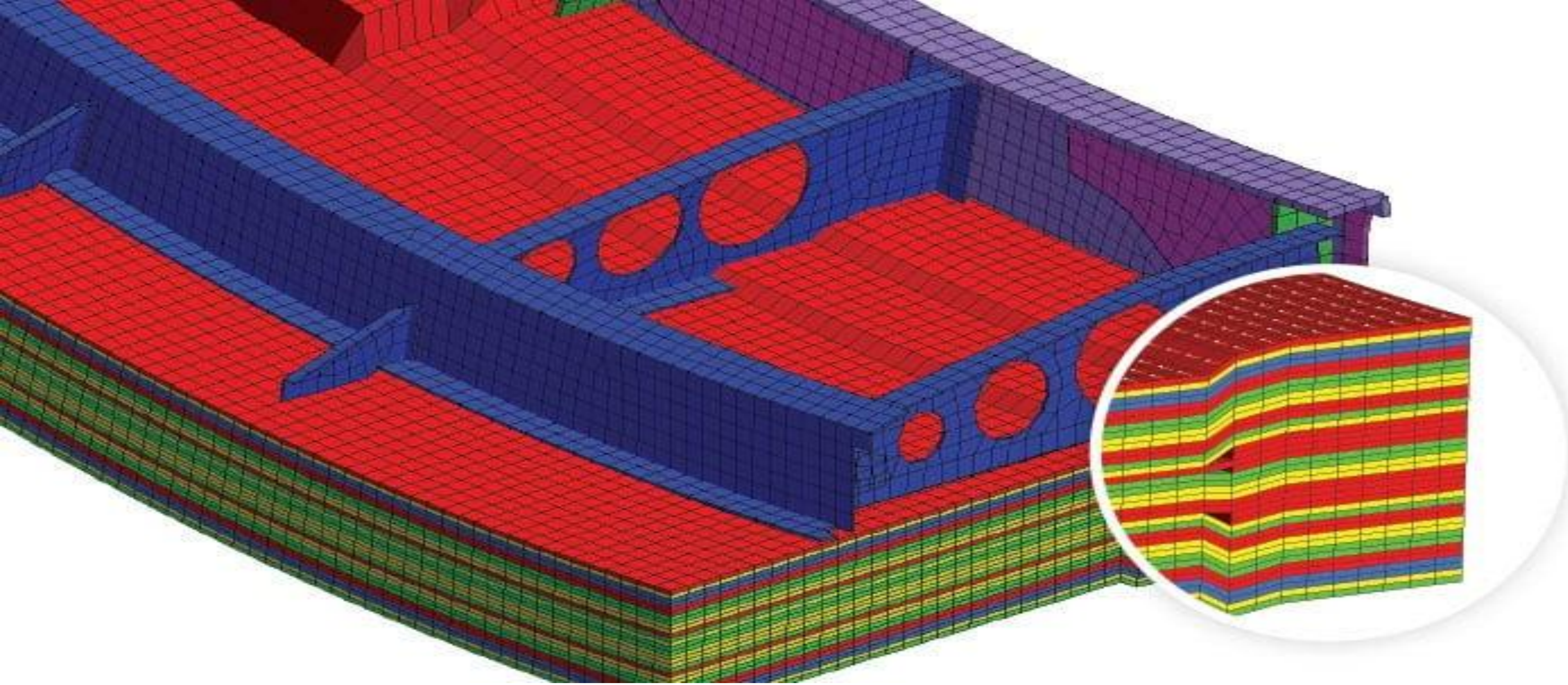

ACCURATE & EFFICIENT SIMULATION OF LAMINATED COMPOSITES

Kory Soukup / 2023

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Agenda

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About Me

- University of Minnesota
  - Aerospace Engineering, 2019
- “Solar Rayces”
  - **FSGP / ASC** 2016, 2018,
  - **WSC** 2015, 2017

Joined Altair Engineering in 2019

- Structural FEA
- Composite Design & Optimization

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What Is a Composite Material?

A composite material is one in which at least two distinct materials with significantly different material characteristics are joined to act as a single material

Composite materials come in a variety of types, including:

- Particulate Composites (Particles + Matrix)
- Laminated Composites (Layers)
- Fibrous-Matrix Laminated Composites (Layers – "Long fiber + Matrix")
- Core Stiffened Laminated Composites

Advantages of Composite Design

Why use composites for creating structural components?

- The material property of the composites can be engineered according to the application requirements.
- The ability to impart the required material property gives them great advantage when compared with traditional homogeneous materials like steel or aluminum.
- Composites have increased strength to weight ratios in use cases against isotropic metals

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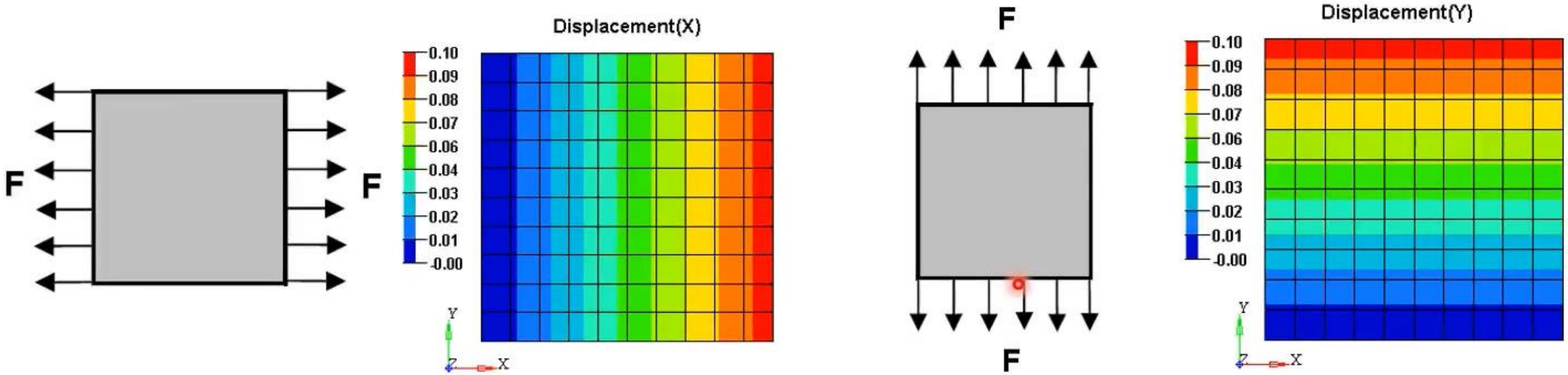
Composite Designable Material Properties

Take the following example:

A simple square steel plate in tension needs to have displacement of 0.1 in x-direction.

- Designing for above requirement is a simple task
- What is the associated displacement of the part for the same loading in the y-direction?

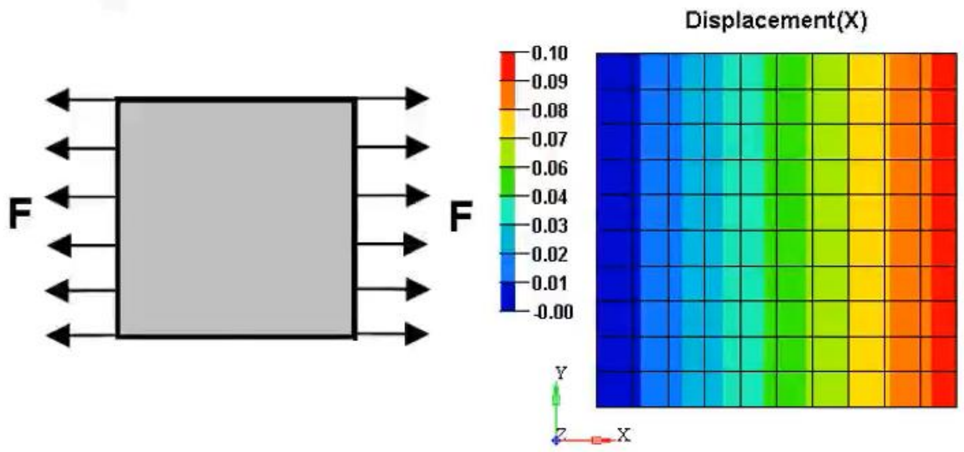


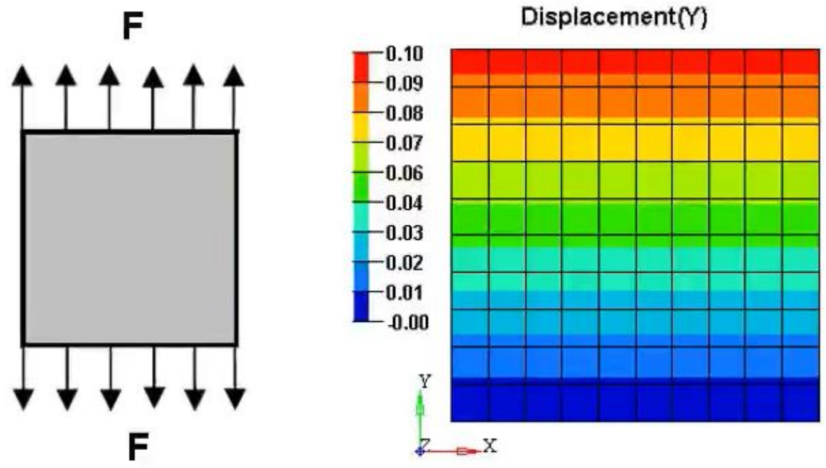
What if the displacement in the y-direction needs to be no more than 0.025 units?

Composite Designable Material Properties

Using isotropic vs orthotropic materials force different approaches to this design problem

- Steel, being an isotropic material, can not change its properties in different directions. Hence different behavior in different directions needs to be achieved through changing the geometry.
- In case of composites, achieving the above is as simple as determining the correct number of plies in x and y directions.





- Ability to design the material property gives lot of freedom to the designers but increases the complexity of the design task.
- Orthotropic designs must take into account undesirable behaviors like extensional–shear coupling, bending-twist coupling, etc

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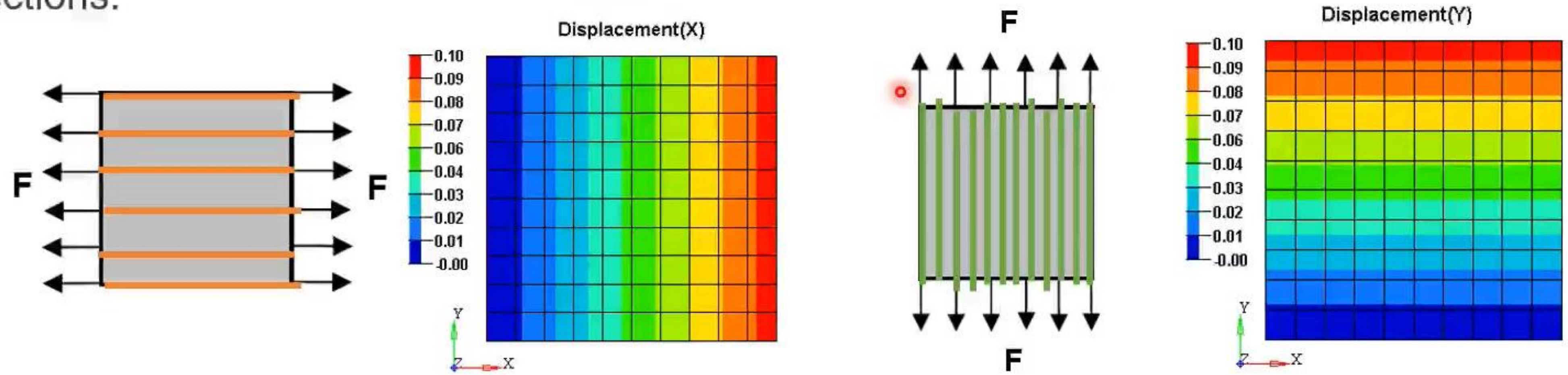
Composite Designable Material Properties

Using isotropic vs orthotropic materials force different approaches to this design problem

- Steel, being an isotropic material, can not change its properties in different directions. Hence different behavior in different directions needs to be achieved through changing the geometry.
- In case of composites, achieving the above is as simple as determining the correct number of plies in x and y directions.

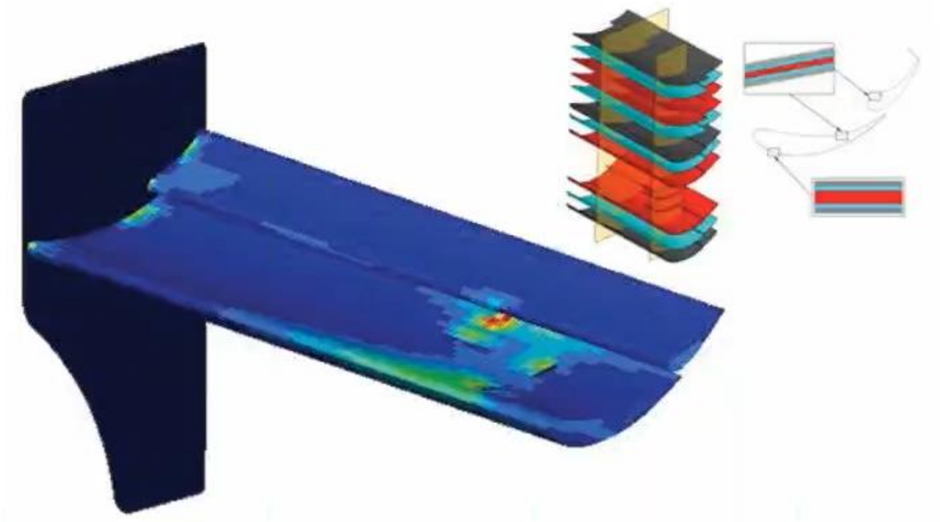


- Ability to design the material property gives lot of freedom to the designers but increases the complexity of the design task.
- Orthotropic designs must take into account undesirable behaviors like extensional–shear coupling, bending-twist coupling, etc

Finite Element Simulation: Metals vs. Composites

FE of Metal Structures

- Geometry
- Material Properties (Isotropic)
- Loads and BC's
- Visualization of Results on the Geometry
- Failure based on Invariants



FE of Composite Structures

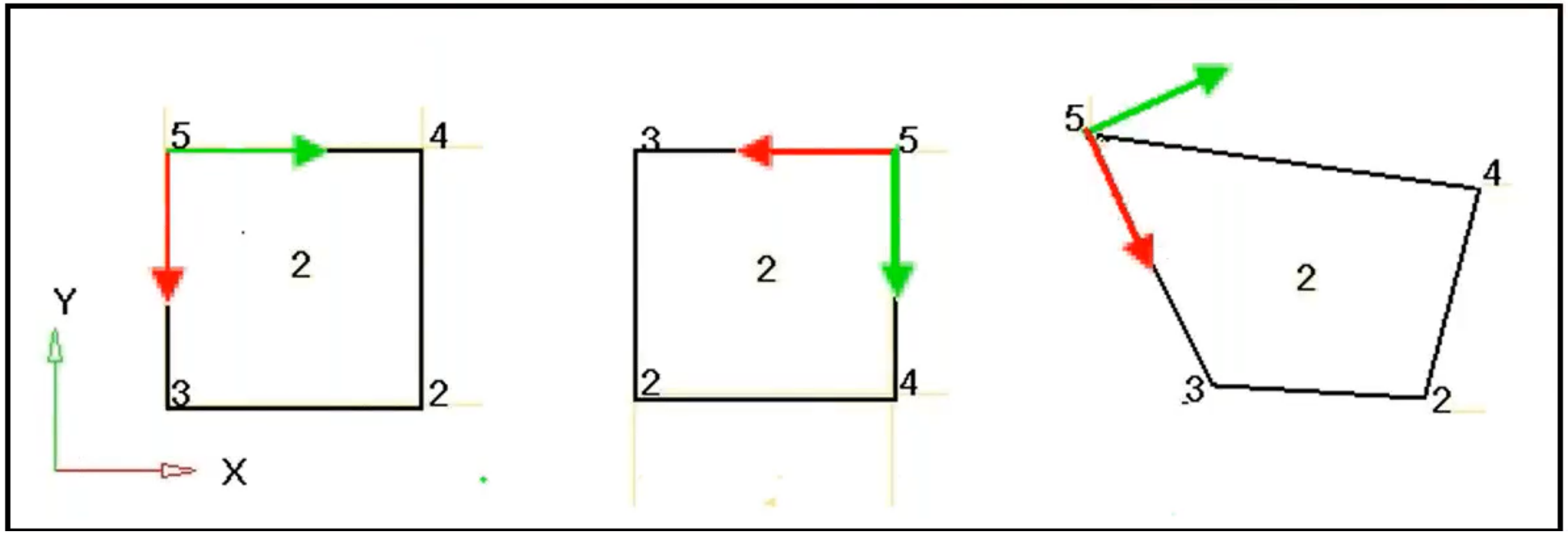
- Geometry
- Material Properties (Non-Isotropic)
- Ply Orientations
- Constituent Properties
- Loads and Boundary Conditions
- Visualization of Results on Geometry, Thru-Laminate, and Constituent Level
- Failure is based on 3D Stress State, is Directional, and Dependent on Constituent Properties

Composite Material and Element Orientation and Ply Alignment

For shell elements using anisotropic materials, the x-axis of the material system defaults to the vector from G1-G2, parallel to the first and second nodes of the element definition

- Note that the element coordinate system and the material coordinate system are not the same concept
- The element coordinate system is always defined by the bi-section of vectors from G1-G3 and G2-G4

	EID	PID	G1	G2	G3	G4
CQUAD4	2	1	5	3	2	4



Understanding Composite Material Properties

The strain-stress relationship for isotropic linear elastic materials is given by:

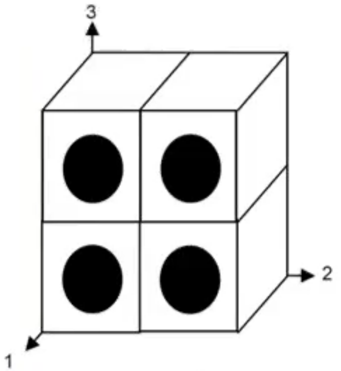
$$\begin{Bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \\ \gamma_{12} \\ \gamma_{23} \\ \gamma_{13} \end{Bmatrix} = \begin{bmatrix} \frac{1}{E} & \frac{-\upsilon}{E} & \frac{-\upsilon}{E} & 0 & 0 & 0 \\ \frac{-\upsilon}{E} & \frac{1}{E} & \frac{-\upsilon}{E} & 0 & 0 & 0 \\ \frac{-\upsilon}{E} & \frac{-\upsilon}{E} & \frac{1}{E} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1}{G} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{G} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1}{G} \end{bmatrix} \begin{Bmatrix} \sigma_1 \\ \sigma_2 \\ \sigma_3 \\ \tau_{12} \\ \tau_{23} \\ \tau_{13} \end{Bmatrix}$$

As shown, isotropic linear elastic materials have only two independent engineering constants. Any two of E, G, or ν which are related by the equation:

$$G = \frac{E}{2(1+\upsilon)}$$

Understanding Composite Material Properties

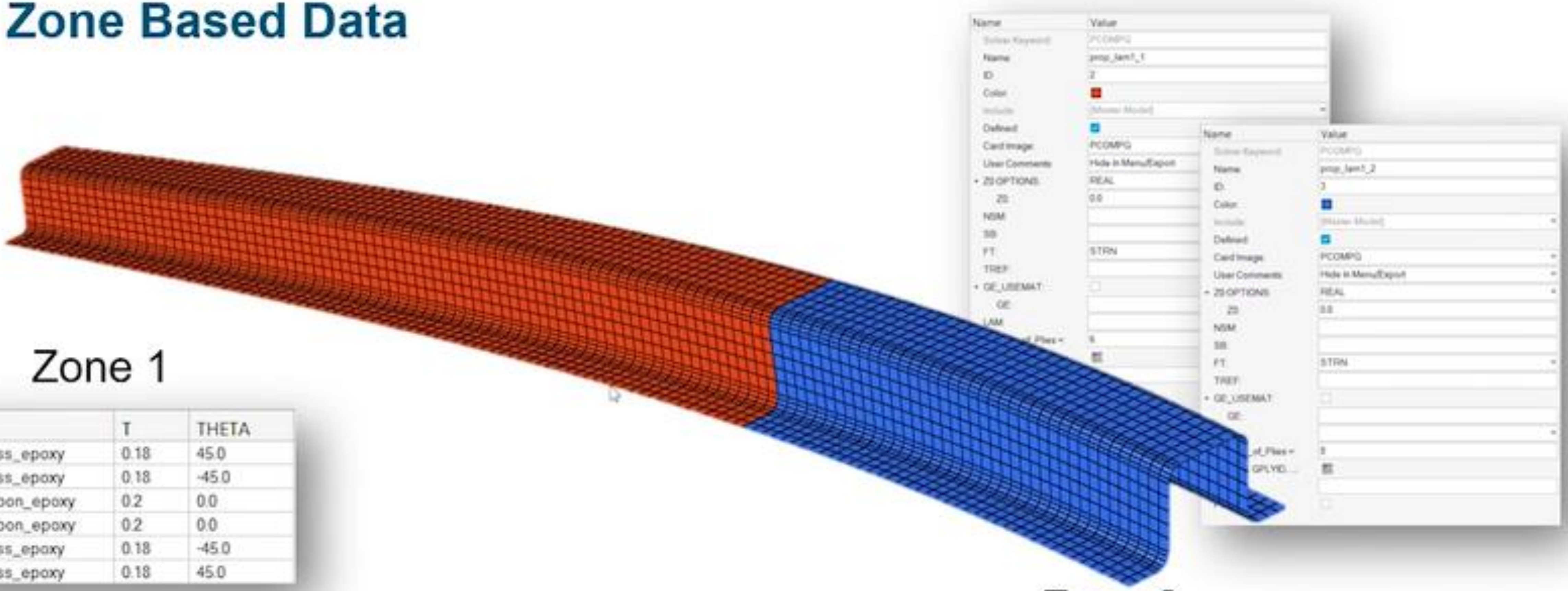
Laminated composite material properties are generally modeled as orthotropic materials



Thus, the strain-stress relationship can be rewritten as the following:

$$\begin{Bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \\ \gamma_{12} \\ \gamma_{23} \\ \gamma_{13} \end{Bmatrix} = \begin{bmatrix} \frac{1}{E_1} & \frac{-\upsilon_{21}}{E_2} & \frac{-\upsilon_{31}}{E_3} & 0 & 0 & 0 \\ \frac{-\upsilon_{12}}{E_1} & \frac{1}{E_2} & \frac{-\upsilon_{32}}{E_3} & 0 & 0 & 0 \\ \frac{-\upsilon_{13}}{E_1} & \frac{-\upsilon_{23}}{E_2} & \frac{1}{E_3} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1}{G_{12}} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{G_{23}} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1}{G_{13}} \end{bmatrix} \begin{Bmatrix} \sigma_1 \\ \sigma_2 \\ \sigma_3 \\ \tau_{12} \\ \tau_{23} \\ \tau_{13} \end{Bmatrix}$$

Zone Based Data



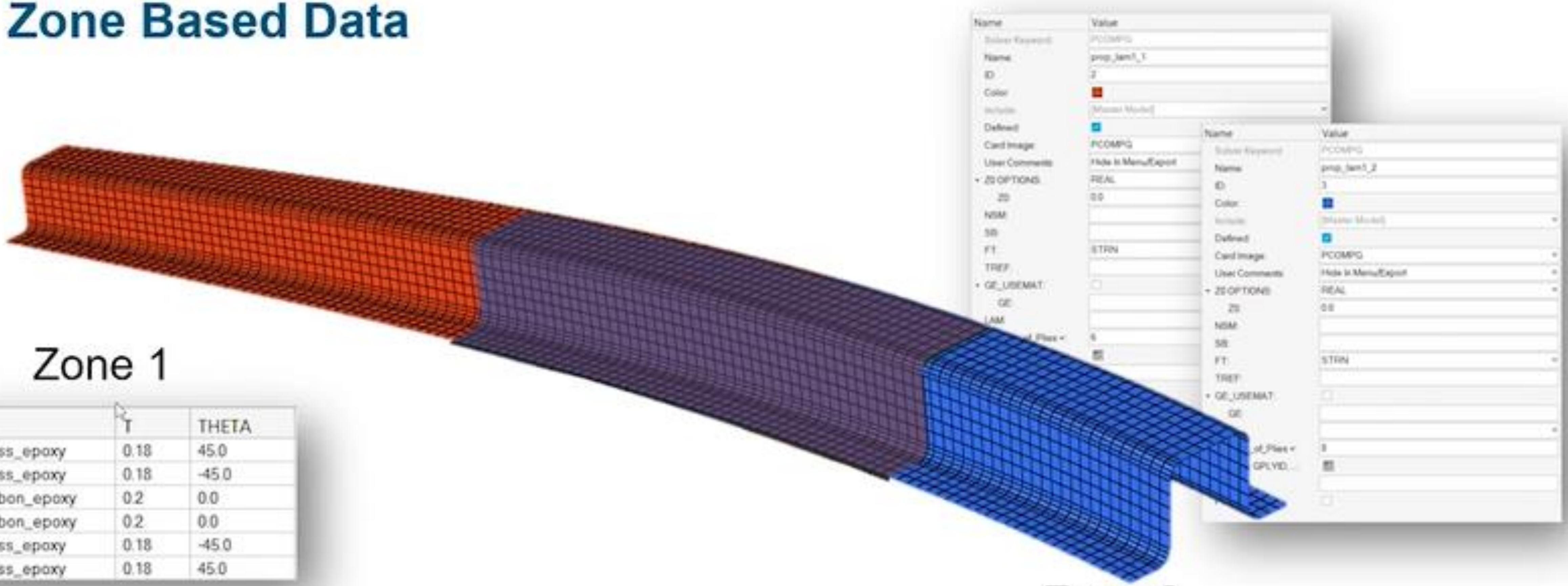
Zone 1

MID	T	THETA
(2) glass_epoxy	0.18	45.0
(2) glass_epoxy	0.18	-45.0
(1) carbon_epoxy	0.2	0.0
(1) carbon_epoxy	0.2	0.0
(2) glass_epoxy	0.18	-45.0
(2) glass_epoxy	0.18	45.0

Zone 2

MID	T	THETA
(2) glass_epoxy	0.18	45.0
(2) glass_epoxy	0.18	-45.0
(1) carbon_epoxy	0.2	0.0
(1) carbon_epoxy	0.2	90.0
(1) carbon_epoxy	0.2	90.0
(1) carbon_epoxy	0.2	0.0
(2) glass_epoxy	0.18	-45.0
(2) glass_epoxy	0.18	45.0

Zone Based Data



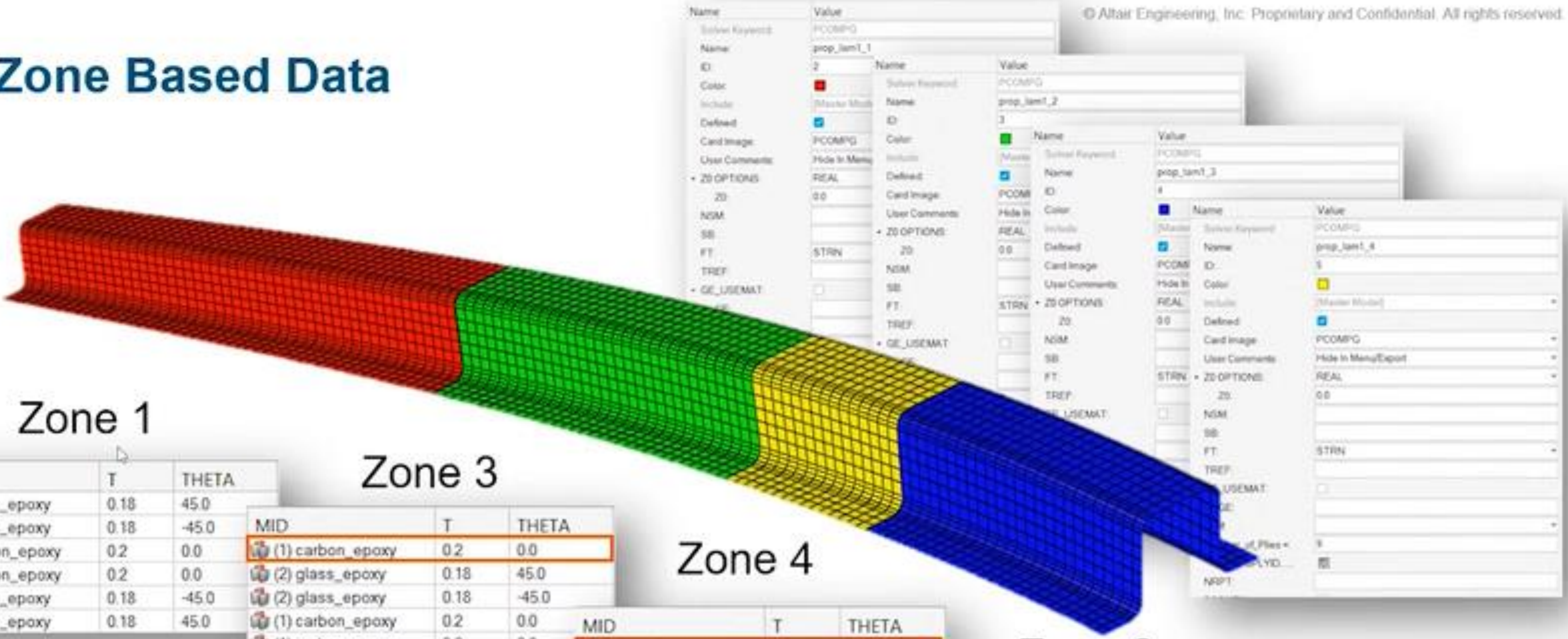
Zone 1

MID	T	THETA
(2) glass_epoxy	0.18	45.0
(2) glass_epoxy	0.18	-45.0
(1) carbon_epoxy	0.2	0.0
(1) carbon_epoxy	0.2	0.0
(2) glass_epoxy	0.18	-45.0
(2) glass_epoxy	0.18	45.0

Zone 2

MID	T	THETA
(2) glass_epoxy	0.18	45.0
(2) glass_epoxy	0.18	-45.0
(1) carbon_epoxy	0.2	0.0
(1) carbon_epoxy	0.2	90.0
(1) carbon_epoxy	0.2	90.0
(1) carbon_epoxy	0.2	0.0
(2) glass_epoxy	0.18	-45.0
(2) glass_epoxy	0.18	45.0

Zone Based Data



Zone 1

MID	T	THETA
(2) glass_epoxy	0.18	45.0
(2) glass_epoxy	0.18	-45.0
(1) carbon_epoxy	0.2	0.0
(1) carbon_epoxy	0.2	0.0
(2) glass_epoxy	0.18	-45.0
(2) glass_epoxy	0.18	45.0

Zone 3

MID	T	THETA
(1) carbon_epoxy	0.2	0.0
(2) glass_epoxy	0.18	45.0
(2) glass_epoxy	0.18	-45.0
(1) carbon_epoxy	0.2	0.0
(1) carbon_epoxy	0.2	0.0
(2) glass_epoxy	0.18	-45.0
(2) glass_epoxy	0.18	45.0

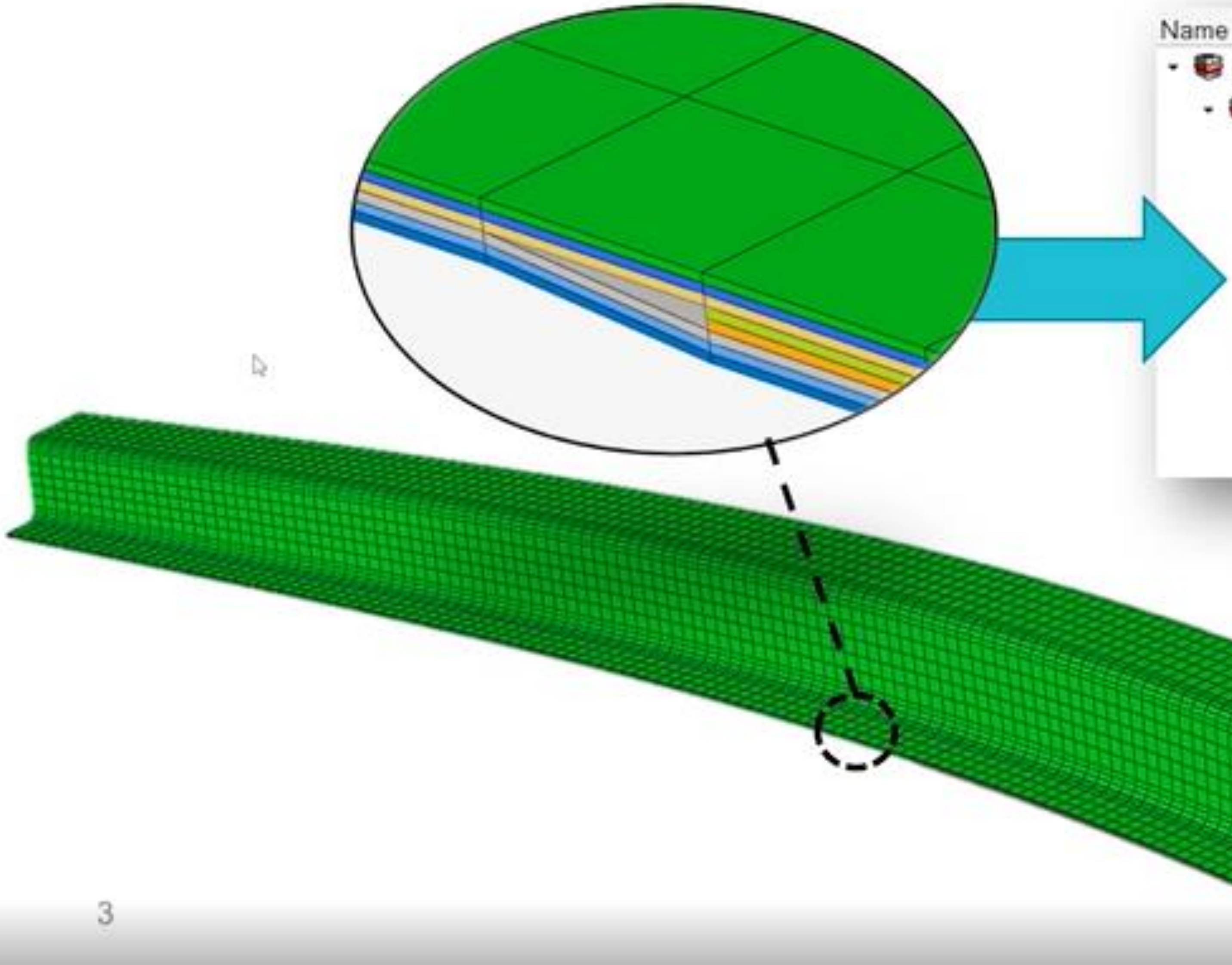
Zone 4

MID	T	THETA
(1) carbon_epoxy	0.2	0.0
(2) glass_epoxy	0.18	45.0
(2) glass_epoxy	0.18	-45.0
(1) carbon_epoxy	0.2	0.0
(1) carbon_epoxy	0.2	90.0
(1) carbon_epoxy	0.2	90.0
(1) carbon_epoxy	0.2	0.0
(2) glass_epoxy	0.18	-45.0
(2) glass_epoxy	0.18	45.0

Zone 2

MID	T	THETA
(2) glass_epoxy	0.18	45.0
(2) glass_epoxy	0.18	-45.0
(1) carbon_epoxy	0.2	0.0
(1) carbon_epoxy	0.2	90.0
(1) carbon_epoxy	0.2	90.0
(1) carbon_epoxy	0.2	0.0
(2) glass_epoxy	0.18	-45.0
(2) glass_epoxy	0.18	45.0

Ply Based Data



Name	ID	Color	Orientation	Thickness	Material	Shape
Laminates (1)						
laminate	1					
fiberglass_1	1		45.0	0.18	glass_epoxy	full
fiberglass_2	2		-45.0	0.18	glass_epoxy	full
carbon_uni_1	3		0.0	0.2	carbon_epoxy	full
carbon_uni_2	4		90.0	0.2	carbon_epoxy	partial
carbon_uni_3	5		90.0	0.2	carbon_epoxy	partial
carbon_uni_4	6		0.0	0.2	carbon_epoxy	full
fiberglass_3	7		-45.0	0.18	glass_epoxy	full
fiberglass_4	8		45.0	0.18	glass_epoxy	full

Name	Value
Solver Keyword	PCOMPP
Name	property1
ID	1
Color	
Include	[Master Model]
Defined	
Card Image	PCOMPP
Laminate	<Unspecified>
User Comments	Hide In Menu/Export
ZO OPTIONS	REAL
Z0	0.0
NSM	
SB	
FT	
TREF	
GE_USEMAT	
GE	

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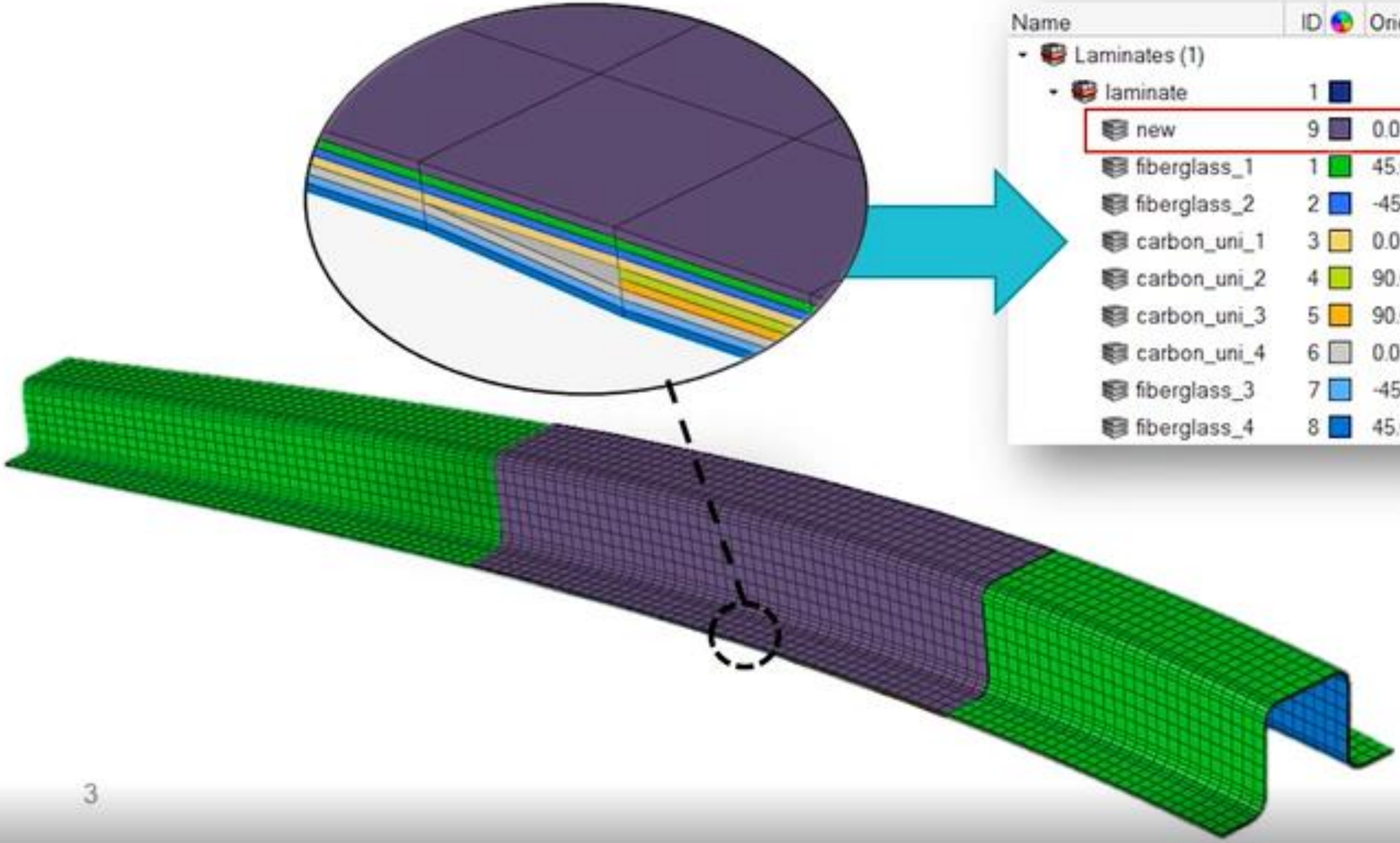
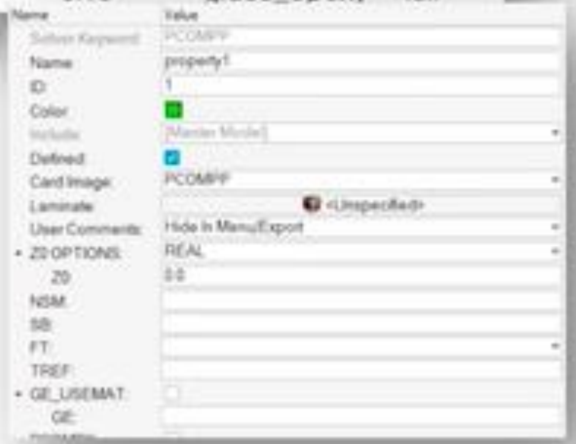
Ply Based Data



Name	ID	Color	Orientation	Thickness	Material	Shape
Laminates (1)						
laminate	1					
new	9		0.0	0.2	carbon_epoxy	new
fiberglass_1	1		45.0	0.18	glass_epoxy	full
fiberglass_2	2		-45.0	0.18	glass_epoxy	full
carbon_uni_1	3		0.0	0.2	carbon_epoxy	full
carbon_uni_2	4		90.0	0.2	carbon_epoxy	partial
carbon_uni_3	5		90.0	0.2	carbon_epoxy	partial
carbon_uni_4	6		0.0	0.2	carbon_epoxy	full
fiberglass_3	7		-45.0	0.18	glass_epoxy	full
fiberglass_4	8		45.0	0.18	glass_epoxy	full



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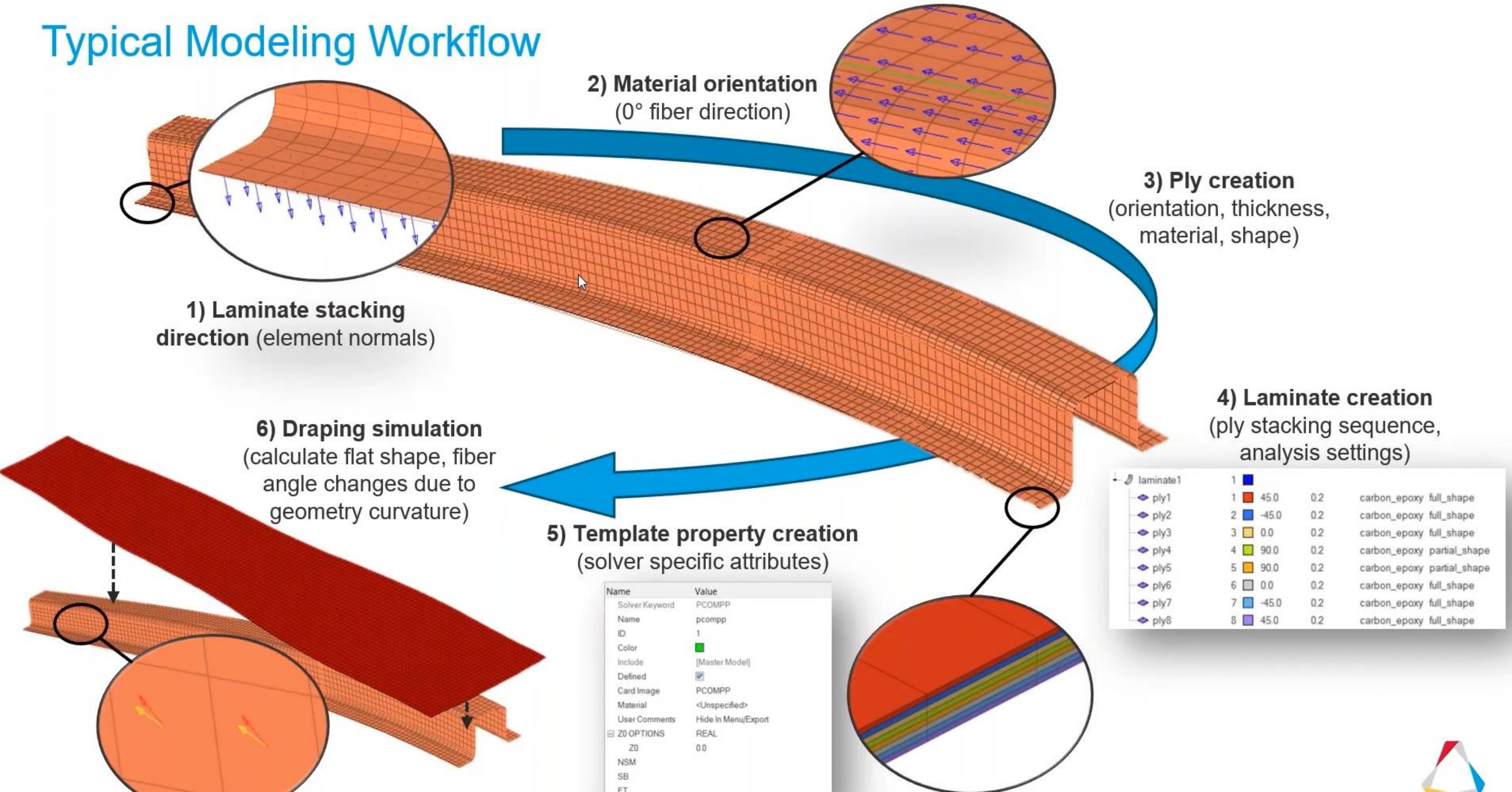
Typical Modeling Workflow



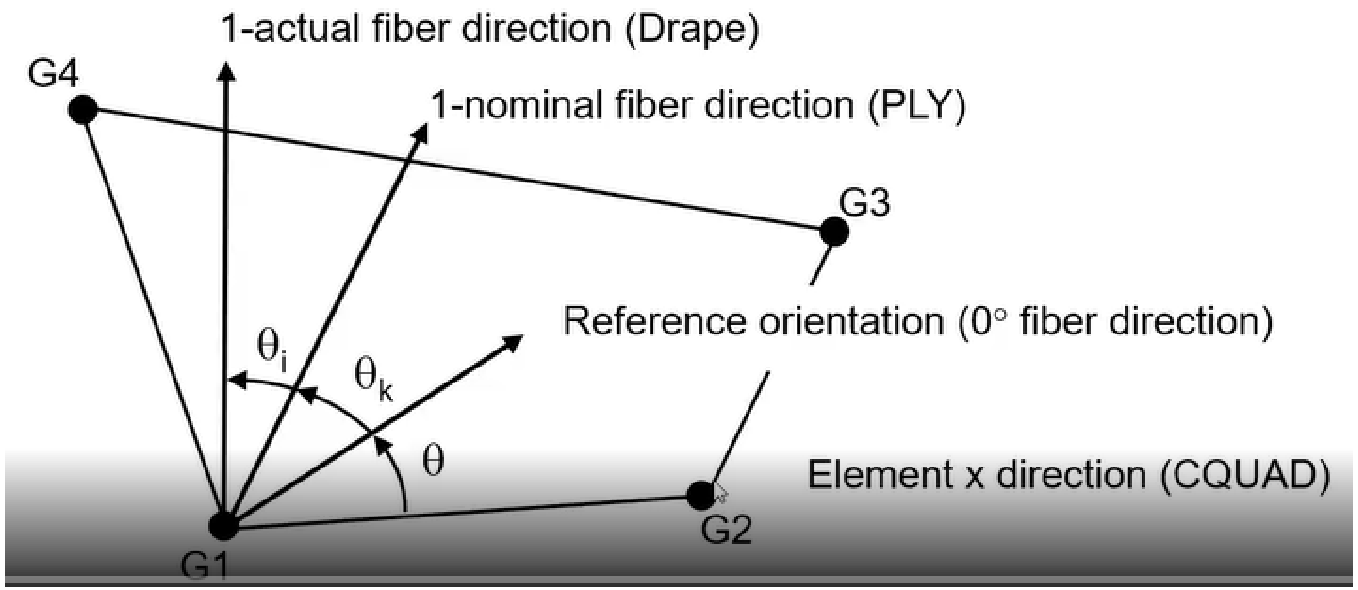
laminate1	1				
ply1	1	45.0	0.2	carbon_epoxy	full_shape
ply2	2	-45.0	0.2	carbon_epoxy	full_shape
ply3	3	0.0	0.2	carbon_epoxy	full_shape
ply4	4	90.0	0.2	carbon_epoxy	partial_shape
ply5	5	90.0	0.2	carbon_epoxy	partial_shape
ply6	6	0.0	0.2	carbon_epoxy	full_shape
ply7	7	-45.0	0.2	carbon_epoxy	full_shape
ply8	8	45.0	0.2	carbon_epoxy	full_shape

Name	Value
Solver Keyword	PCOMPP
Name	pcompp
ID	1
Color	
Include	[Master Model]
Defined	☑
Card Image	PCOMPP
Material	<Unspecified>
User Comments	Hide In Menu/Export
Z0 OPTIONS	REAL
Z0	0.0
NSM	
SB	
FT	

Orientations

In OptiStruct, the final fiber direction of a given ply is determined by as many as three rotations:

1. Reference orientation is a rotation from the element x axis (THETA field on element) at each element, or the x axis of a local system
2. Orientation defined on a ply applies an additional rotation on the reference orientation
3. Drape table (typically from a draping simulation) applies an additional rotation on the ply orientation



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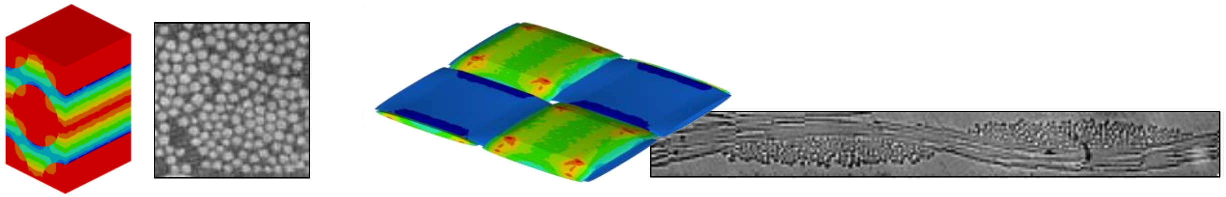
DEMO

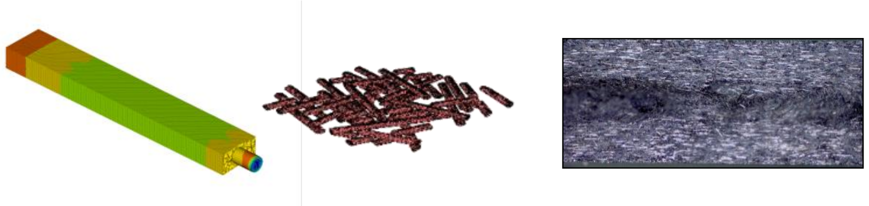
Advanced Material Model Development

Transition from Traditional Homogeneous Isotropic
to Accurate Heterogeneous Anisotropic Material Models

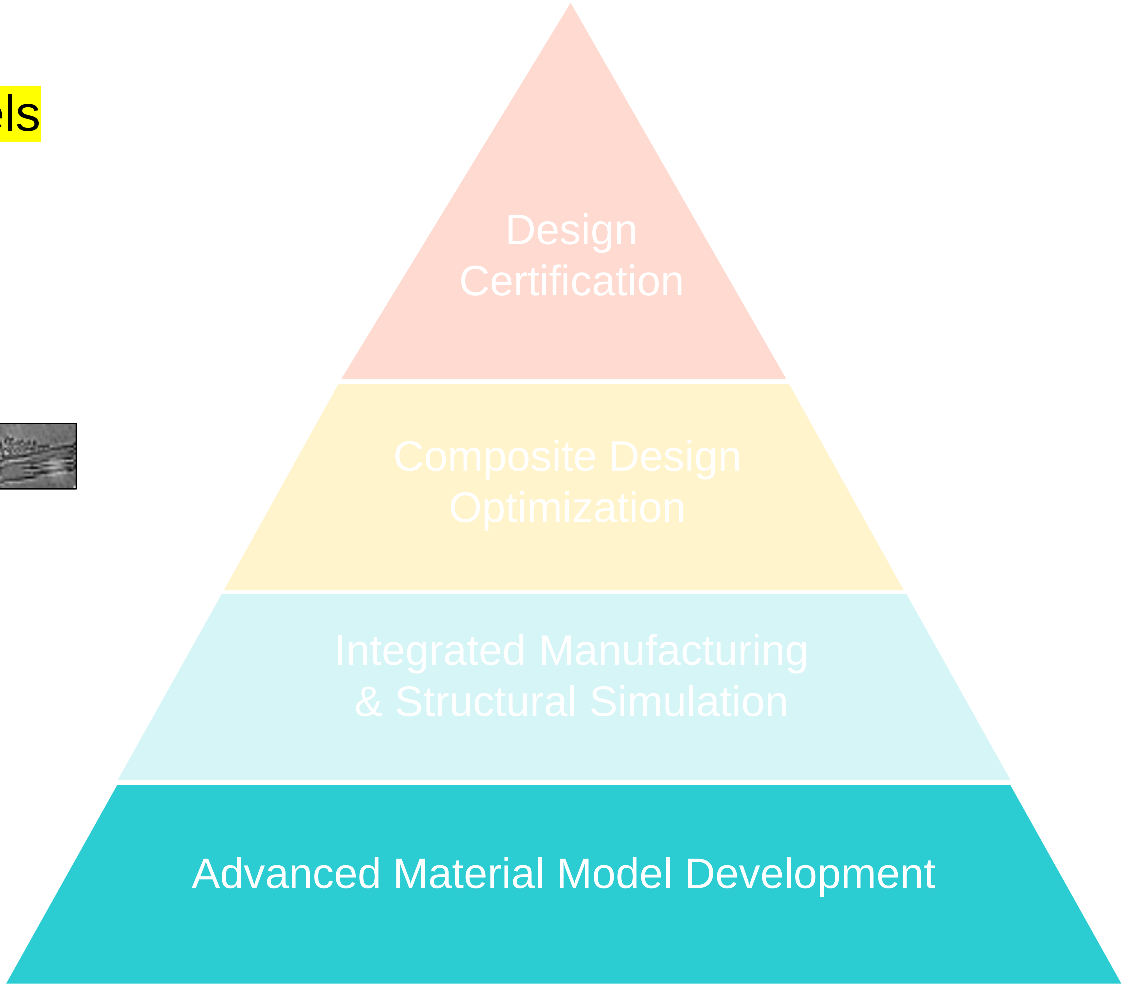
Continuous Products (Unidirectional and Weaves)



Discontinuous Products (Injection Molding)



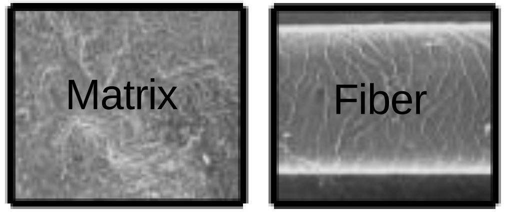
Reduce Time/Cost in the Design Process
due to incomplete material understanding;
Reduce experimental data requirements,
Increase simulation accuracy!



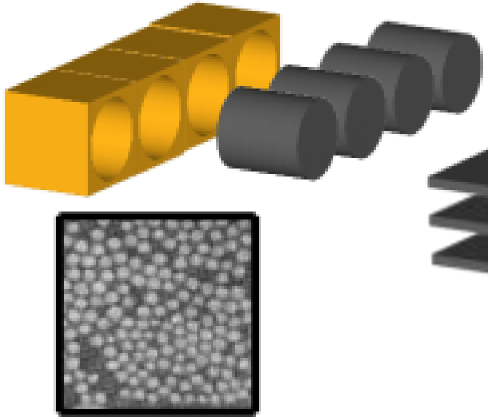
What do we mean by Multiscale?

An example of a unidirectional material

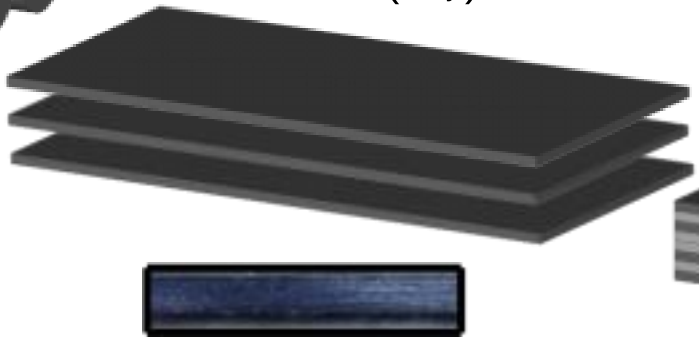
Scale0 ($\sigma_{Constituent\ MicroStructure}$)



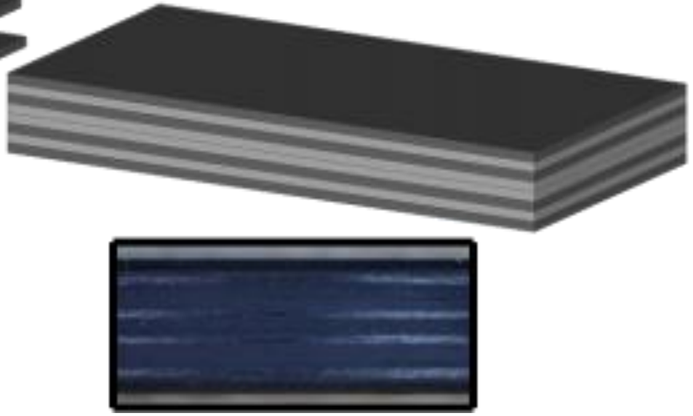
Scale1 ($\sigma_{Fiber/Matrix}$)



Scale2 (σ_{Ply})



Scale3 ($\sigma_{Laminate}$)



The stress at any scale is the volume average stress of the scale below

Example:

σ_{Ply} is the volume average stress of $\sigma_{Fiber/Matrix}$

$$\sigma^{Ply} = \sigma^{Fiber}V^{Fiber} + \sigma^{Matrix}V^{Matrix}$$

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What do we mean by Multiscale?

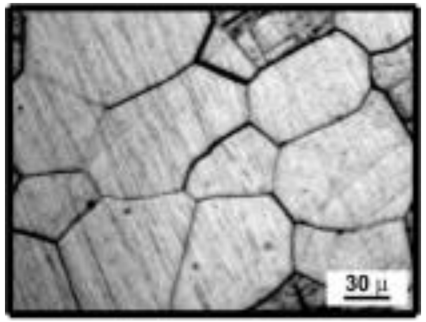
An example of a metal

The stress at any scale is the
volume average stress of the scale below

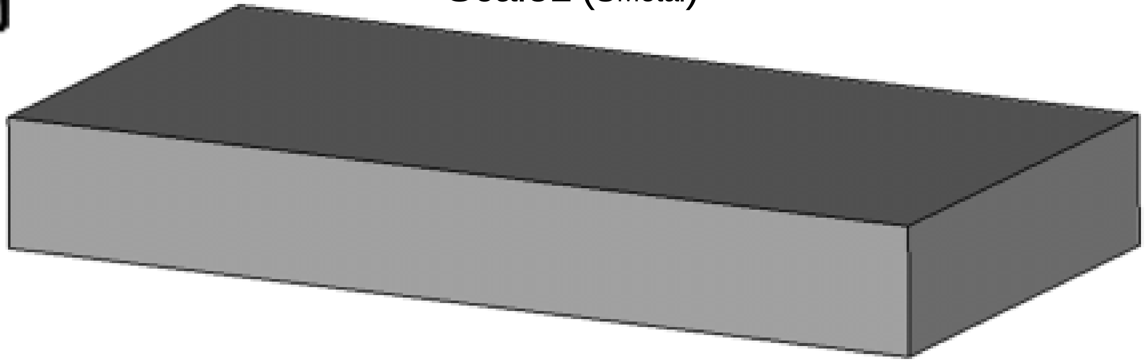
Example:
s_{Metal} is the volume average stress of s_{Grain}

$$\sigma^{Metal} = \sum \sigma^{Grain} V^{Grain}$$

Scale0 (s_{Grain})



Scale1 (s_{Metal})



Currently perform simulations one scale above the constituent microstructure (Scale 1) to achieve predictive accuracy!

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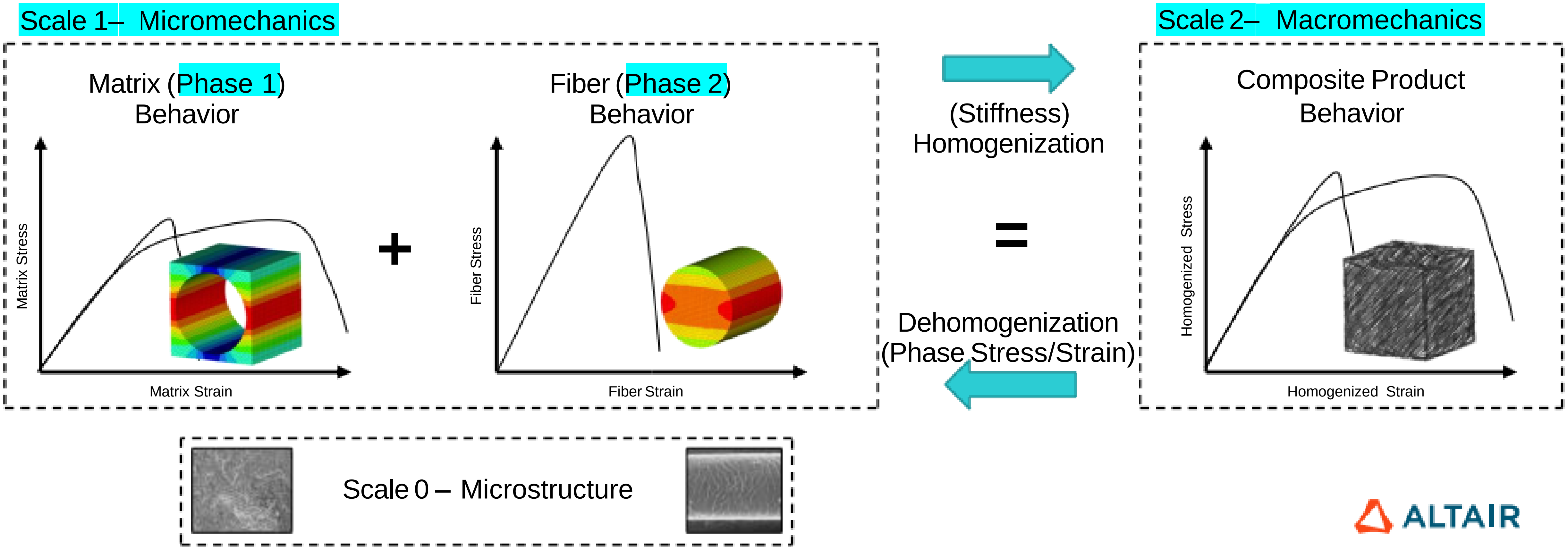
Multiscale Material Model Development (MMMD)

Develop Predictive Material Models from the Linear Regime to Ultimate Failure with Minimal Experimental Data Requirements by Extracting Properties at Scale 1 (Fiber/Matrix)

2-Scale, N-Phase Framework



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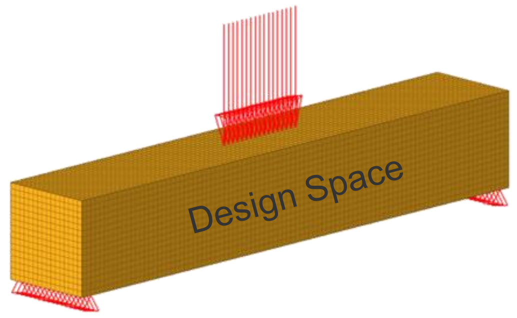
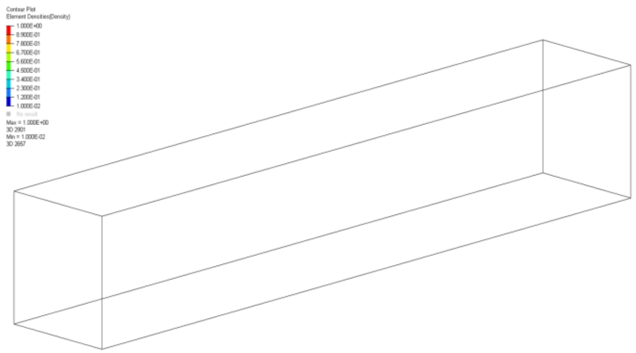
Composite Design Optimization with OptiStruct

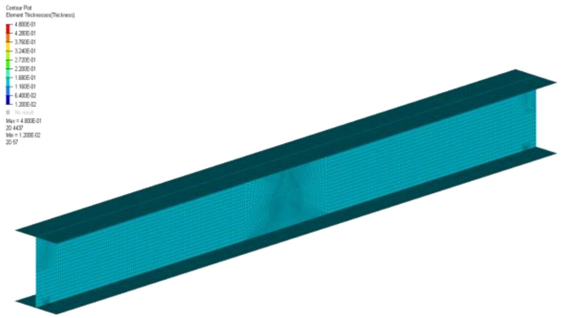
① Initial Design Space



② Topology Optimization
(What is the most efficient **part shape**?)

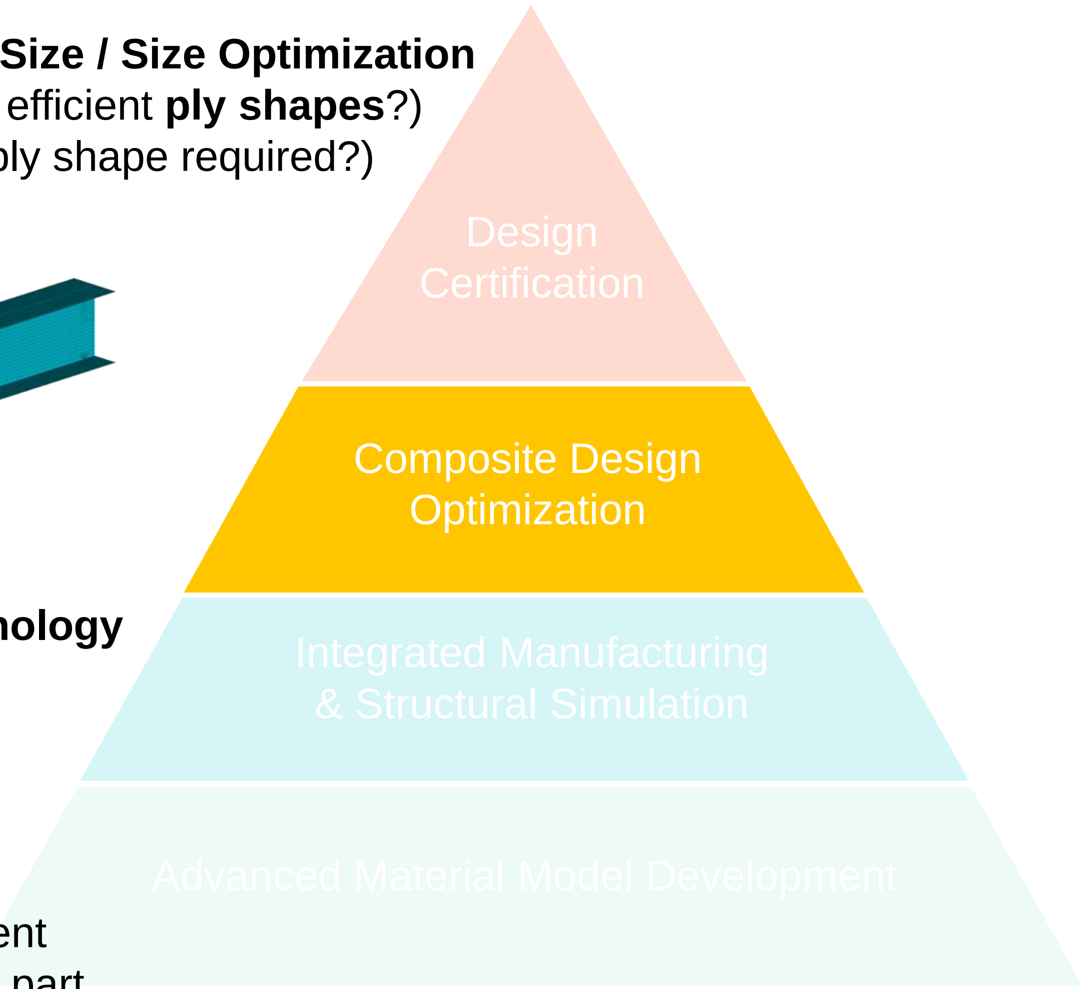


③ Composite Free-Size / Size Optimization
(What are the most efficient **ply shapes**?)
(How many of each ply shape required?)



Repeat Laminate Technology
Double-Double
$(\theta/0/-\theta/90)_{Ns}$
$(\theta/-\theta)_{Ns}$
$(\theta/-\theta/\phi/-\phi)_{Ns}$

Solves N for every element
Solves θ, ϕ for the global part



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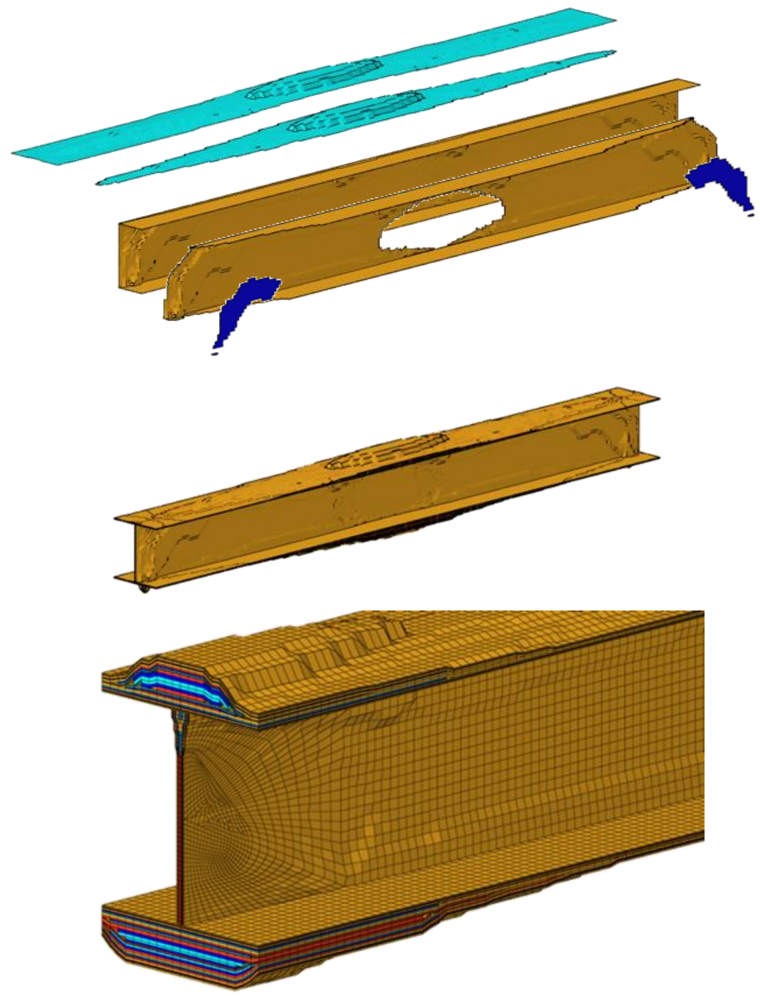
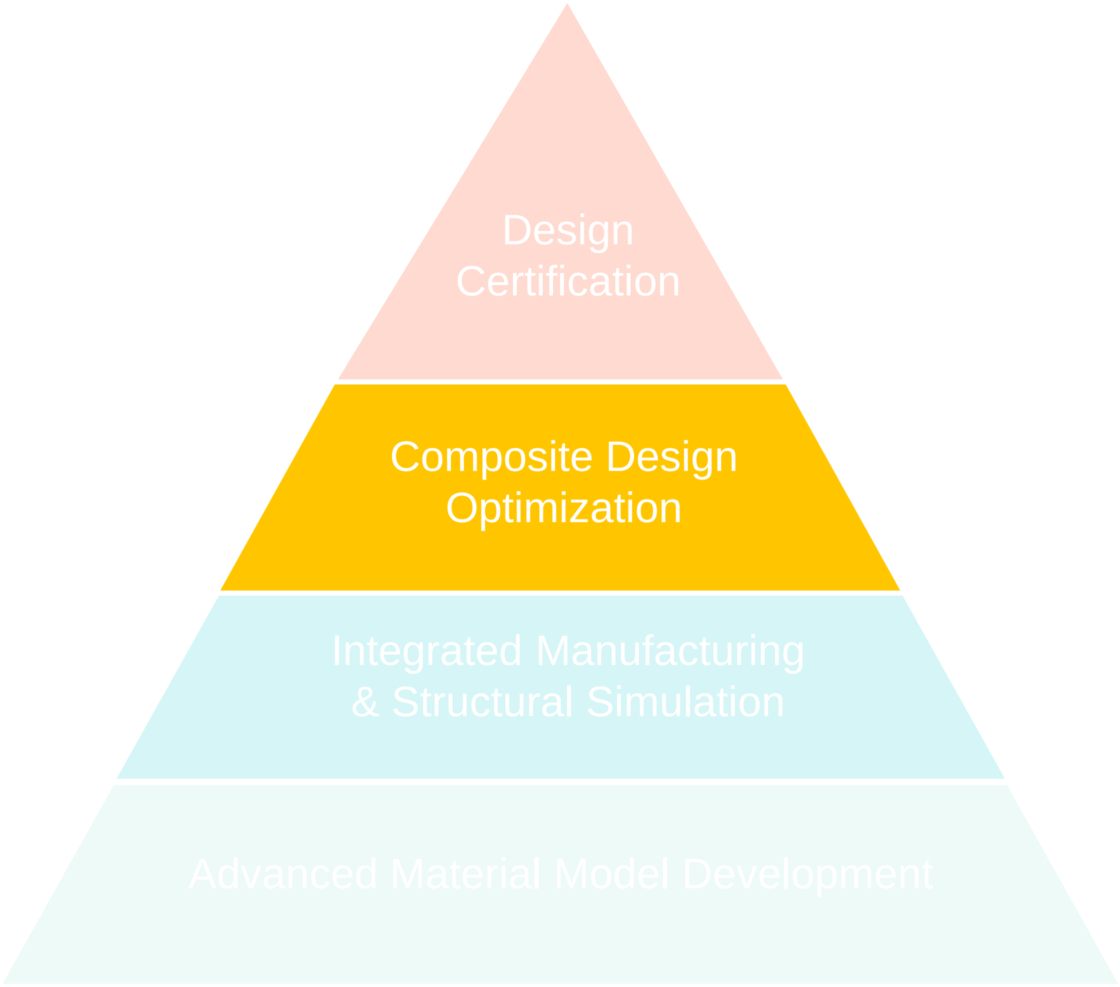
Composite Design Optimization with OptiStruct

Ply Shape Concepts and Final Design





Contact Us

My Email:

Soukup@altair.com "Kory Soukup"

Solar Car Success Stories:

https://altairuniversity.com/solar-car-page/

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