Automated Fiber Placement Composites for Improved Structural Efficiency of Aircrafts

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May 16th, 2013
UTIAS National Colloquium on Sustainable Aviation

Outline

- Introduction
  - A sustainable aircraft : Boeing 787
  - Composite design concepts
  - Automated Fiber Placement
- Talk objectives
- Research expertise of the Lab
- Concluding remarks

A sustainable aircraft : Boeing 787

- Fuel use reduced
- Automated manufacturing technologies
- Emissions cut
- Quieter take-offs and landings
- Point-to-point travel enabled
- End-of-life recycling
- A life cycle approach

Boeing 787 (a sustainable aircraft)

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Boeing 787 (a sustainable aircraft)

- Fuel use reduced
  - Increased use of light weight composite materials
  - New engines
  - More-efficient system applications
  - Modern aerodynamics

- Advanced manufacturing technologies
  - Automated Fiber Placement

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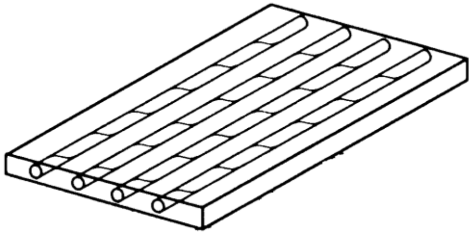
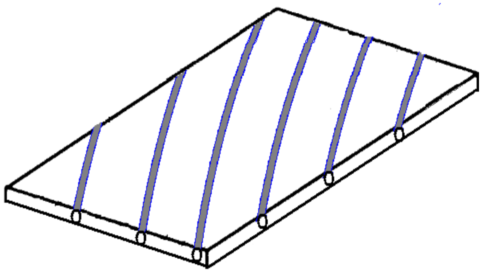
- Advanced manufacturing technologies
    - Automated Fiber Placement

Composite design concepts

- Constant stiffness (CS)
  - Traditional composite design
  - Keeping the fiber angle constant within each layer
- Variable stiffness (VS)
  - Allowing fibers to follow curvilinear paths
  - More favorable stress distribution



Constant stiffness



variable stiffness

Automated Fiber Placement machine (AFP)

- Robotic arm which places strips of material side-by-side to create a band
- Lays down bands to create the laminate
- Pros:
  - High manufacturing flexibility
  - Fully automated process
  - Speeds up the layup time
  - Ideal for large structures

Source: Coriolis website.

- Cons:
  - Defects produced during the manufacturing

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Variable stiffness defects

Defects can be categorized as gaps and overlaps

Gaps

Overlaps

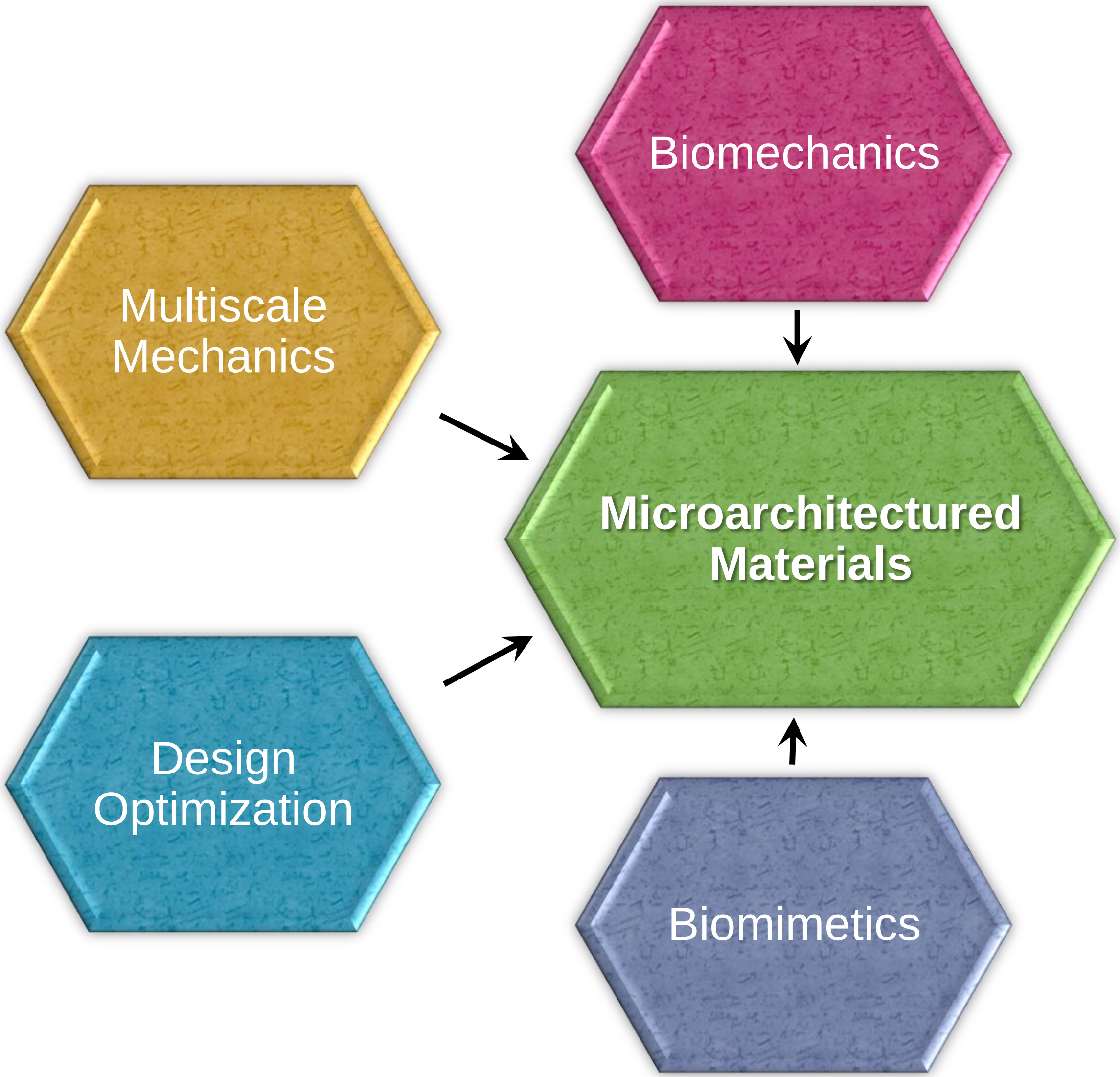
Talk objectives

- Exploiting variable stiffness design to improve mechanical efficiency of lightweight laminate composites
- Development of a simulation toolbox to capture the mechanical impact of AFP defects
- Incorporating the effect of defects in the analysis and optimization of variable stiffness composite laminates

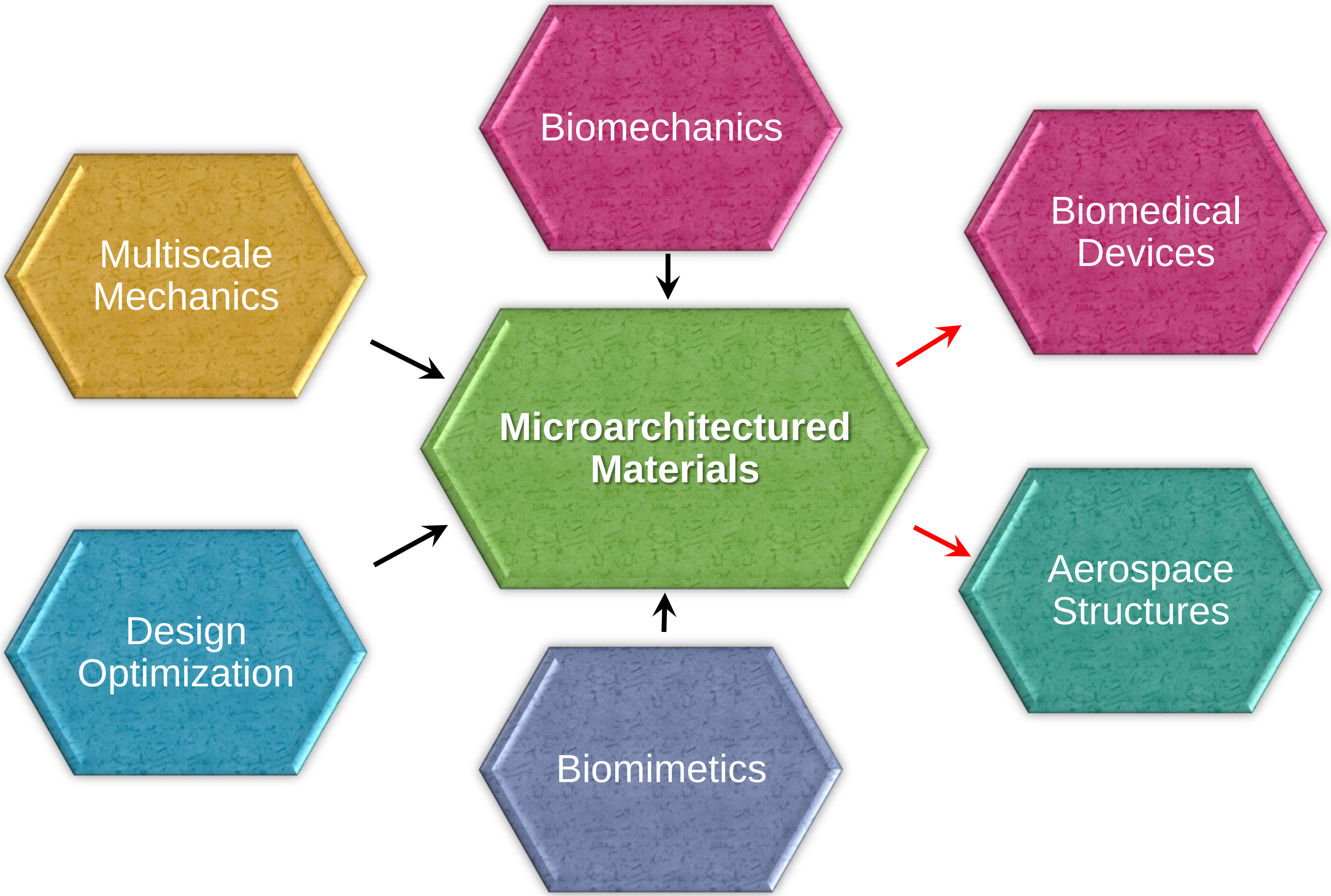
Lab Expertise

Microarchitectured
Materials

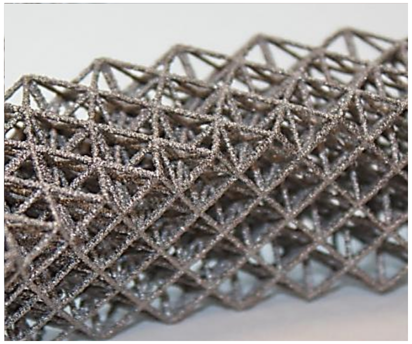
Lab Expertise



Lab Expertise

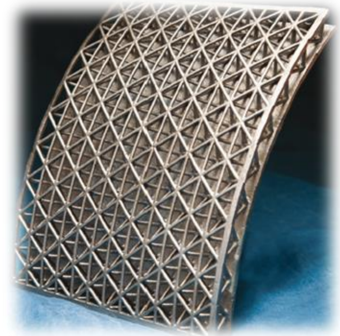


Current Projects



Multiphysics of lattice materials

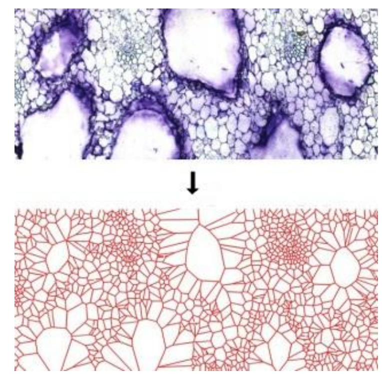
AFP variable stiffness laminate composites



Ultralightweight lattice panels via additive manufacturing

Cellular hip replacement implants

Lattice stent-like devices



Plant cellular tissue inspired materials

Talk objectives

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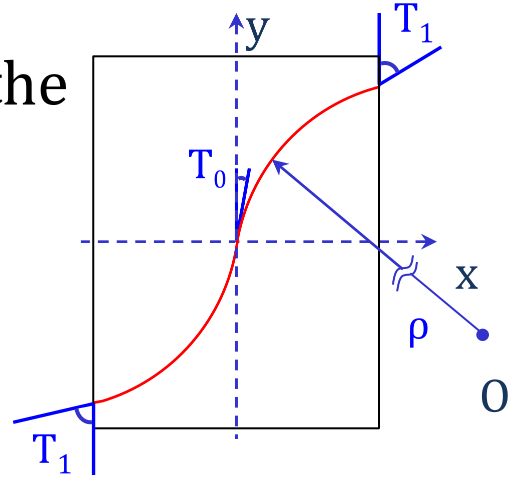
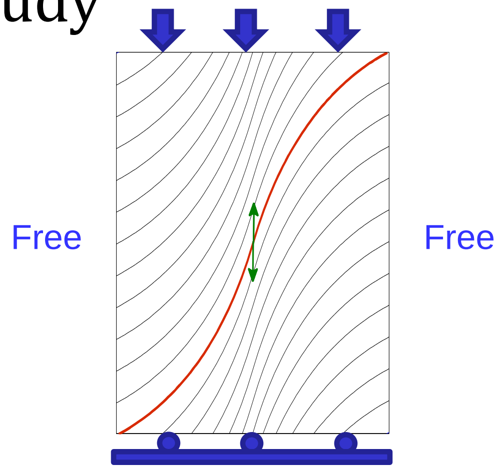
Curvilinear fiber path

- Constant curvature fiber path is used as the reference fiber path*
- The reference fiber path is shifted to manufacture the whole laminate
- 10 x 16 in plate is considered as a case study



$[+<T_1|T_0|T_1>]$



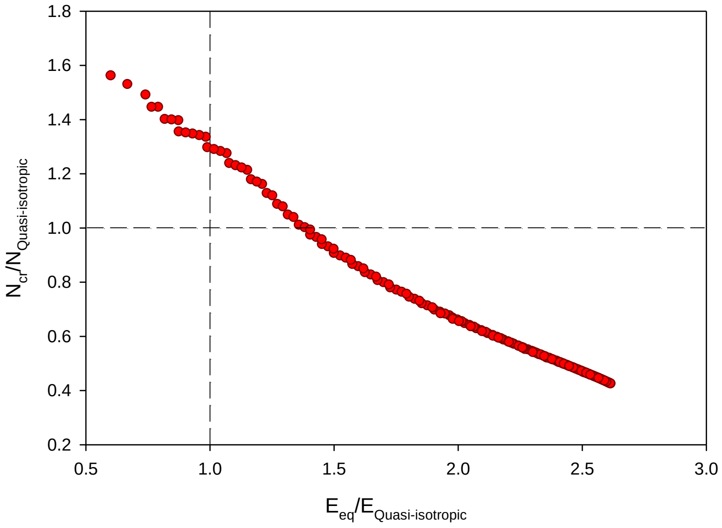
*Blom et al., Journal of Composite Materials (2009).

Multi-objective optimization

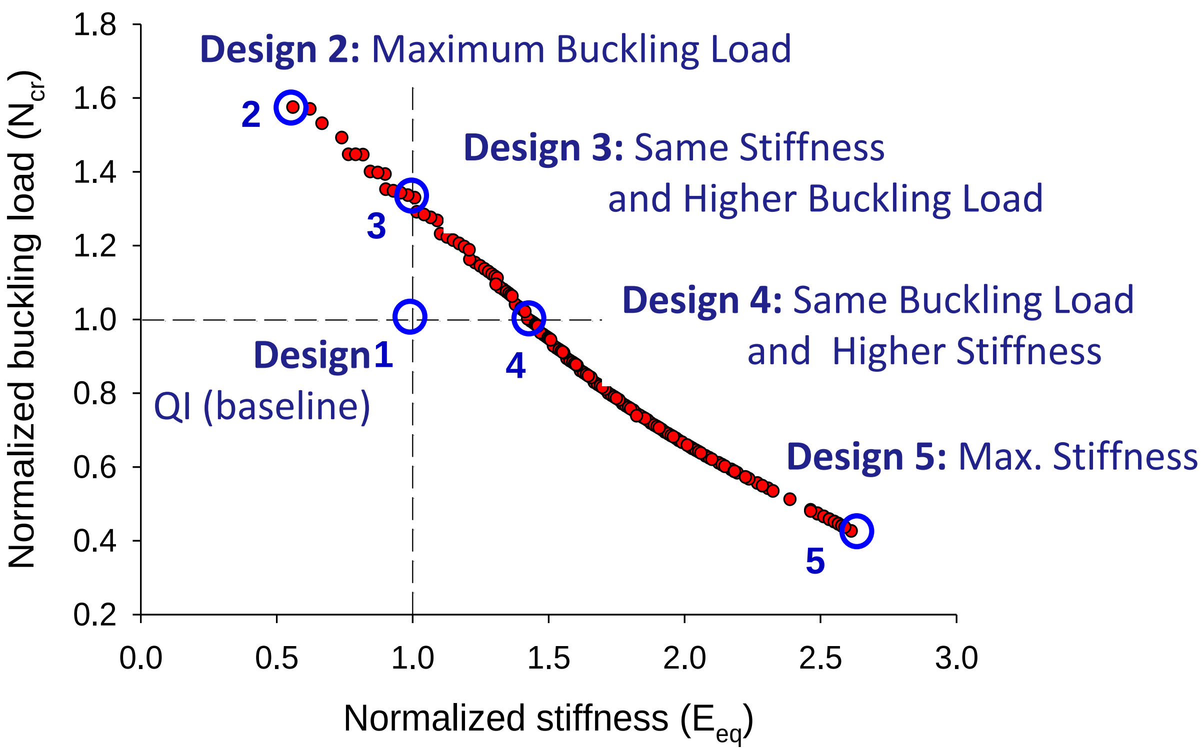
- Simultaneously optimization of $[\pm<T_1|T_0|T_1>]_{4s}$ for
  - In-plane Stiffness
  - Buckling Load

$$\min_{\mathbf{x}} \{1/E_{eq}(\mathbf{x}),\ 1/N_{cr}(\mathbf{x})\};\mathbf{x}=(T_0,T_1)^T$$
$$s.t.\ \{T_0,T_1 \in [0^\circ,90^\circ]\ \&\ R \geq 25in\},$$

  - The effect of defects is ignored.



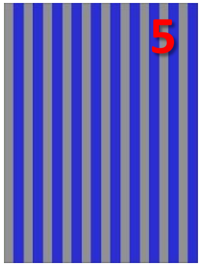
Performance of VS design without defects



$N_{cr} = 1.56$
$E_{eq} = 0.60$

$N_{cr} = 1.33$
$E_{eq} = 1$

$N_{cr} = 1$
$E_{eq} = 1.30$



$N_{cr} = 0.42$
$E_{eq} = 2.62$

Variable stiffness defects

Defects can be categorized as gaps and overlaps

Gaps

Overlaps

Talk objectives

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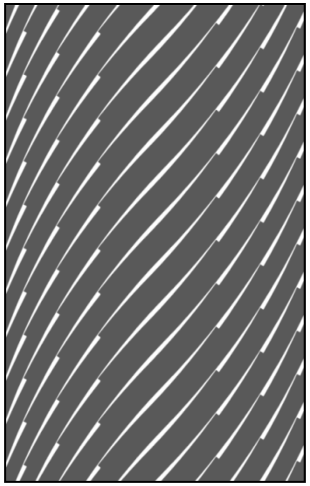
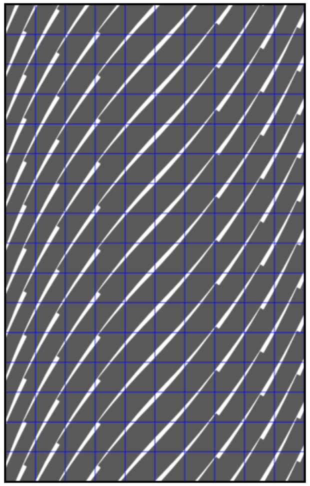
AFP defects analysis toolbox

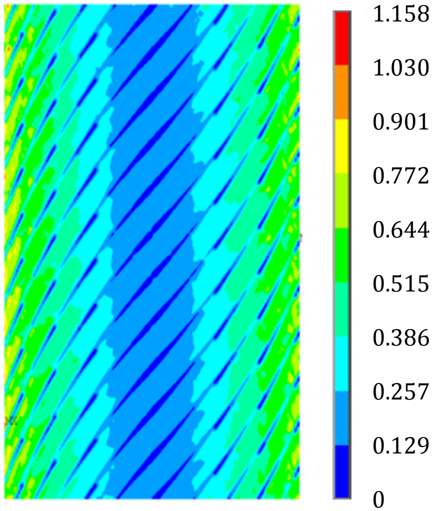
Module 1: Locating defects (Defect image creation) → **Module 2**: Interface between MATLAB and FEA (Image processing) → **Module 3**: Defect layer method (Building FE model)



A lamina with gaps

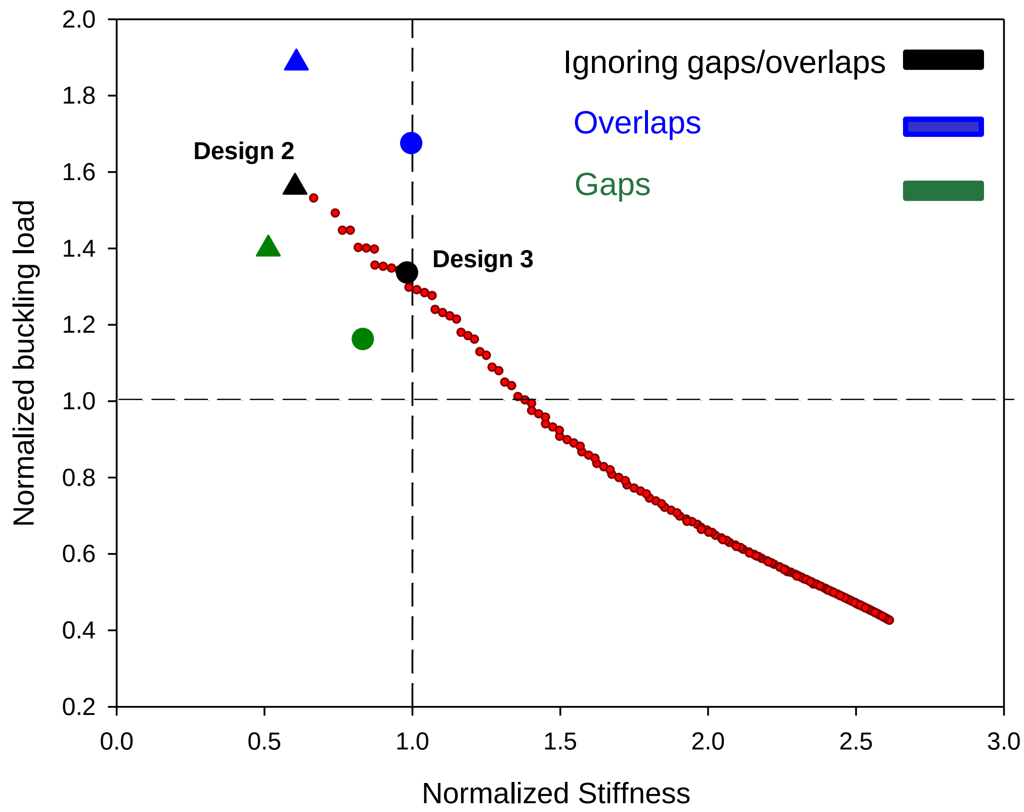


Mesh generation



Stress in y-direction

The effect of defects on VS laminates performance



	Normalized buckling load	Normalized buckling load	Normalized buckling load
Design 2	**1.56**	**1.40**	**1.88**
Design 3	**1.33**	**1.16**	**1.67**

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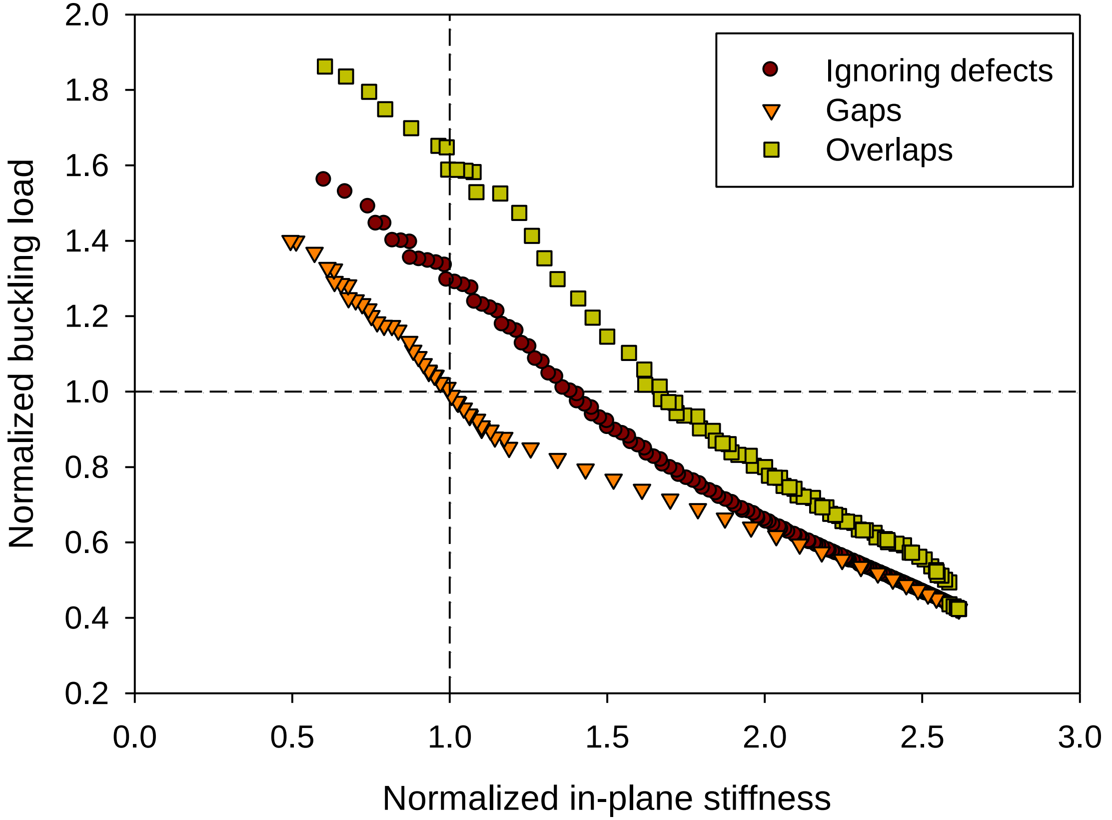
Multi-objective optimization including defects

- Simultaneously maximize objectives of [±<T_1|T_0|T_1>]$_{4s}$:
  - In-plane Stiffness.
  - Buckling Load.

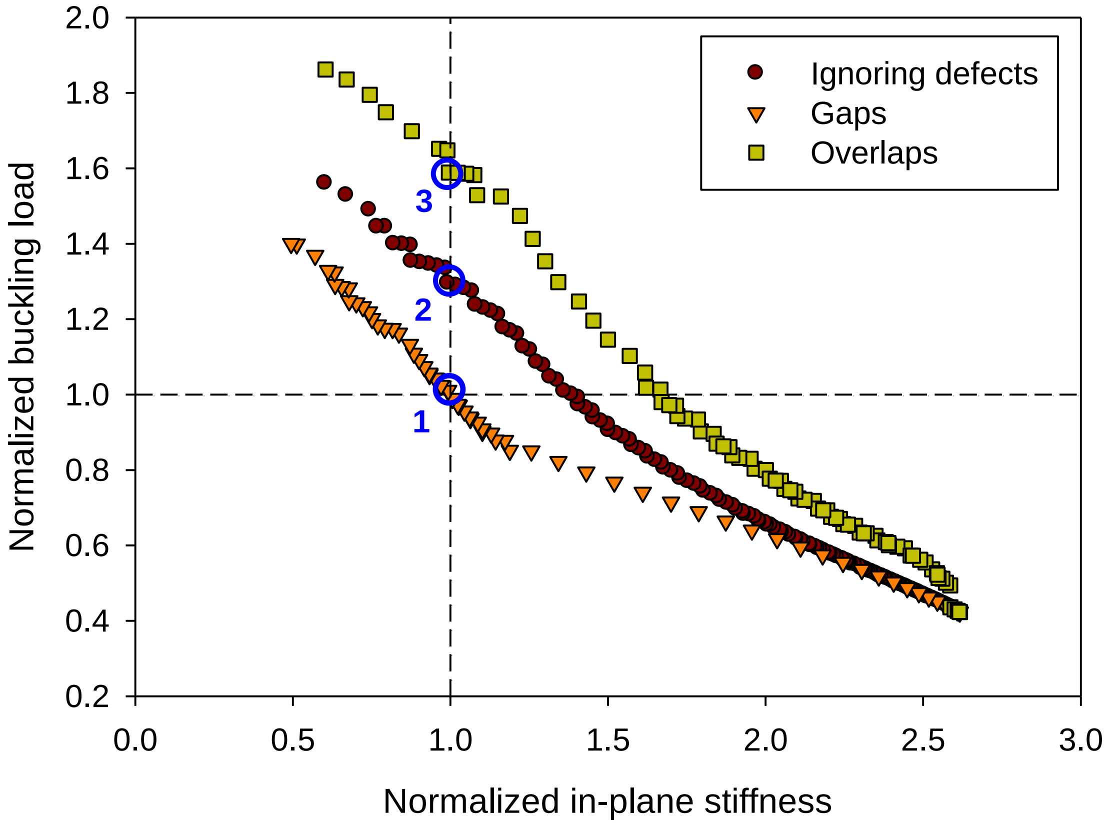
$$\min_{\mathbf{x}} \left\{ 1/E_{eq}(\mathbf{x}),\ 1/N_{cr}(\mathbf{x}) \right\}; \mathbf{x} = \left(T_0, T_1\right)^T$$
$$s.t.\ \left\{T_0, T_1 \in [0^\circ, 90^\circ] \,\&\, R \geq 25in \right\},$$

- The effect of defects is considered during the optimization process.
  - Defect layer method is used.

Impact on the mechanical properties

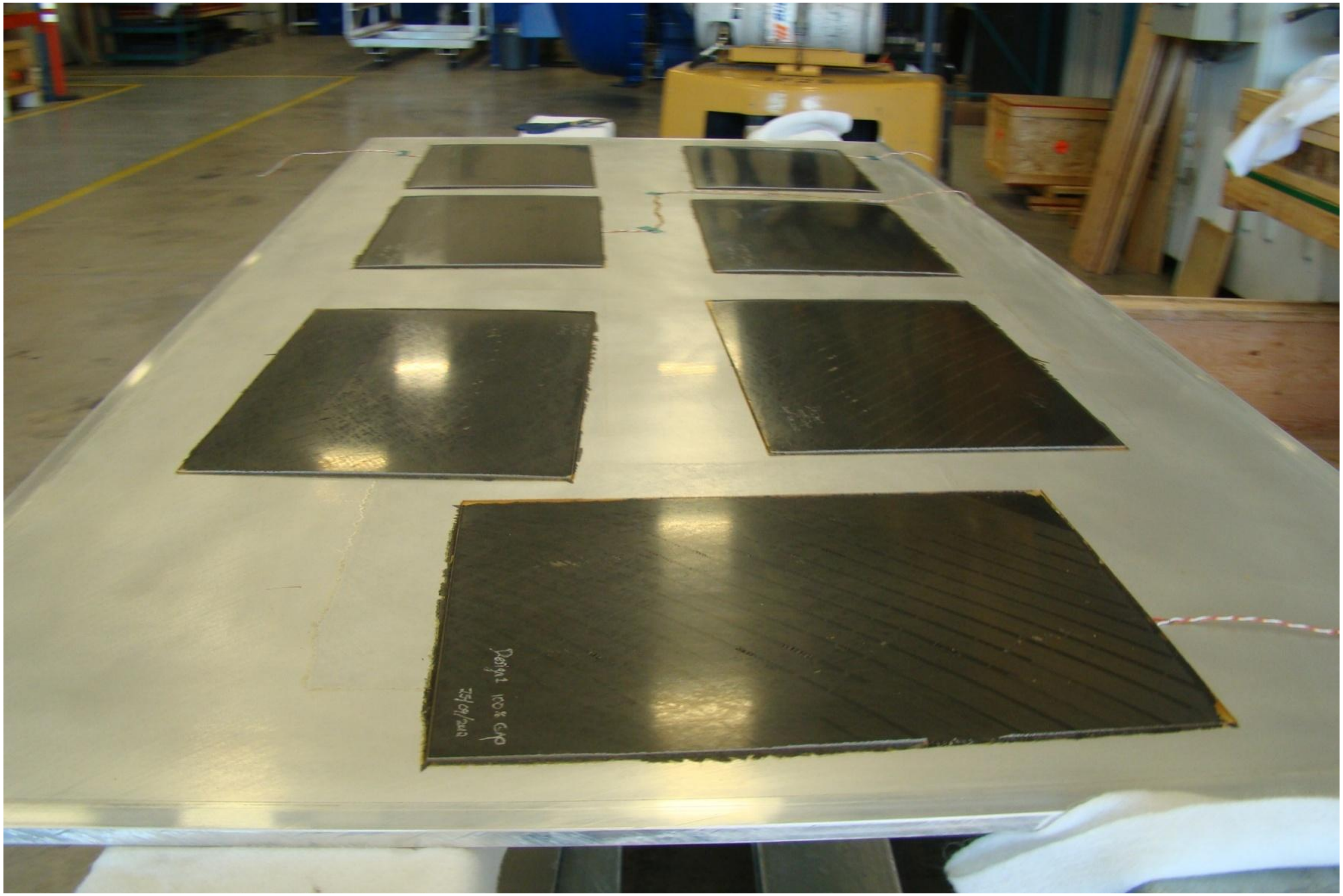


Impact on the optimum fiber paths



#	Design
1	$[\pm\langle 14\vert 36\vert 14\rangle]_{4s}$
2	$[\pm\langle 17\vert 39\vert 17\rangle]_{4s}$
3	$[\pm\langle 19\vert 41\vert 19\rangle]_{4s}$

Work underway: manufacturing and testing



Work underway: manufacturing and testing

Design 2: highest buckling load
compared to the baseline

Concluding remarks

- Exploiting variable stiffness design to improve mechanical efficiency : 56% improvement in buckling load
- Development of a simulation toolbox to capture the mechanical impact of AFP defects:
  - 88% improvement in buckling load for laminates with overlaps
  - 40% improvement in buckling load for laminates with gaps
- Optimization of variable stiffness composite laminates including defects

Concluding remarks

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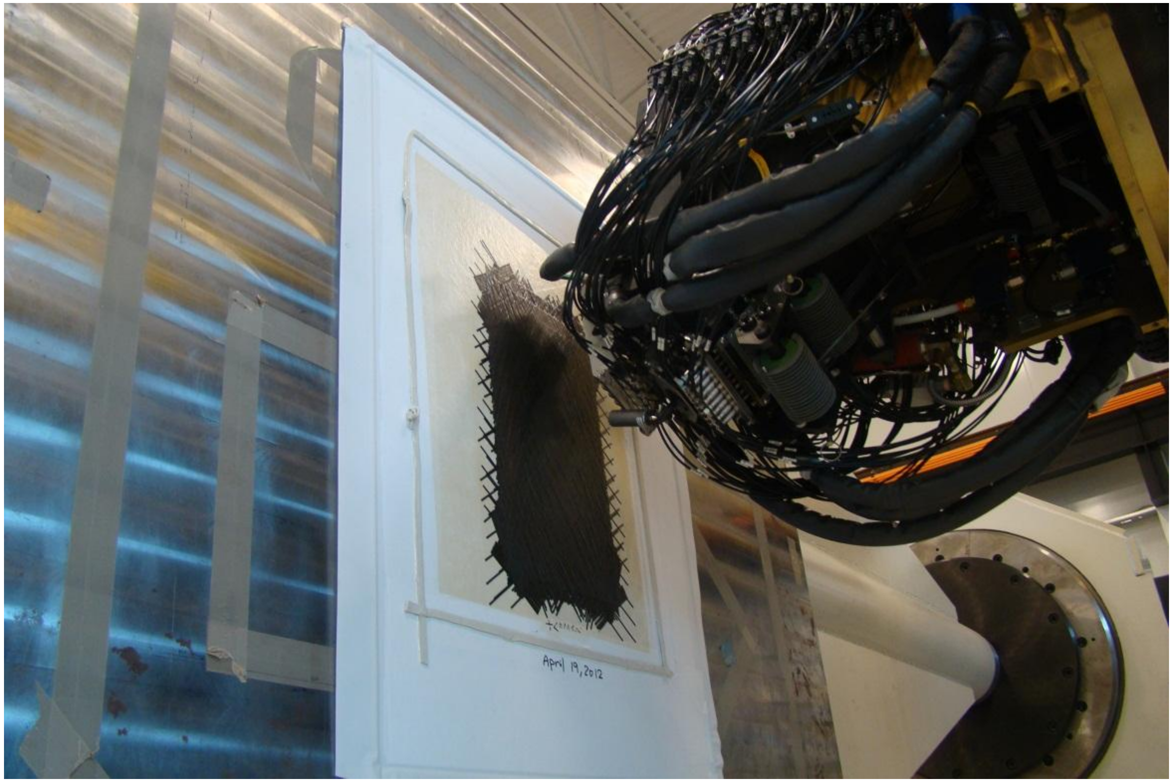
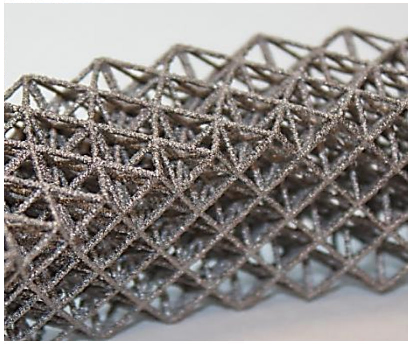
A lighter structure, more fuel efficient and sustainable

BOMBARDIER AEROSPACE · EADS COMPOSITES ATLANTIC · National Research Council Canada / Conseil national de recherches Canada NRC·CNRC · McGill

Questions ?



Current Projects



Multiphysics of
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AFP variable stiffness
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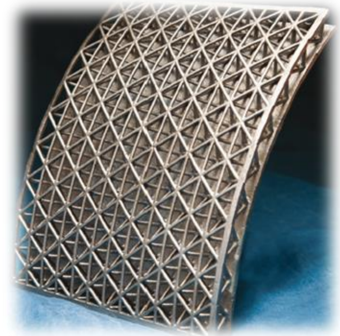

Ultralightweight lattice
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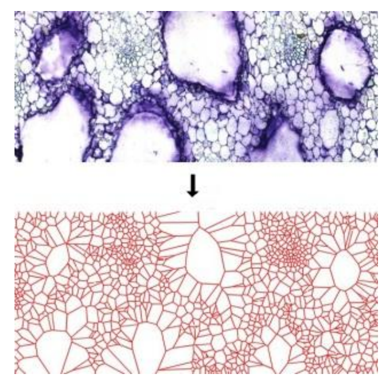
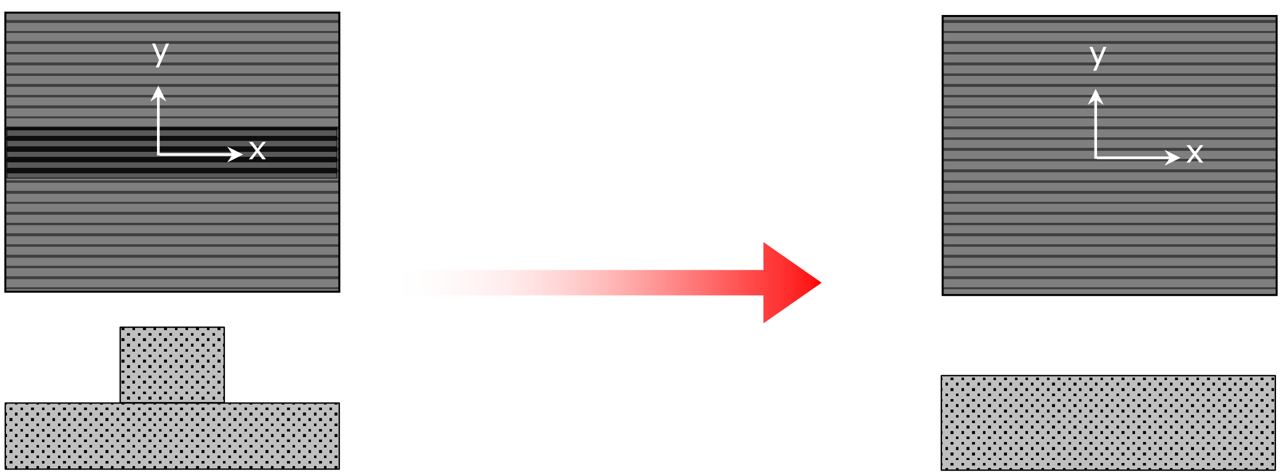


Plant cellular tissue
inspired materials

Overlap-modified defect element

- A single layer $[0]_T$ laminate.
- An overlap is at the plate center and along fiber direction.
- Material and strength properties are the same as regular composite material.
- The effective element thickness is the average of the thickness in the element.

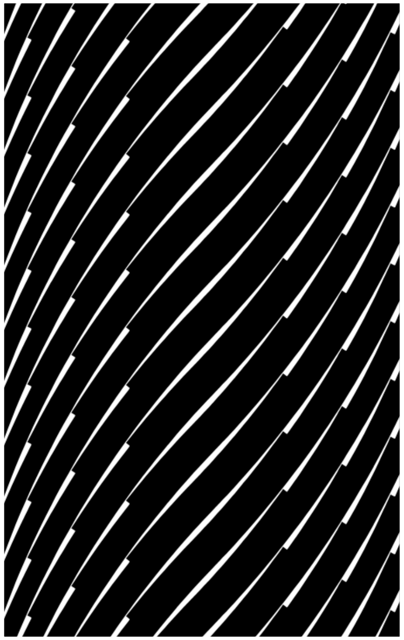


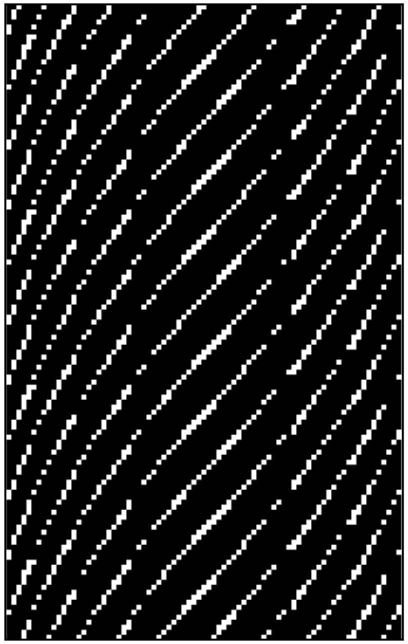
Superiority of defect element approach

- The element length is half of the tow width.
- The FE model for [+<26|45|26>] layer:

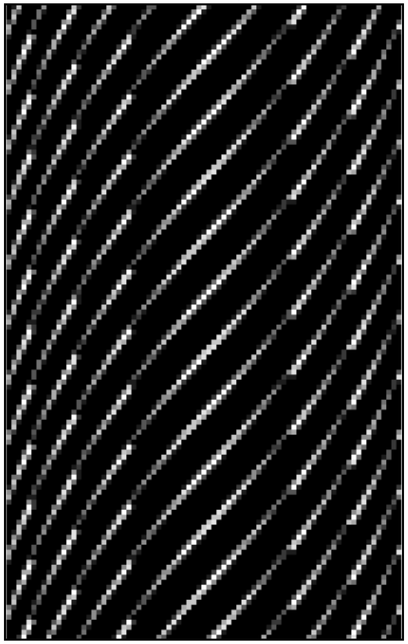
Real gap distribution

Gap distribution in FE model





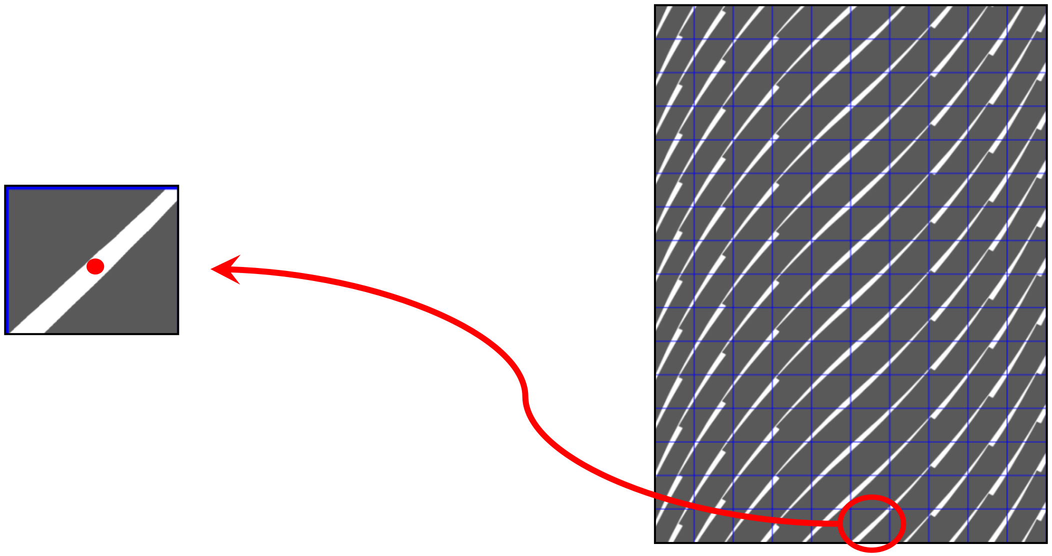
Existing approach in the literature



Defect element approach

FE model for capturing defects (module 3)

- A novel approach, defect layer, is proposed to capture defects precisely.
  - Gap-modified defect layer.
  - Overlap-modified defect layer.
- Each element may contain any defect area percentage.
- Fiber orientation at the element midpoint is calculated and used as the element fiber orientation.



Gap-modified defect element

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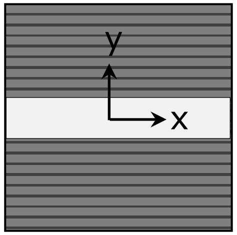
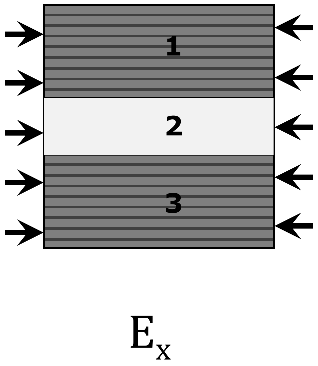
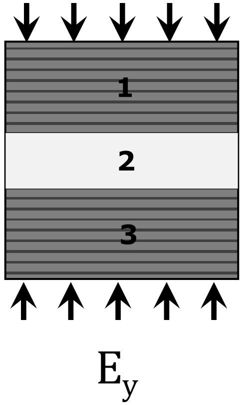
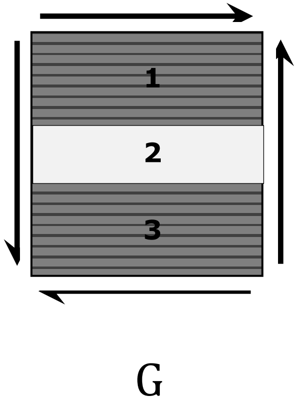


- Test simulations are used to find material and strength properties.

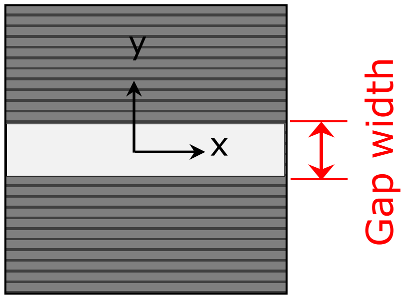


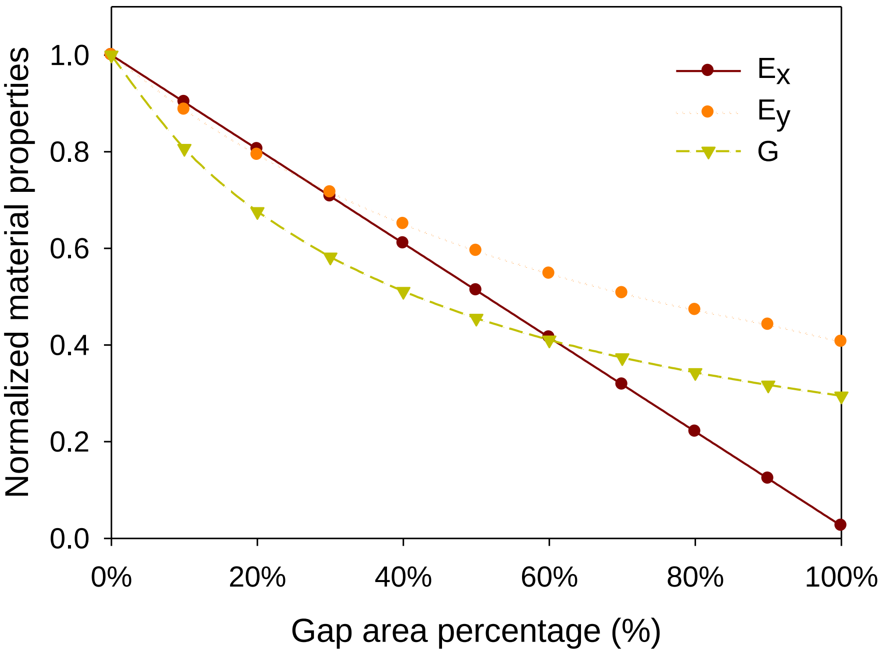




Modified material and strength properties

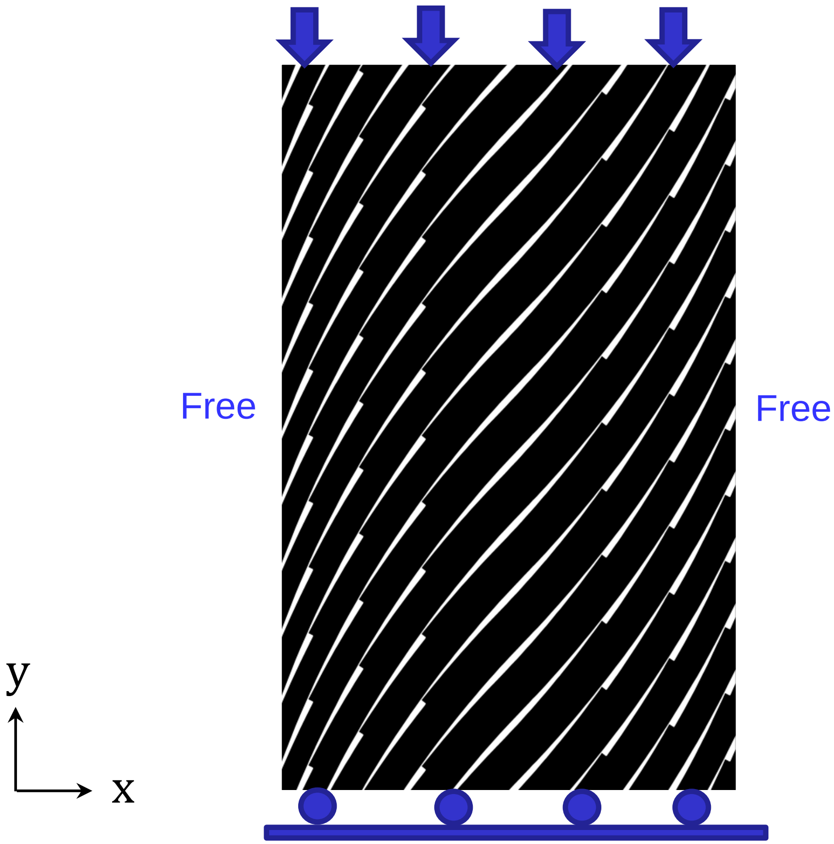
- Gap area percentage is varied with the gap width.
- The graphs are used in APDL codes to calculate properties of a defect element with any defect area percentage.



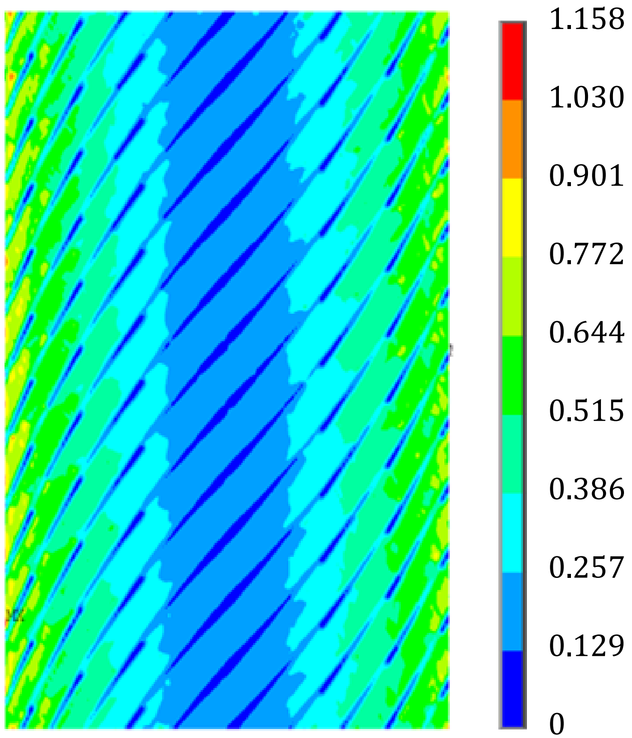


Stress distribution

- The stress in y-direction for [+<26|45|26>] layer in Design (A) with gaps



Real gap distribution



Stress in y-direction