Stress Analysis and Optimization Tools for Composite Automated Fiber Placement Structures

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August Noevere, PhD
Collier Research Corporation

Co-authors:
Craig Collier, Collier Research Corporation

Outline

Introduction and Overview

AFP Stress Analysis Framework

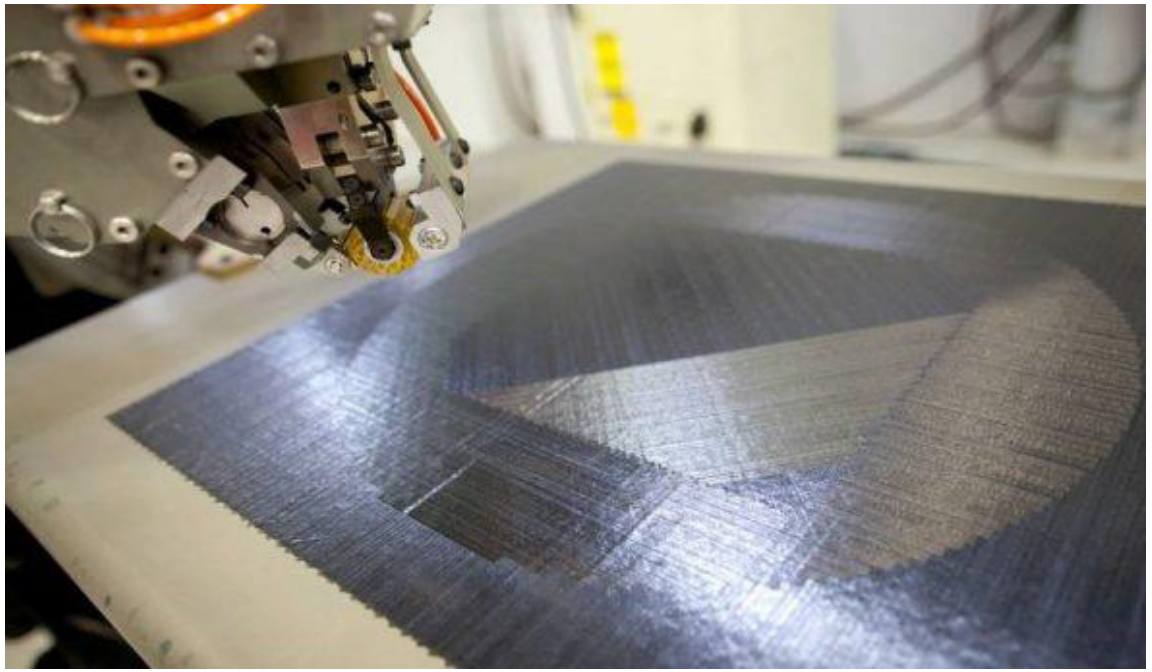
Incorporation of CAD-Based Fiber Paths in FEM-Based Stress Analysis

Composite Optimization with As-Manufactured Fiber Directions

Example on Fairing Model

Automated Fiber Placement (AFP)

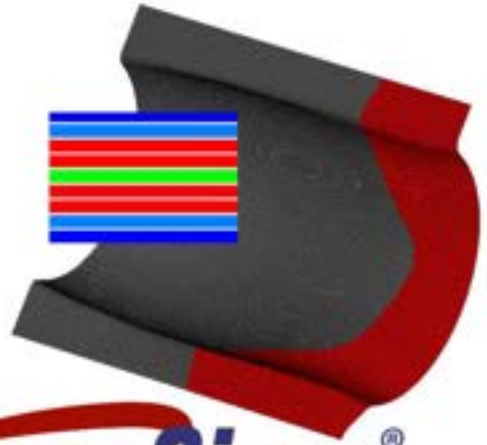
- AFP is an increasingly popular manufacturing technique for composite structures
  - “Slit tape” or “tows” 1/8in to ~1in in width
  - Laid down in multiple tows per course
  - Tows are steered to achieve desirable laminate properties on complex curvature



Automated Dynamics AFP Machine

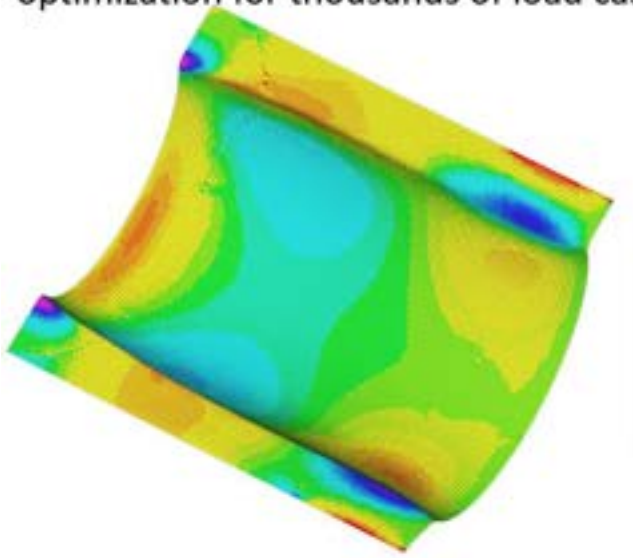
ISAAC (Electro Impact) AFP Machine, NASA Langley

Design for Manufacturing

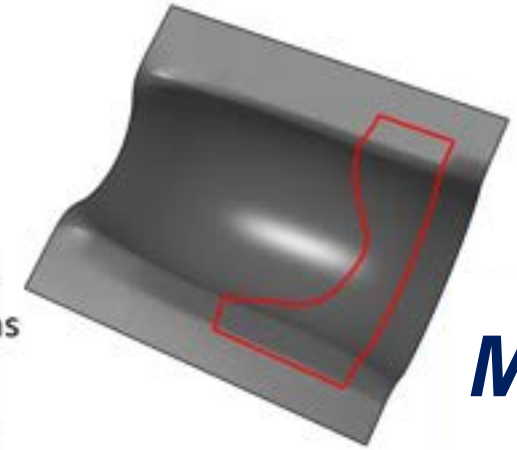


HyperSizer®

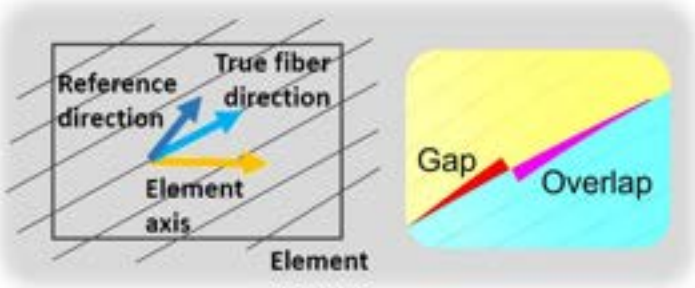
Stress analysis and laminate optimization for thousands of load cases



Optimized ply shapes, counts, and orientations

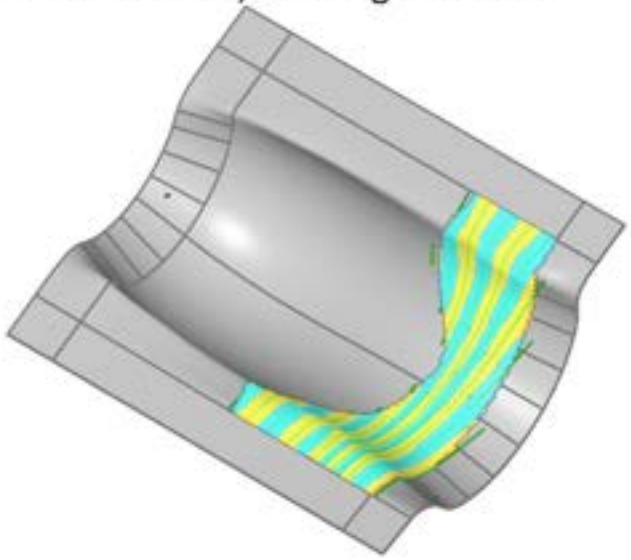


Mapped AFP data



AFP Manufacturing Simulation

Tow path generation, lap/gap identification, steering violations



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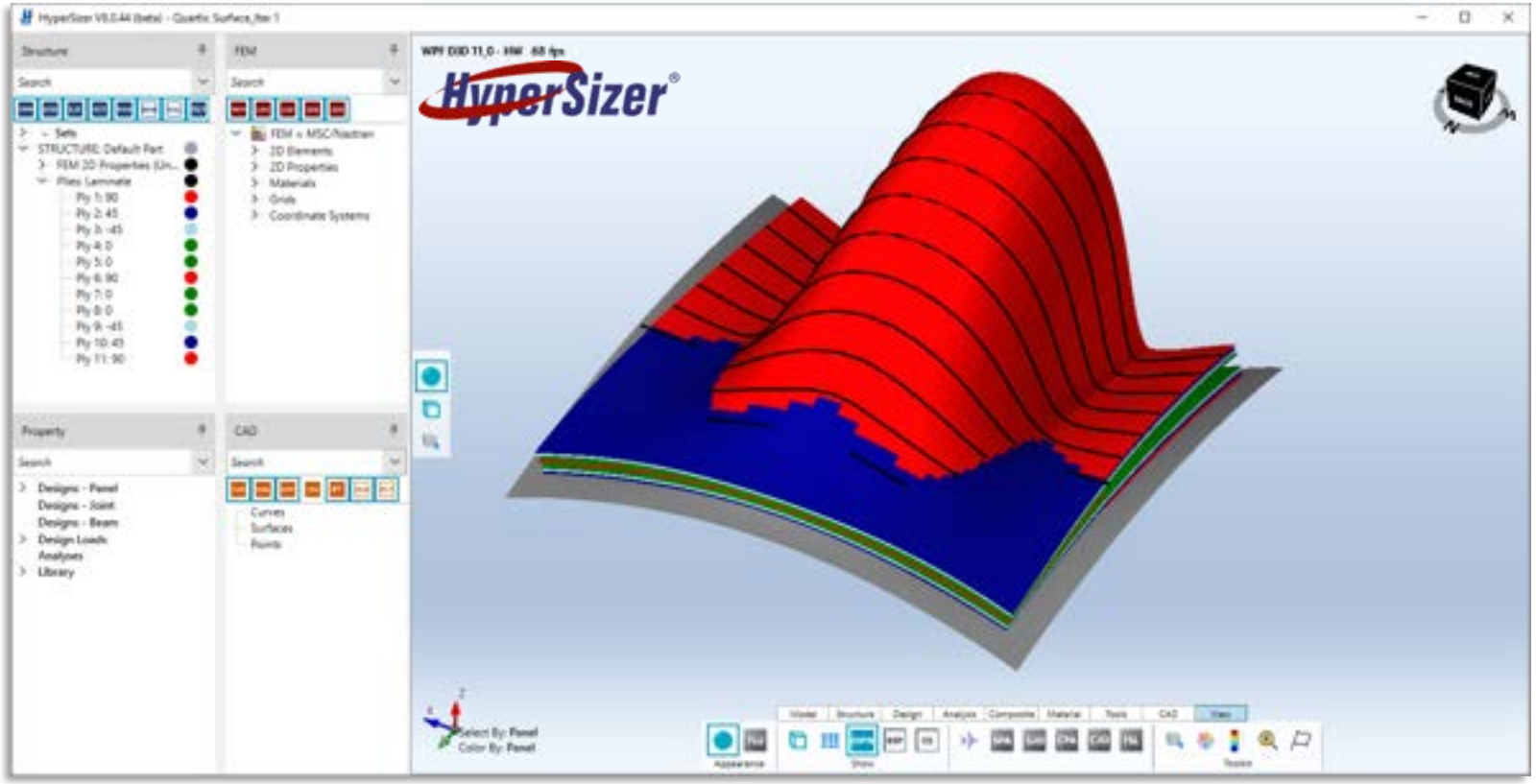
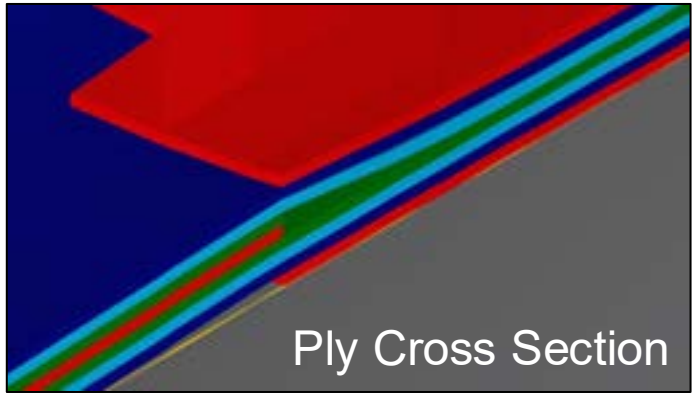
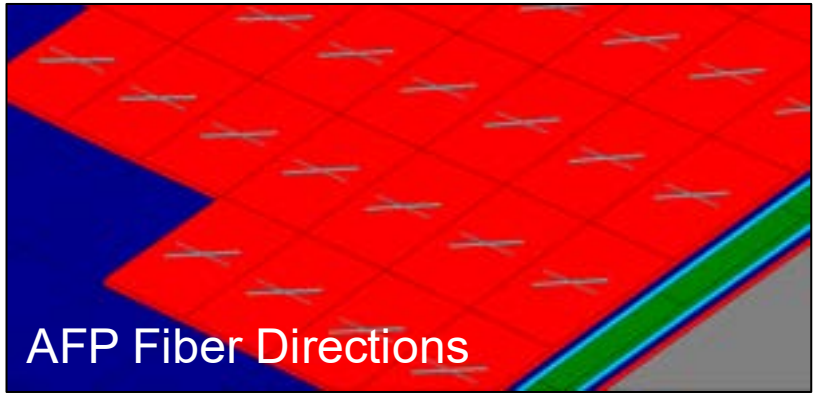
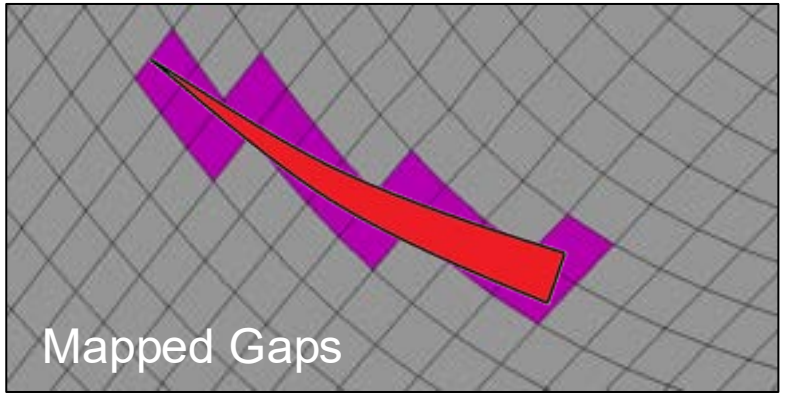
Central Optimizer Interface





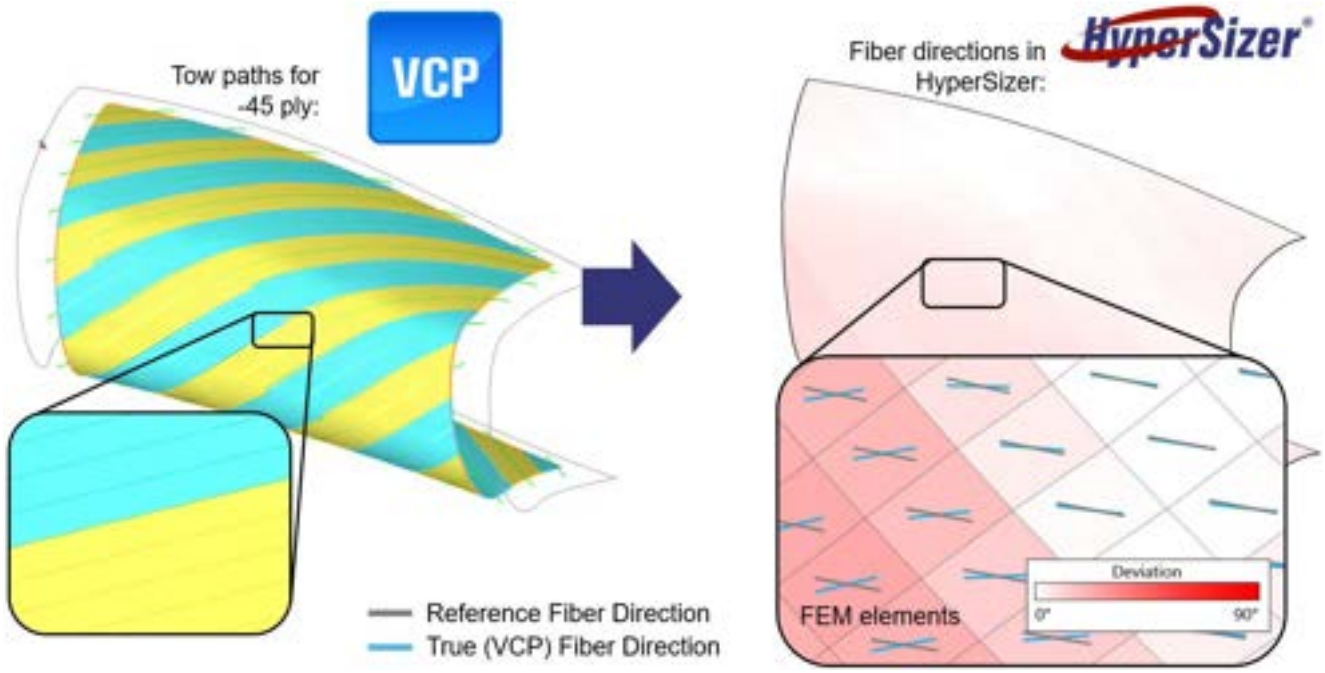




Summary of Central Optimizer Capabilities

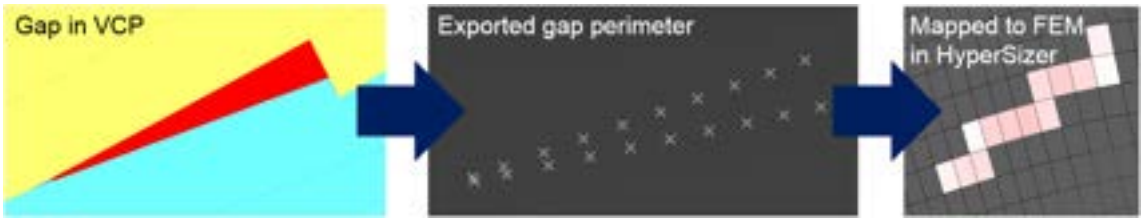
Fiber orientation mapping

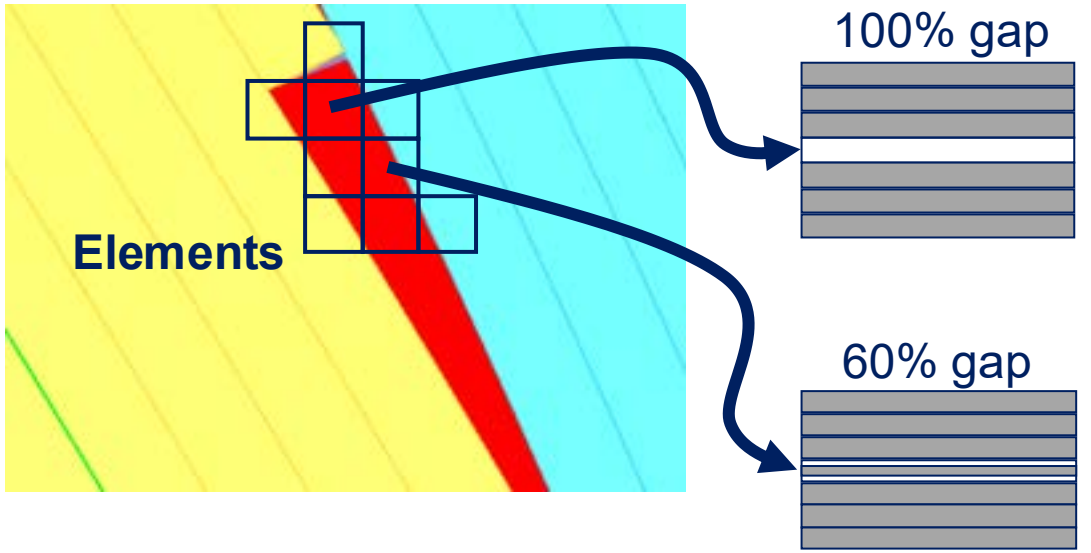
- VCP generates AFP fiber paths
- Fiber directions mapped to HyperSizer per ply, per FEM element



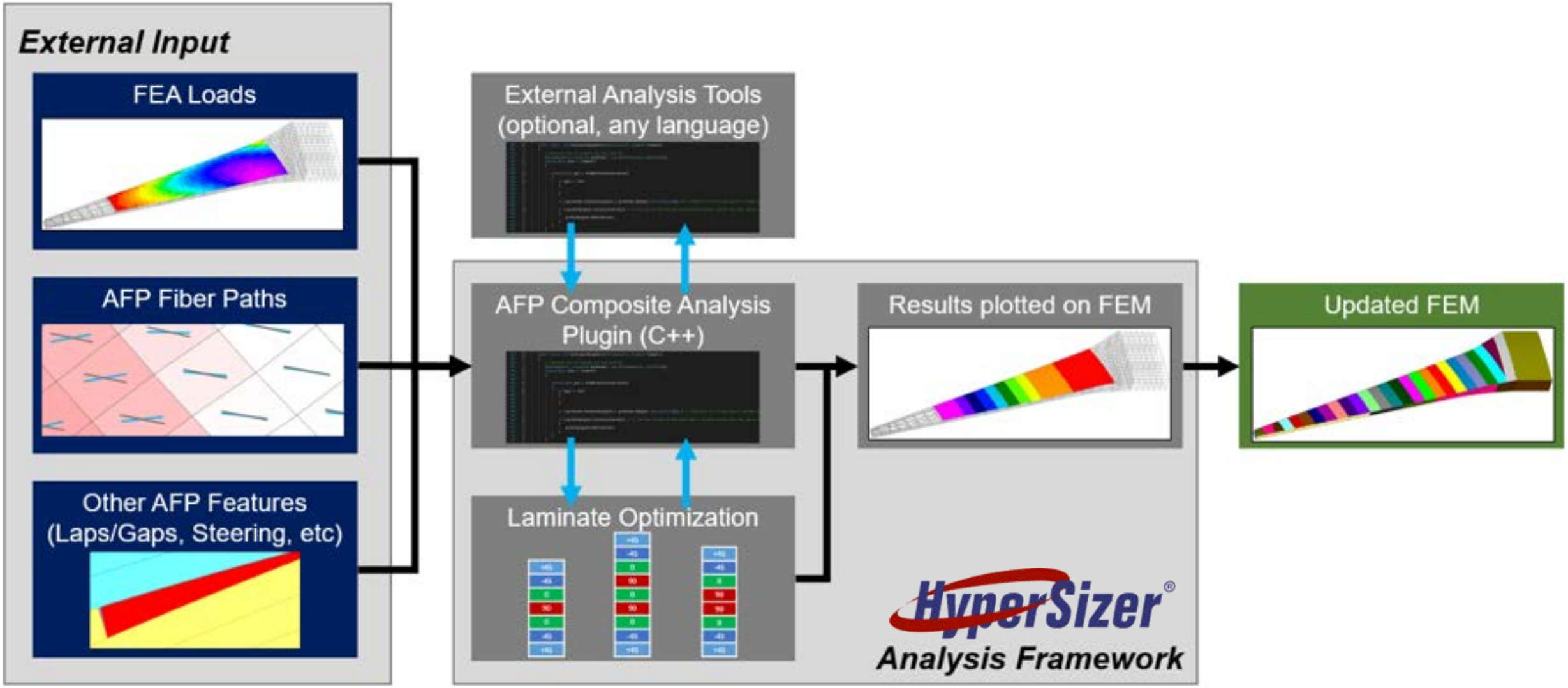
Overlap and gap mapping

- Overlap and gap locations calculated in VCP
- Geometry mapped to FEM elements in HyperSizer

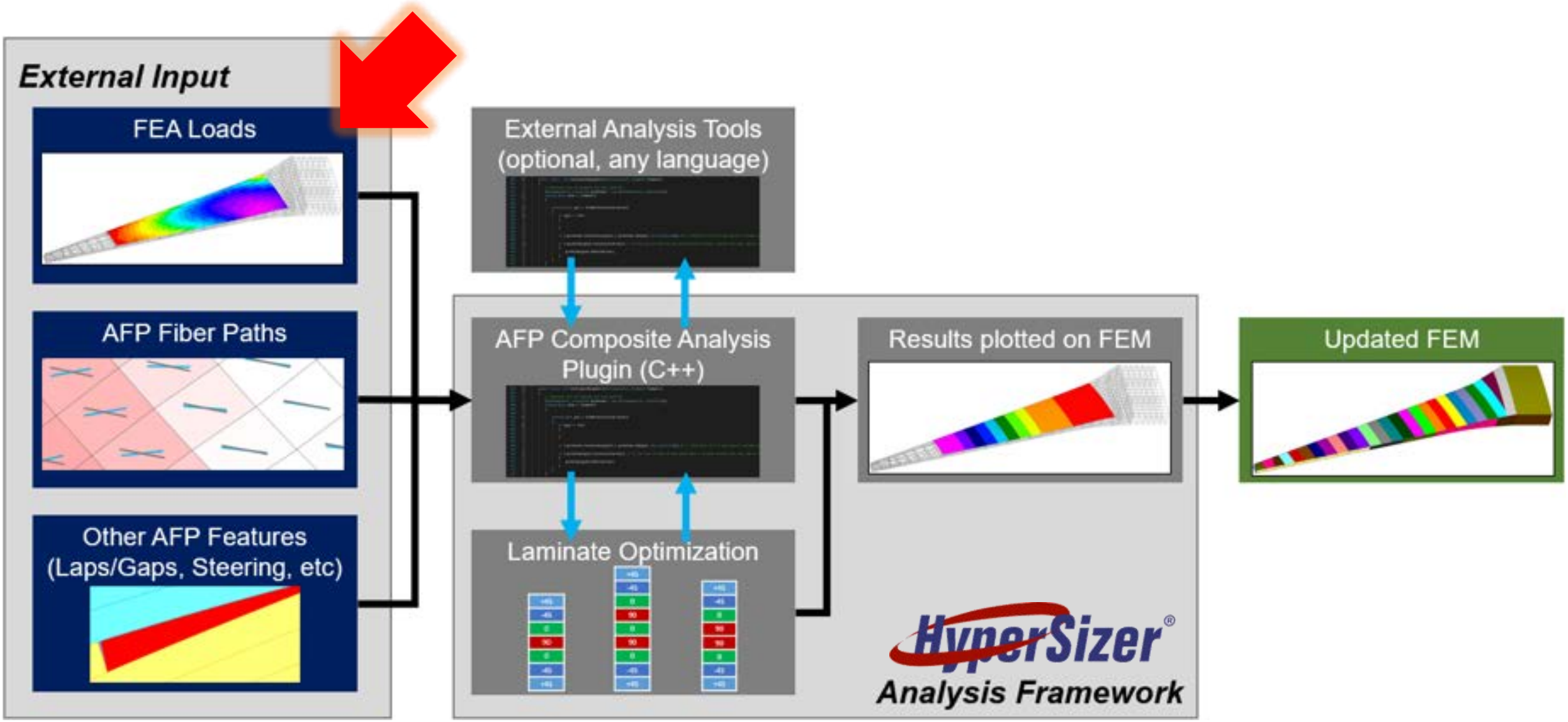




AFP Stress Analysis Framework



AFP Stress Analysis Framework



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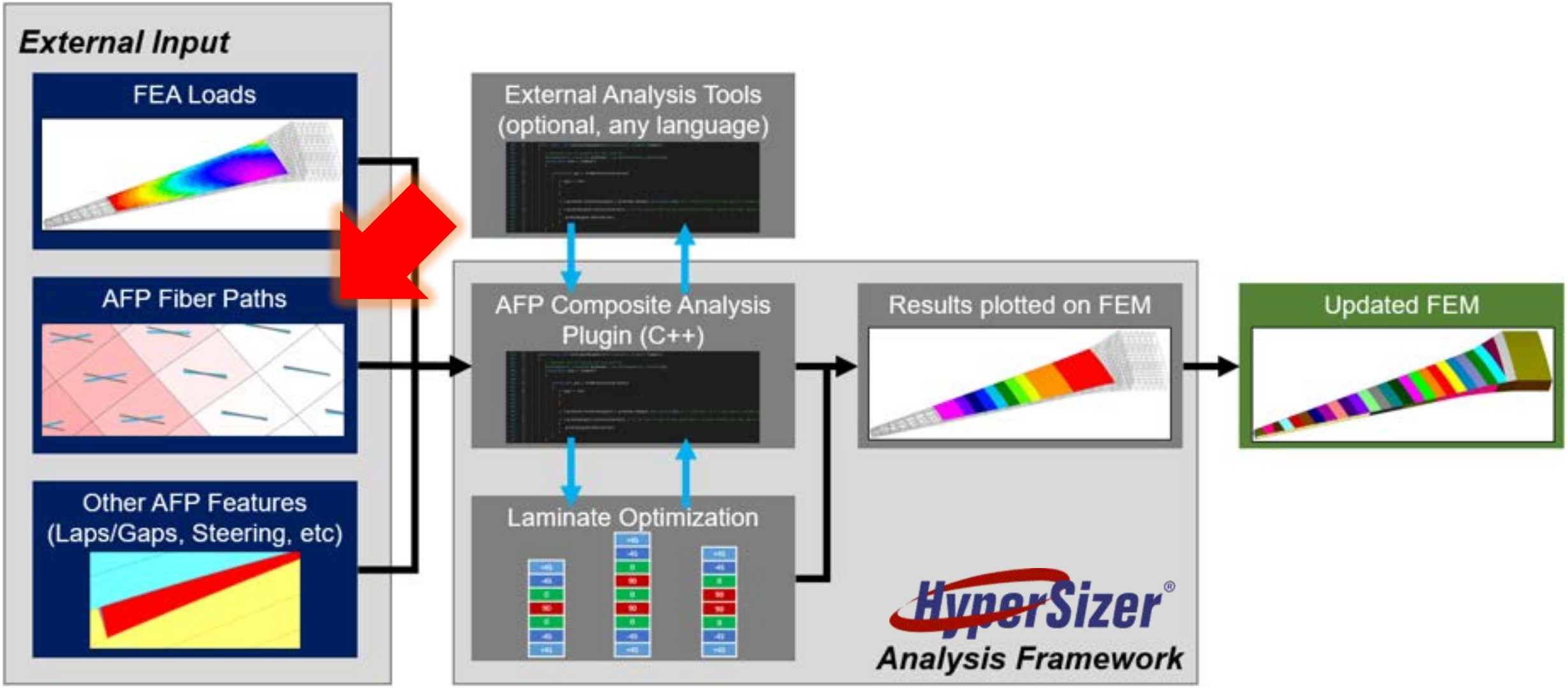

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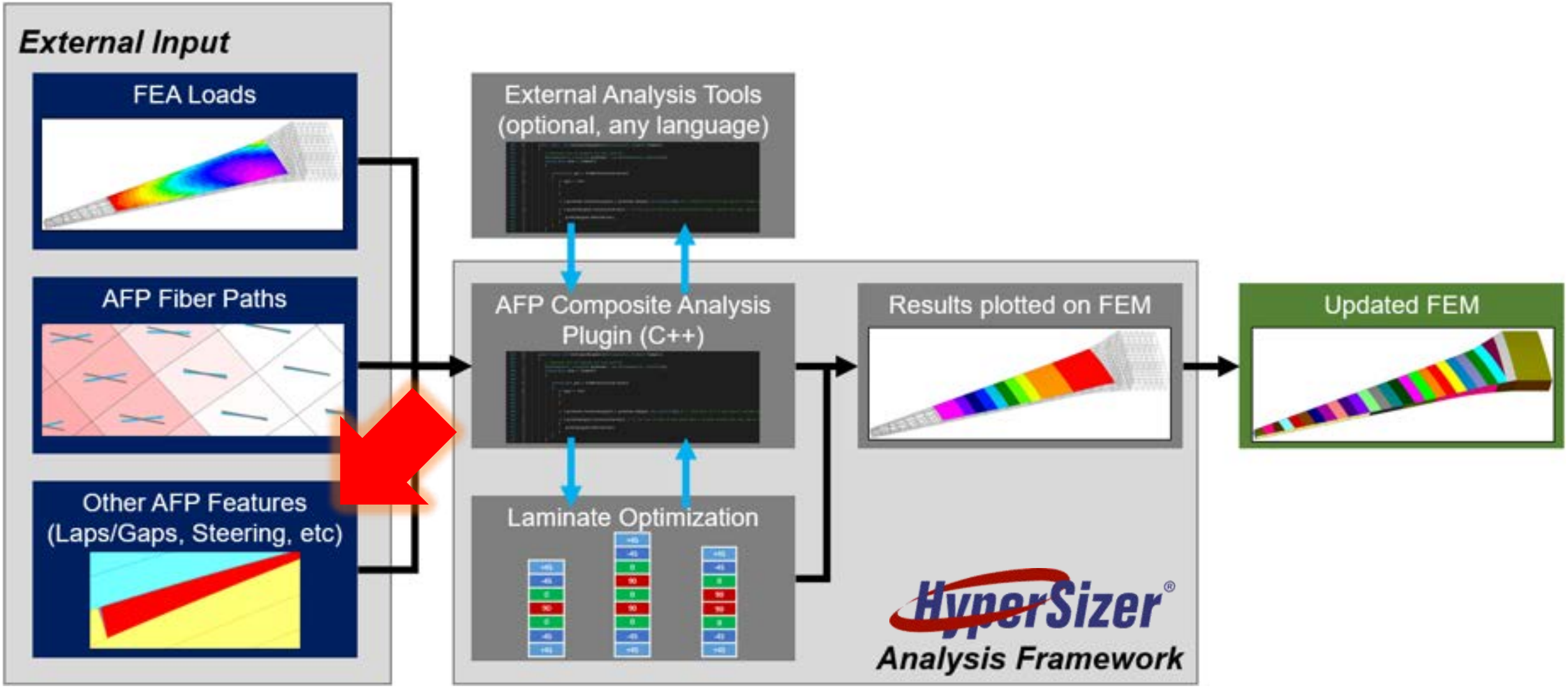

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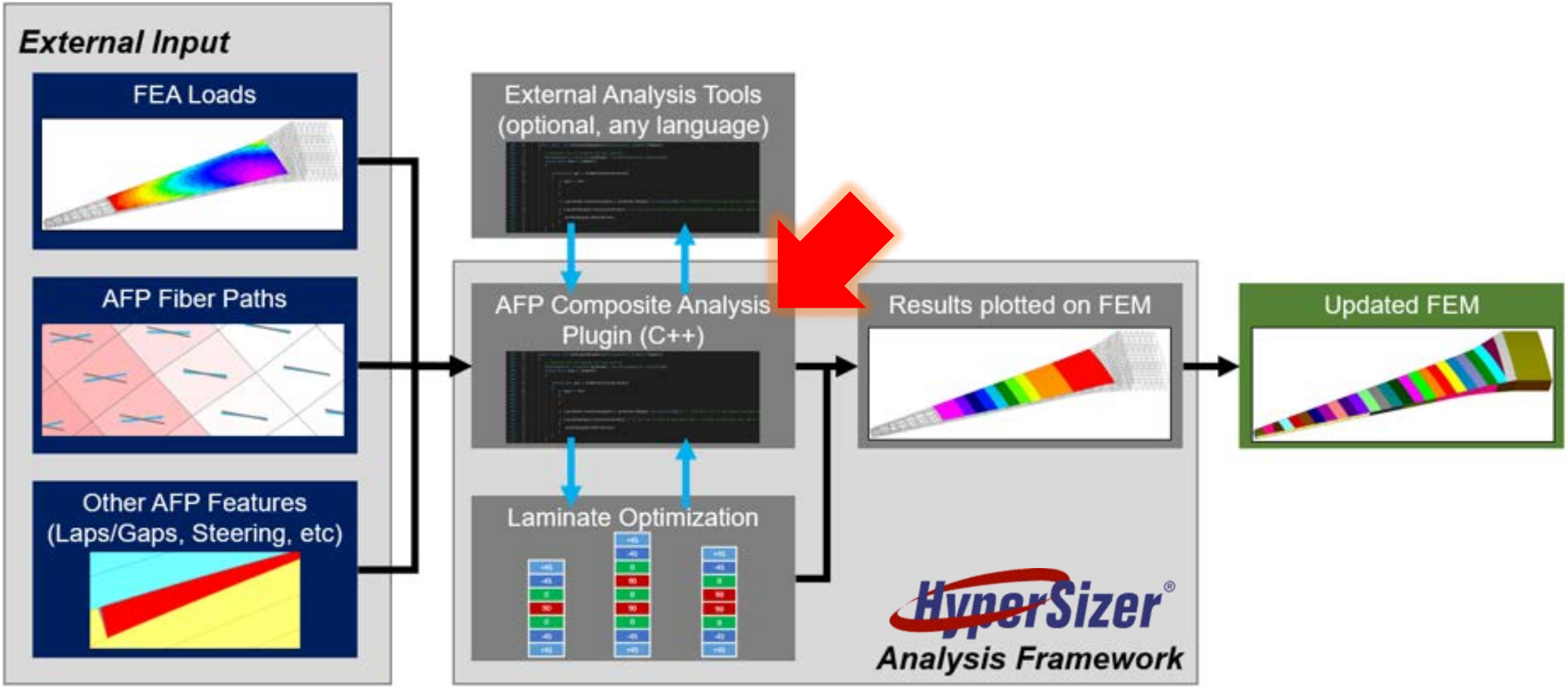

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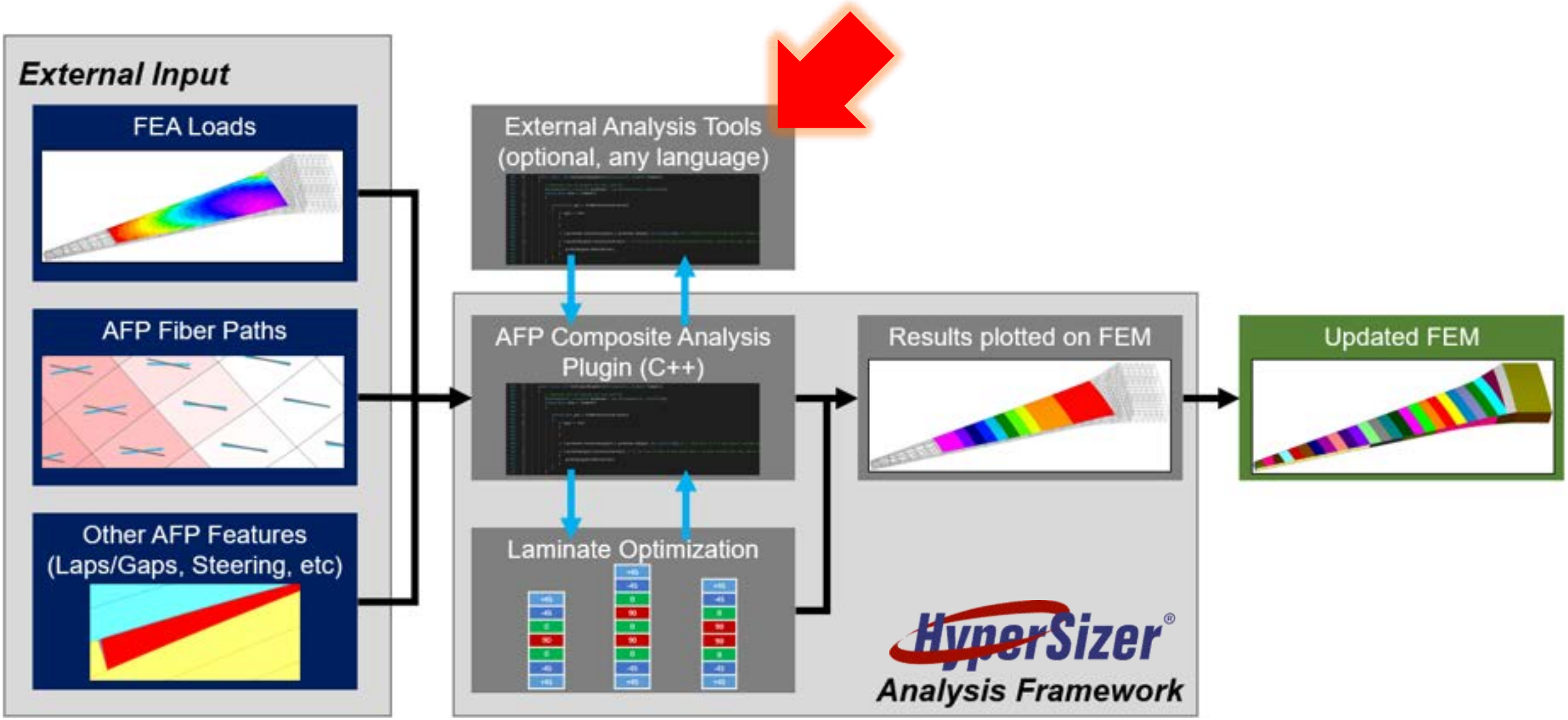
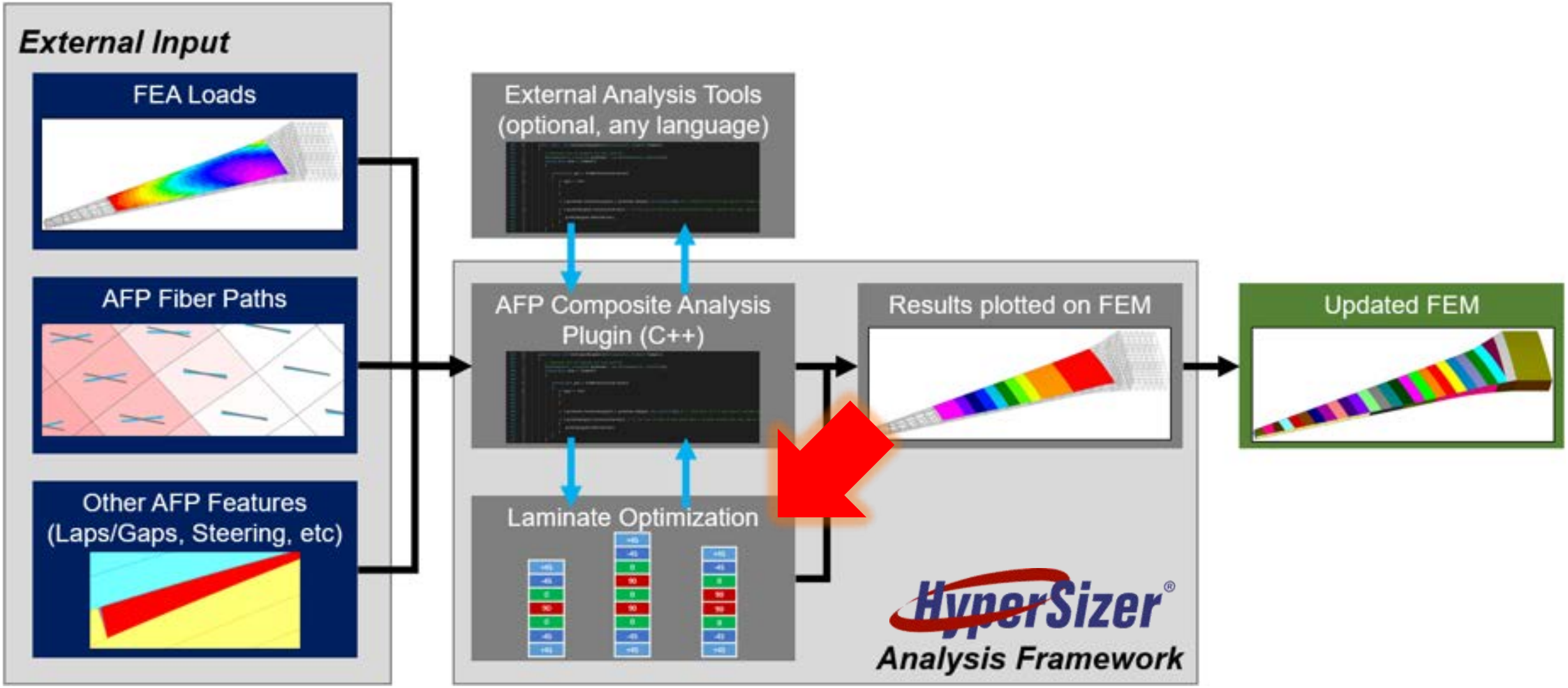


Examples of Stress Analysis with AFP Data

- As-manufactured fiber directions
  - Ply-by-ply analysis (Tsai-Wu, Tsai-Hahn, etc)
  - Laminate-based approaches
    - AML-type
    - Principle stress
- Laps and gaps
  - Ply thickness reduction
  - Local breakout models
- Other effects of defects analyses
  - Knockdowns for tape wrinkles
  - Knockdowns for porosity

AFP Stress Analysis Framework



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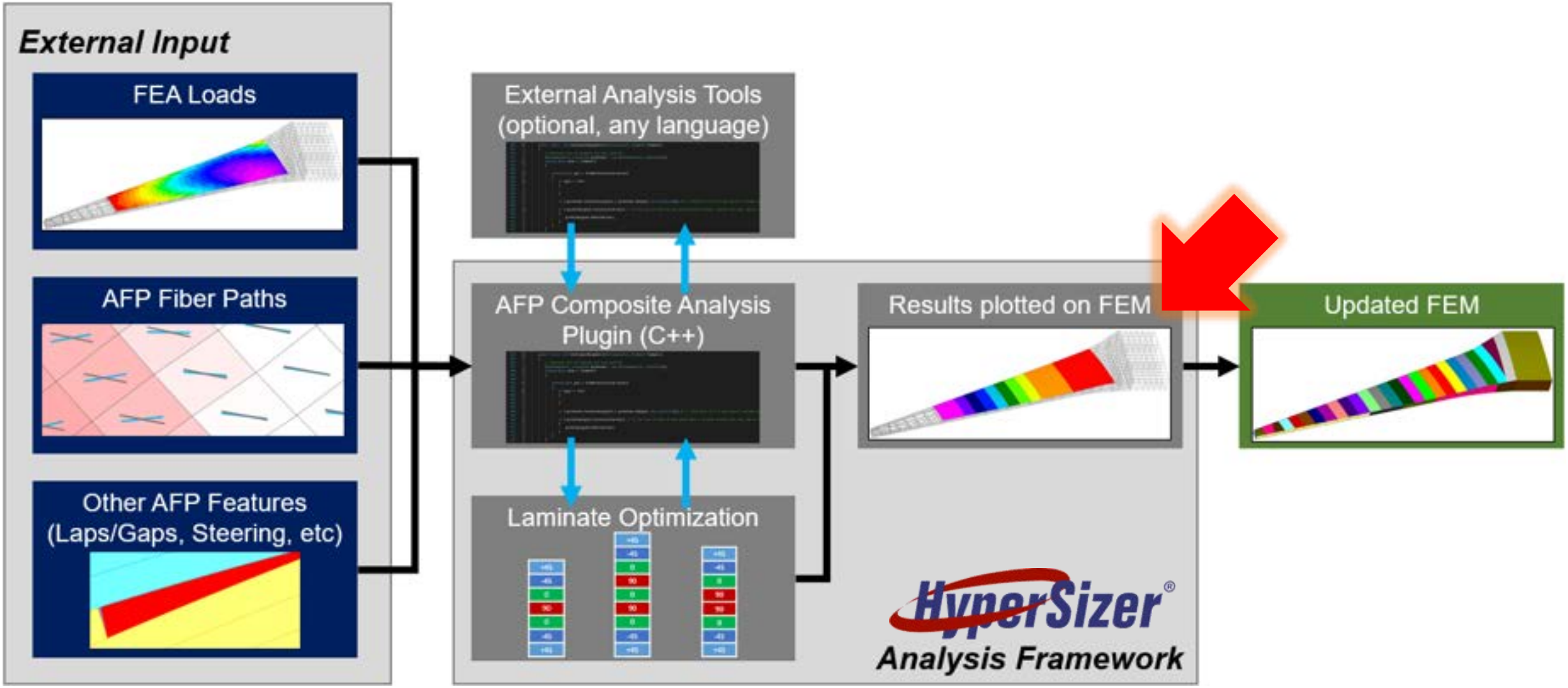

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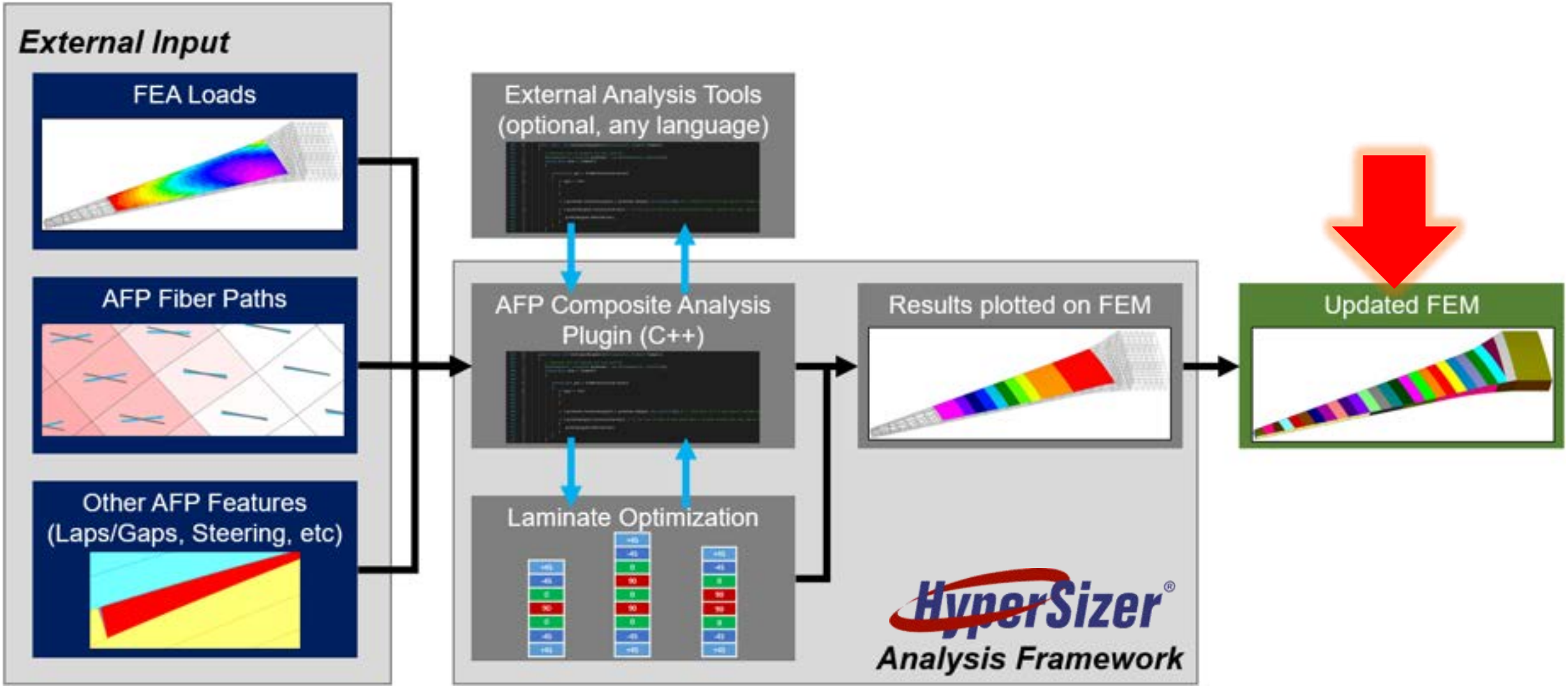

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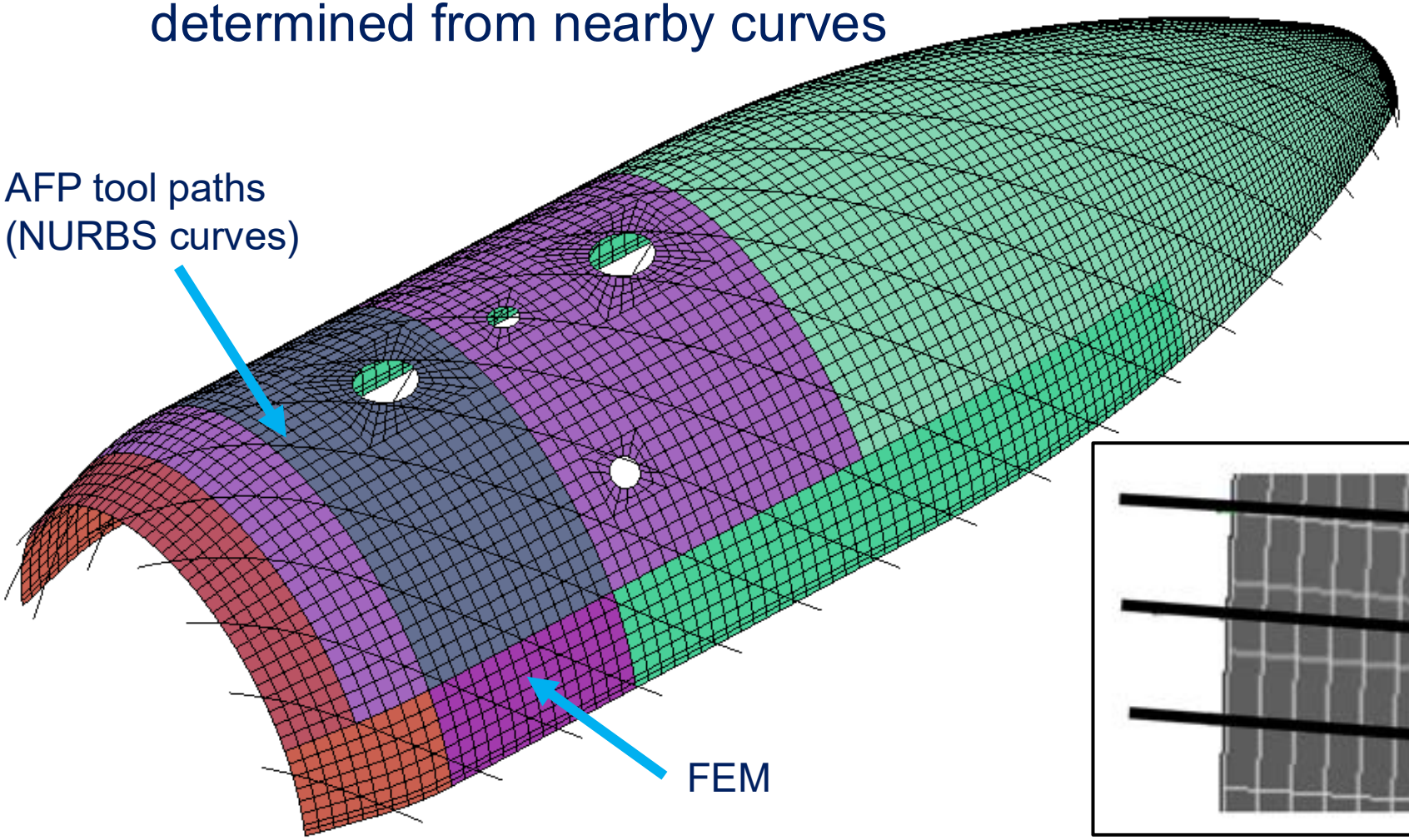
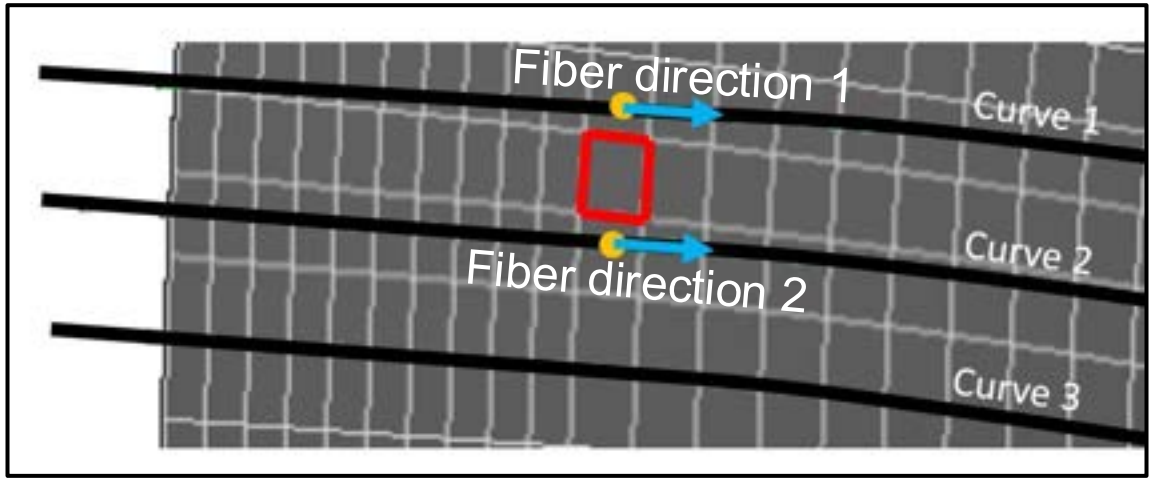
Import and Mapping of CAD AFP Paths

- CAD imported and overlaid on FEM model
- Fiber directions on each element determined from nearby curves



For each element
- Find 2 closest curves
- Project element centroid onto each curve
- Extract tangent vectors
- Average tangent vectors



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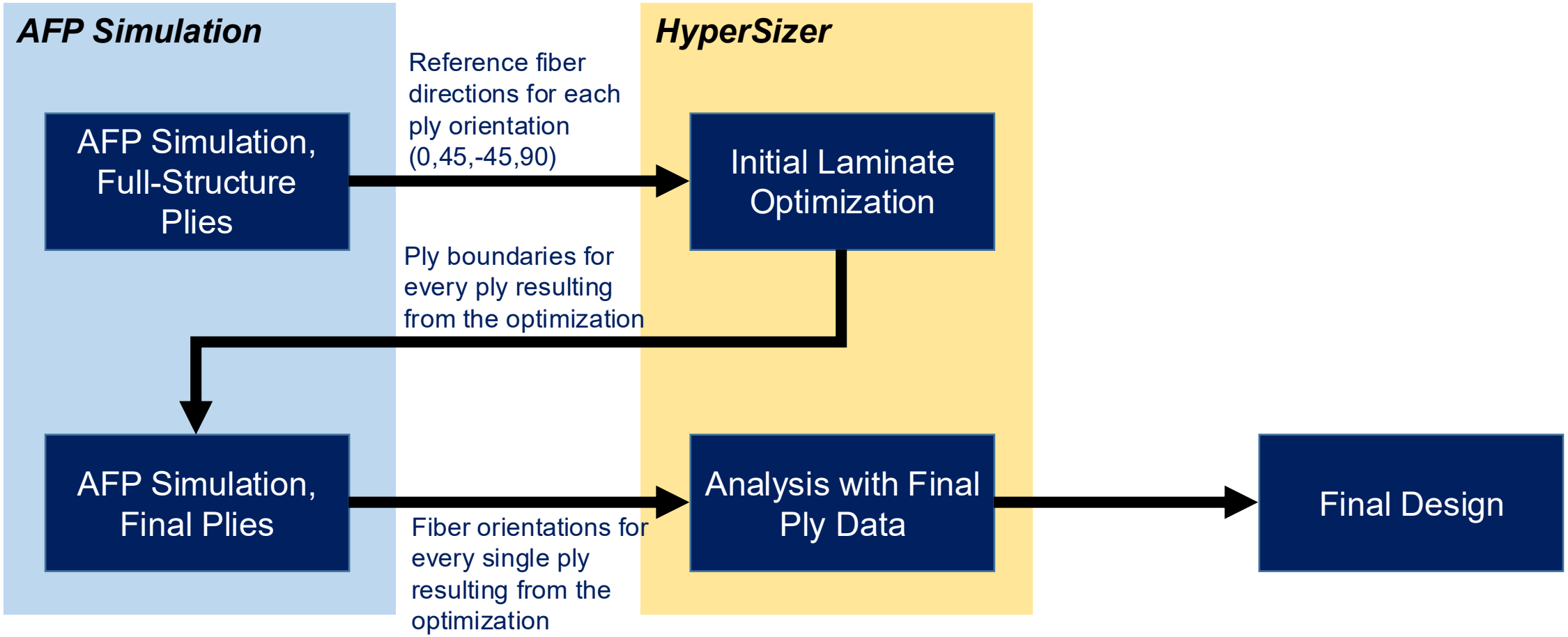
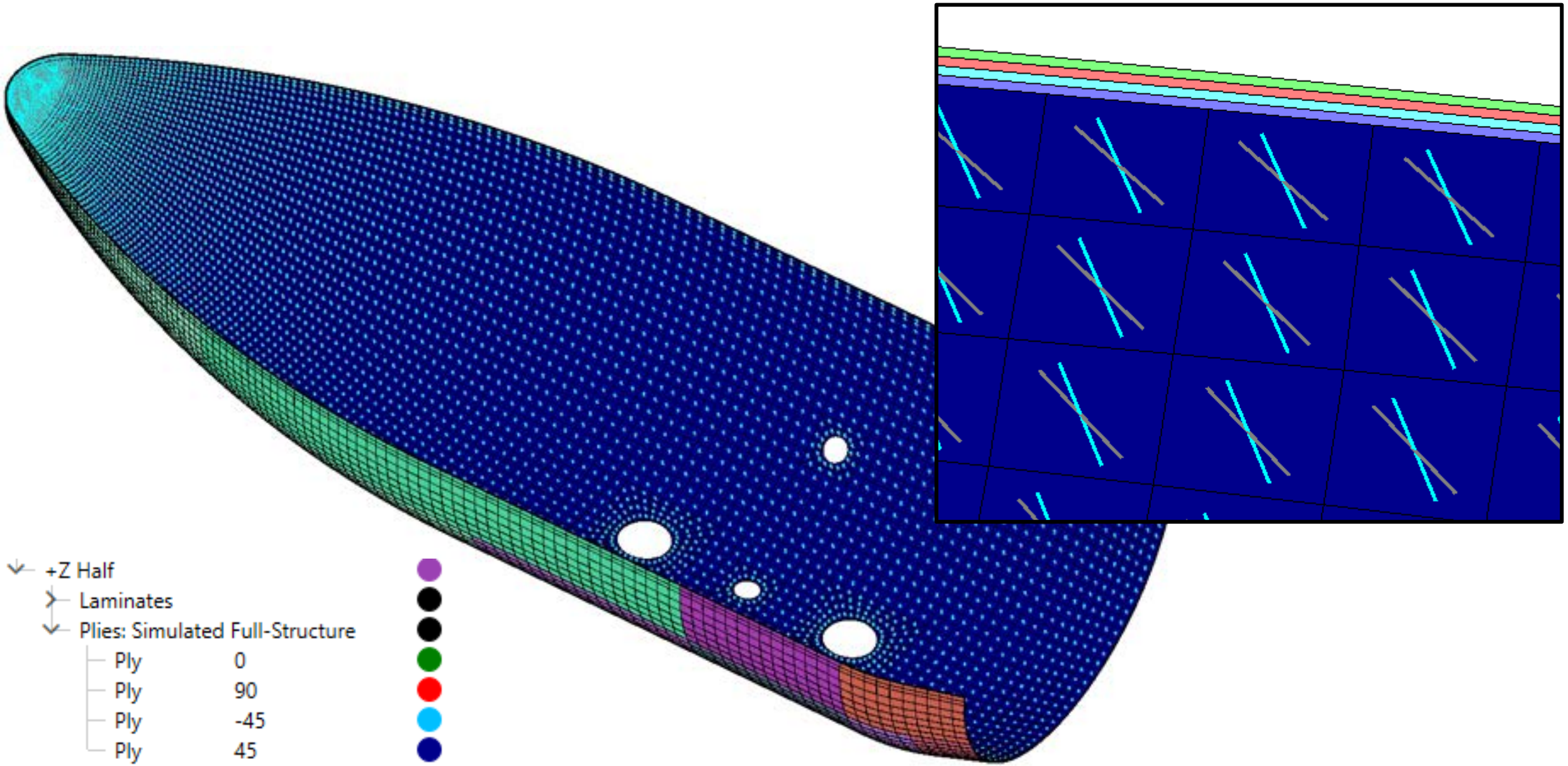
Optimization with As-Manufactured Fiber Directions

HyperSizer®

- Challenge:
  - AFP fiber directions are path dependent
  - Paths will vary depending on ply position and size on structure
  - This requires paths to be regenerated in every step of the laminate optimization
    - Can be very time-consuming
- Approach:
  - Generate “full-structure” simulation plies for each ply orientation
  - The laminate optimization references these fiber paths during iterations
    - No path simulation is rerun during optimization
  - Once the optimization is complete:
    - Export final ply boundaries
    - Rerun path simulation for final plies
    - Reimport final paths and assess strength and buckling margins

Optimization with As-Manufactured Fiber Directions




+Z Half
Laminates
Plies: Simulated Full-Structure
Ply 0
Ply 90
Ply -45
Ply 45

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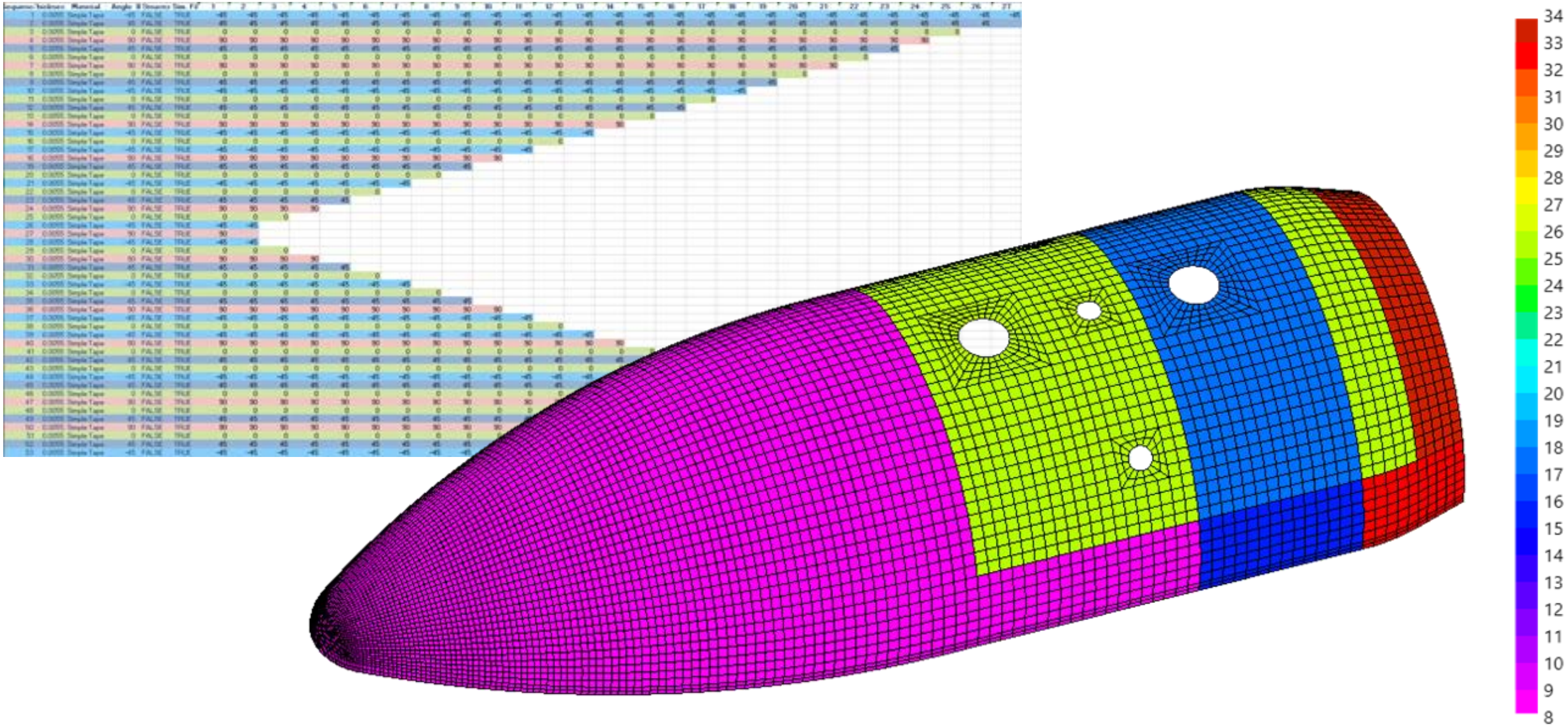
Initial Optimization, FEM-Based Fiber Directions

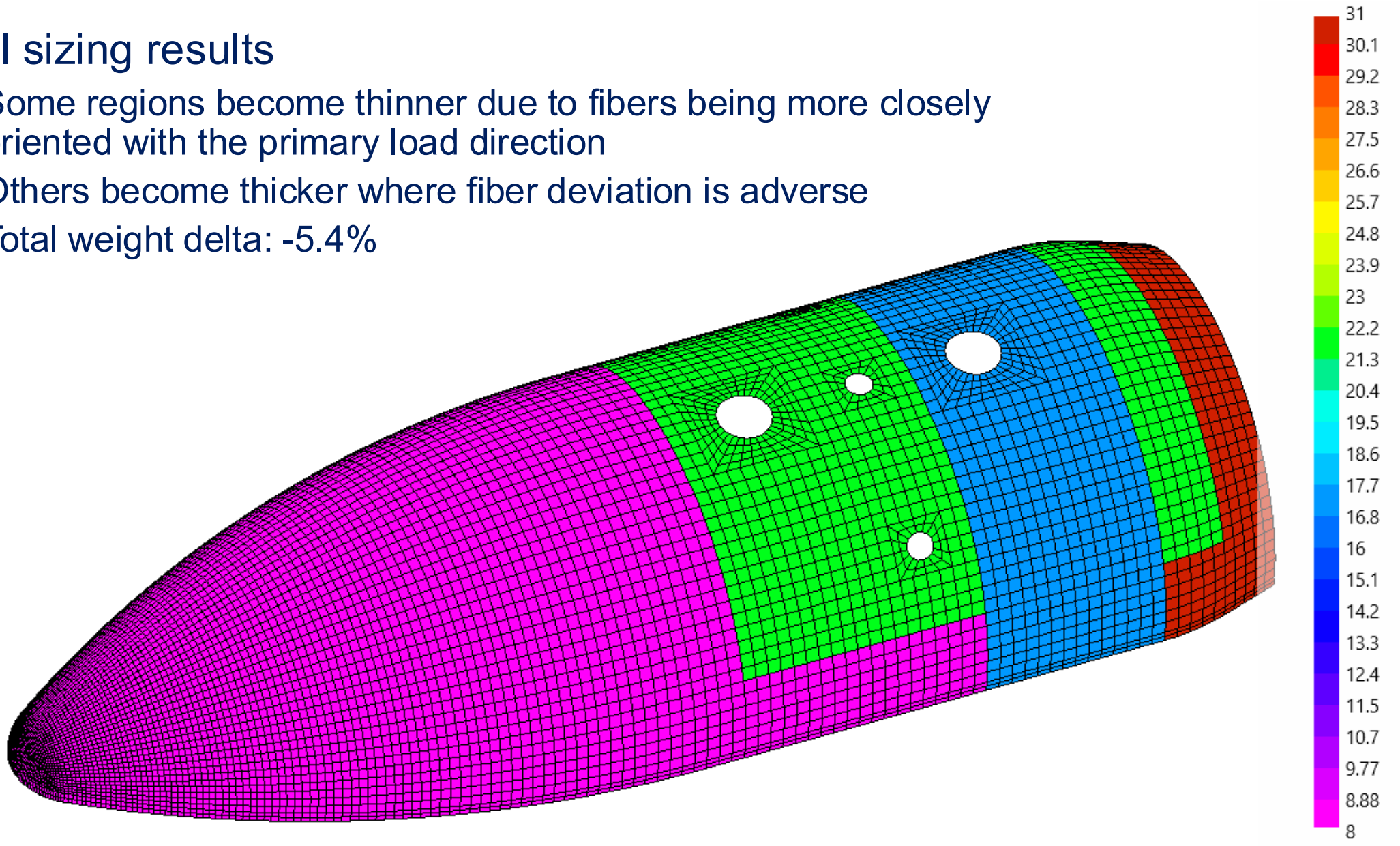
HyperSizer®

Laminate family generated and used in sizing



Final Sizing Results

- Final sizing results
  - Some regions become thinner due to fibers being more closely oriented with the primary load direction
  - Others become thicker where fiber deviation is adverse
  - Total weight delta: -5.4%



Thank you for your attention!