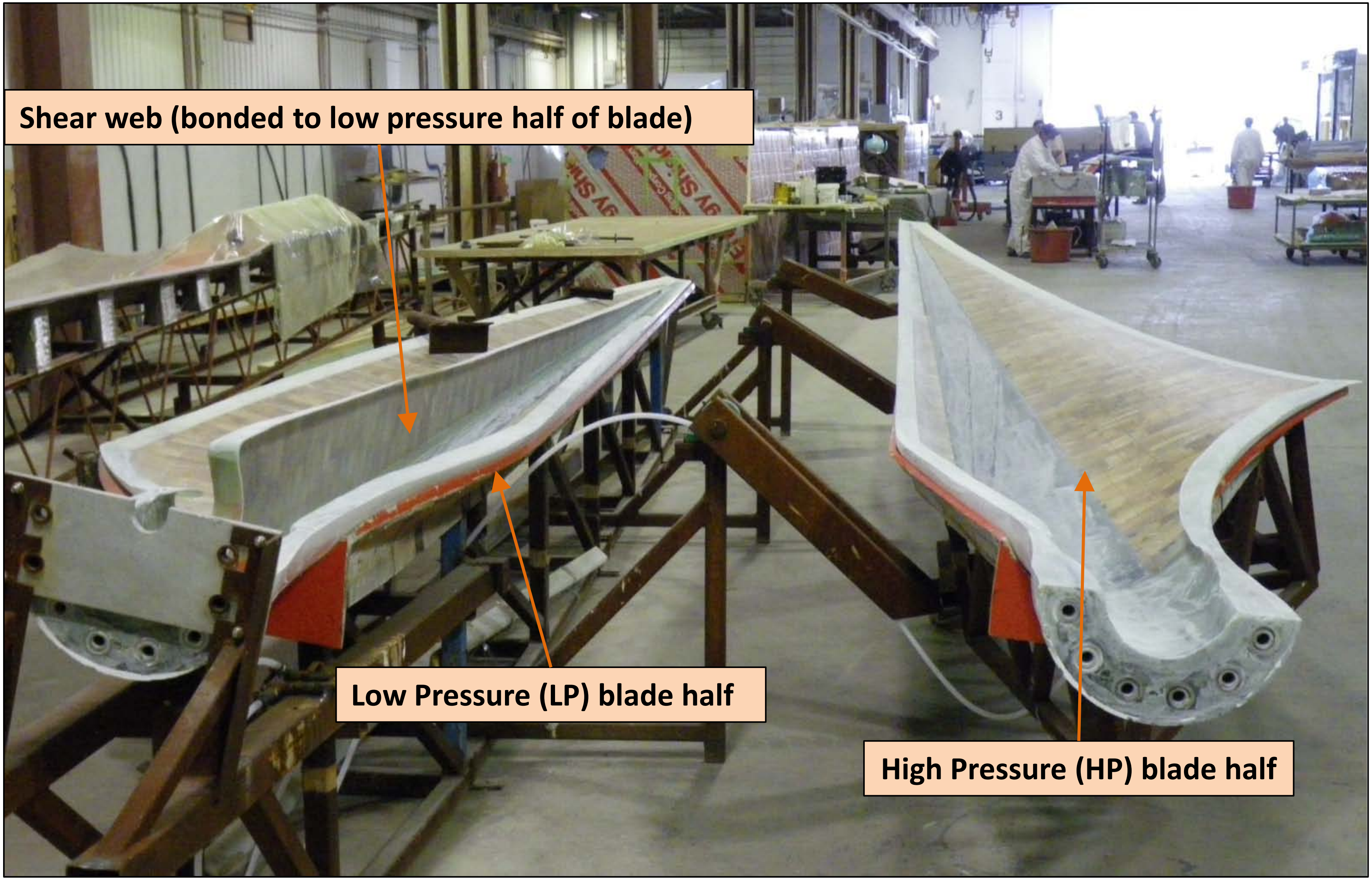


TPI Composites, Inc. - May, 2010

Fabrication of CX-100 Blade at TPI Composites in Warren, R.I.

TPI Composites, Inc. - May, 2010



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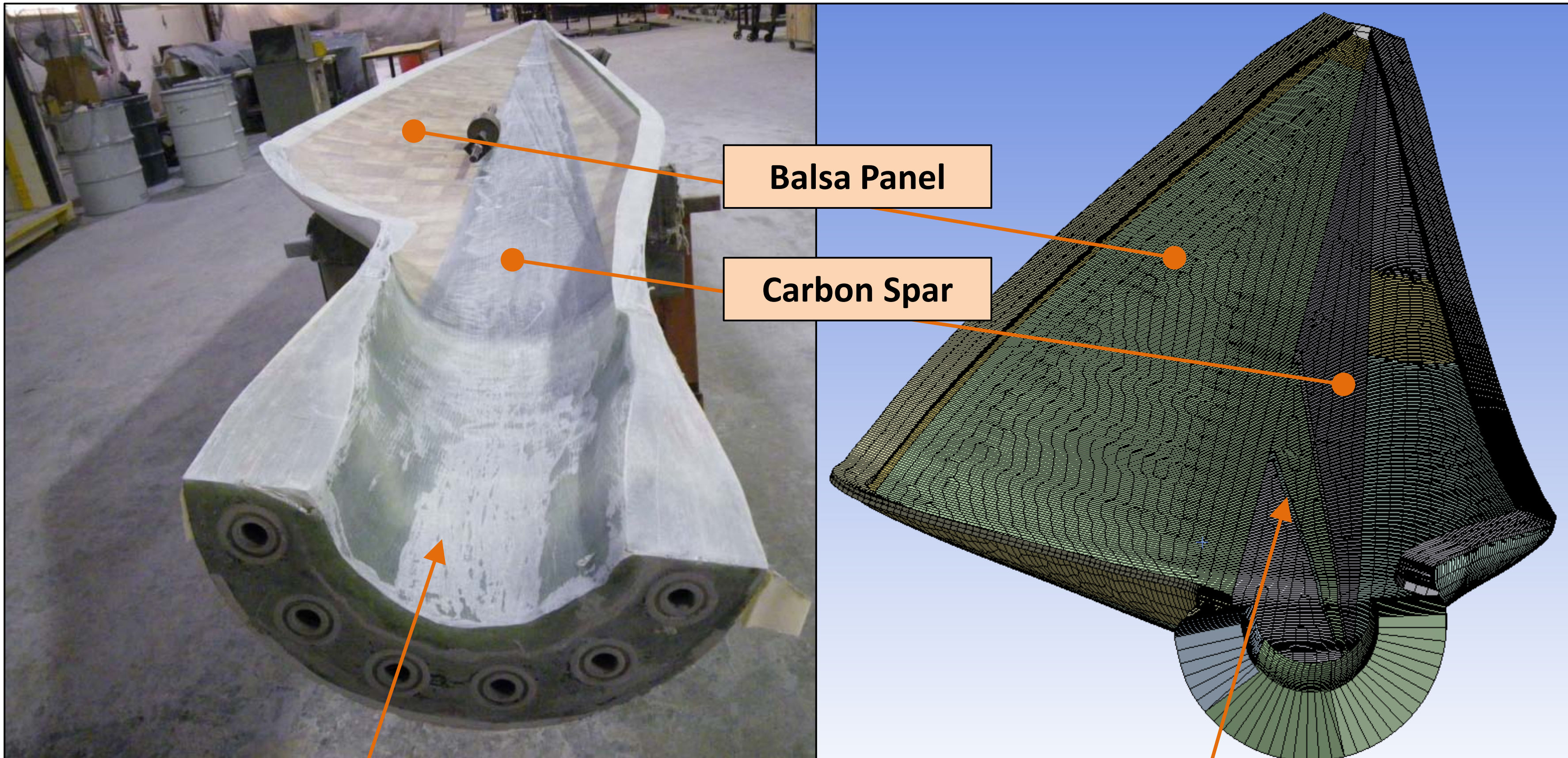
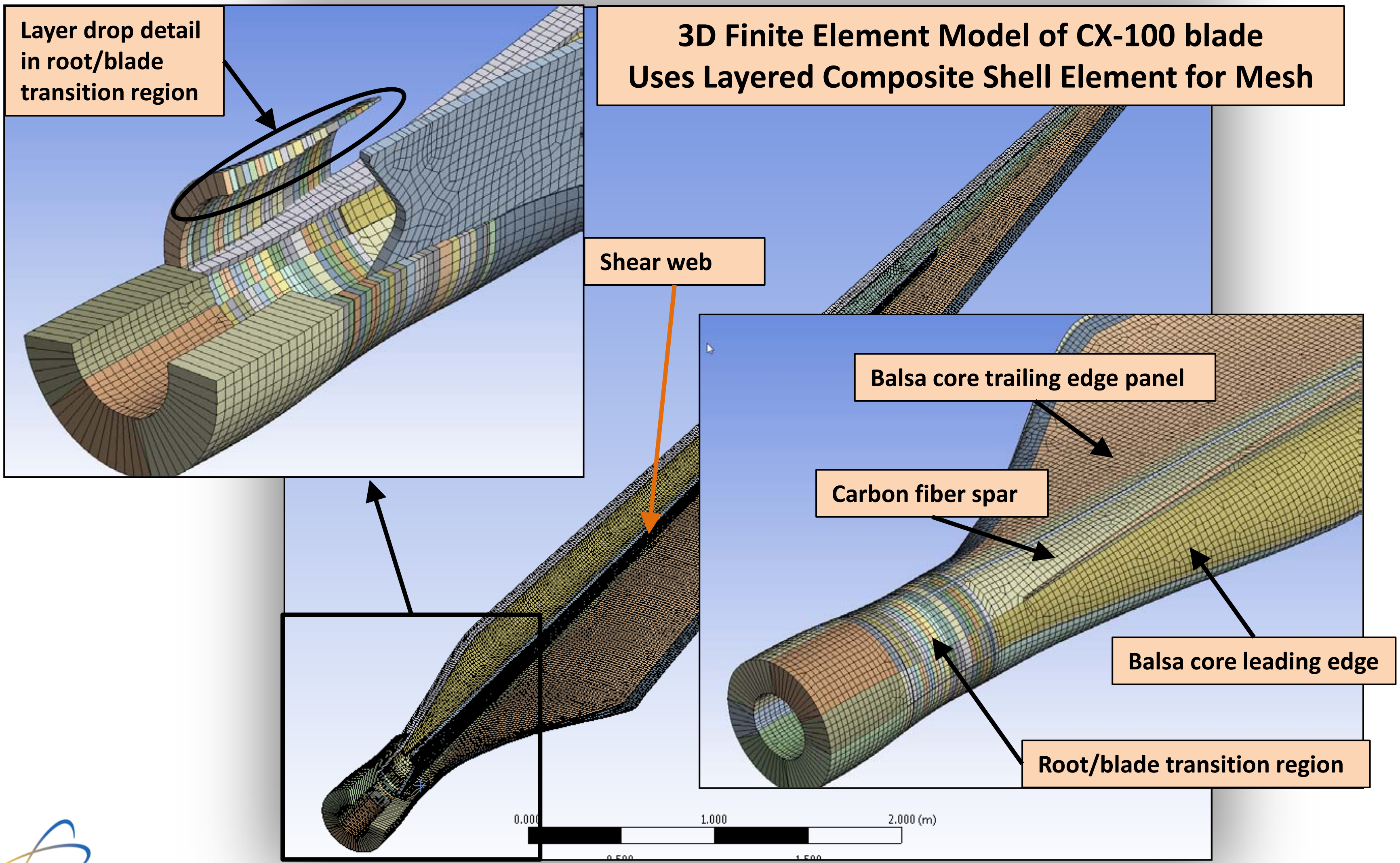


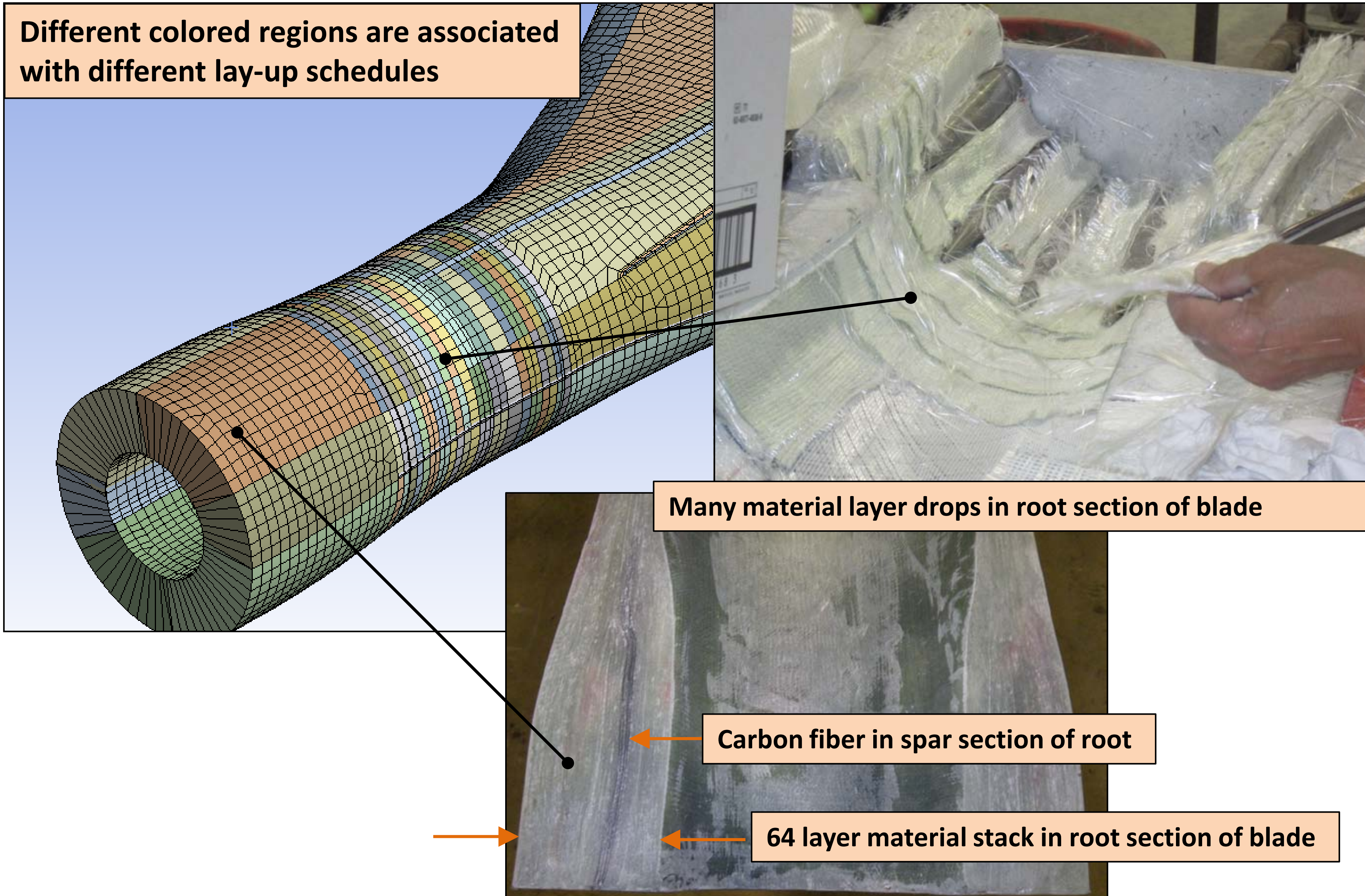
Looking down LP half of CX-100 blade

ANSYS finite element model of LP blade half

ANSYS Structural FE Model

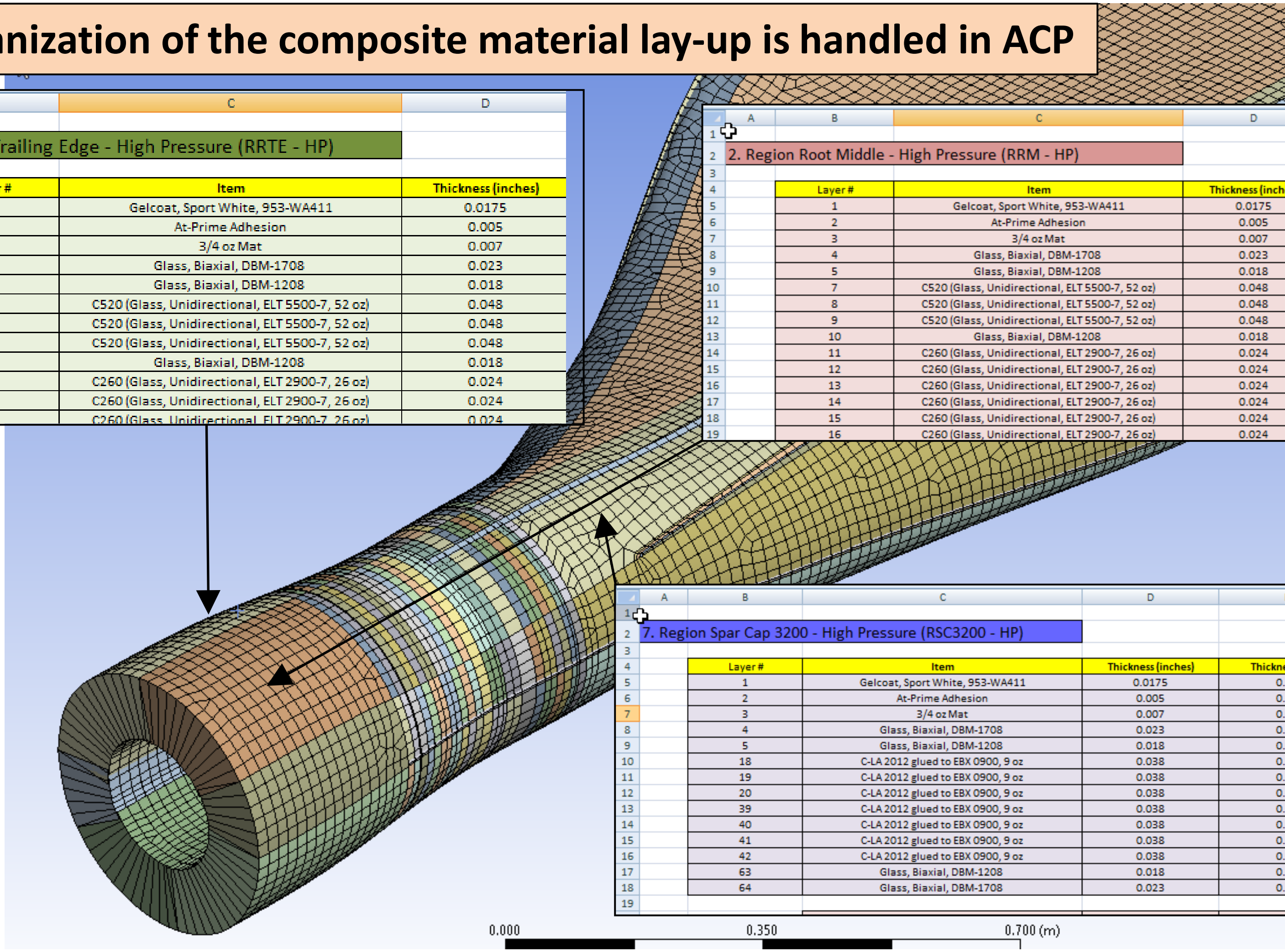


ANSYS Structural FE Model



ANSYS Structural FE Model – ACP Composite Prep Post

Organization of the composite material lay-up is handled in ACP



3. Region Root Trailing Edge - High Pressure (RRTE - HP)

Layer #	Item	Thickness (inches)
1	Gelcoat, Sport White, 953-WA411	0.0175
2	At-Prime Adhesion	0.005
3	3/4 oz Mat	0.007
4	Glass, Biaxial, DBM-1708	0.023
5	Glass, Biaxial, DBM-1208	0.018
7	C520 (Glass, Unidirectional, ELT 5500-7, 52 oz)	0.048
8	C520 (Glass, Unidirectional, ELT 5500-7, 52 oz)	0.048
9	C520 (Glass, Unidirectional, ELT 5500-7, 52 oz)	0.048
10	Glass, Biaxial, DBM-1208	0.018
11	C260 (Glass, Unidirectional, ELT 2900-7, 26 oz)	0.024
12	C260 (Glass, Unidirectional, ELT 2900-7, 26 oz)	0.024
13	C260 (Glass, Unidirectional, ELT 2900-7, 26 oz)	0.024

2. Region Root Middle - High Pressure (RRM - HP)

Layer #	Item	Thickness (inches)
1	Gelcoat, Sport White, 953-WA411	0.0175
2	At-Prime Adhesion	0.005
3	3/4 oz Mat	0.007
4	Glass, Biaxial, DBM-1708	0.023
5	Glass, Biaxial, DBM-1208	0.018
7	C520 (Glass, Unidirectional, ELT 5500-7, 52 oz)	0.048
8	C520 (Glass, Unidirectional, ELT 5500-7, 52 oz)	0.048
9	C520 (Glass, Unidirectional, ELT 5500-7, 52 oz)	0.048
10	Glass, Biaxial, DBM-1208	0.018
11	C260 (Glass, Unidirectional, ELT 2900-7, 26 oz)	0.024
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13	C260 (Glass, Unidirectional, ELT 2900-7, 26 oz)	0.024
14	C260 (Glass, Unidirectional, ELT 2900-7, 26 oz)	0.024
15	C260 (Glass, Unidirectional, ELT 2900-7, 26 oz)	0.024
16	C260 (Glass, Unidirectional, ELT 2900-7, 26 oz)	0.024

7. Region Spar Cap 3200 - High Pressure (RSC3200 - HP)

Layer #	Item	Thickness (inches)	Thickness (mm)	
1	Gelcoat, Sport White, 953-WA411	0.0175	0.44	Entire Bla
2	At-Prime Adhesion	0.005	0.13	Entire Bla
3	3/4 oz Mat	0.007	0.18	Entire Bla
4	Glass, Biaxial, DBM-1708	0.023	0.58	Entire Bla
5	Glass, Biaxial, DBM-1208	0.018	0.46	1, 2, 3, 4, 5,
18	C-LA 2012 glued to EBX 0900, 9 oz	0.038	0.97	2,
19	C-LA 2012 glued to EBX 0900, 9 oz	0.038	0.97	2,
20	C-LA 2012 glued to EBX 0900, 9 oz	0.038	0.97	2,
39	C-LA 2012 glued to EBX 0900, 9 oz	0.038	0.97	2
40	C-LA 2012 glued to EBX 0900, 9 oz	0.038	0.97	
41	C-LA 2012 glued to EBX 0900, 9 oz	0.038	0.97	
42	C-LA 2012 glued to EBX 0900, 9 oz	0.038	0.97	
63	Glass, Biaxial, DBM-1208	0.018	0.46	1, 2, 3, 4, 5,
64	Glass, Biaxial, DBM-1708	0.023	0.58	Entire Bla

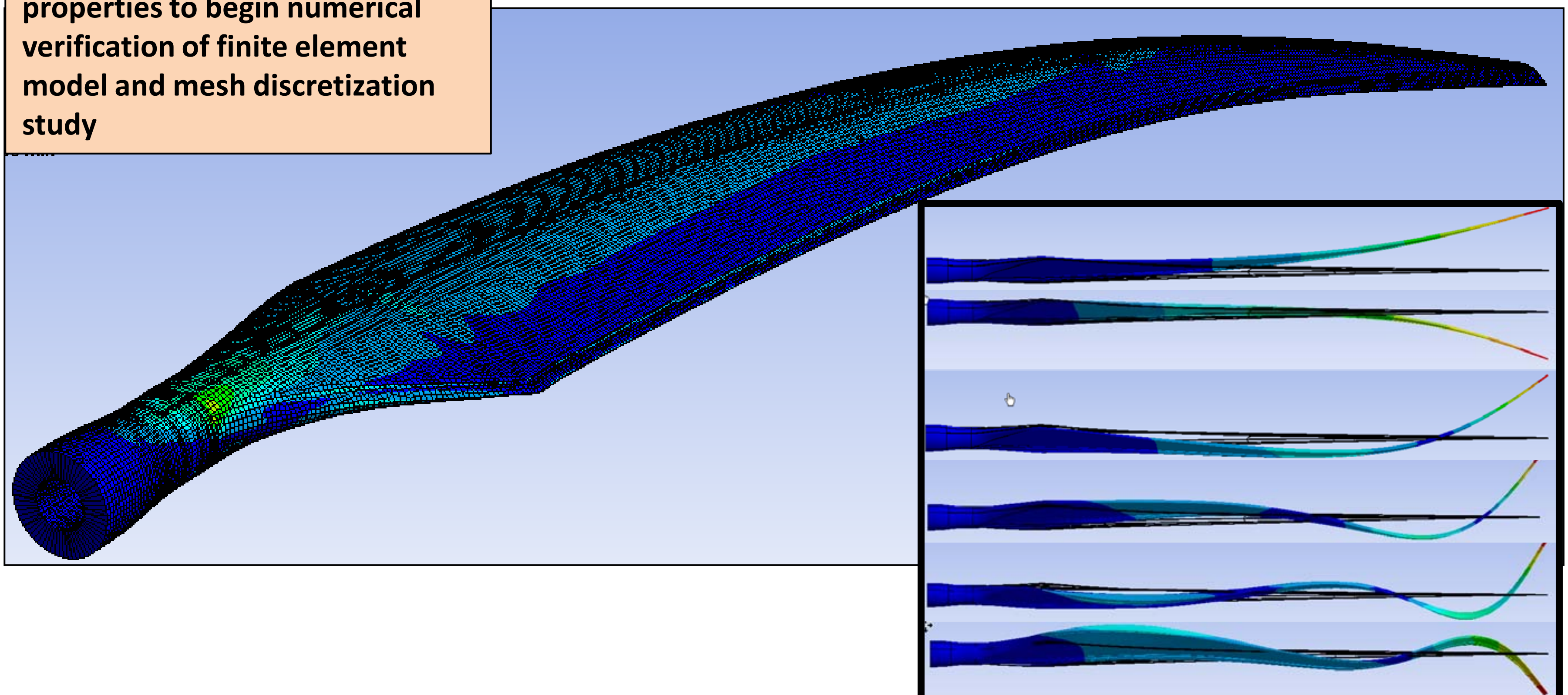
ANSYS Structural FE Model

Have working blade model reflecting:

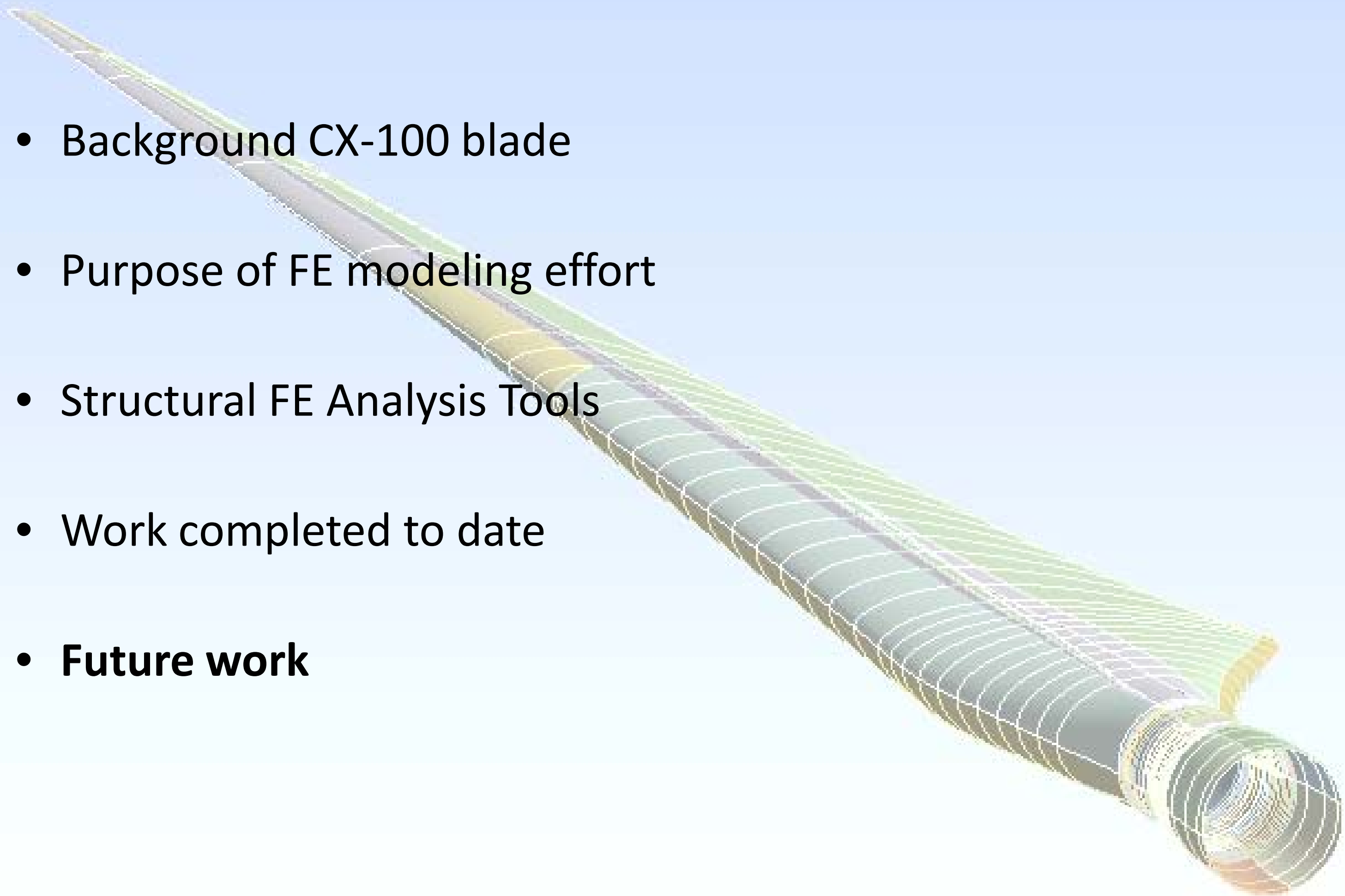
- proper geometry and all relevant blade features
- accurate section thicknesses
- “smeared” material properties

Have detailed lay-up schedule descriptions with nominal layer thicknesses and material properties for discrete layers

Using isotropic material properties to begin numerical verification of finite element model and mesh discretization study



CX-100 Blade Structural Finite Element Modeling Effort



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Where are we going from here?

Much work remains…

- Verification and Validation of CX-100 Finite Element Model
- Use finite element model to provide data for the development of a nonlinear elastodynamic beam finite element model to be used in WindBlade
- Provide feedback for SHM activities
    - Sensor placement and critical crack size
    - Fatigue and field testing data interpretation

Verification and Validation (V&V) Activities

Verification and Validation is integral to a Predictive Analysis Capability

- **Uncertainty quantification/sensitivity analysis**
- **Computational expense/resource allocation**
  - mesh density
  - discrete modeling of composite layers (as opposed to "averaged properties" approximation)
  - linear dynamic response vs. nonlinear inertial response calculations
- **Assess the balance of**

- **Comparison to published results, field test data, lab test data, etc.**

Summary

- We have finite element model of CX-100 blade developed with a high level of fidelity and parametric capability to support the multiple efforts of our project, including:
  - Aero-elasto-dynamic modeling
  - Sensor placement, flaw detection, sub-blade scale modeling
  - Formal V&V process to reflect meaningful predictive analysis capability
- We've used the Ansys Workbench simulation platform as the framework for our modeling effort to explore its state-of-the-art "workflow technology" capabilities
- We have started using a formal V&V process to address model validity, uncertainty quantification, sensitivity analysis, computational expense, resource allocation

References

1.) **"Finite Element Modeling of Wind Turbine Blades",** Daniel L. Laird and Felicia C. Montoya, David J. Malcolm, 43rd AIAA Aerospace and Sciences Meeting and Exhibit, 10-13 January, 2005, Reno, Nevada

2.) **"Design of 9-Meter Carbon-Fiberglass Prototype Blades: CX-100 and TX-100",** Derek Berry, Principal Investigator, TPI Composites, Inc., 373 Market Street, Warren, RI 02885. SANDIA REPORT, SAND2007-0201, Unlimited Release, Printed September 2007

3.) **"Composite Materials for Innovative Wind Turbine Blades",** Thomas D. Ashwill and Joshua A. Paquette, Wind Energy Technology Department , Sandia National Laboratories, Albuquerque, NM, 87185

4.) **"Effects of Glass Fabric and Laminate Construction on the Fatigue of Resin Infused Blade Materials",** Daniel D. Samborsky, Pancasatya Agastra and John F. Mandell. Department of Chemical and Biological Engineering, Montana State University, Bozeman, MT, 59717, USA

5.) **"Boundary Condition Considerations for Validation of Wind Turbine Blade Structural Models",** D. Todd Griffith, Patrick S. Hunter, David W. Kelton, Thomas G. Carne, Joshua A. Paquette. Sandia National Laboratories, Albuquerque, NM, 87185-0557. SEM Annual Conference and Exposition on Experimental and Applied Mechanics, June 1-4, 2009, Albuquerque, NM, USA.

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7.) **" Structural Testing of 9 m Carbon Fiber Research Blades",** J. Paquette, Sandia National Laboratories, J. van Dam and S. Hughes, National Renewable Energy Laboratory. To be presented at the AIAA 2007 Wind Energy Symposium, Reno, Nevada, January 8-11, 2007. Conference Paper, NREL/CP-500-40985, January 2007.

8.) **"Materials and Innovations for Large Blade Structures: Research Opportunities in Wind Energy Technology",** Thomas Ashwill, Sandia National Laboratories, Albuquerque, NM, 87185. 50th AIAA Structures, Structural Dynamics, and Materials Conference, Palm Springs, May, 2009. AIAA-2009-2407.