Composite Lattice Reinforced Part Optimization with FEA: An Automotive Door Component Case Study

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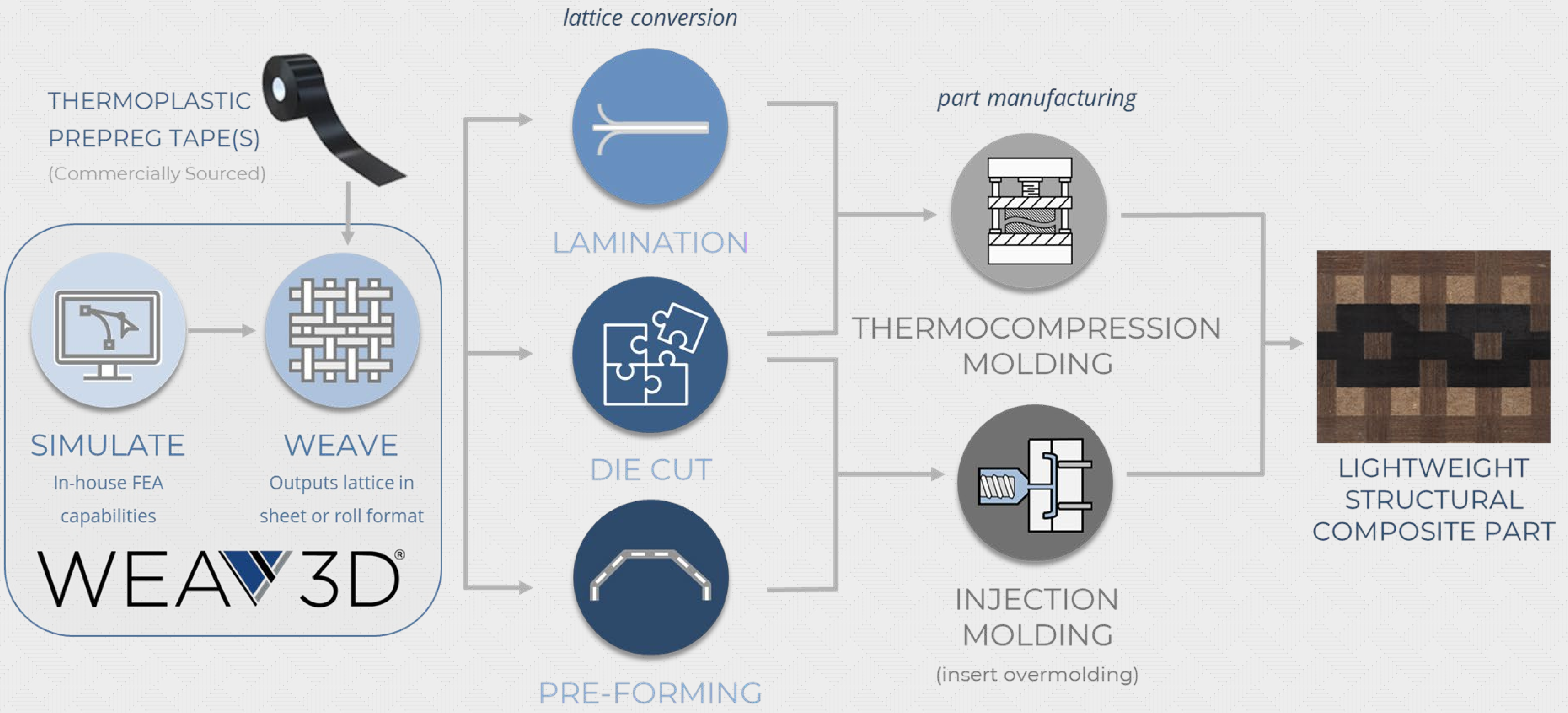
Outline

- Hybrid Overmolding – Rebar for Plastics®
- What are Composite Lattices & Key Terminologies
- Previous Challenges & Approach
- Altair Hypermesh Explicit Method
  - Overview
  - Explicit Method – FEA Validation
  - Optimization Process Overview
- Case Study
- Summary & Future Work

Rebar for Plastics® — Process Overview



What is a Composite Lattice ?

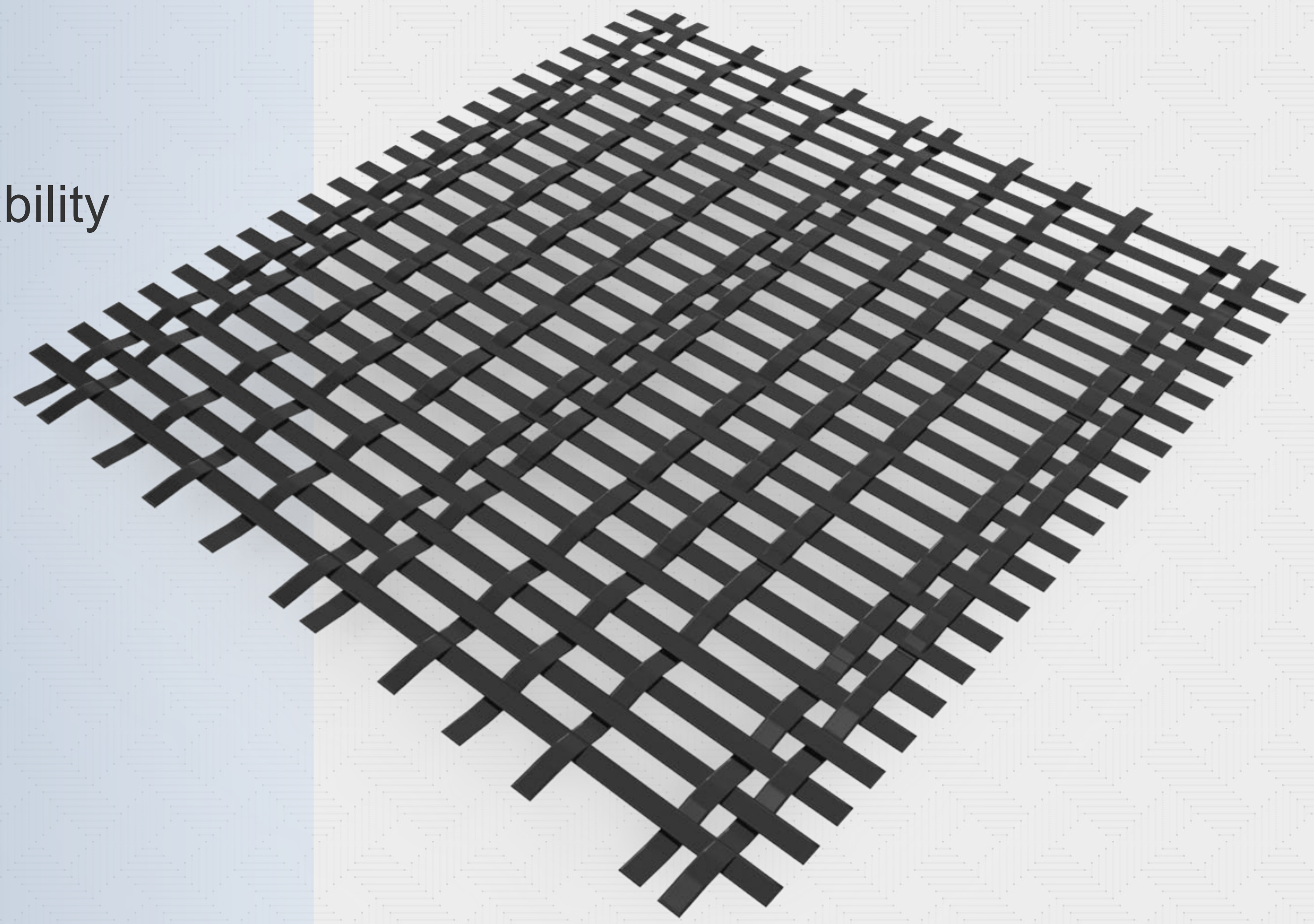
HANDLEABLE

- Made of UD prepreg tapes
- Woven and welded at interface for stability
- Sheet or roll format

TUNABLE

Locally optimized:

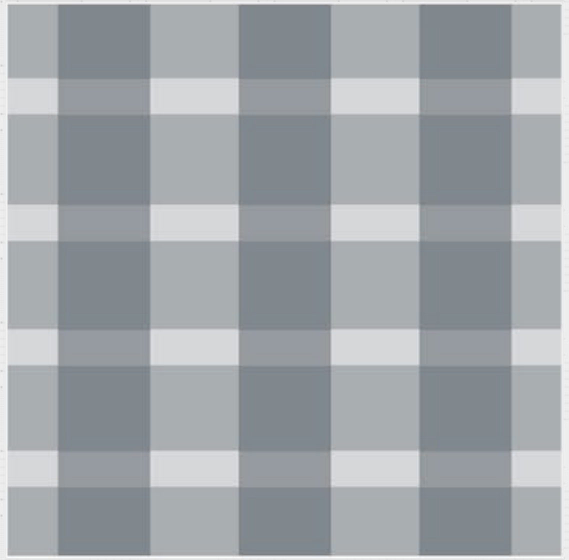
- Lattice density
- Tape material



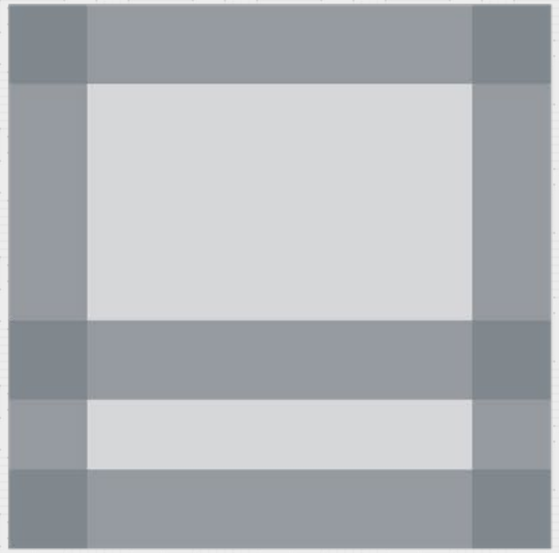
Strategic use of UD tapes in lattice provides a cost-effective and adaptable solution

Key Terminologies

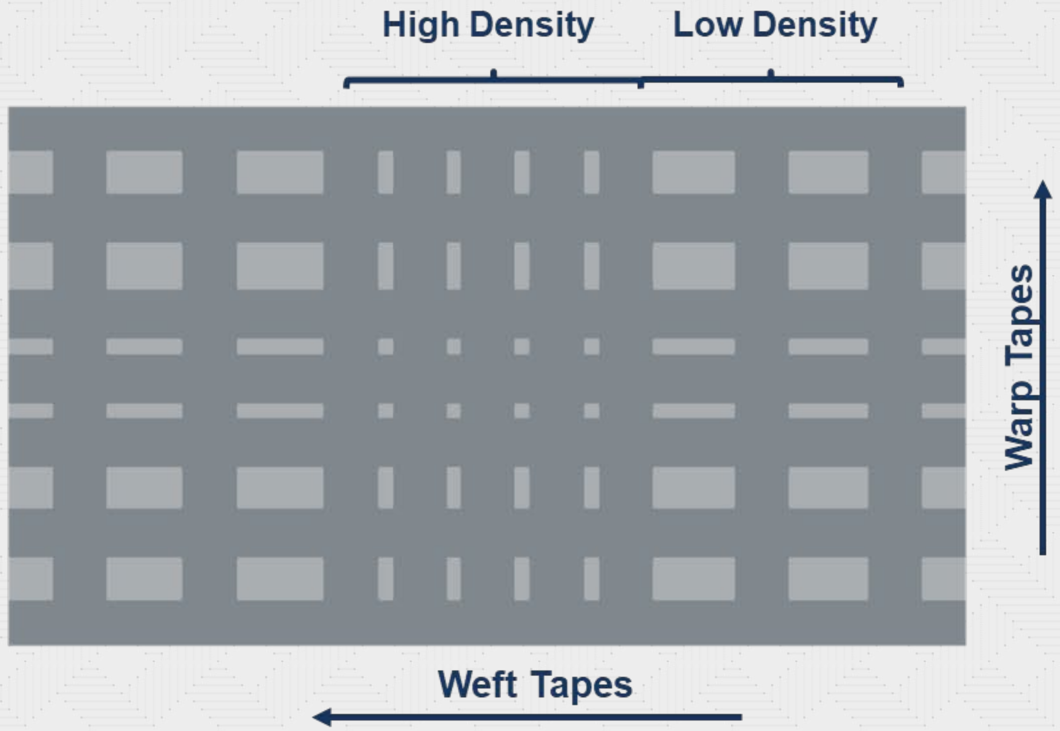
- **UD Tape:** a unidirectional fiber reinforced polymer tape / tow(1 in)
- **Warp Tape:** a UD tape that runs in the machine direction (Y-axis)
- **Weft Tape:** a UD tape that runs in the cross-machine direction (X-axis)
- **Homogenous lattice** : Centre to Centre tape (C-to-C) spacing between tapes and tape materials are constant throughout the part geometry
- **Heterogenous lattice** : C-to-C spacing between tapes and/or tape materials varies throughout the part geometry
- **Weave Density:** relative C-to-C spacing within lattice
- **Cover Factor:** % of the area covered by the tape material in a specified dimension



Homogenous Lattice



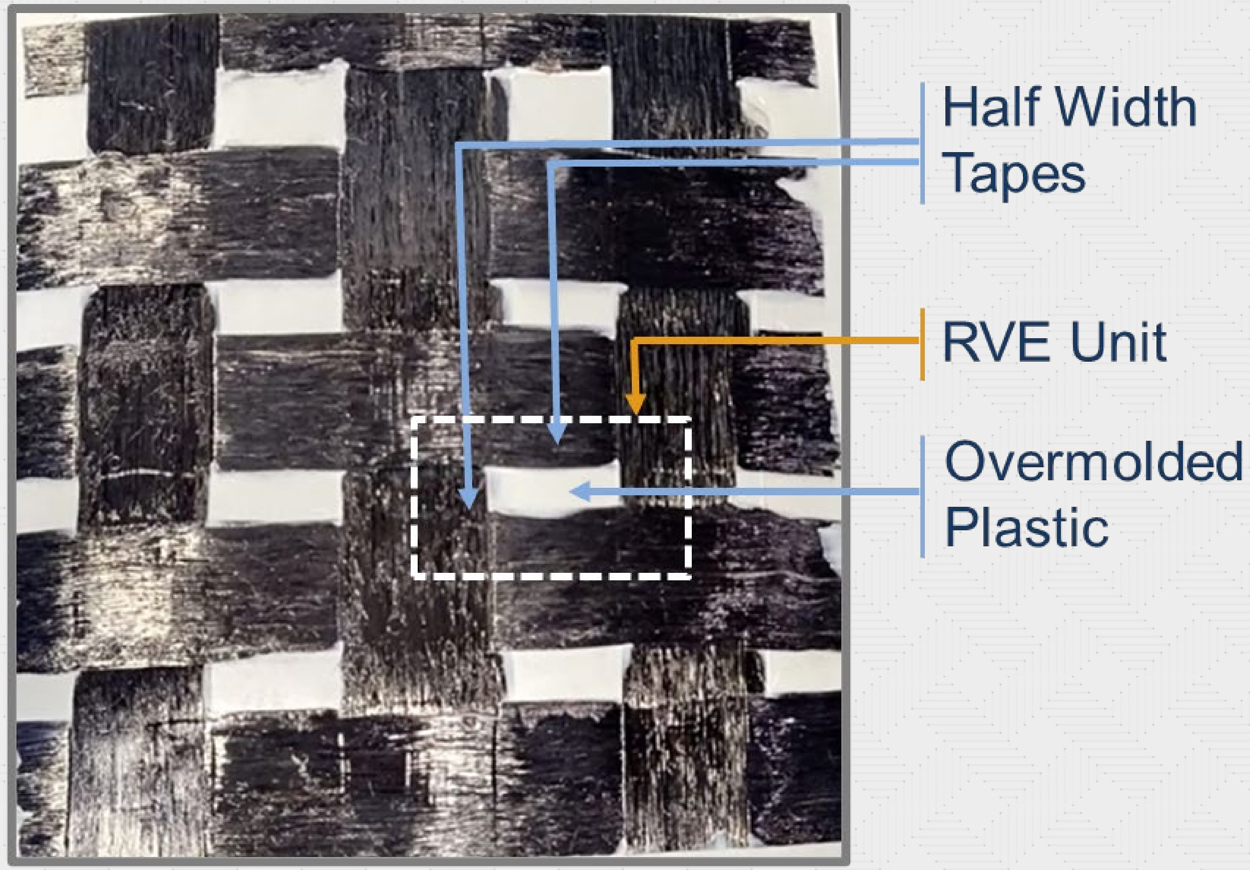
Heterogenous Lattice



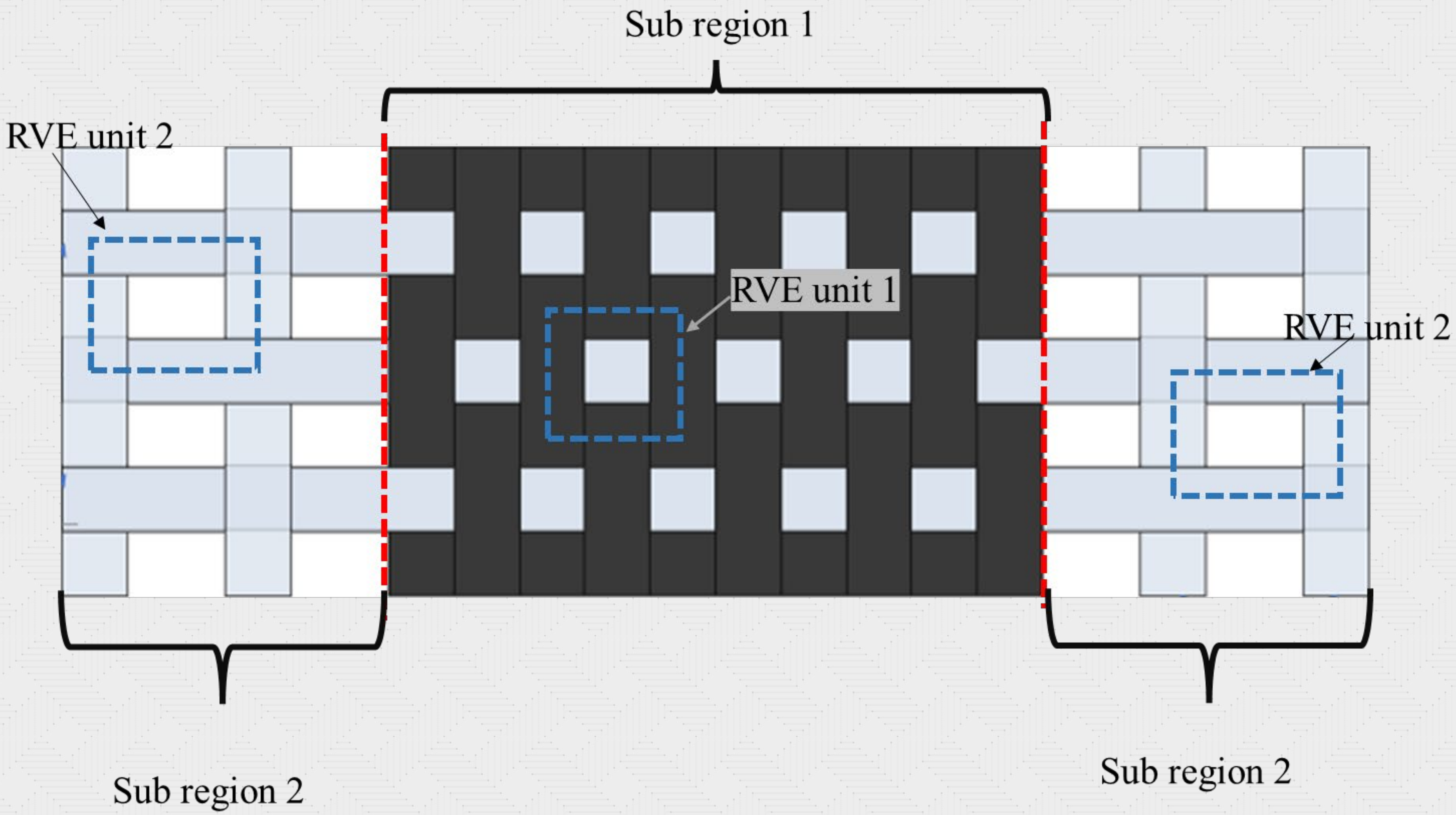
Previous Approach and Challenges

- Most commercially available FEA models are designed for ply-based composites, with fiber type, orientation, volume fraction, and weave type defined on a “per-ply” basis
- Hybrid structures, particularly lattice-reinforced hybrid structures, have additional degrees of freedom that cannot be fully captured within traditional ply-based models
- Previously ANSYS Representative Volume Elements (RVE) method was developed utilizing homogenization. While an improvement, it has limitations

Representative Volume Elements (RVEs)



RVE in Homogenous Lattice Design



RVE in Heterogenous Lattice

A RVE is defined as the smallest volume element of a material with a very accurate statistical representation of the typical material properties used in a full scale/macroscale model.

IMPLICIT METHOD - ANSYS RVE WORKFLOW

Each step requires separate CAD models, effectively addresses limitations of traditional ply-based composites FEA but is labor-intensive

Altair Explicit Model - FEA Workflow

Altair FEA Workflow (Script Based Explicit Model)

Develop Explicit Model Script
- Input Text File
- Meshed shell geometry With local coordinates

Generate

3D Shell Part with tows in HyperWorks using the text file

Solve

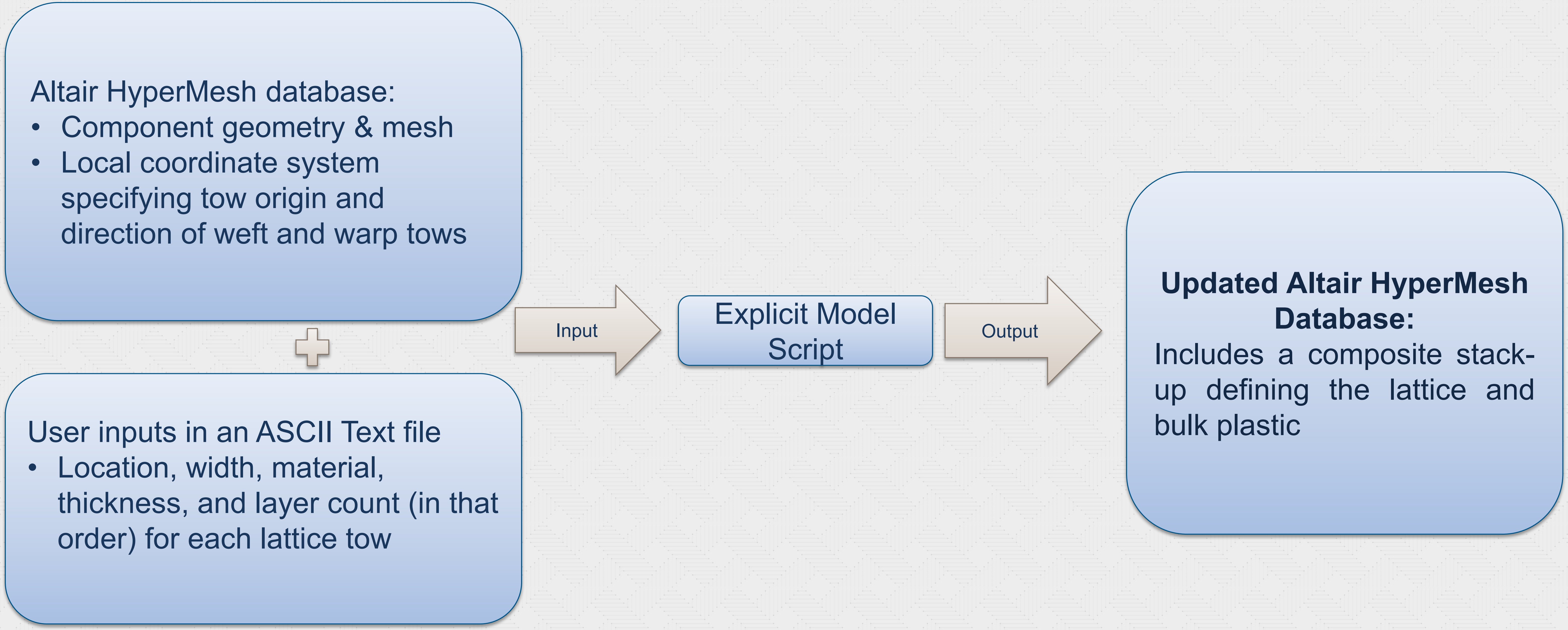
FEA

Post Process
- Deformation Results
- Stresses in tows and plastic

Altair FEA Workflow Overview

- Specific tow or bulk properties assigned to elements, automated process through scripting.
- Preprocessing : A part-level CAD model needed, material data, lattice design properties
- Postprocessing : Single post-processing step to obtain deformation and stress in tows and bulk layers

Explicit Model Script



FEA EXPLICIT MODEL VALIDATION (THREE-POINT BEND TEST)

Experiment Design for Flexure Test Samples

Design No.	Molded Plastic Material	Weft Tape Material	Weft Tape		No. of Lattice layers
			No. of layers	Spacing (mm)	
1	Braskem Ti4003F PP	Glass/PP (45 % Vf)	2	25.4	2
2		Carbon /PP (40 % Vf)	2	50.8	2
3			2	25.4	2
4		Mixed -Alternating Glass/PP (45 % Vf) & Carbon /PP (40 % Vf)	2	25.4	2

Results: Chord Modulus Comparison

Design No.	Altair Chord Modulus (GPa)	Experimental Chord Modulus (GPa)	% Deviation
			Altair vs. Experiment
Design 1	25.98	25.64	1.32 %
Design 2	27.23	25.19	8.09 %
Design 3	53.14	52.99	0.28 %
Design 4	44.3	39	13.5 %

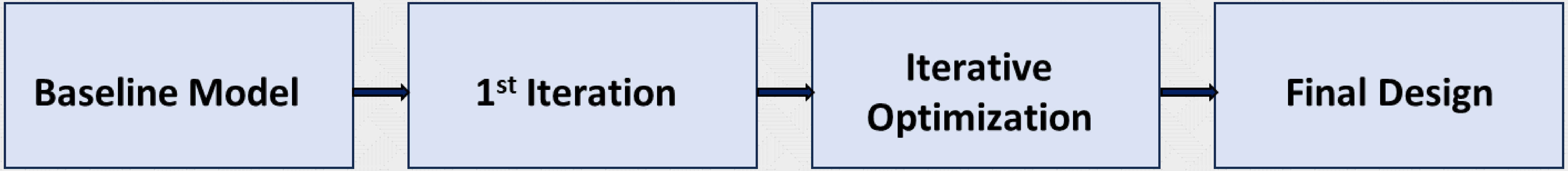
Altair's Explicit model exhibited good correlation with experimental results, overpredicting the experimental modulus by an average of 5.8 % (0.3 % - 13.5 %).

Comparison of Methodologies: Time to Set & Solve Flexure Load Case

ANSYS RVE Method			Altair Explicit Method		
Overview of Steps	**Setup Time**	**Solve Time**	**Overview of Steps**	**Setup Time**	**Solve Time**
RVE CAD	~ 3 minutes	~ 1 minute	*Input Text File*	~1 minute	N/A
ANSYS Pre	~5 minutes	~ 30 seconds	*FEA of the Part*	~ 8 minutes	~ 40 seconds
FEA of Part	~ 5 minutes	~ 1 minute			
Submodel	~7 minutes	~ 1 minute			
Total Setup and Solve Time ~23 minutes			*Total Setup and Solve Time* ~10 minutes		

Compared to the ANSYS RVE method, Altair Explicit FEA is over 50% faster in flexure tests

Optimization Overview



- Boundary Conditions
- Maintain Part Dimensions & Material
- Experimental Comparison
- Set Design Targets

- Homogeneous Lattice
- 50% Cover Factor
- Compare Targets

- Adjust Layers count
- Adjust Tow Materials &Spacing
- Select Regions of reinforcement
- Verify Design Targets

- Custom Lattice

Case Study :
Optimizing Lattice Design for an Automotive Part Using Altair's Explicit FEA Method

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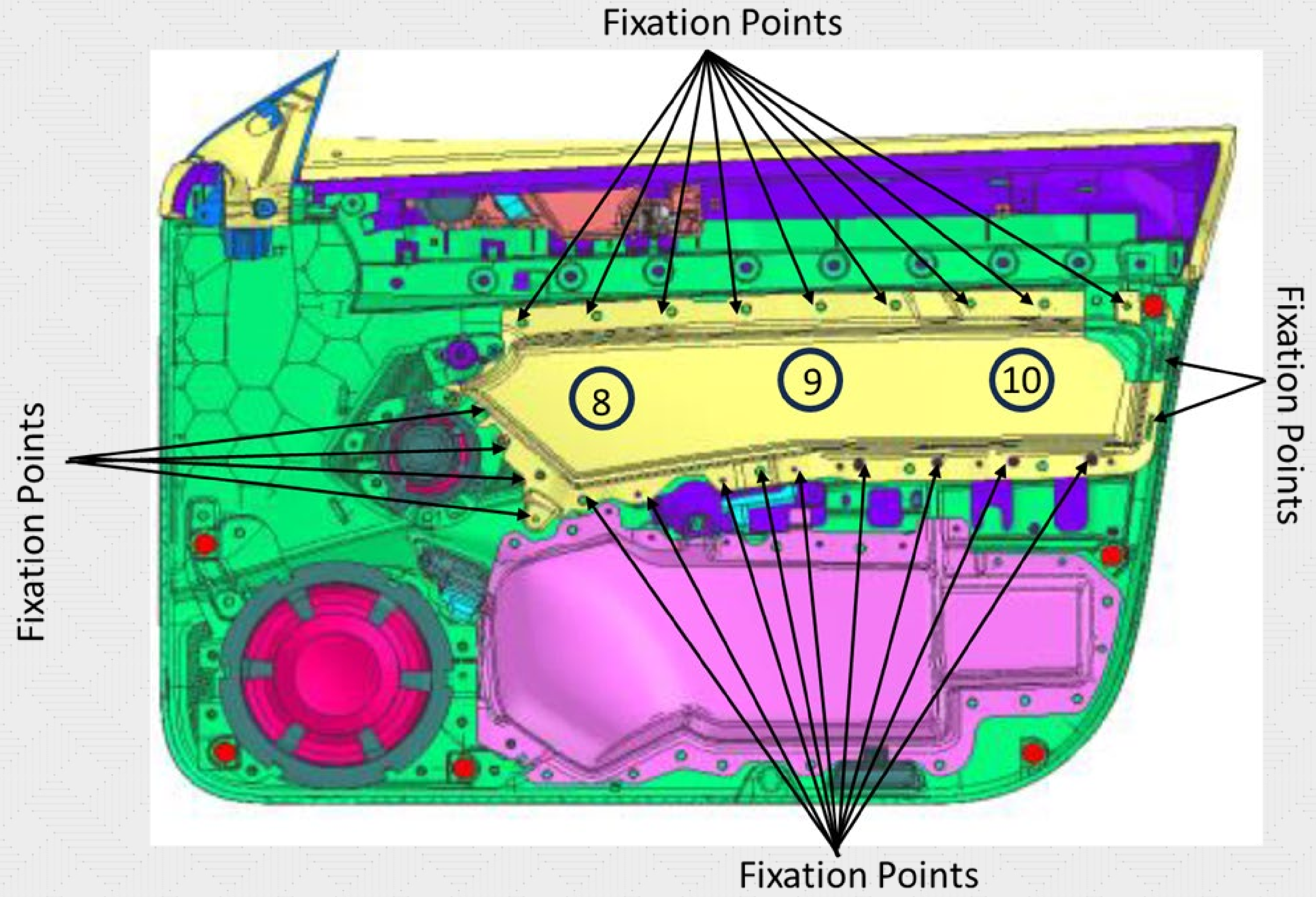
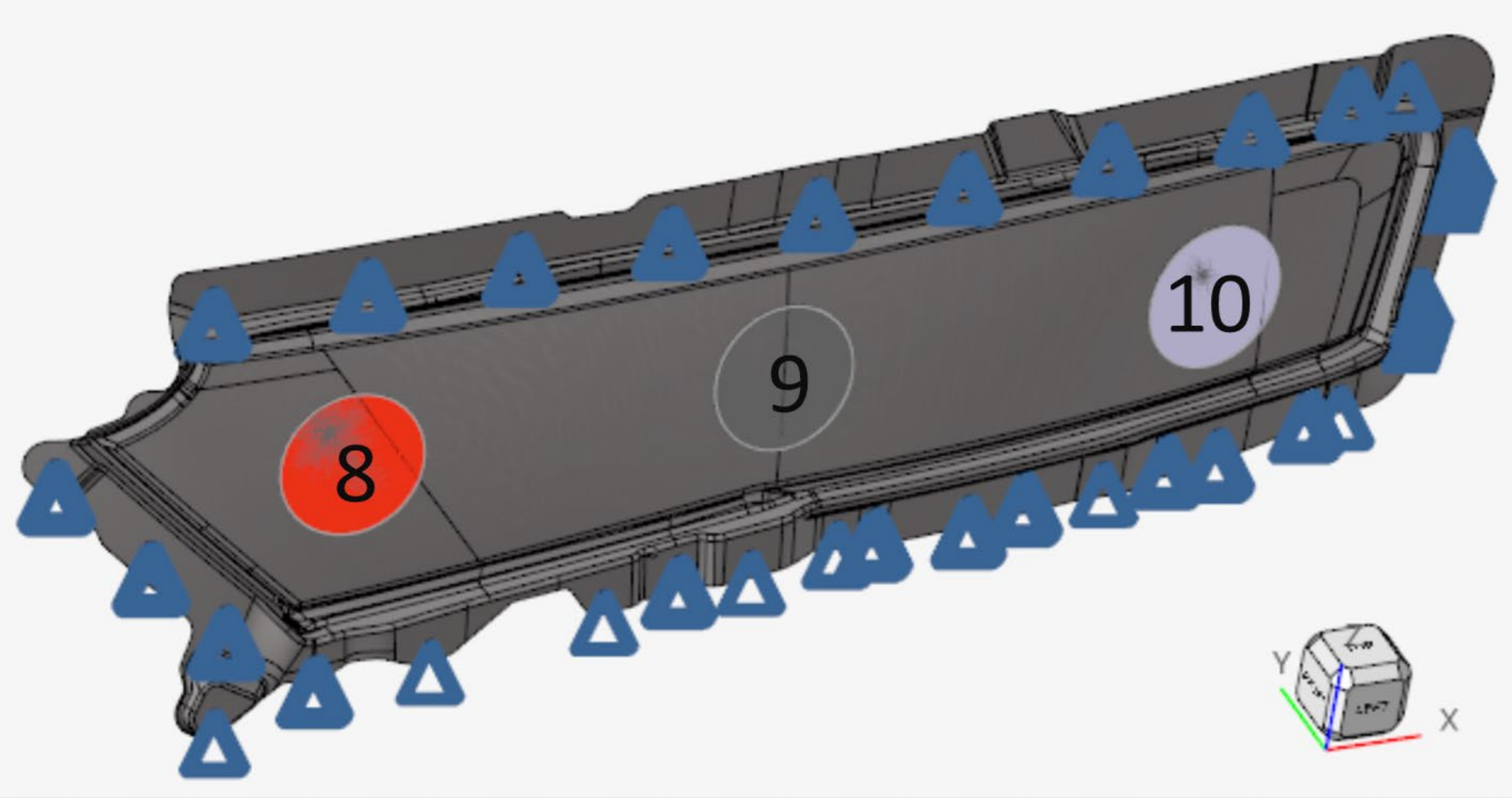
Baseline FEA & Design Targets

Assembly



FEA Setup



- Load =150N applied over d = 60mm at points 8, 9 & 10 individually
- Baseline part material & thickness : NFPP 1700 gsm , 1.8mm thick
- Design target : Achieve weight & cost neutrality, maintaining deflection < 8.6 mm

Baseline FEA Model Validation

Load Location	Experimental Deflection (1700 gsm NFPP) (mm)	FEA Deflection (1700 gsm NFPP) (mm)	% Deviation FEA vs. Experiment
8	7.48	7.7	3%
9	8.21	8.6	5%
10	6.35	5.9	-7%

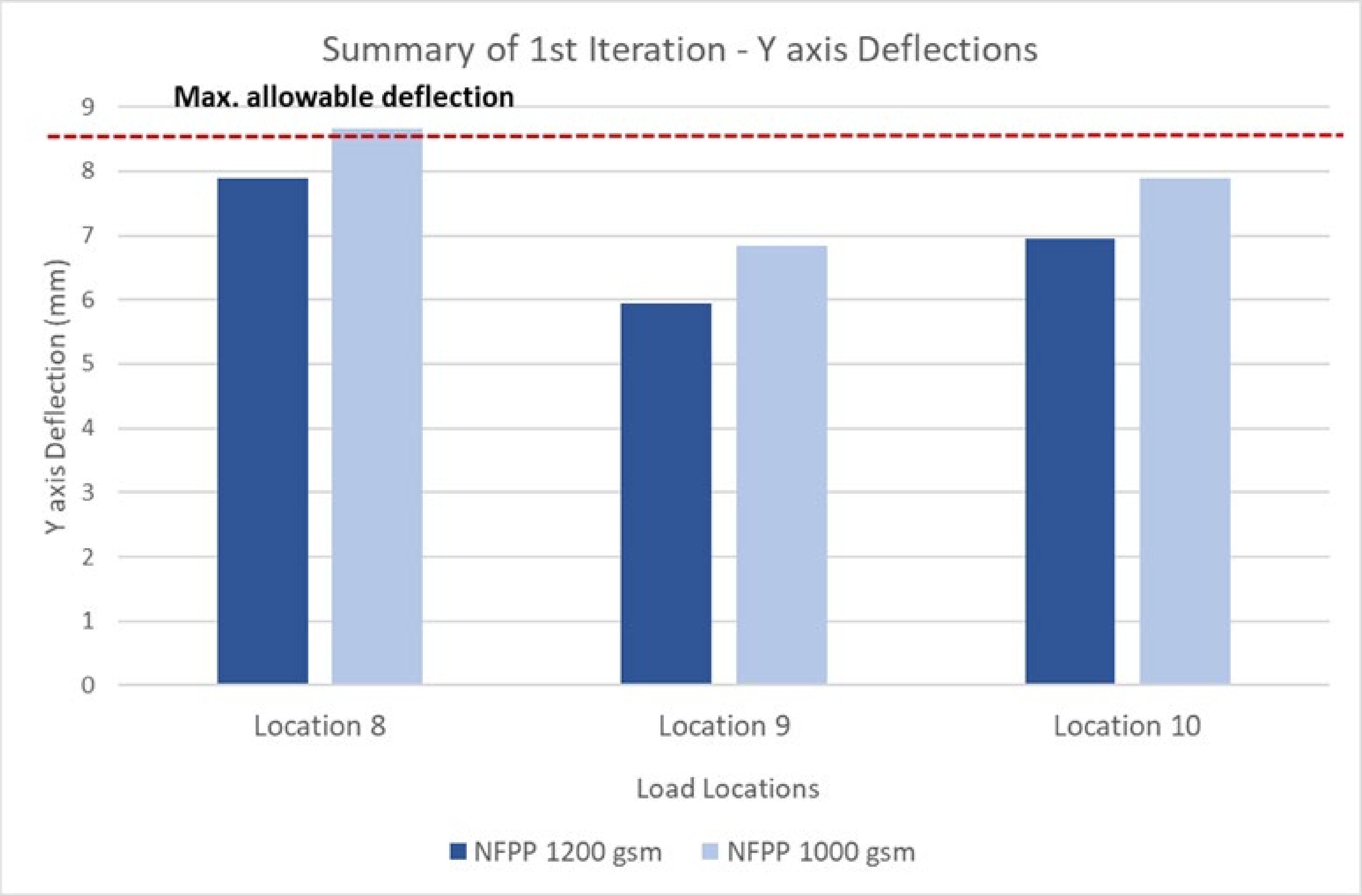
Good experimental correlation achieved.

Optimization Strategy

- To achieve cost and weight neutrality **thinner mat** (1200 & 1000 gsm) were reinforced with WEAV3D Lattice
- Door inserts solely fabricated using thinner mats **exceeded** max. deflection limit

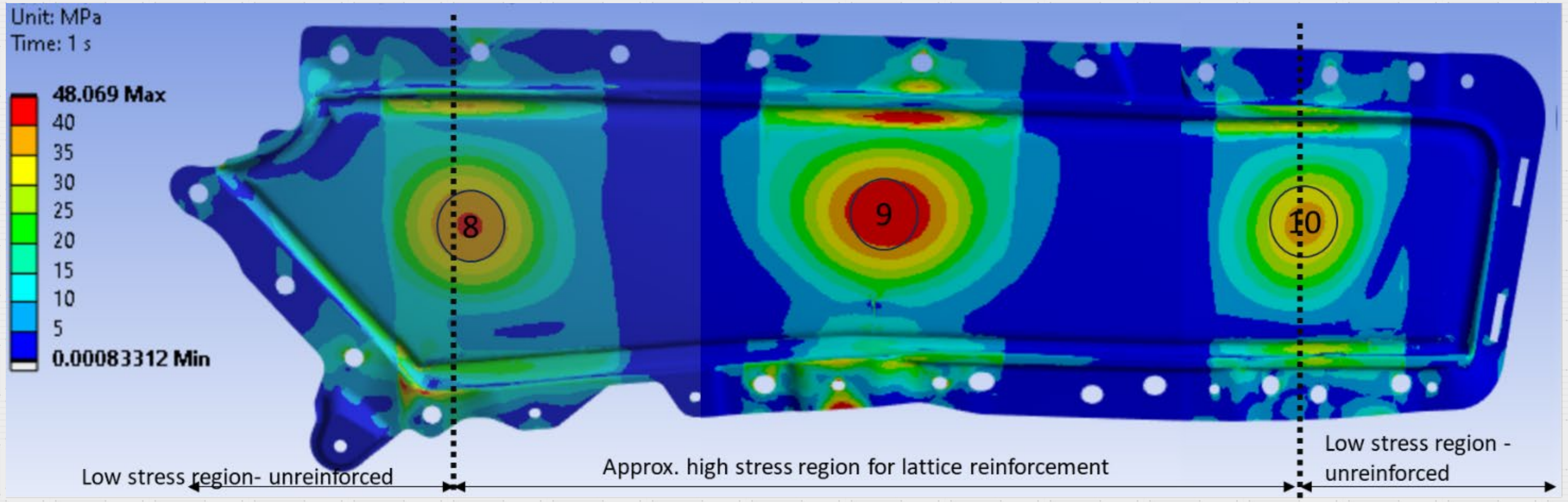
Door Insert Material	Deflection at Pt. 8	Deflection at Pt. 9	Deflection at Pt. 10
NFPP 1700 gsm	7.7	8.6	5.90
NFPP 1200 gsm	13.66	14.35	8.62
NFPP 1000 gsm	15.18	16.02	9.67

Optimization Strategy Contd. : Review of Iteration 1 Deflection Results

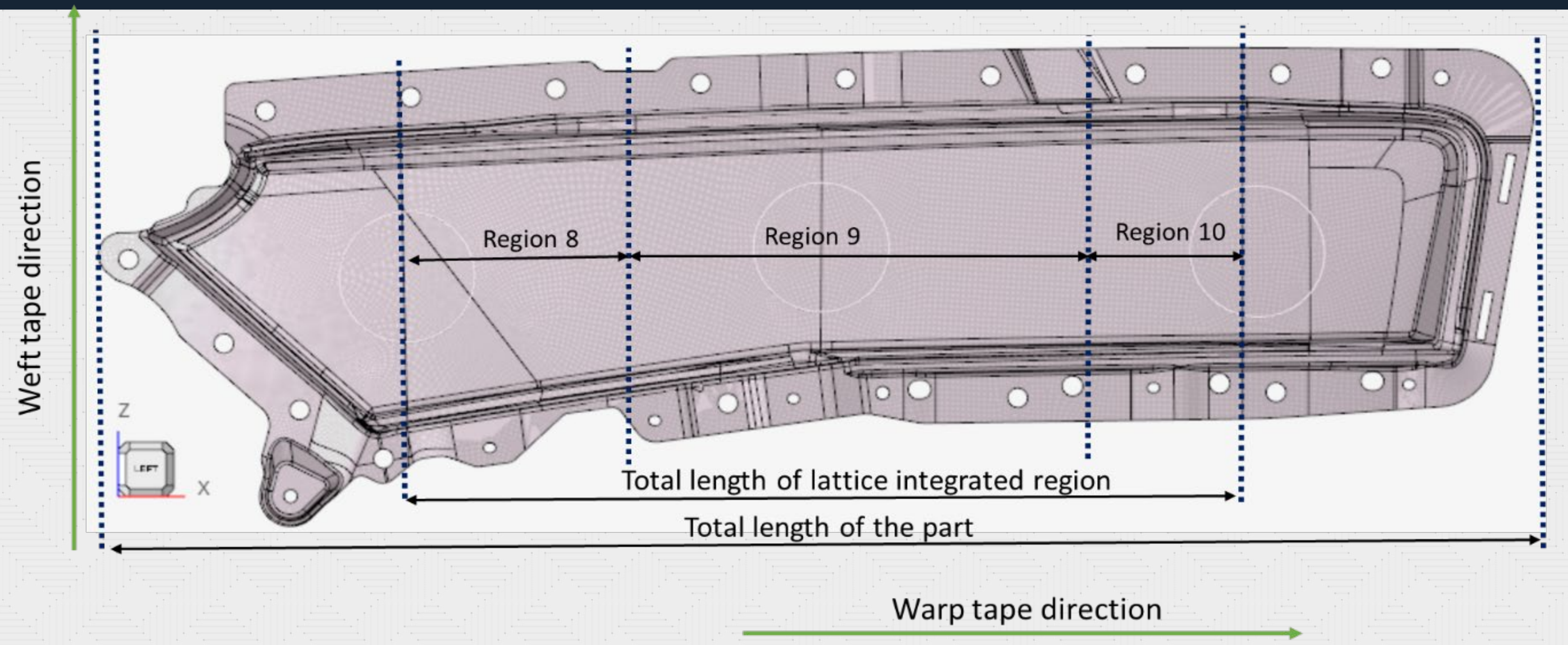


Iteration 1 : NFPP (1200 gsm & 1000 gsm) reinforced with homogenous single layer glass lattice, 50% cover factor, over entire part area

Optimization Strategy Contd. : Stress Plots



Critical regions identified , part divided into lattice reinforced and non reinforced region (overlaid)



Identified lattice reinforcement area divided into three heterogeneous sub-regions, based of stress plots

Summary of Iterative Optimization Strategy

- **Focus Areas**:
  Targeted regions with high deflection near allowable limits.

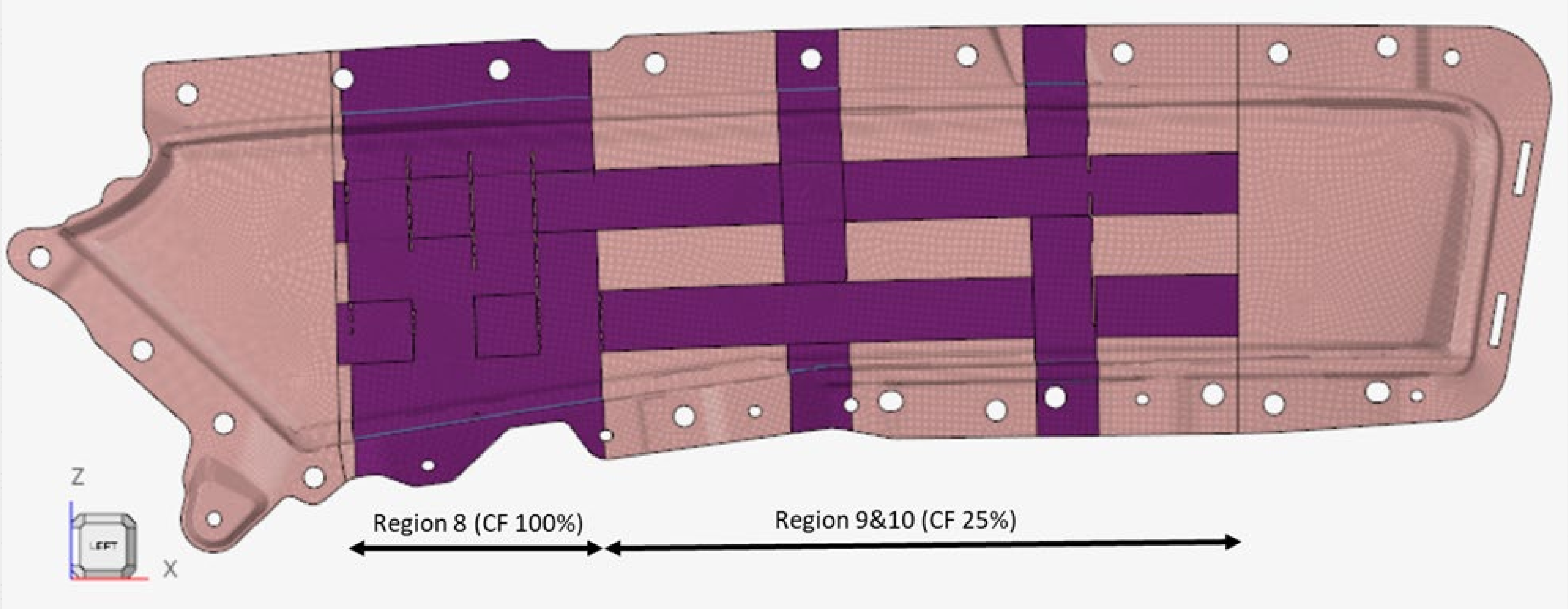
- **Weave Density Adjustments**:
  Assigned denser lattice design to critical areas. & reduced weave density in lower deflections regions.

- **Division into Sub-Regions**:
  Divided identified lattice reinforcement area into 3 homogenous sub-regions based on stress distribution observed in the baseline model

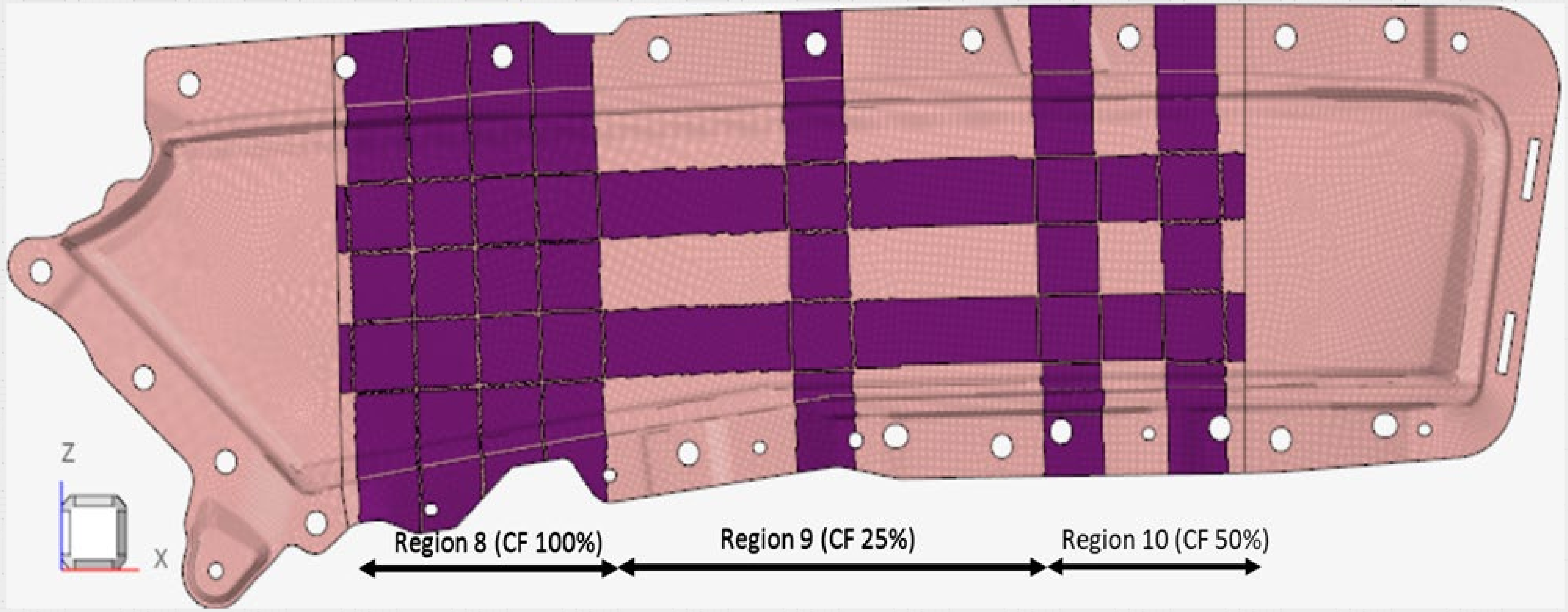
- **Unique Weft Cover Factors**:
  Each sub-region assigned a specific weft cover factor.

- **Warp Tows**:
  Maintained a constant cover factor of 50% to ensure stability during handling and forming

Final Optimized Lattice Designs

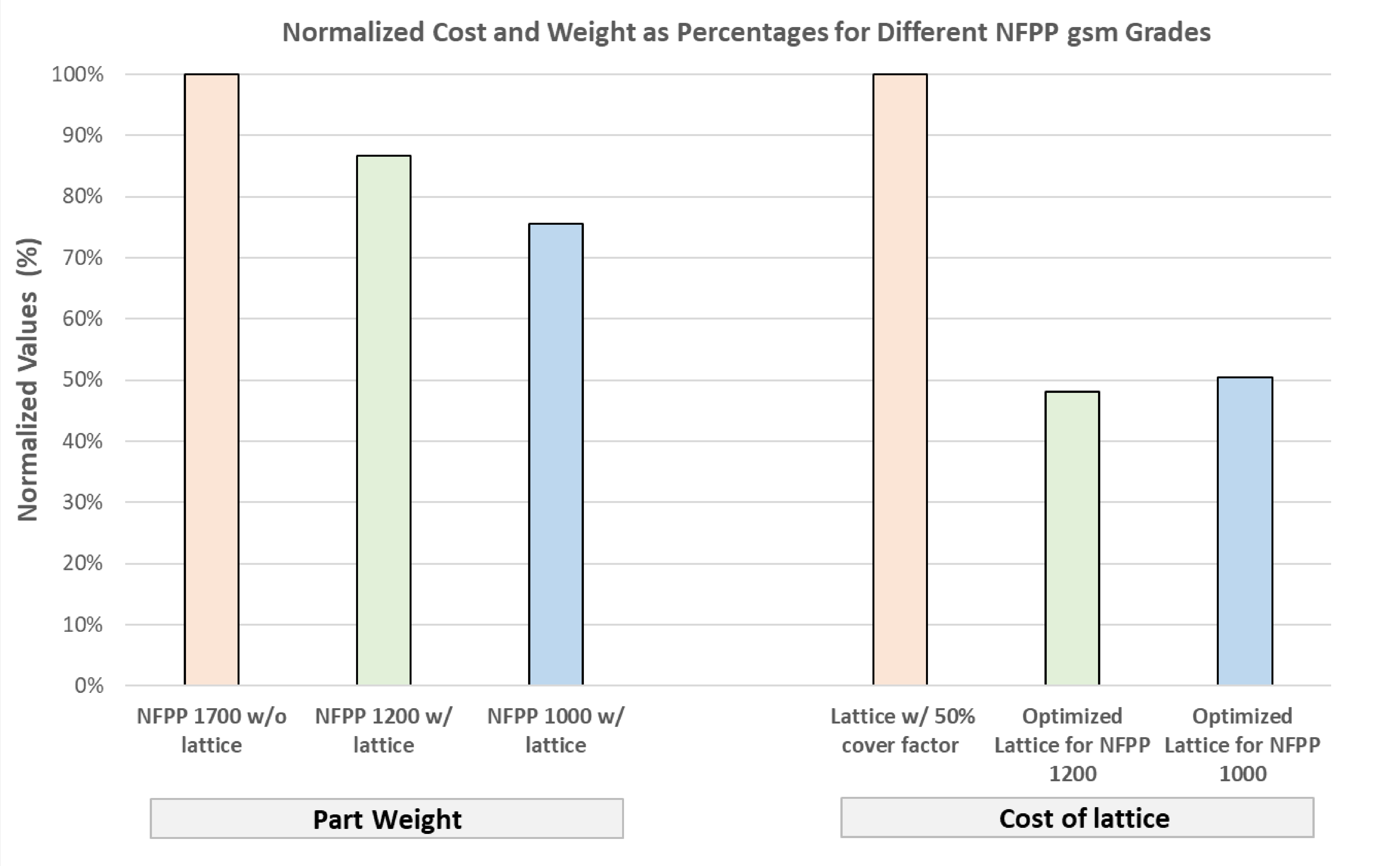


Optimized lattice pattern for NFPP 1200 gsm



Optimized lattice pattern for NFPP 1000 gsm

Cost & Weight Savings



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Summary

❑ **FEA Methodology Advancements:**

- Allowed parameterization of tape materials, spacing, and layer counts.
- Reduced setup and solve time by ~50%.

❑ **Validation through Experimental Testing:**

- FEA predictions validated against experimental data from three-point bend tests showed good correlation
- Confirmed the reliability of the explicit modeling approach

❑ **Optimization and Performance Enhancement:**

- Achieved up to 24% weight savings while maintaining or enhancing mechanical properties.

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Future Work

Enhanced Script Capabilities

- Expand script to handle complex part surfaces using advanced projection or draping algorithms.

Development of Implicit Model

- Create an implicit model in Altair for rapid goal-seek optimization of lattice patterns.
- Use implicit model to identify candidate designs for precise stress distribution verification with the explicit model.