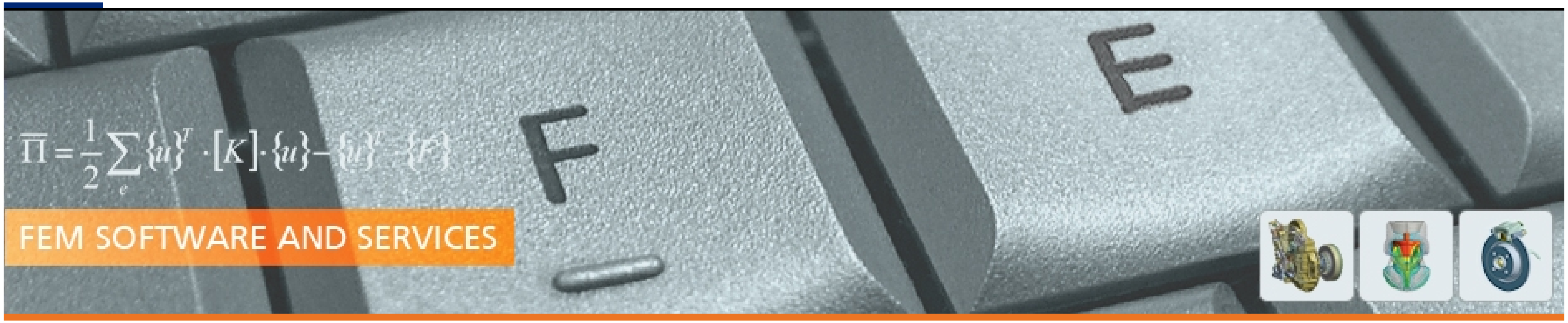
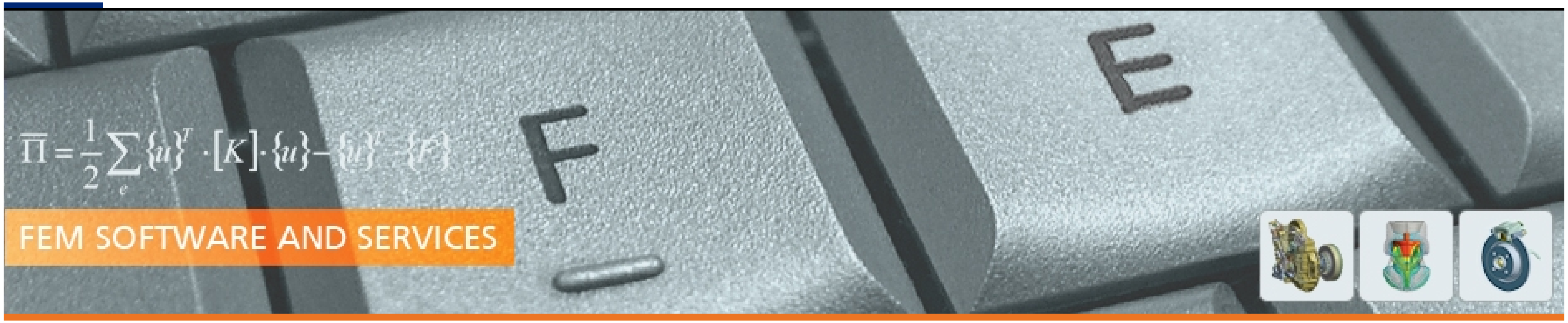


Efficient Design of Composite Rotor Blades using ANSYS

Dipl.-Ing. Steffen Schiele, CADFEM GmbH
sschiele@cadfem.de



Introduction to Lightweight Materials

Usage and Basics

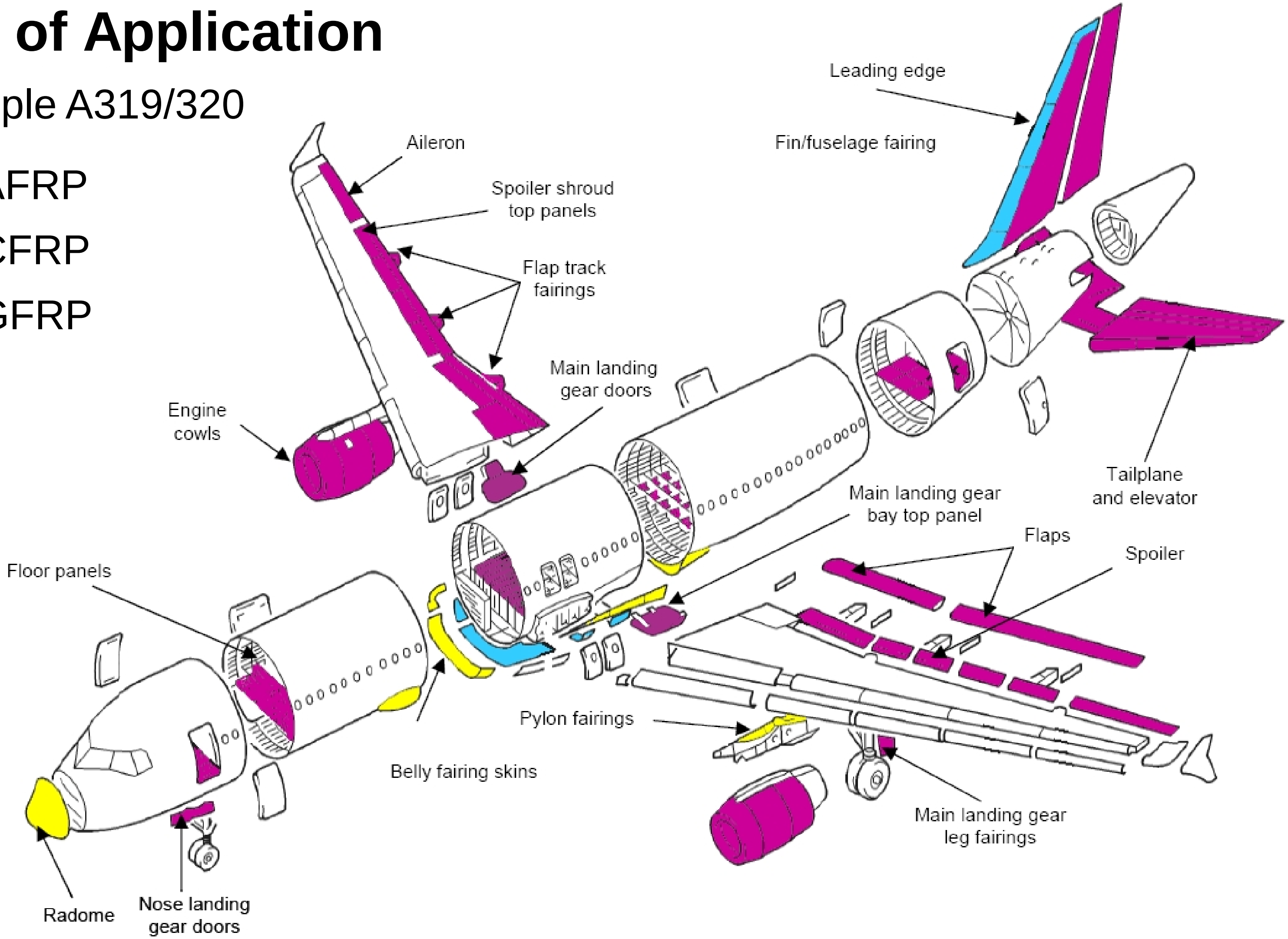
Introduction to Lightweight Materials/Structures

Introduction to Lightweight Materials/Structures

Areas of Application

Example A319/320

- AFRP
- CFRP
- GFRP



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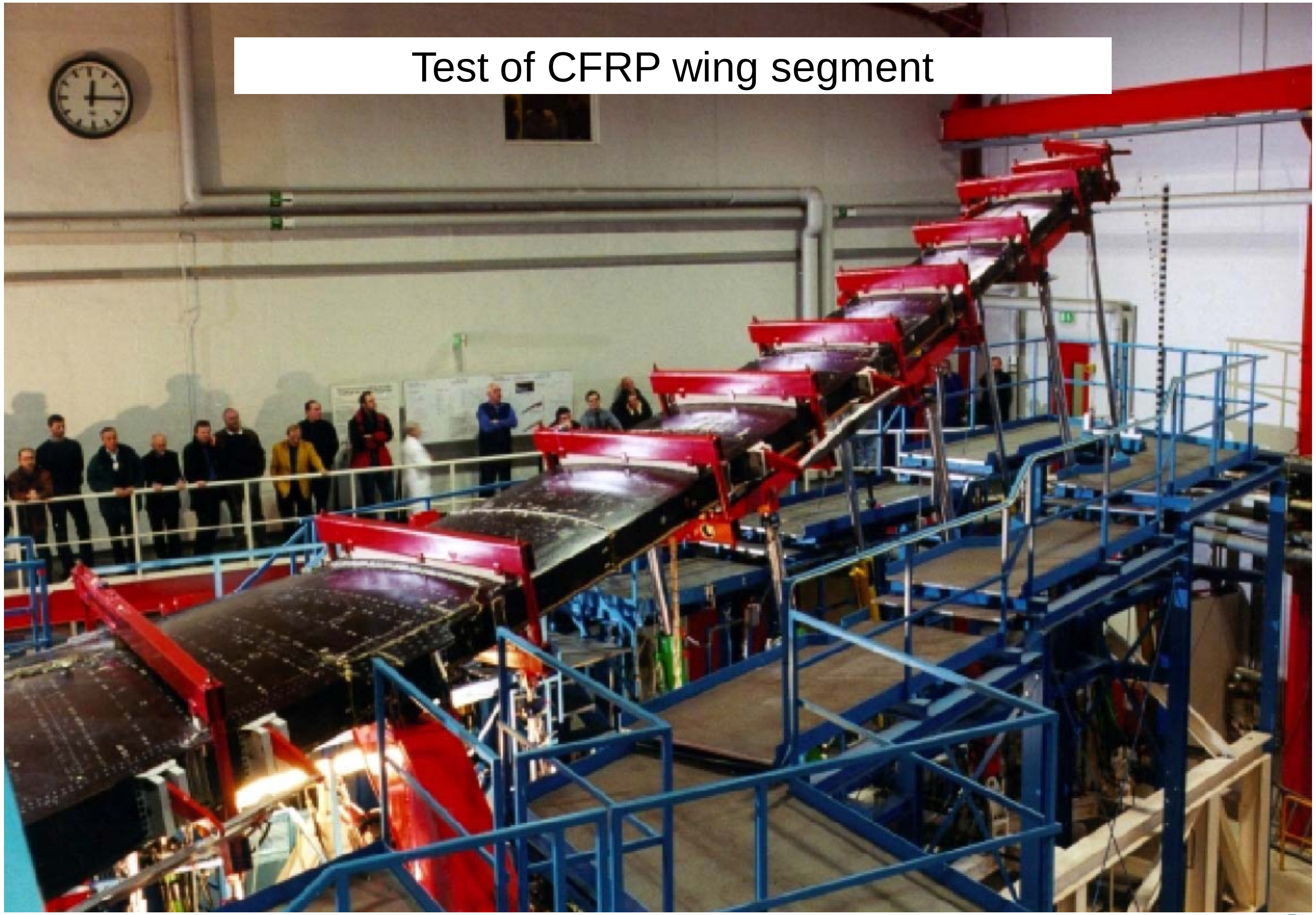
Areas of Application

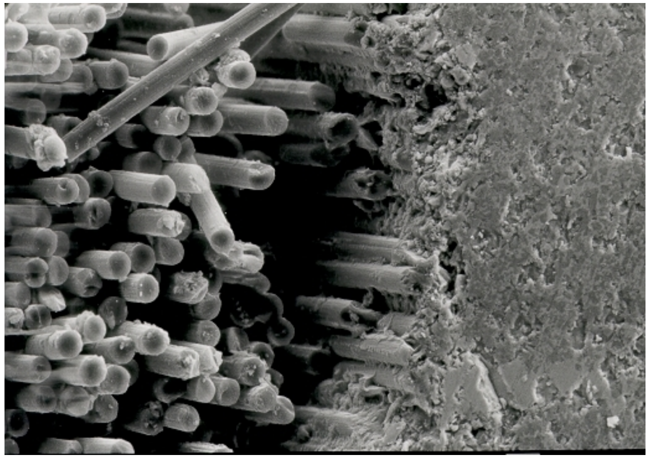


Notion Definition of Composites

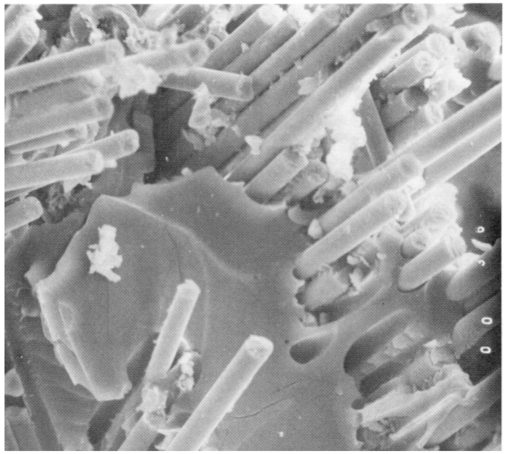
§ Composite materials are made of at least two distinct materials with different material parameters for each phase

§ Fiber reinforced composites (FRC) are composites where one material component (fiber) is used as a reinforcing material for the matrix

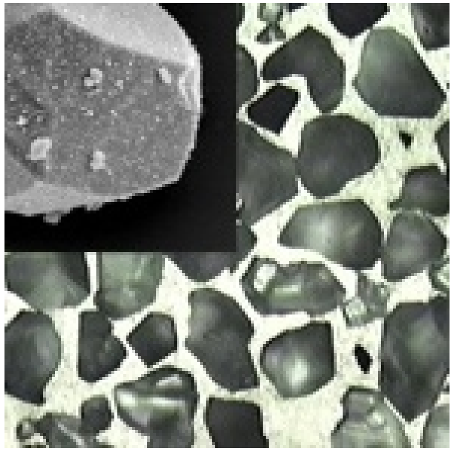
§ Particle reinforced composites consist of particles of one material dispersed in a matrix of a second material. Particles may have any shape or size, but are generally spherical, ellipsoidal, polyhedral, or irregular in shape



carbon fiber - epoxy



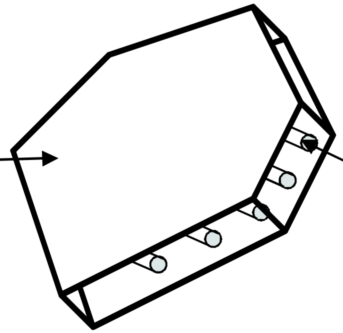
glass fiber - epoxy



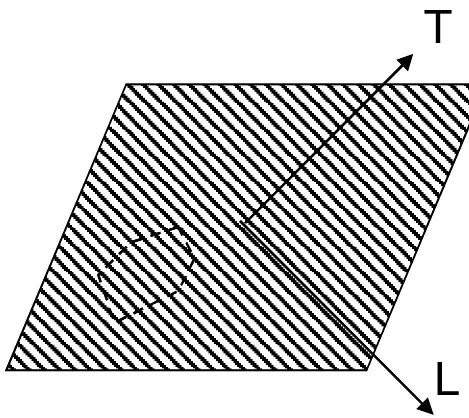
ceramic - aluminum

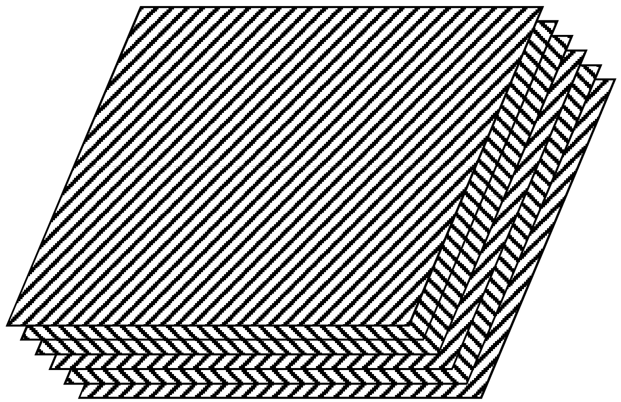
Notion Definition

Matrix- A homogeneous base material that forms the bulk of a composite material layer.



Fibers- Bonded or embedded reinforcing fibers that are usually responsible for the anisotropy of the composite.



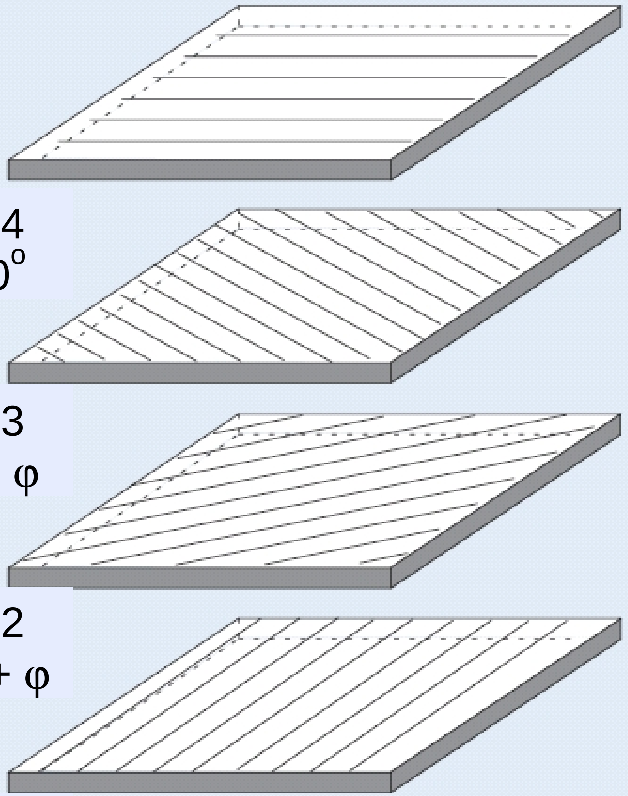


Lamina- A composite material in sheet form usually referred to as a **layer** or **ply**. The material properties of a layer is usually determined through an equivalent homogenization (smearing) process.

Laminate- A stack of lamina joined together in arbitrary directions, referred to as a composite **lay-up** or **stacking-sequence**.

Notion Definition

lamina



layer 4
$\varphi_4 = 0^o$

layer 3
$\varphi_3 = -\varphi$

layer 2
$\varphi_2 = +\varphi$

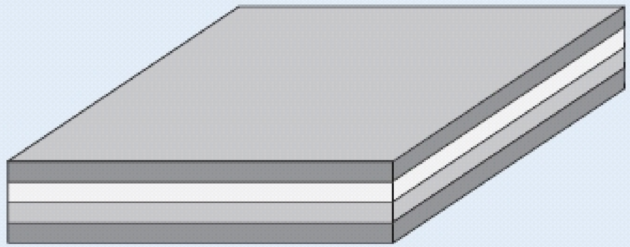
layer 1
$\varphi_1 = 90^o$

stacking sequence

laminating

- wet-in-wet
  - hand-lay-up
  - sprayed-lay-up
- filament winding
- pultrusion
- resin transfer molding

laminate



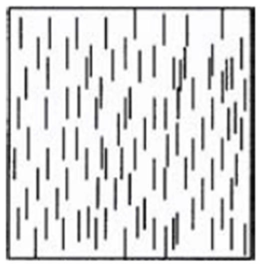
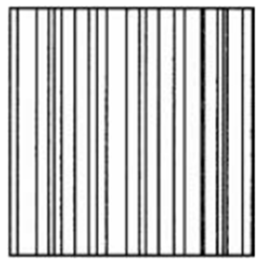
[90^o / $+\varphi$ / $-\varphi$ / 0^o] laminate

angle-ply laminate $\pm\varphi$

cross-ply laminate $\varphi = 0^o / 90^o$

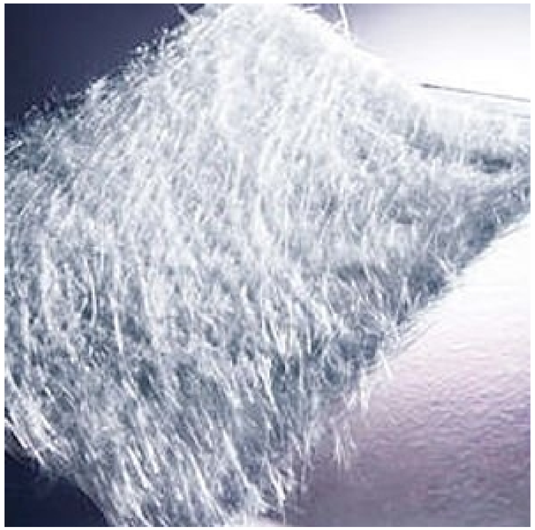
Classification of Fiber Reinforced Composites

Raw Materials	Matrix	Fiber
	- Thermosets - Thermoplastics - Metals - Ceramics	- Glass - Carbon - Aramid (Kevlar) - Bor - Ceramics

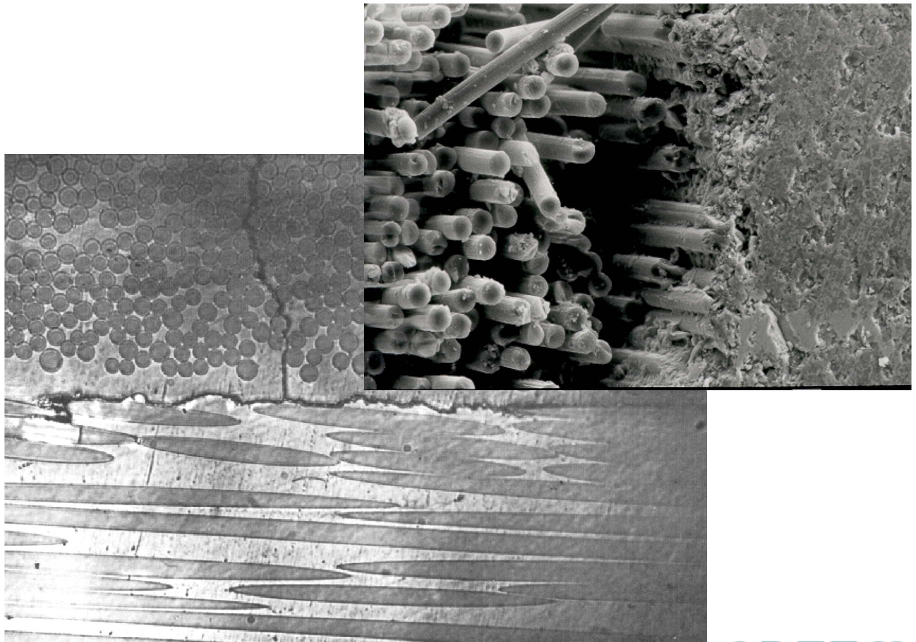
Types of Reinforcement	Short Fibers		Long Fibers	
	random	oriented	random	oriented
				

Short Fiber/Particle vs. Endless Fiber Reinforced

- Particle and short fiber reinforced
  - Account for microstructure in form of size, shape, and orientation
  - Close gap in process chain for injection molding and mechanical simulation
  - Investigate local stresses and strains on fiber-matrix level



- Long fiber reinforced, layered
  - Fast and efficient composite preprocessing
  - Composite optimized postprocessing with up-to-date failure criteria



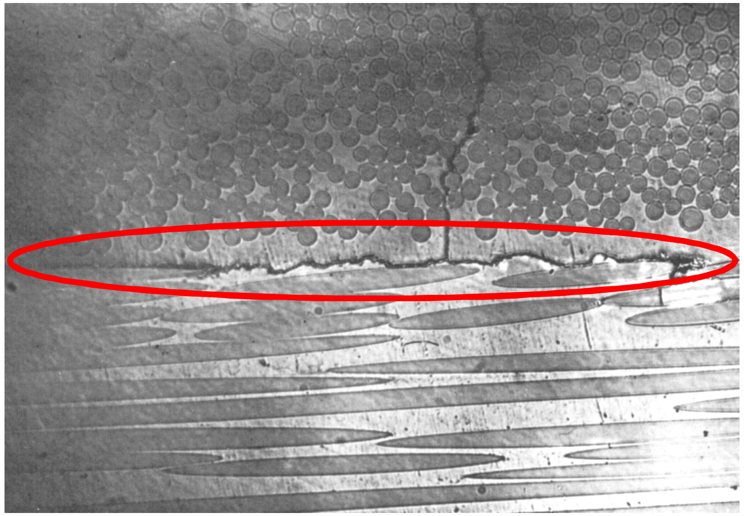
Failure Indicator and Reserve Factors

- FPF – First-Ply-Failure Indicator
  - Mathematical equations indicate first failure of any ply
  - Failure modes predicted
  - Determines reserve factor, inverse reserve factor and margin of safety
  - Typical criteria: max stress, max strain, Tsai-Wu, Tsai-Hill, Hashin, Puck2D, Puck3D, Cuntze, LaRC

- LPF – Last-Ply-Failure
  - Further loading beyond FPF until ultimate failure of laminate
  - Post-failure formulations needed (degradation, ply-discount method)
  - May also include energy dissipating methods

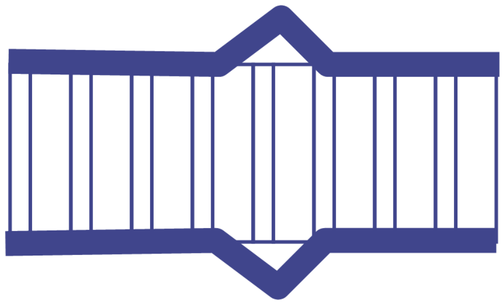
Special Failure Modes in Layered Composites

- Delamination
  - Failure of interface between two plys in normal direction under tension
    → interlaminar failure
  - Normal stress in thickness direction is driver
    → special method in shells needed

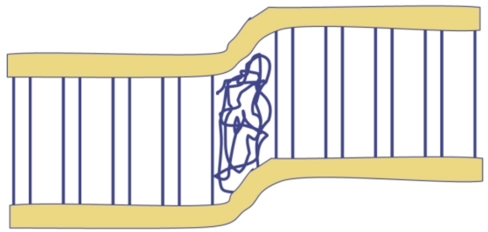


Special Failure Modes in Sandwich Structures

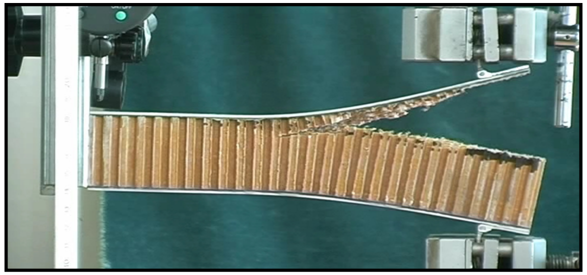
- Wrinkling
  - local buckling of a face sheet under compression
  - failure indicator also possible with shell type of modeling for whole sandwich

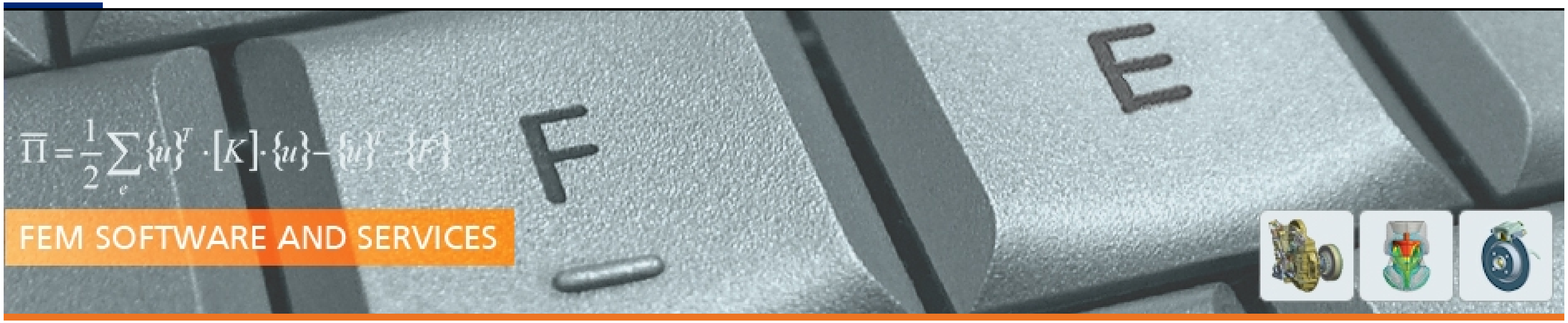


- Core failure
  - local failure of core in shear or tensile loading
  - failure indicator also possible with shell type of modeling for whole sandwich



- Debonding
  - Failure in interface between face sheet and core of sandwich structures
  - Only predictable when core and sheet are separately modeled

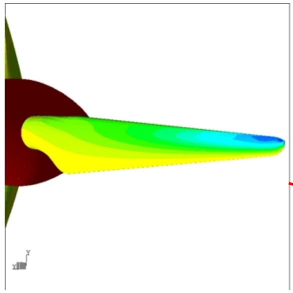




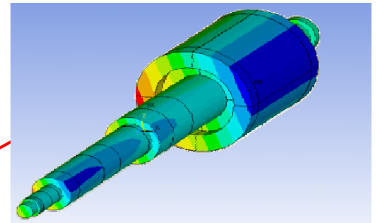
ANSYS in Wind Power Industry

ANSYS in Wind Power Industry

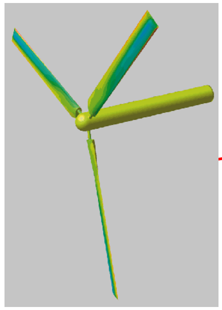
Multiple Physics & Coupling



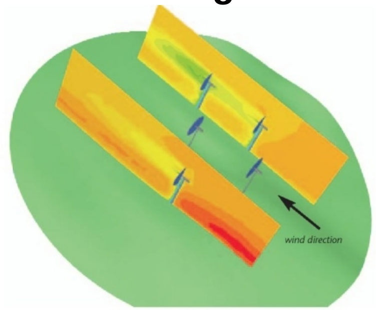
Blade design and performance



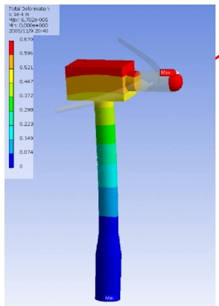
Generator and shaft design



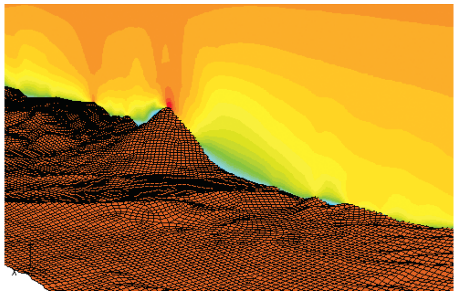
Rotor sizing and acoustics



Wind farm configuration for optimal power generation



Tower design and FSI

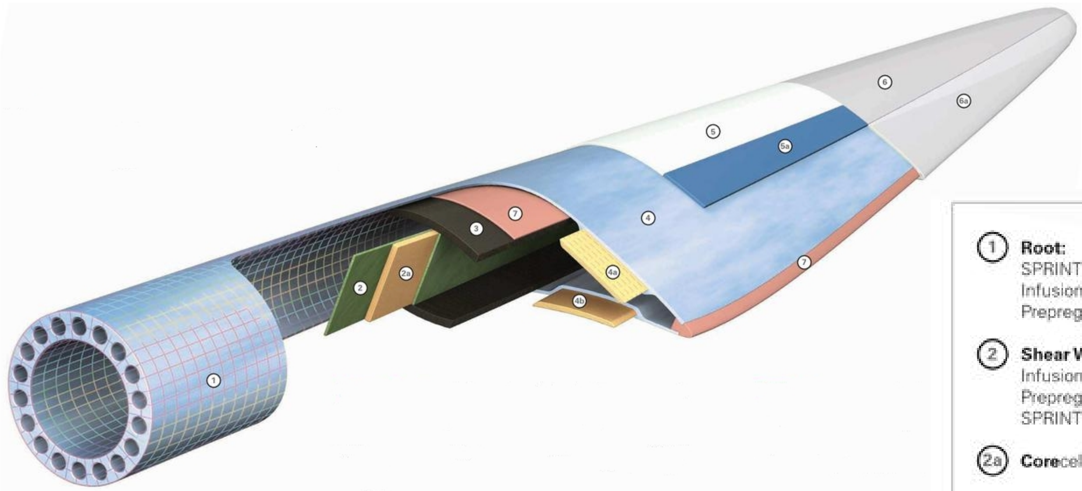


Site selection, land and sea

ANSYS in Rotor Blade Design

Challenges in Structural Modeling

- Laminate & Sandwich
- Free form surface from aerodynamics
- Multiple material systems involved
- Complex layup with huge amount of plies
- Arbitrary fiber orientation
- Ply and sandwich failure



1 **Root:** SPRINT® Infusion Prepreg

2 **Shear Web:** Infusion Prepreg SPRINT®

2a **Core**cell™

3 **Spar:** Glass UD Carbon UD Airstream

4 **Shell:** SPRINT® Prepreg Infusion

4a Infusion Core

4b Prepreg Core

5 **Priming:** UV Gelcoat CR3400

5a SPRINT IPT

6 **Finishing:** PU Paint

6a Epoxy Gelcoat

7 **Structural Adhesive:** SP340 SP340LV

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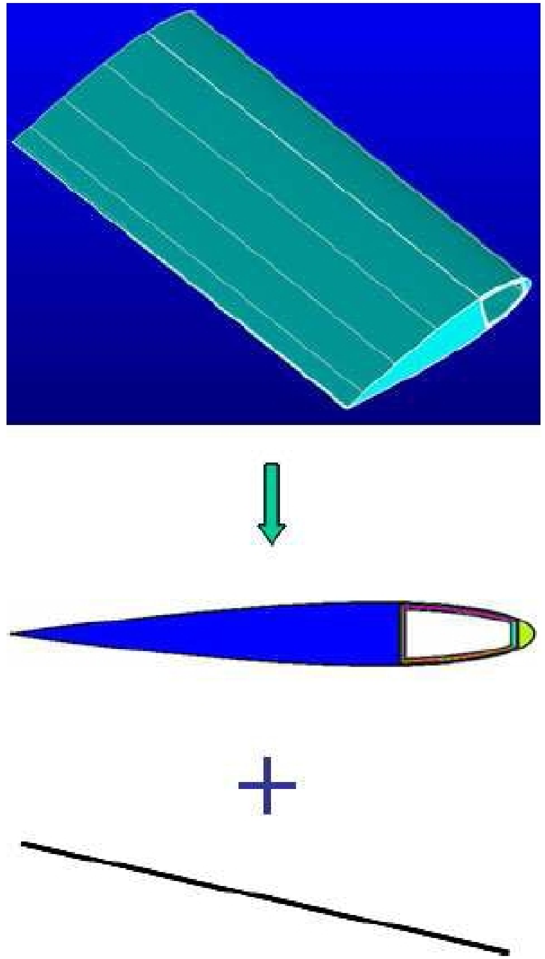
ANSYS in Rotor Blade Design

Levels of Structural Modeling

- Beam Models
  - Fast investigation in preliminary design phase
  - Using variational-asymptotic method to reduced model order

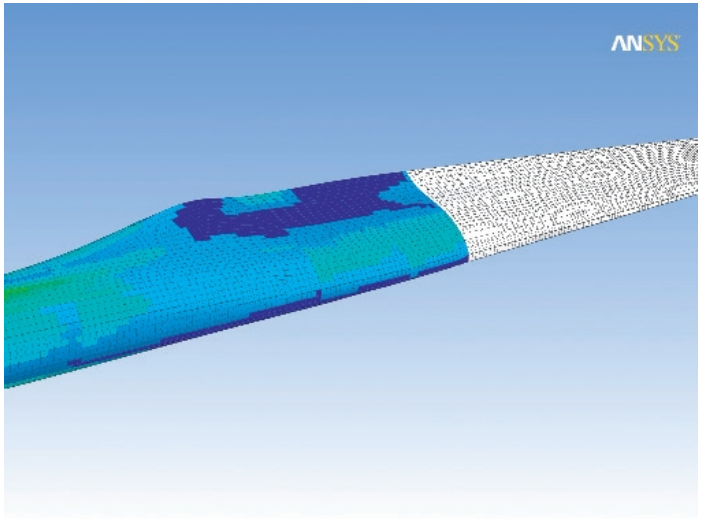


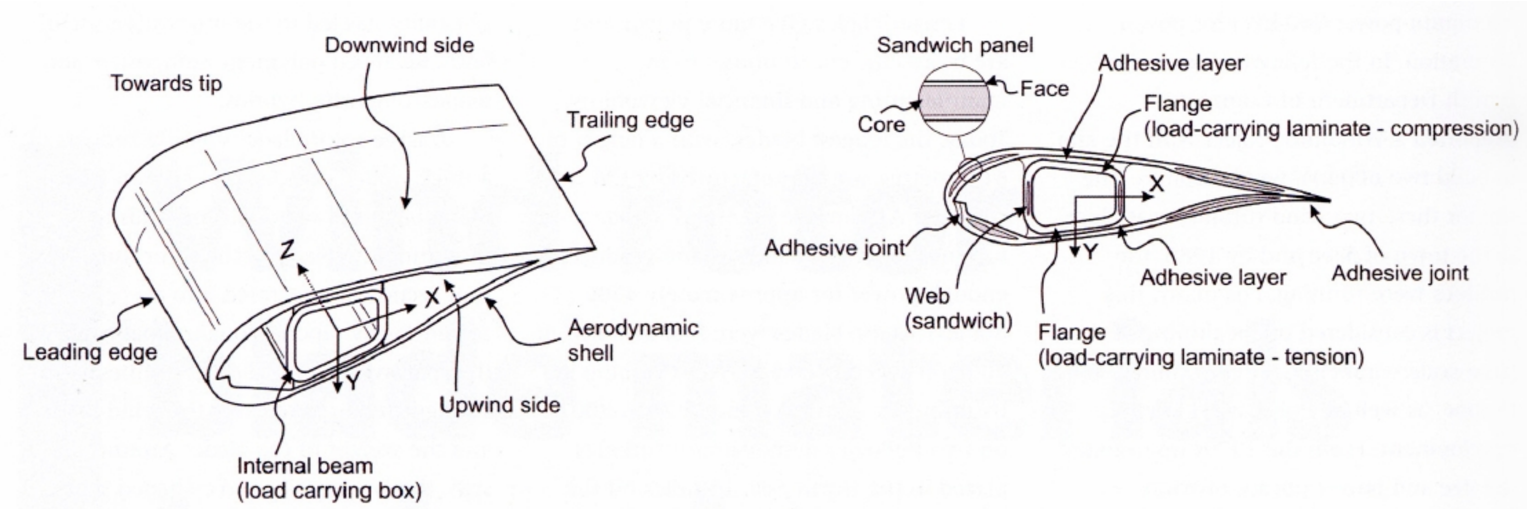
CADFEM

ANSYS in Rotor Blade Design

Levels of Structural Modeling

- Beam Models
  - Fast investigation in preliminary design phase
  - Using variational-asymptotic method to reduced model order
- Shell Models
  - Determine laminate layout in stiffness & strength evaluations
  - Nonlinear simulations including buckling





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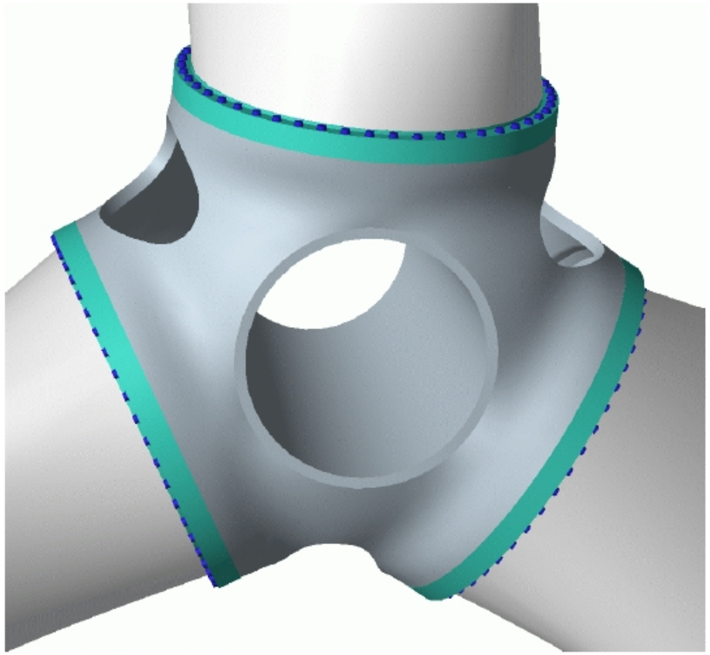
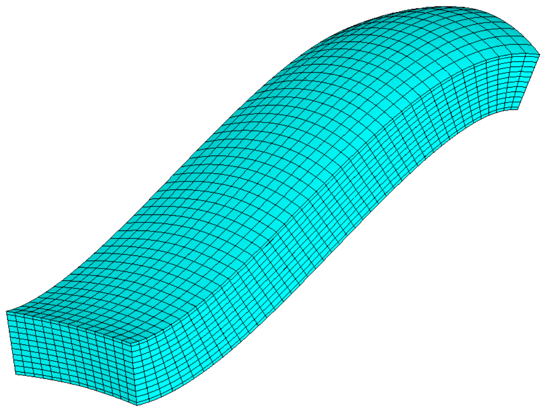
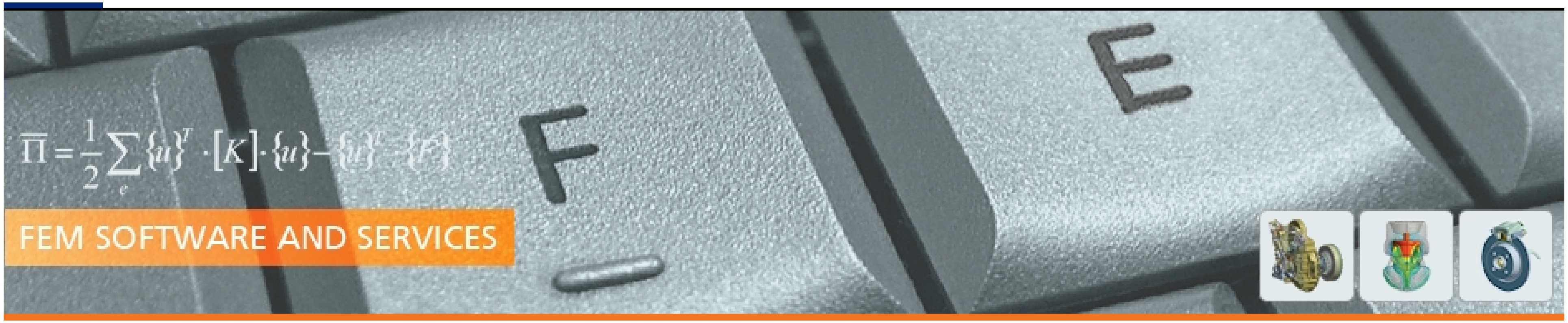
ANSYS in Rotor Blade Design

Levels of Structural Modeling

- Beam Models
  - Fast investigation in preliminary design phase
  - Using variational-asymptotic method to reduced model order
- Shell Models
  - Determine laminate layout in stiffness & strength evaluations
  - Nonlinear simulations including buckling
- Solid Models
  - Detailed investigation of load application areas, supports, inserts
  - Investigation of 3D stress state in curved regions and thick laminates





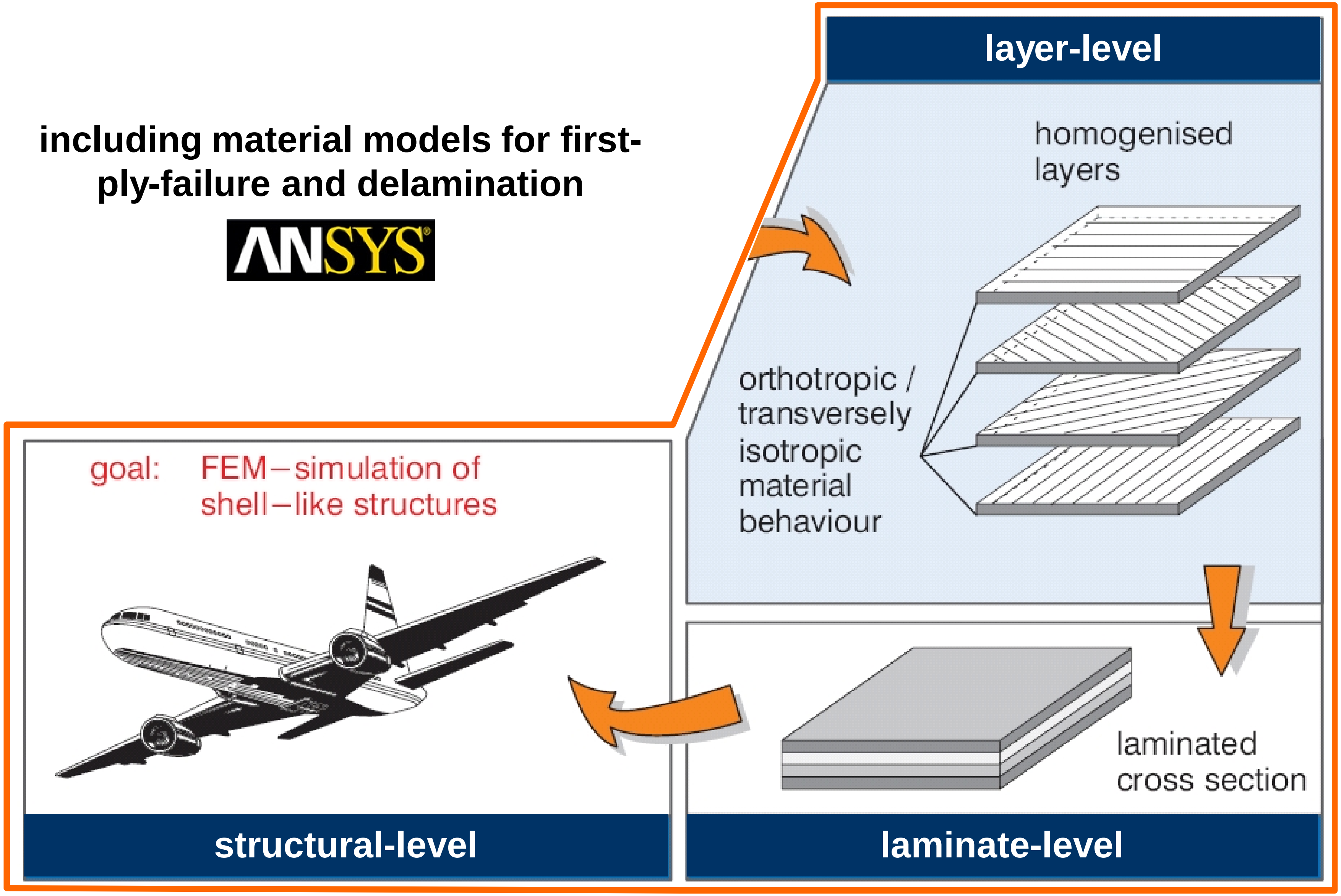


Solutions for Layered Composites

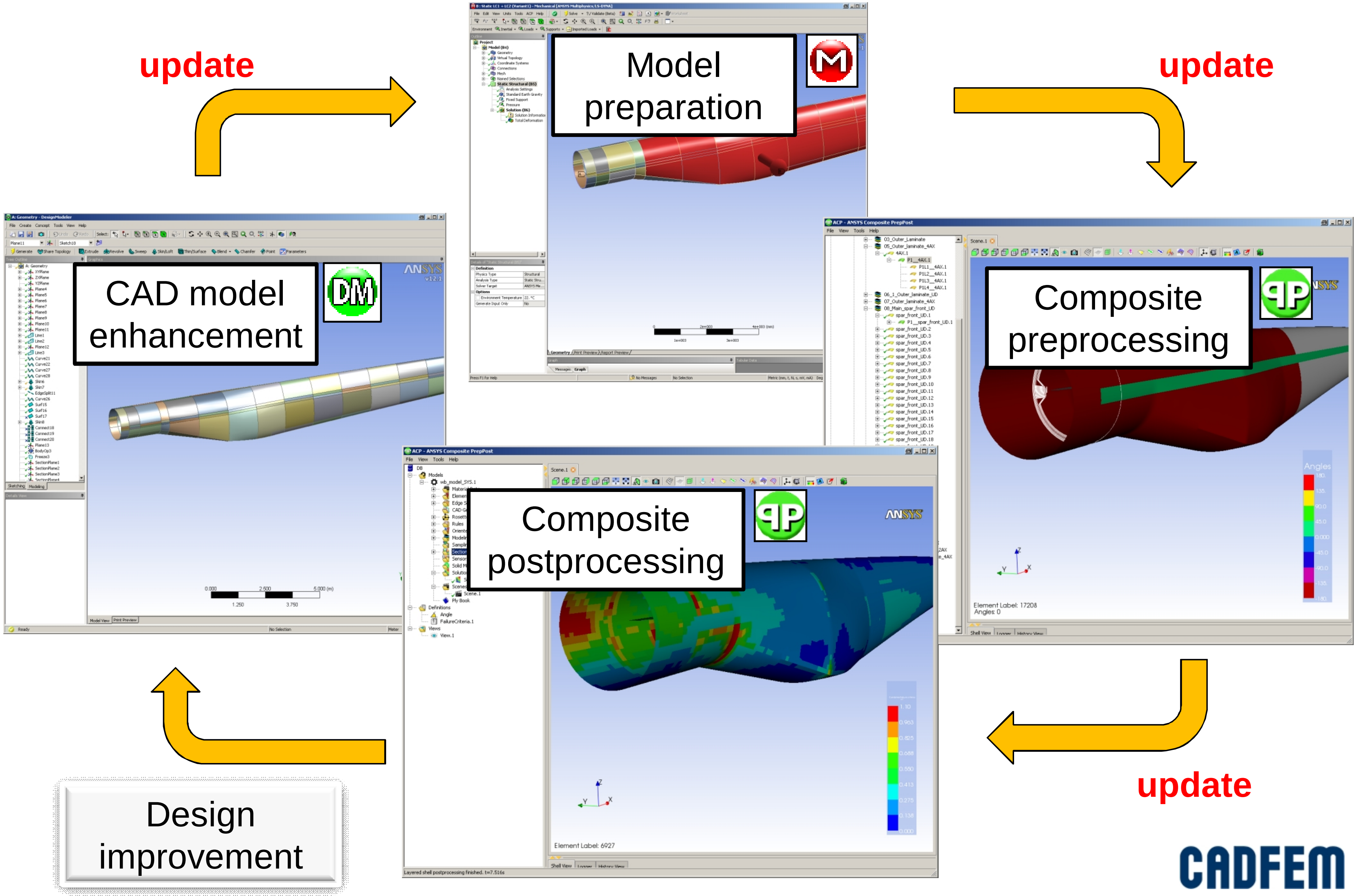
Efficient and Closed Design Loop

Levels of Observation

including material models for first-ply-failure and delamination



Simulation-Driven-Product-Design



ANSYS FE Solver Features

ANSYS Solver Features

- Transversely isotropic and orthotropic material models
- Layered shell, solid and beam elements
- Tapering cross section for shells and beams
- Arbitrary shell offset (reference surface)
- Sandwich option for shells to account for soft core
- Some basic FPF criteria (max stress, max strain, Tsai-Wu)
- Delamination & Debonding with energy release using interface elements

→ Powerful solver features available

→ Efficient pre- and postprocessing suitable for layered composites through ANSYS Composite PrepPost

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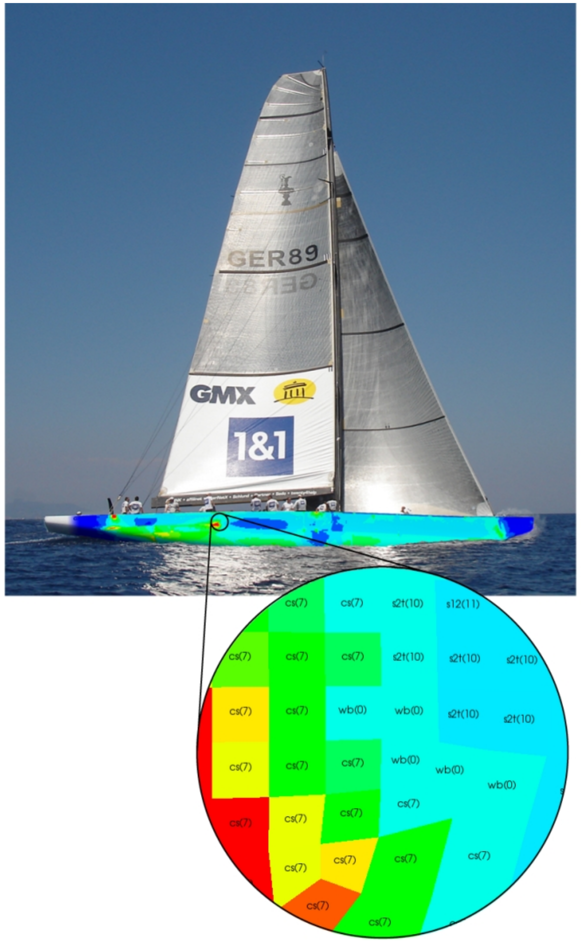
ANSYS Composite PrepPost

Introduction to ANSYS Composite PrepPost

- Dedicated to allow for easy and efficient definition and modification of **layered-composite** structures as well as their specific post-processing
- Integrated in ANSYS Workbench as well as in ANSYS Classic
- Dedicated to provide leading-edge technology in pre- and postprocessing of layered composite structures



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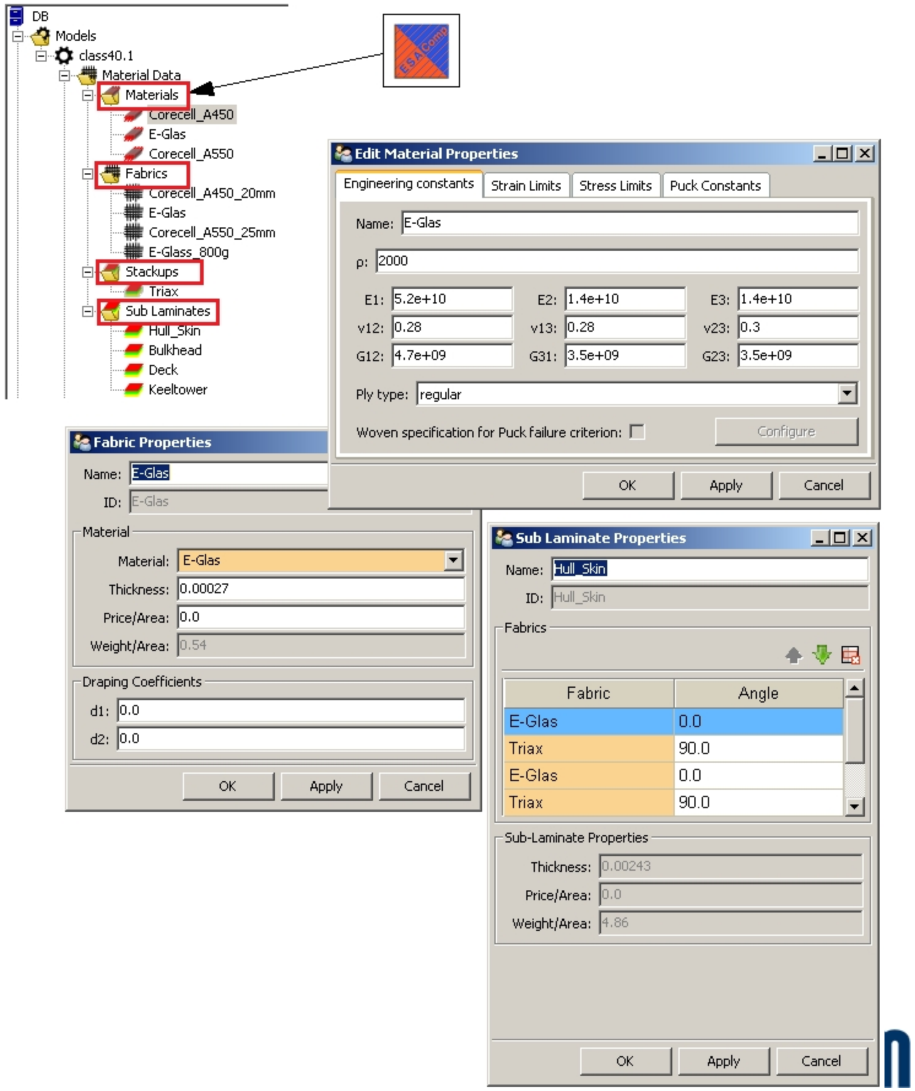
ANSYS Composite PrepPost

Key Features for Composites Preprocessing

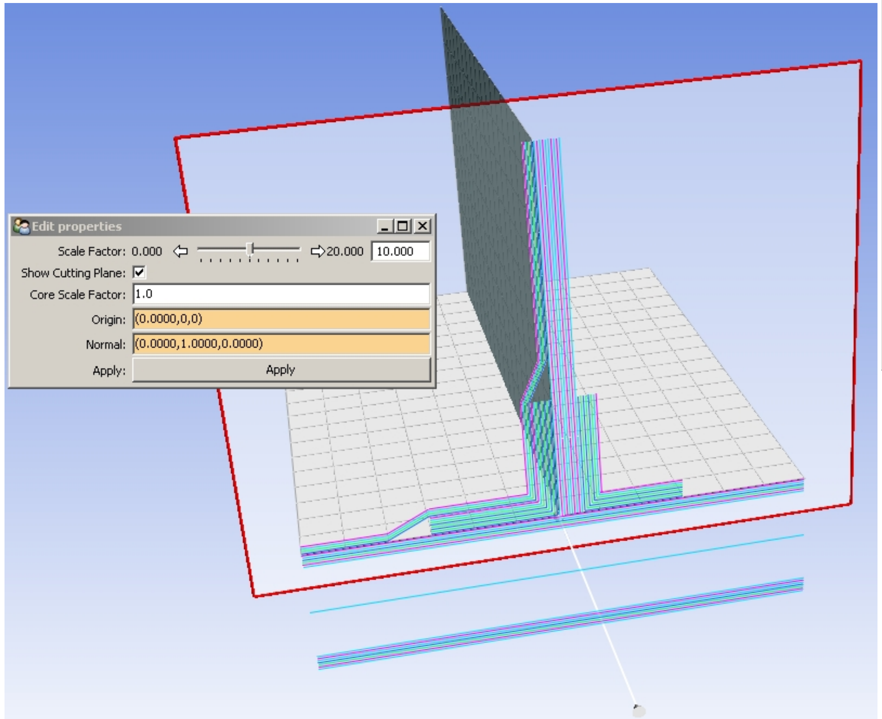
- Unique material definition functionality tailored for modeling layered composite structures
- Fabrics, Stack-ups and Sub-laminates as modeling plies
- Basis engineering data and additional advanced post-processing data provided
- Import material data base from ESAComp

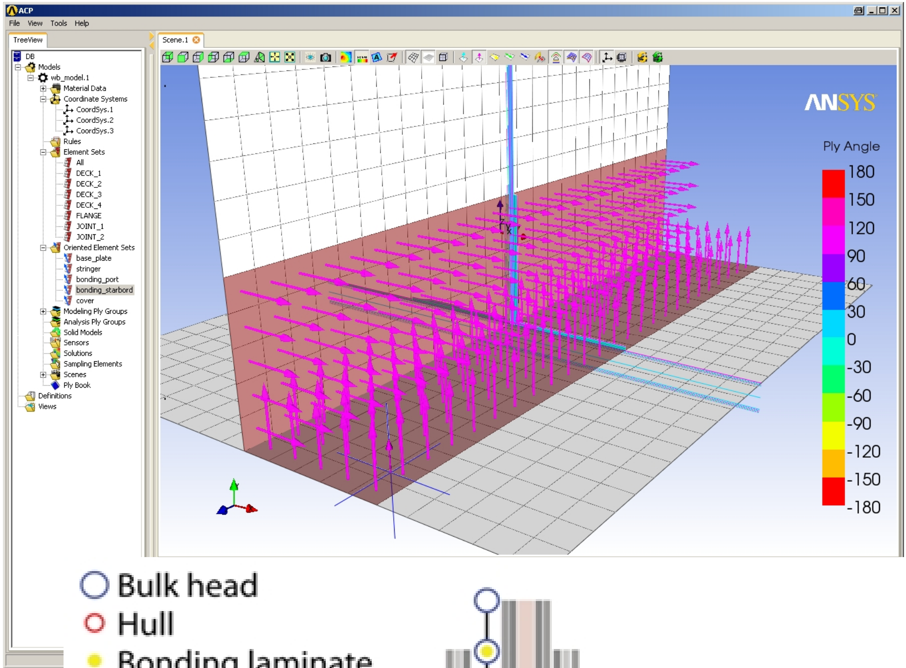


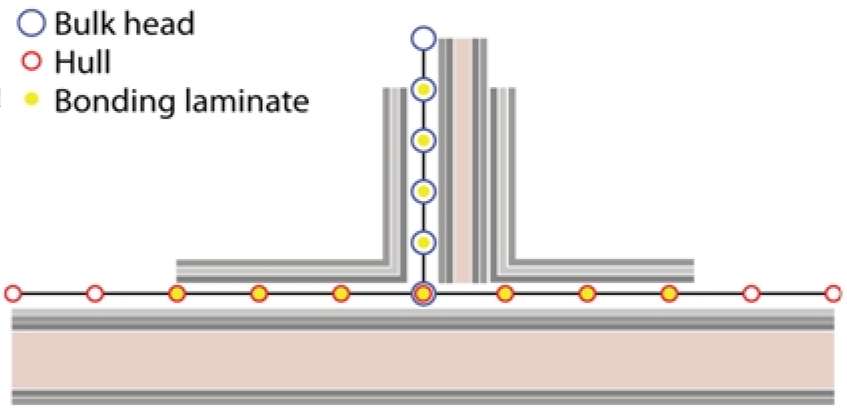
ANSYS Composite PrepPost

Key Features for Composites Preprocessing

- § Arbitrary material application direction and material 0° direction
- § Multiple material application direction for easy asymmetric laminate definition

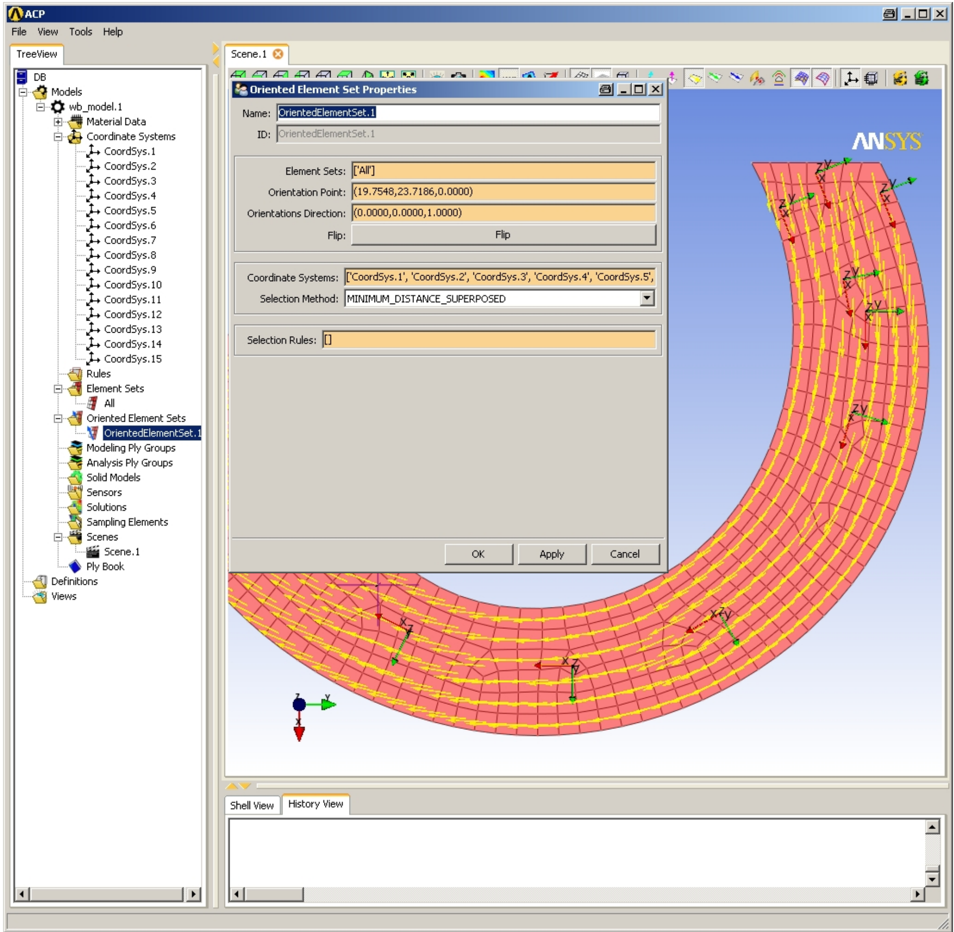






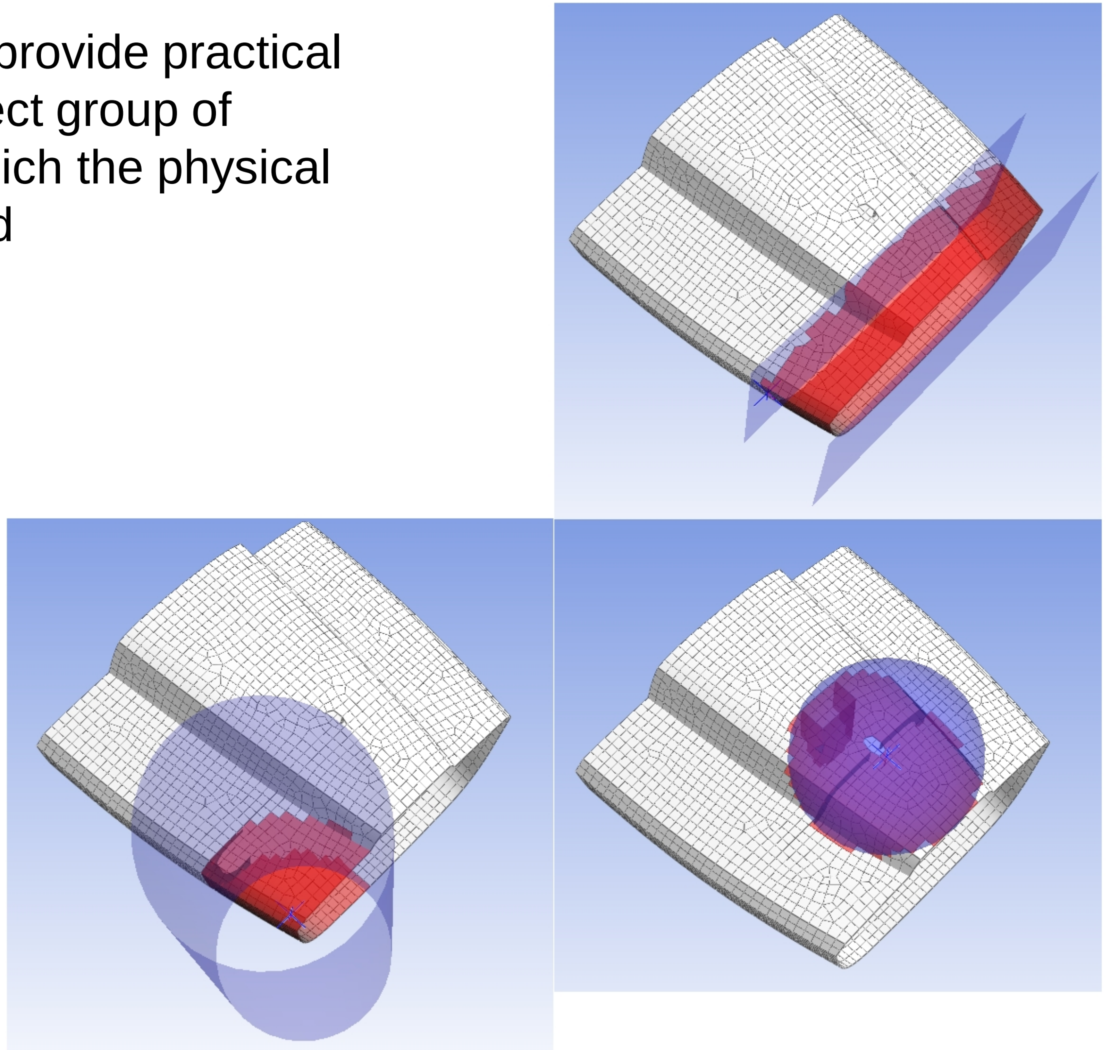
Key Features for Composites Preprocessing

- Cartesian, cylindrical and spherical coordinate systems for material reference direction
- Arbitrary material reference direction through multiple coordinate systems and interpolation



Key Features for Composites Preprocessing

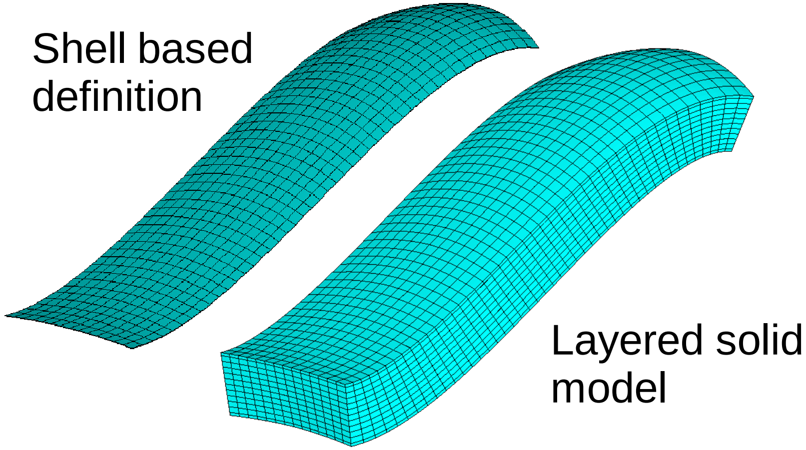
- Selection rules provide practical means to reselect group of elements for which the physical plies are applied



ANSYS Composite PrepPost

Key Features for Composites Preprocessing

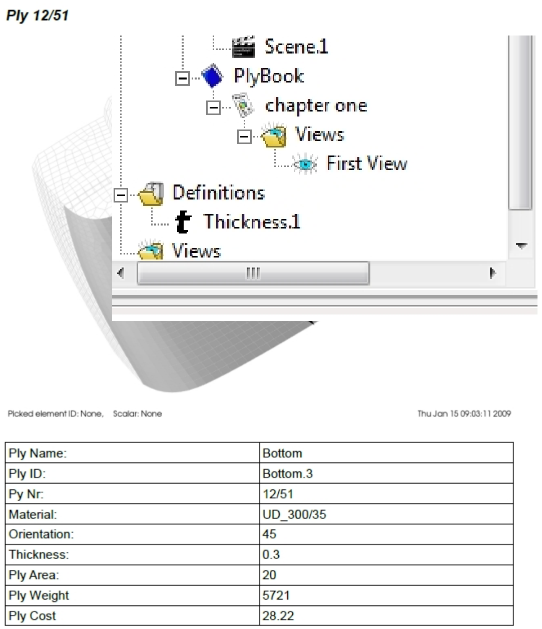
- Generation of layered-solid composite models in same way as layered shell-models
- Layer-wise post-processing of layered-solid models identically to the post-processing of layered shell-models



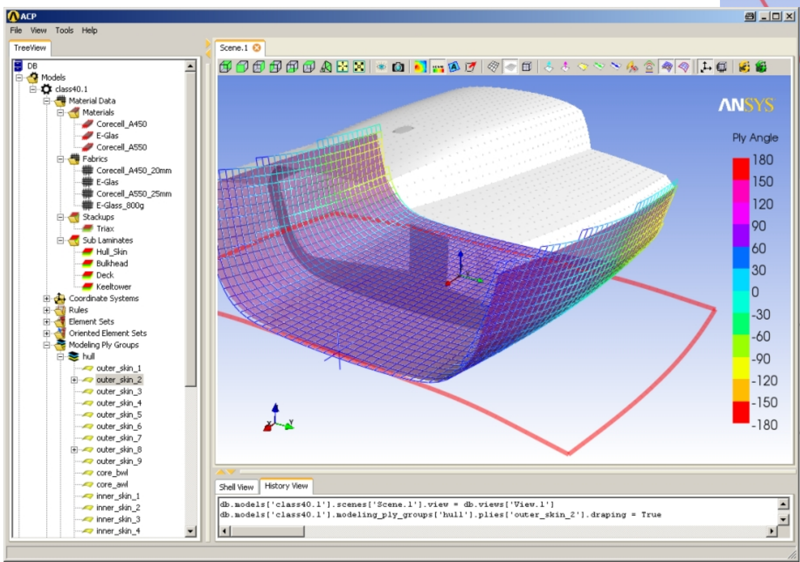
ANSYS Composite PrepPost

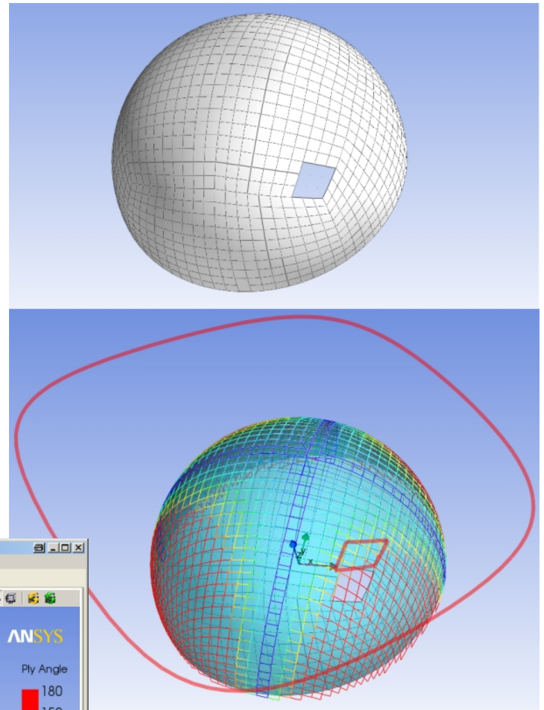
Key Features for Composites Preprocessing

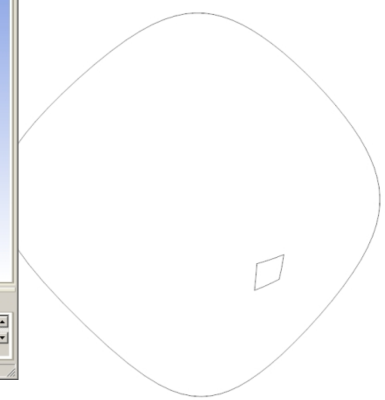
- § Draping functionality to predict ability to drape and fiber-angle correction
- § Flat-wrap of plies in *.dxf and boundaries as *.stp & *.iges
- § Generation of individually formatted ply-books and export in various formats (*.html, *.pdf, *.odt...)



Ply Name:	Bottom
Ply ID:	Bottom.3
Py Nr:	12/51
Material:	UD_300/35
Orientation:	45
Thickness:	0.3
Ply Area:	20
Ply Weight	5721
Ply Cost	28.22



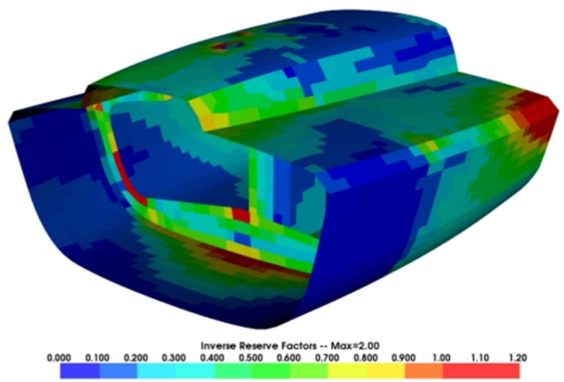




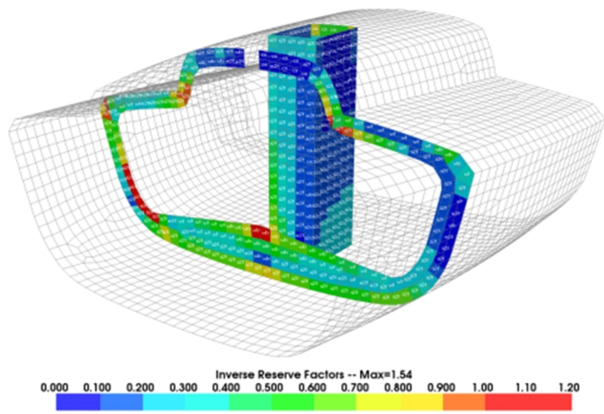
ANSYS Composite PrepPost

Key Features for Composites Postprocessing

- Evaluation of Inverse Reserve Factors (IRF's) for several composite failure criteria at all integration points of all layers of all requested layered Finite Elements.
- Definition and configuration of arbitrary combinations of failure criteria. Currently available:
  - Tsai-Wu, Tsai-Hill, Hashin
  - Puck 2D and 3D for UD and weave materials
  - LaRC (Langley Research Center)
  - Core failure and face sheet wrinkling for sandwich structures

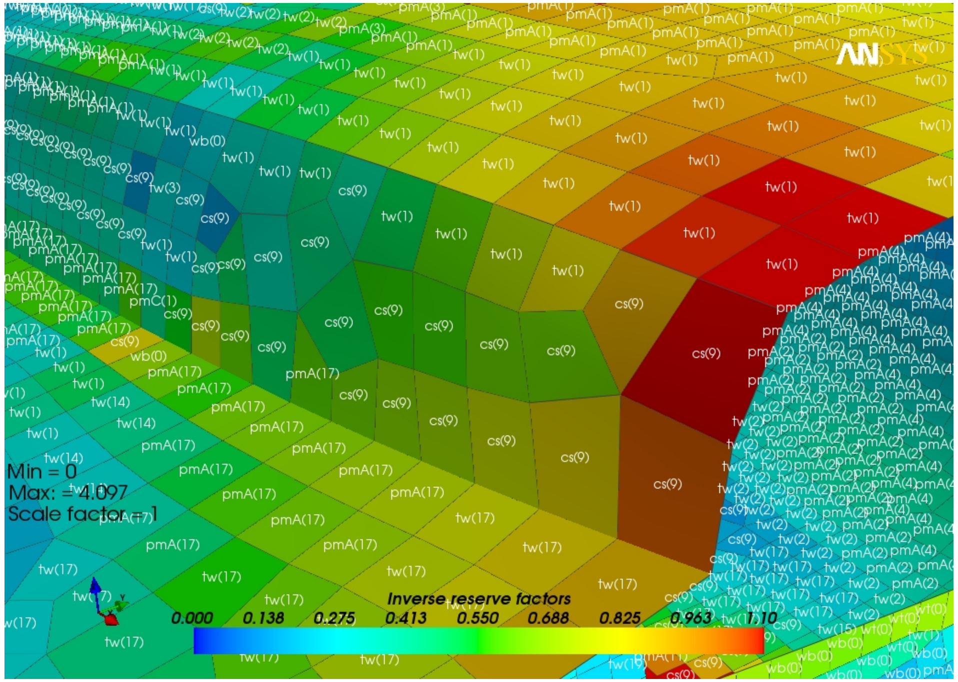


- ACP computes four result values per in-plane data point:
  - Maximum IRF of all criteria of all layers
  - Active failure mode (criterion with highest IRF)
  - Layer index where highest IRF occurs
  - Critical load case



Key Features for Composites Postprocessing

- Text plot highlights critical failure mode, layers and load case
  - Failure modes
    - tw = Tsai-Wu
    - s1t = Fiber failure due to tension
    - s2c = Matrix failure due to compression
    - cs = core failure
  - Critical layer
    - (7) = layer 7
  - Critical load case

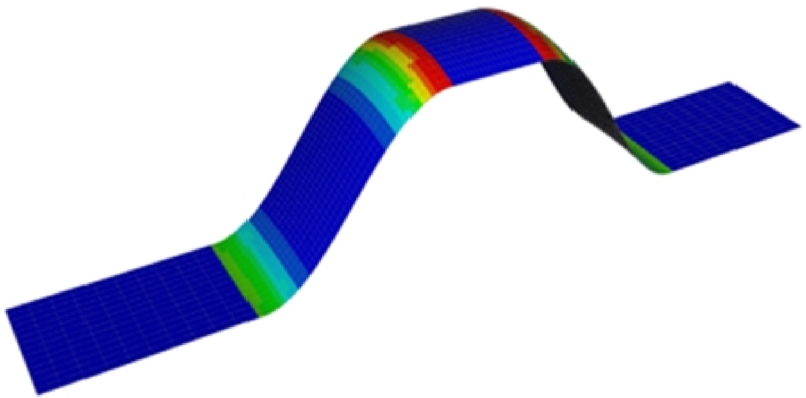


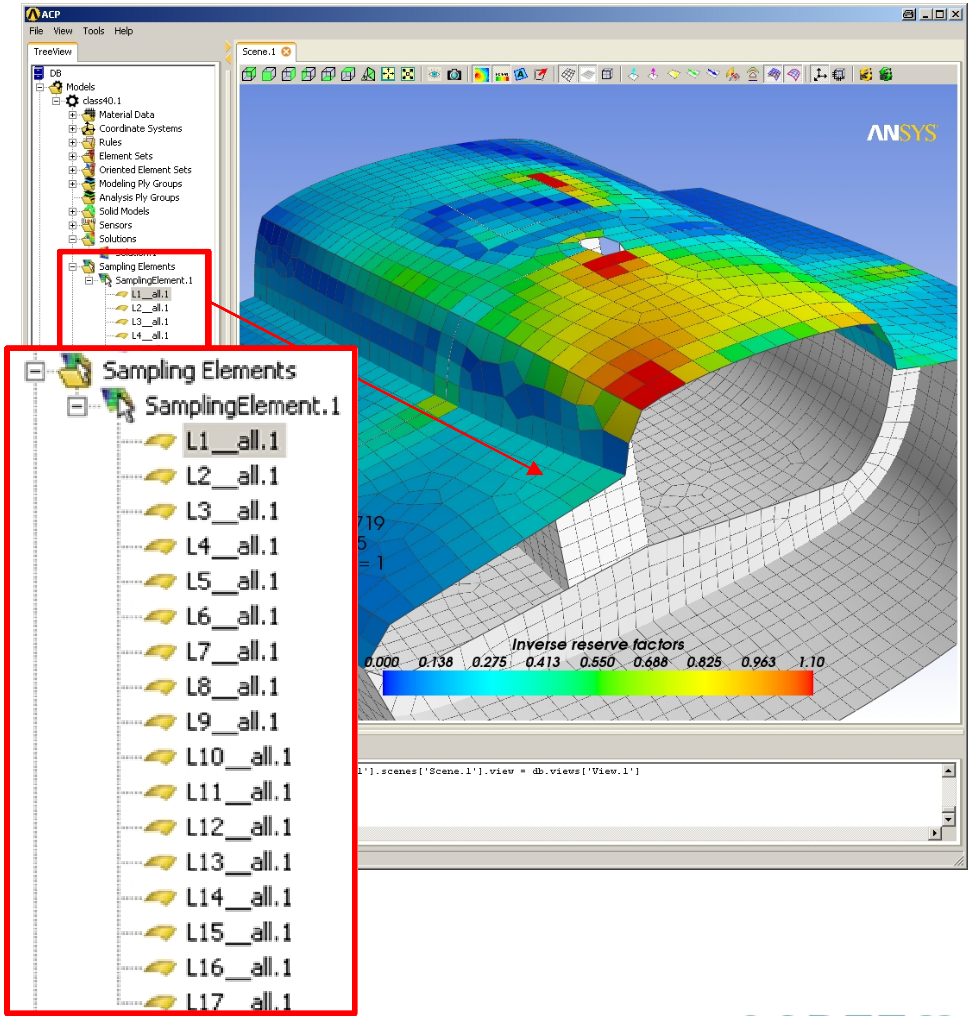
ANSYS Composite PrepPost

Key Features for Composites Postprocessing

- Sampling element provides stacking sequence (laminate) of specific element
- Enables ply-based strain and stress visualization.
- Each ply of laminate can be select from ply-list for result visualization

- Normal thickness stress calculation in shell elements





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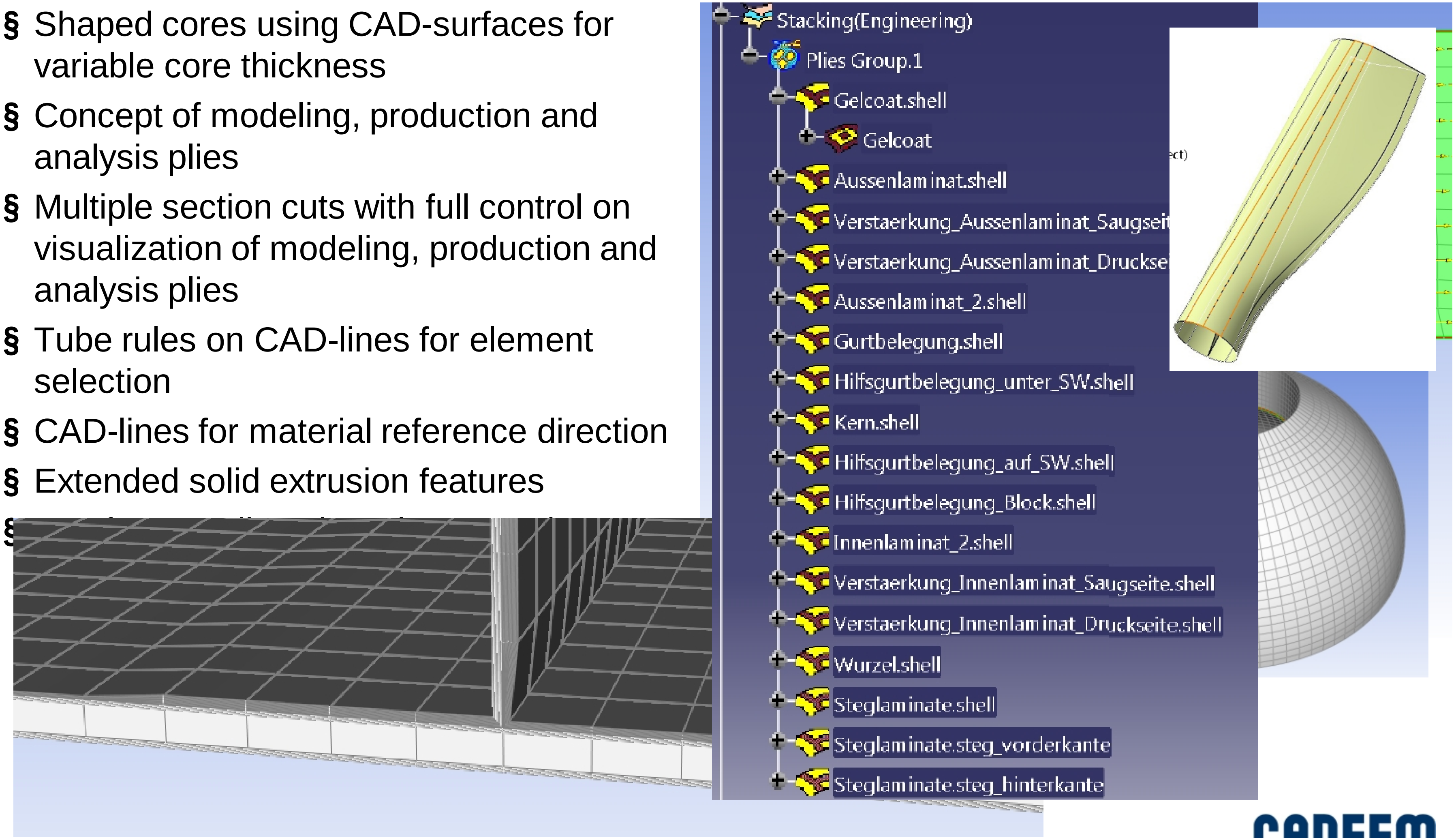
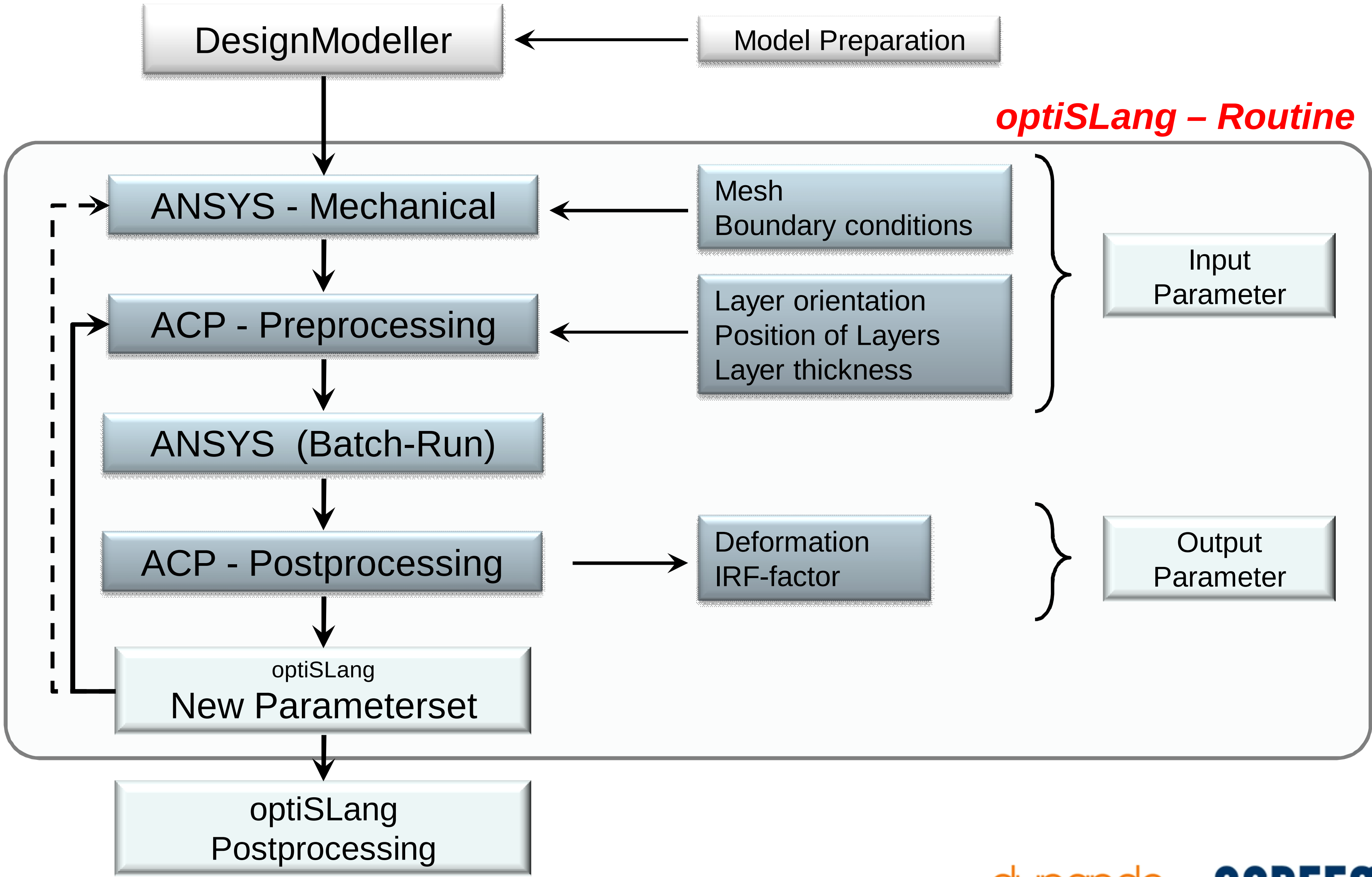
Latest Features

Latest Features in ANSYS Composite PrepPost

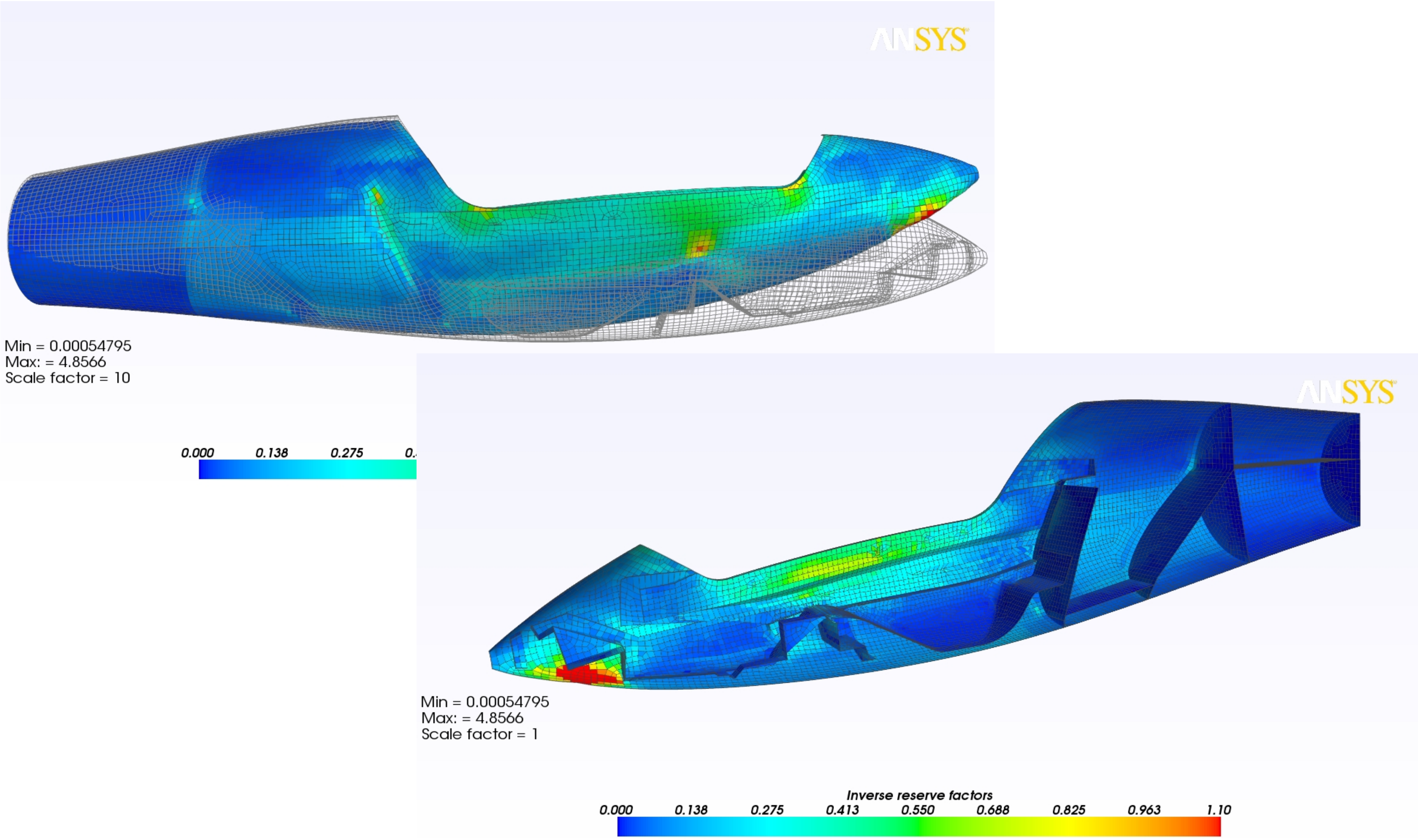
- Shaped cores using CAD-surfaces for variable core thickness
- Concept of modeling, production and analysis plies
- Multiple section cuts with full control on visualization of modeling, production and analysis plies
- Tube rules on CAD-lines for element selection
- CAD-lines for material reference direction
- Extended solid extrusion features

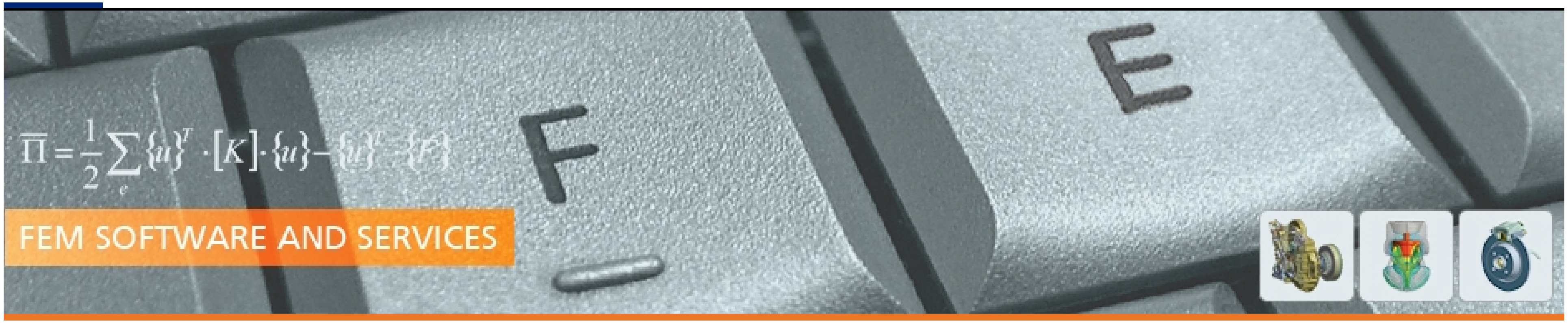


Composites & Optimization



Cockpit of Sail Plane





Live-Demonstration

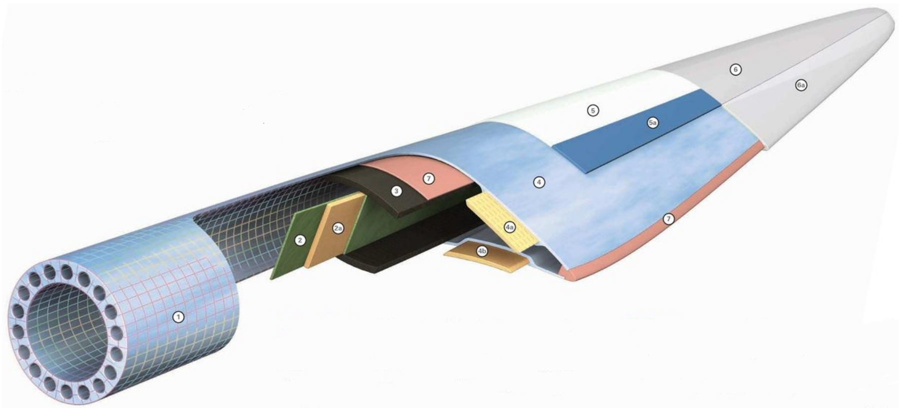
Rotorblade

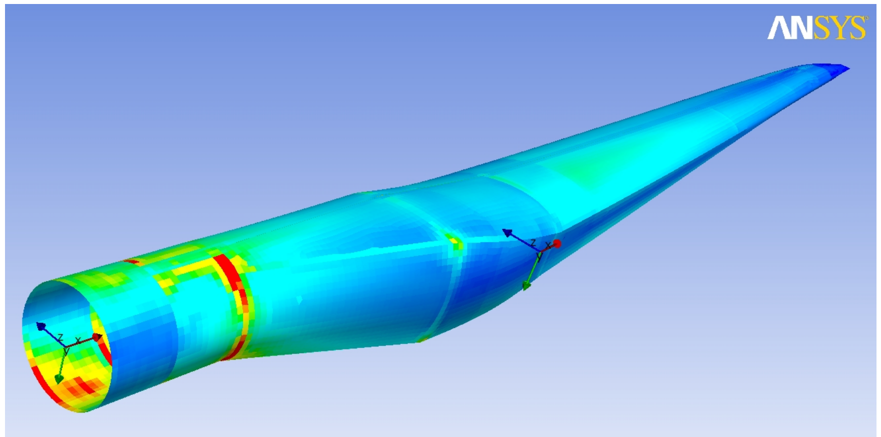
Summary

Composites – Catch the Wind!

- Particle and short fiber reinforced
  - Account for microstructure in form of size, shape, and orientation
  - Close gap in process chain for injection molding and mechanical simulation
  - Investigate local stresses and strains on fiber-matrix level
  - **Solution: ANSYS + Digimat**

- Long fiber reinforced, layered
  - Fast and efficient composite preprocessing
  - Composite optimized postprocessing with up-to-date failure criteria
  - **Solution: ANSYS + ANSYS Composite PrepPost**





CADFEM