Integration of Structural Analysis and Manufacturing Process Planning for Global Optimization with Automated Fiber Placement

August Noevere
Collier Aerospace

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Co-Authors:
Von Jamora, Collier Aerospace
Ramy Harik, University of South Carolina

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Conference & Exhibition

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Background and Introduction

Software Integration

Optimization Approaches

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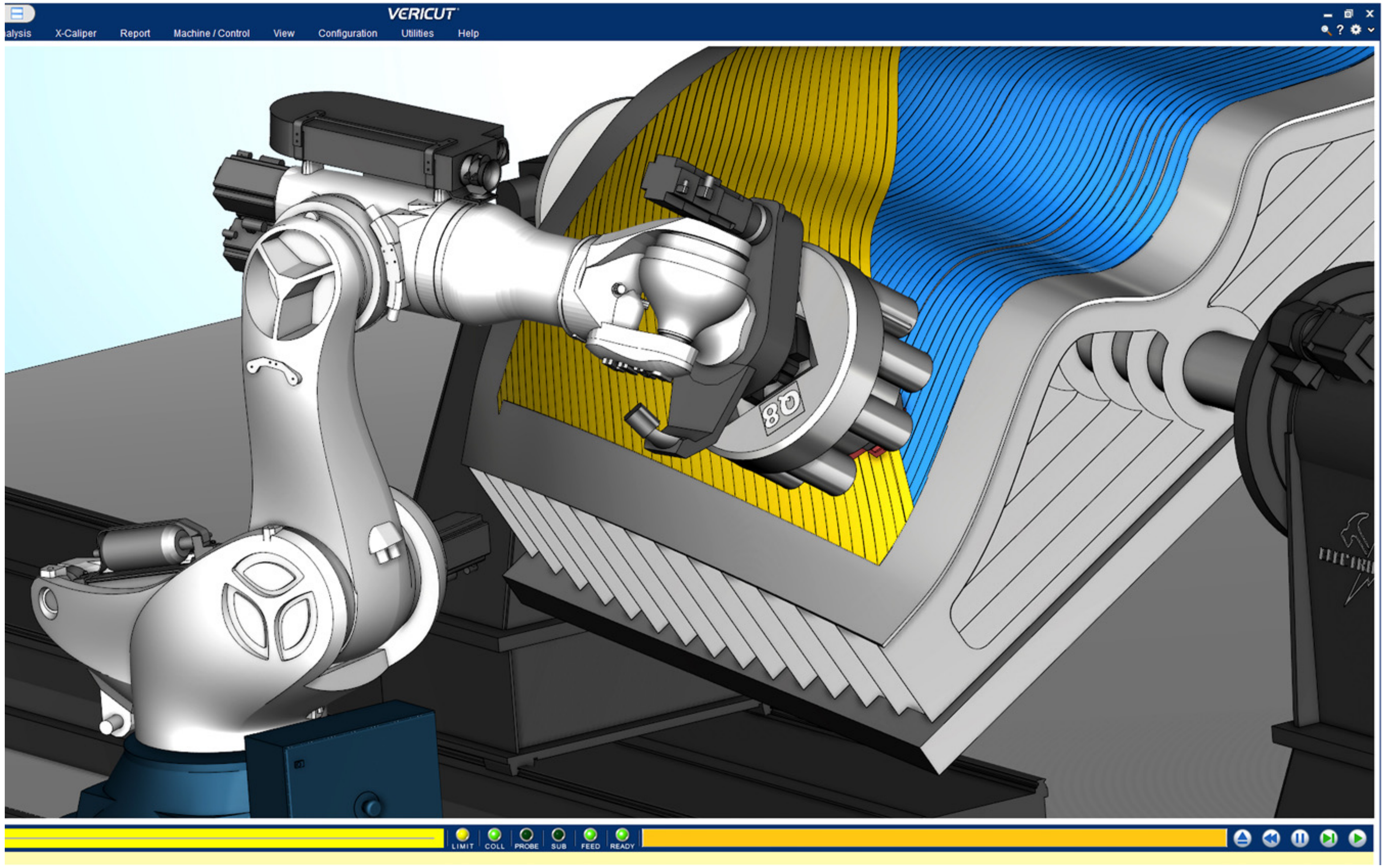
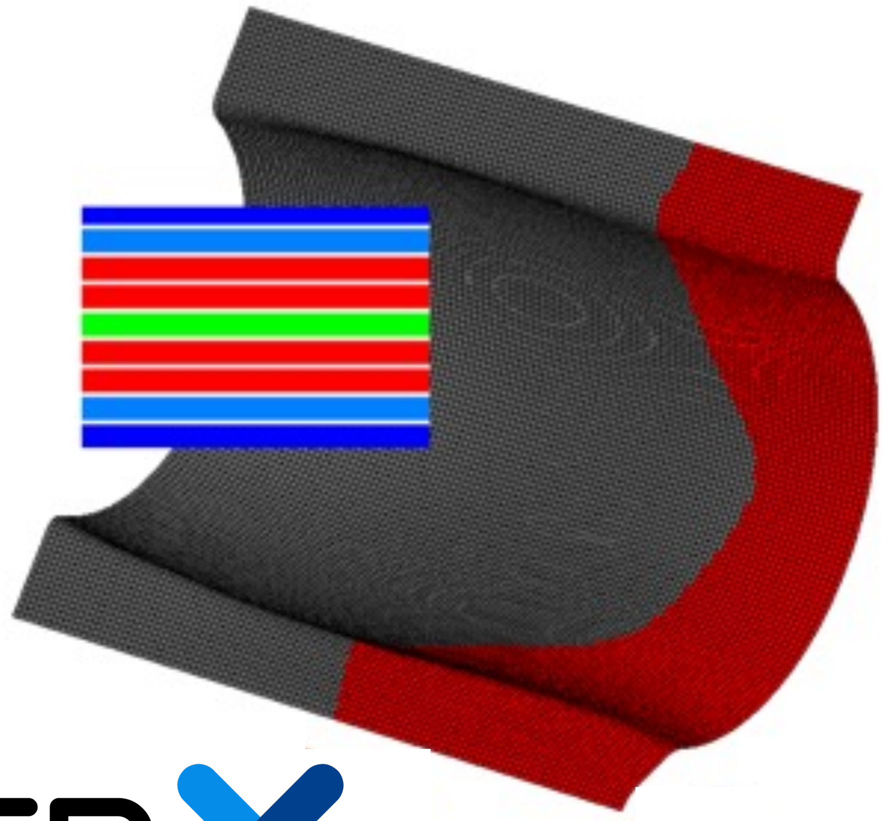
Introduction

- NASA's Hi-Rate Composite Aircraft Manufacturing (**HiCAM**) project is focused on addressing an aviation industry need for more rapid production of composite aircraft to meet increasing global demand for lightweight transport aircraft.
- Much of the technology being considered in HiCAM uses Automated Fiber Placement (**AFP**)
- The Design For Manufacturing (**DFM**) HiCAM task is focused on development of software to optimize AFP structures for weight and manufacturability

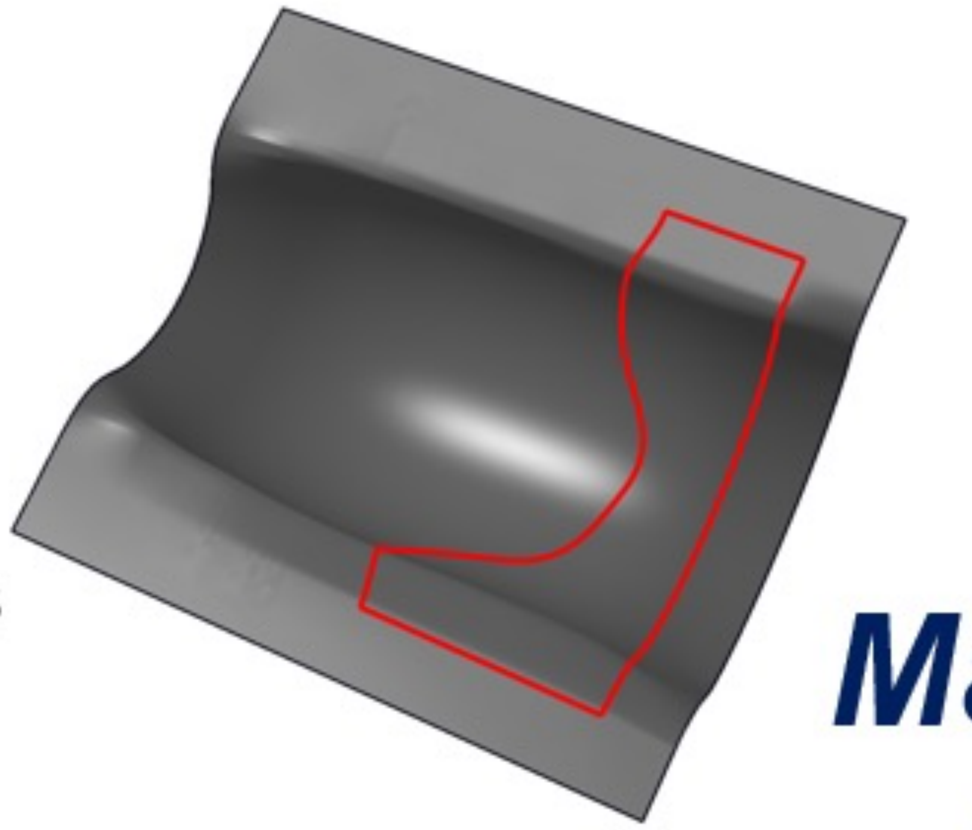


Background: HiCAM Design for Manufacturing (DFM) Project



HYPERX

Optimized ply shapes, counts, and orientations

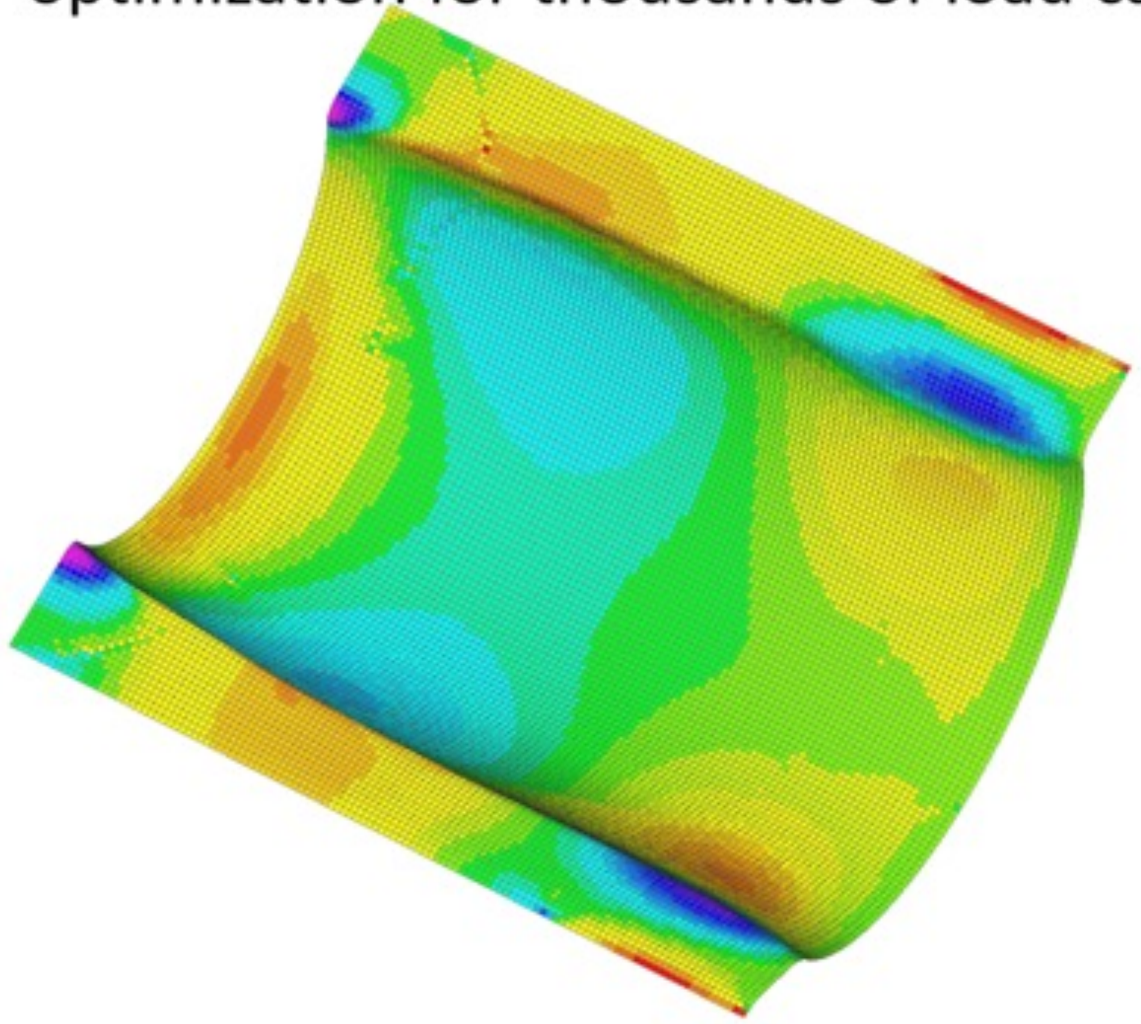


AFP Manufacturing Simulation

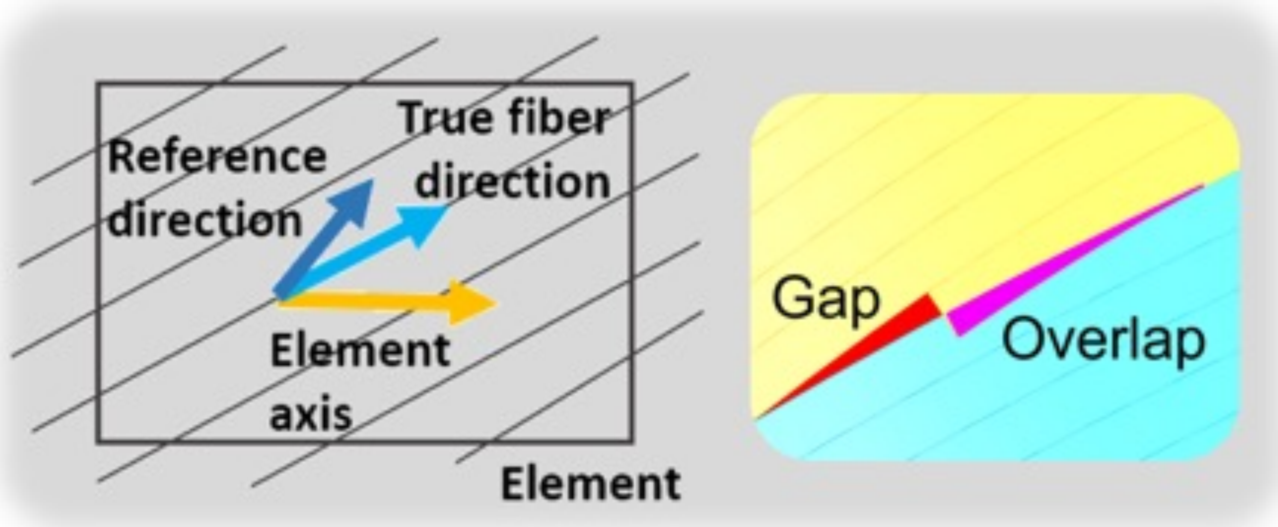
Stress analysis and laminate optimization for thousands of load cases

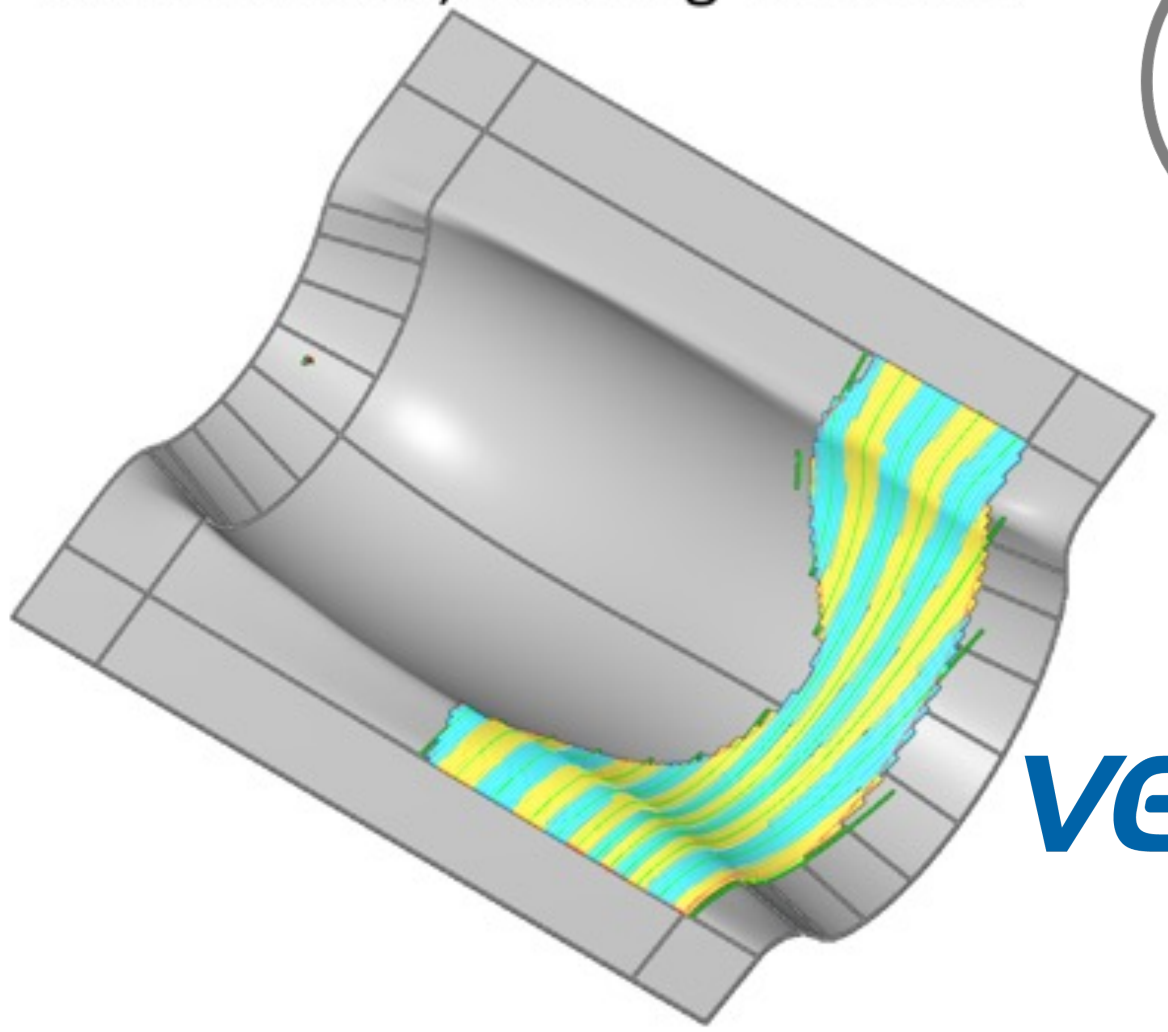
Tow path generation, lap/gap identification, steering violations

CAPP



Mapped AFP data

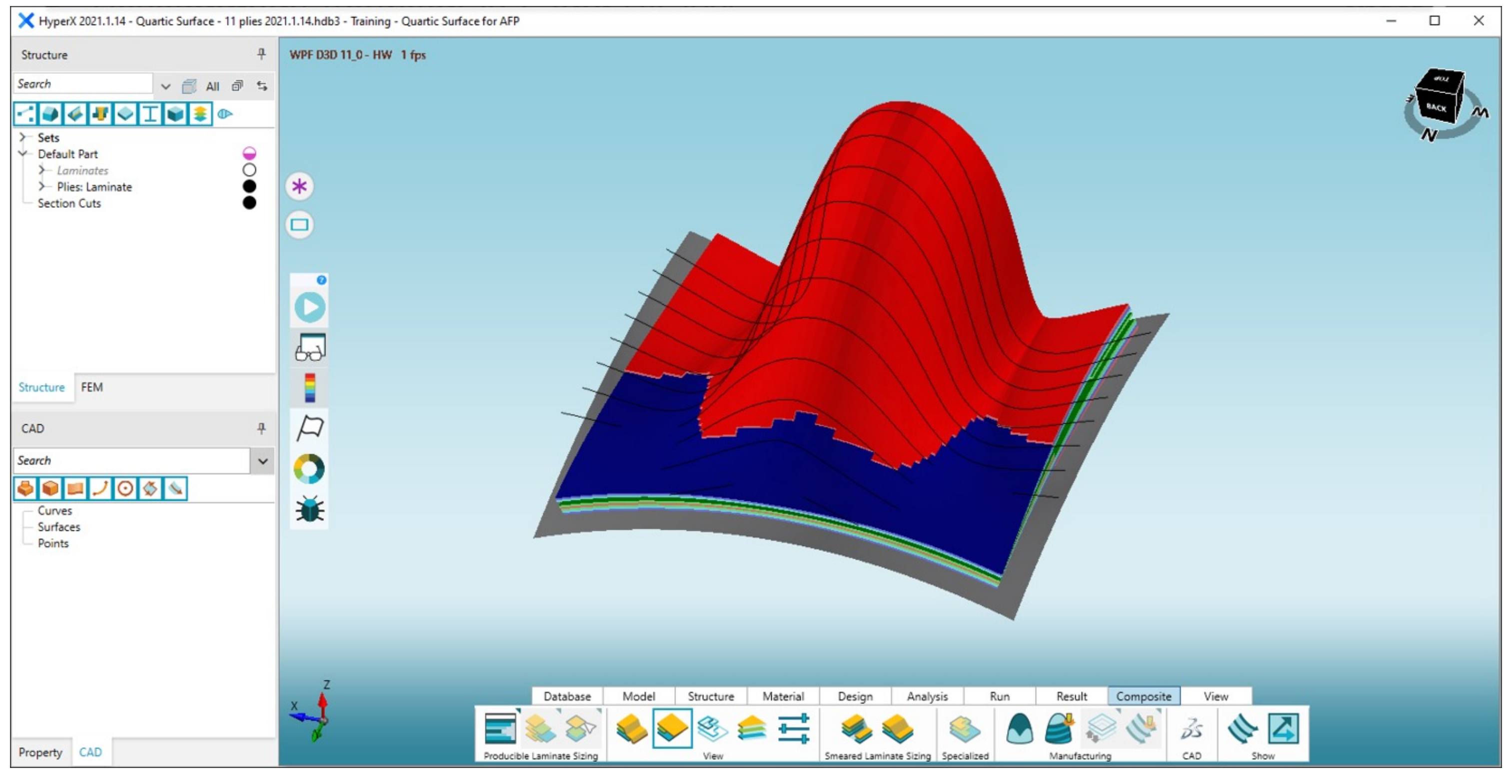




VERICUT® Composite Applications

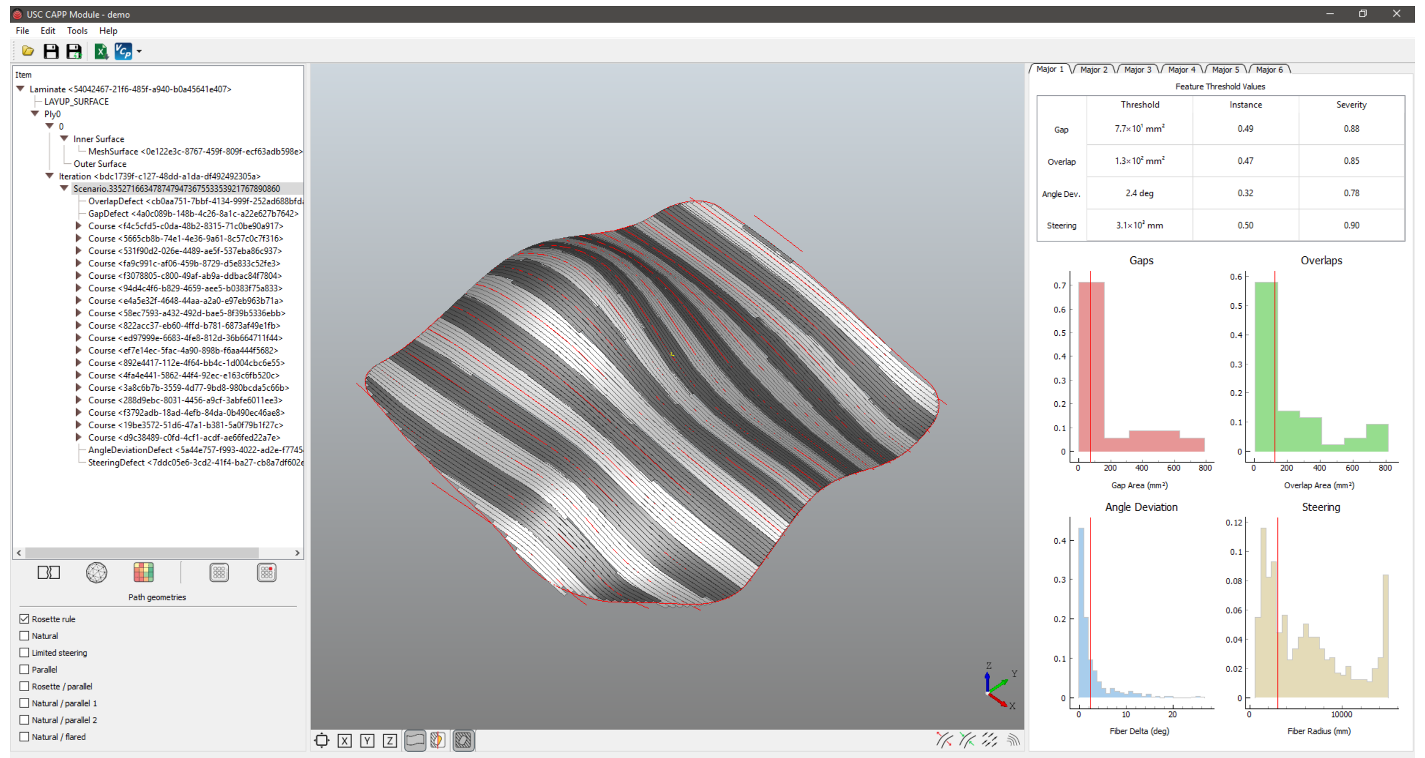
Overview of DFM Software

HyperX performs stress analysis and composite optimization for thousands of load cases and a variety of failure criteria. Generates optimized ply shapes, stacking sequences, and ply counts.



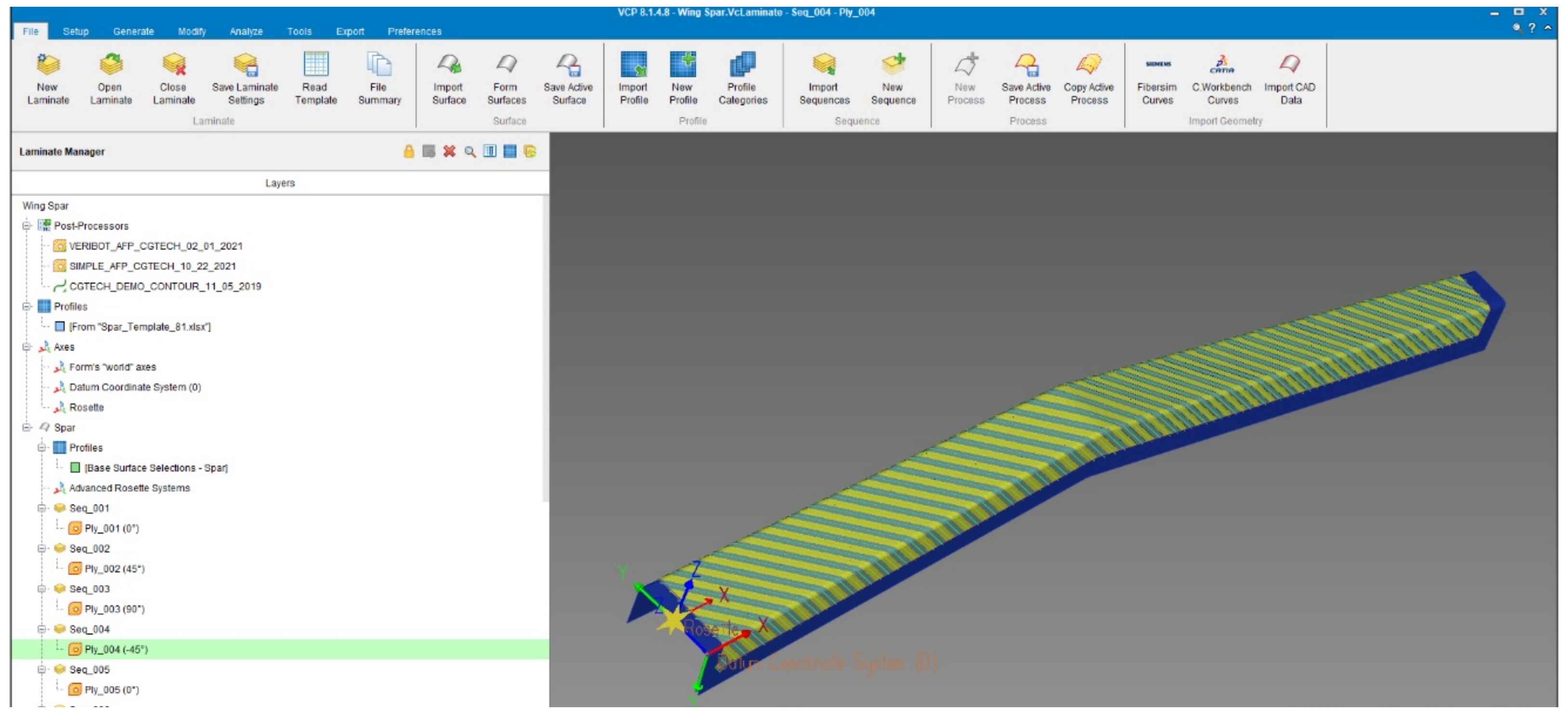
CAPP

The Computer Aided Process Planning (CAPP) software automates process planning functions within AFP. Combining the automation with optimization schemes reduces the occurrence of geometry related fiber defects throughout a laminate.



VERICUT® Composite Applications

Vericut Composites Programming (VCP) provides a suite of path planning tools to generate machine motion for multiple composites processes. VCP also contains tools to analyze these processes as well as pass data for analysis to other software.



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Software Integration

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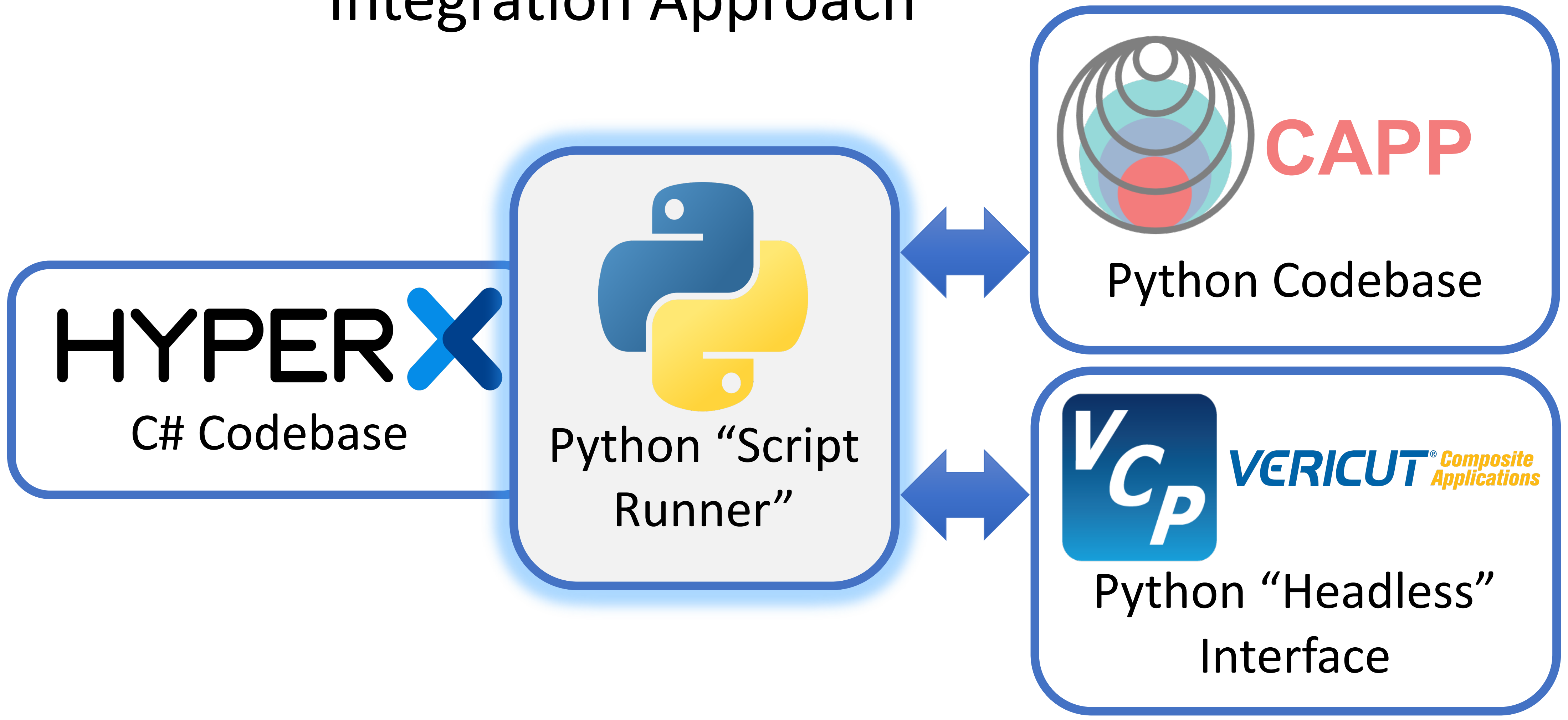
- Integration with the three software accomplished via Python scripting
- A native integration platform was developed on top of HyperX – the "Script Runner"
- Allows custom UI development and process automation for HyperX as well as external tools

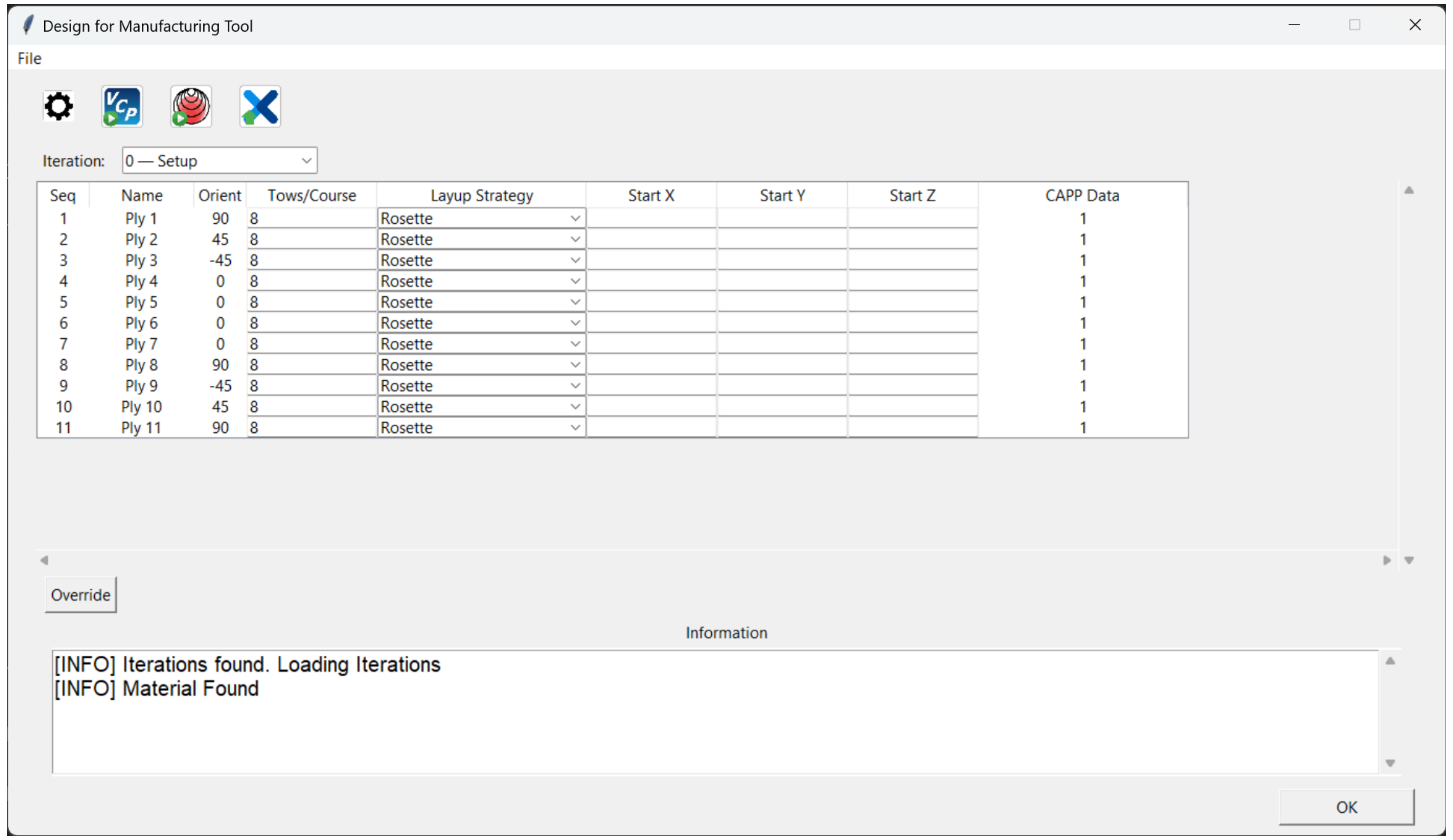
Integration Approach



Custom UI

Execute external tools

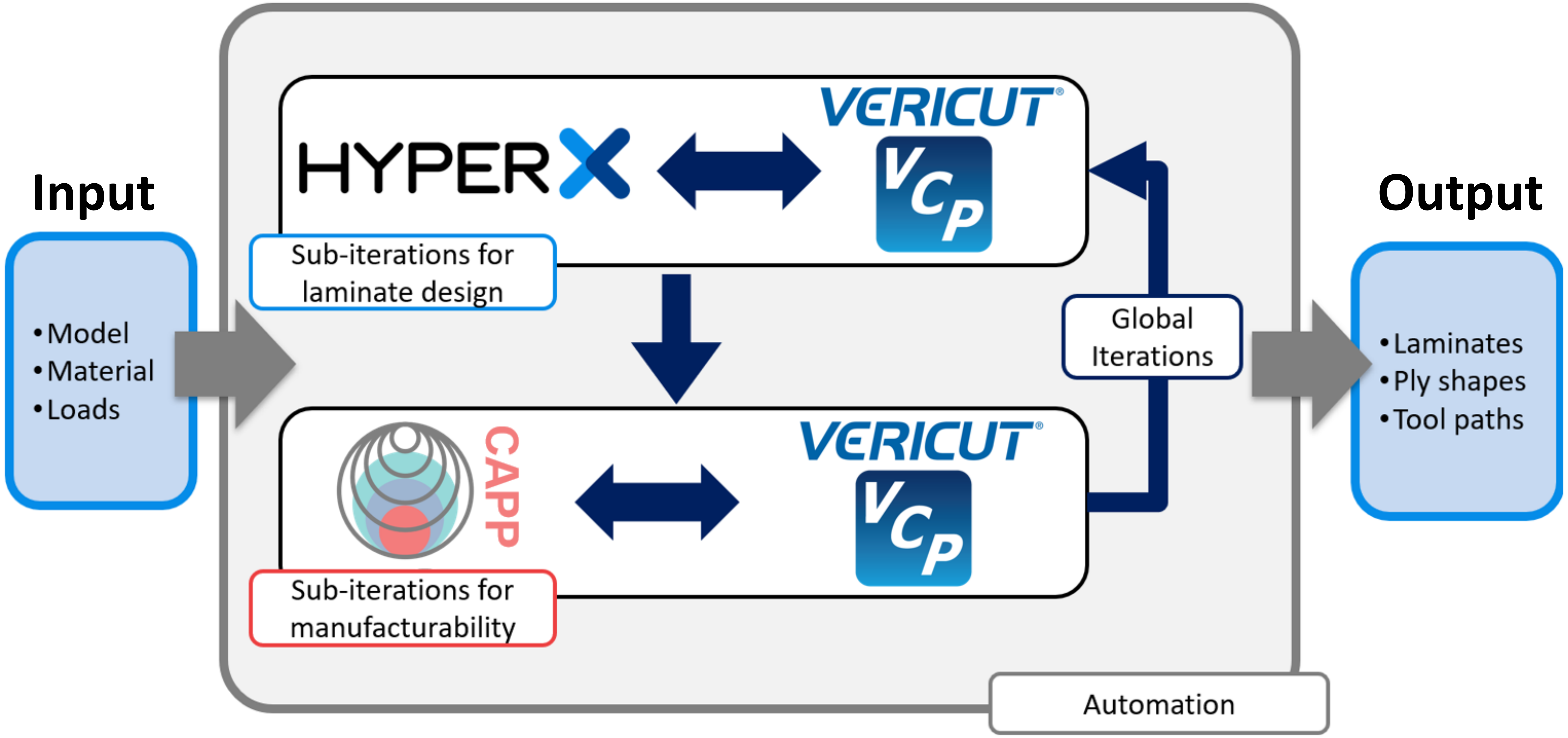
Plies



Outline

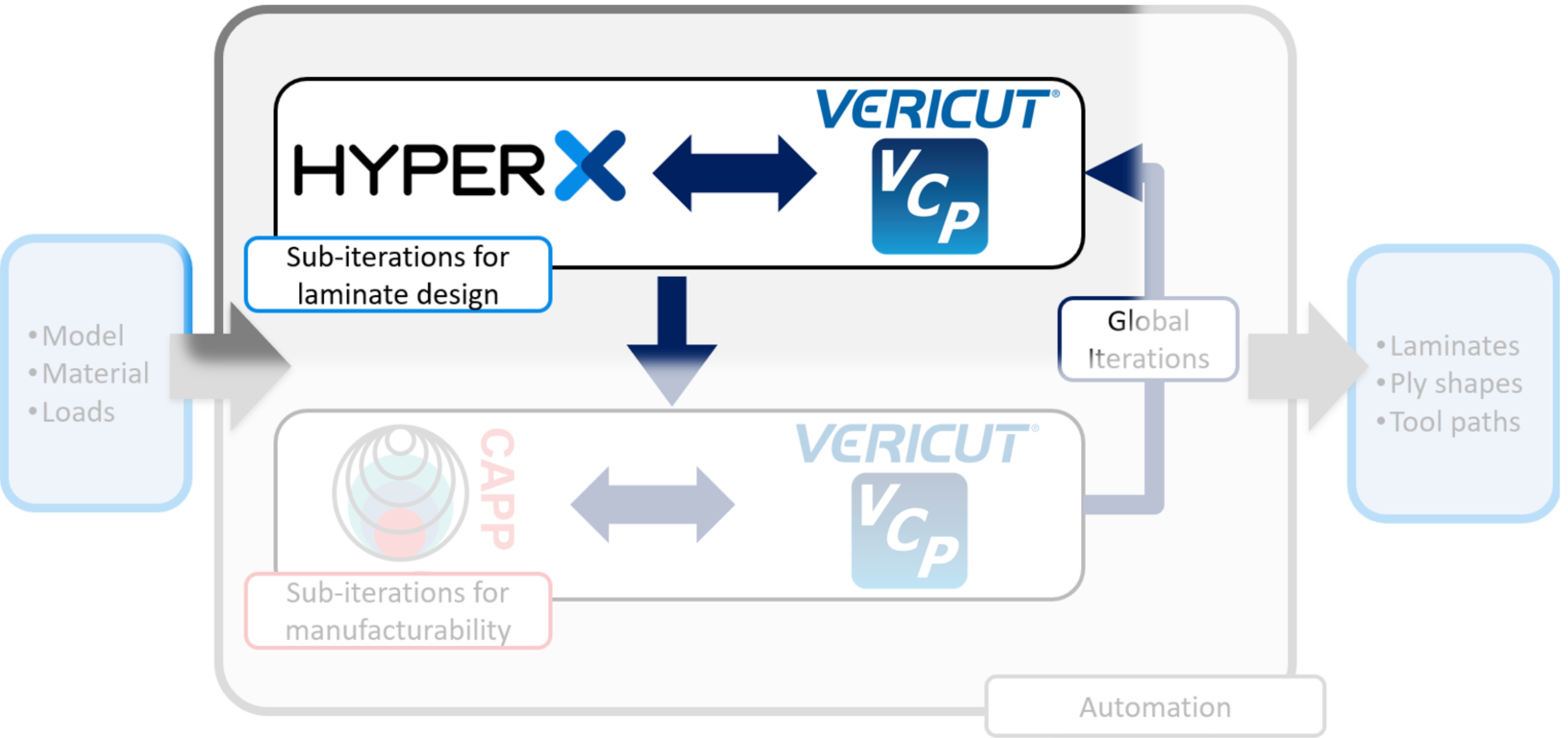
Overall Optimization Approach

- Objective: develop laminate design that satisfies both stress and manufacturing reqs.
- Bi-level strategy selected due to complexity and runtime of software involved
  - Lower level: HyperX and CAPP iterate with VCP to optimize for stress and manufacturing respectively
  - Upper level: global iterations to converge the solution

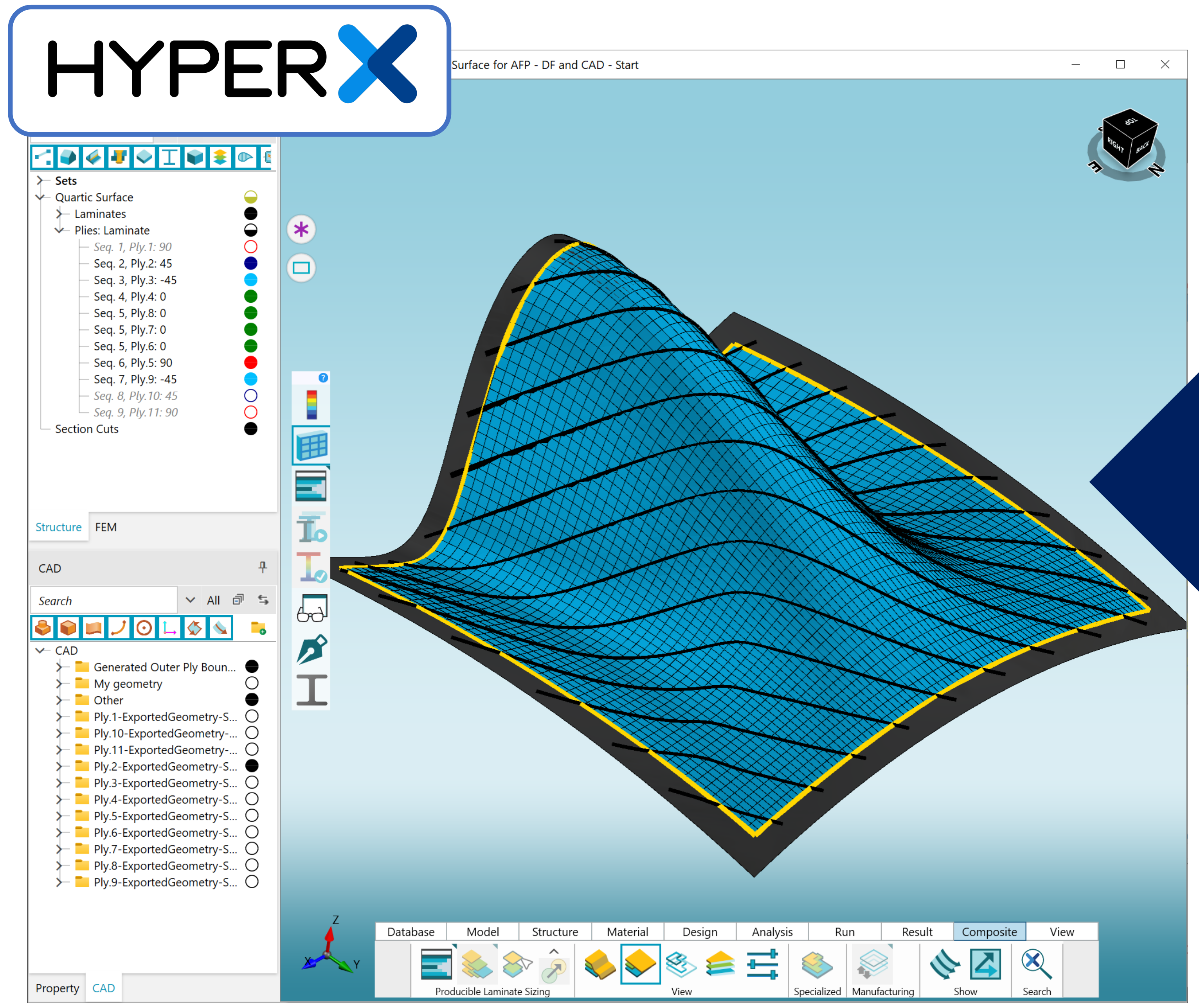


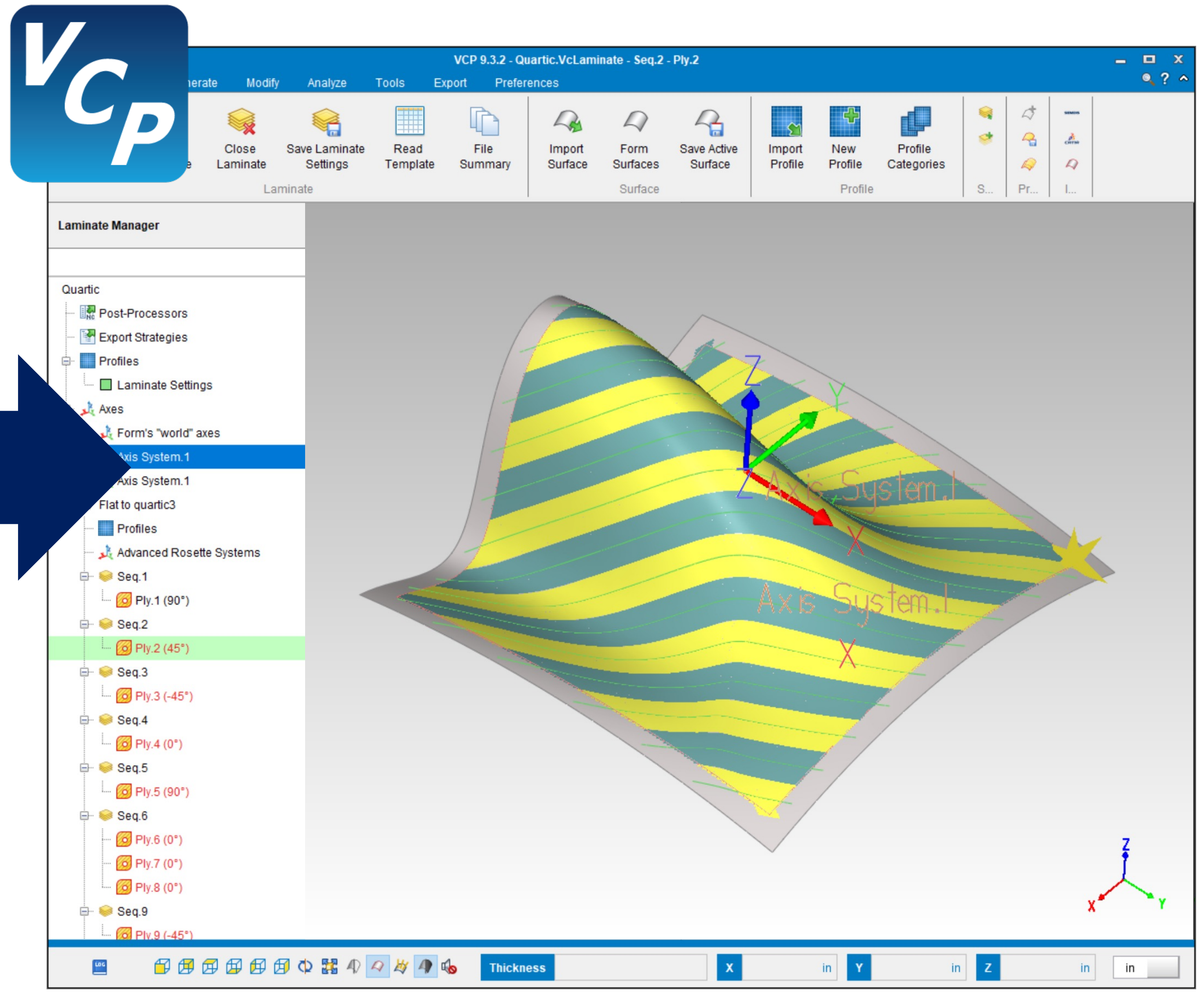
Overall Optimization Approach: HyperX-VCP

- Objective: get HyperX analysis sync'd up with as-manufactured fiber directions
- Initially, HyperX assumes fiber directions based on FEM material axis
- VCP provides accurate fiber directions for each ply and HyperX re-optimizes the laminate



Uses FEA loads to optimize ply shapes, counts, and orientations

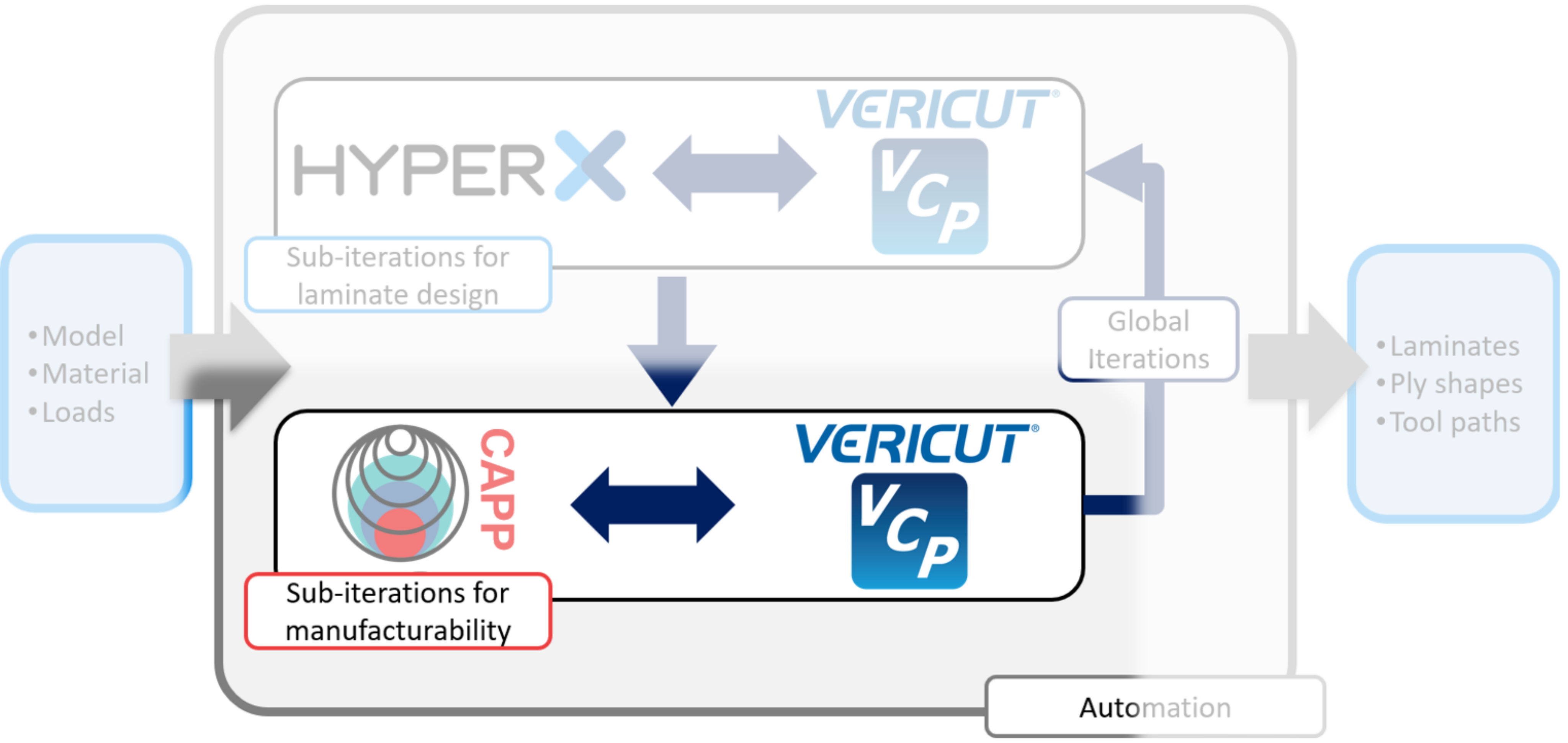




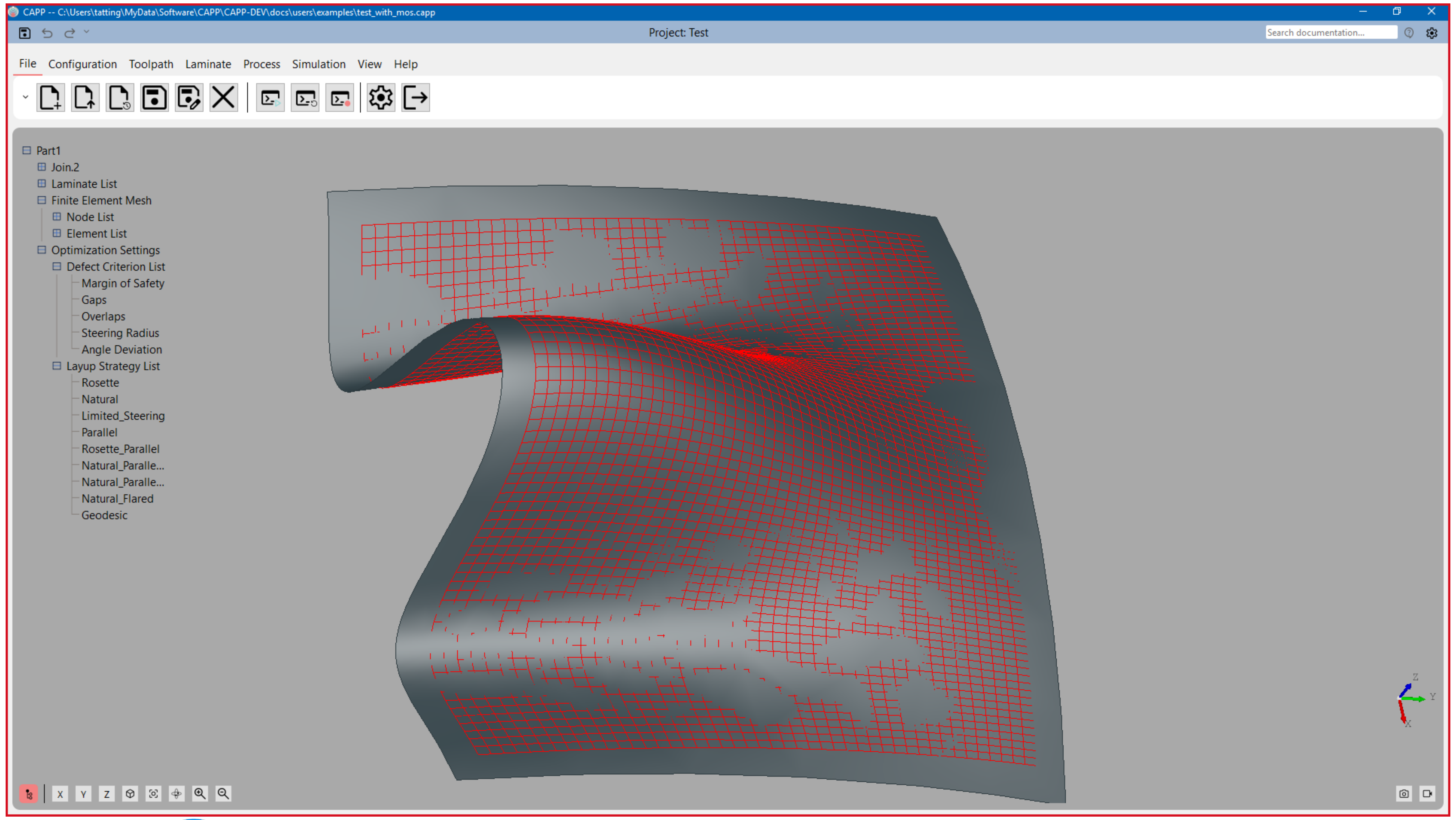
Generates tow paths on the tool surface within the prescribed ply boundaries

Overall Optimization Approach: CAPP-VCP

- The Computer Aided Process Planning (CAPP) software matchmakes the design and manufacturing parameters.
- The goal is to minimize the deviation between the as-manufactured and the as-designed structure..

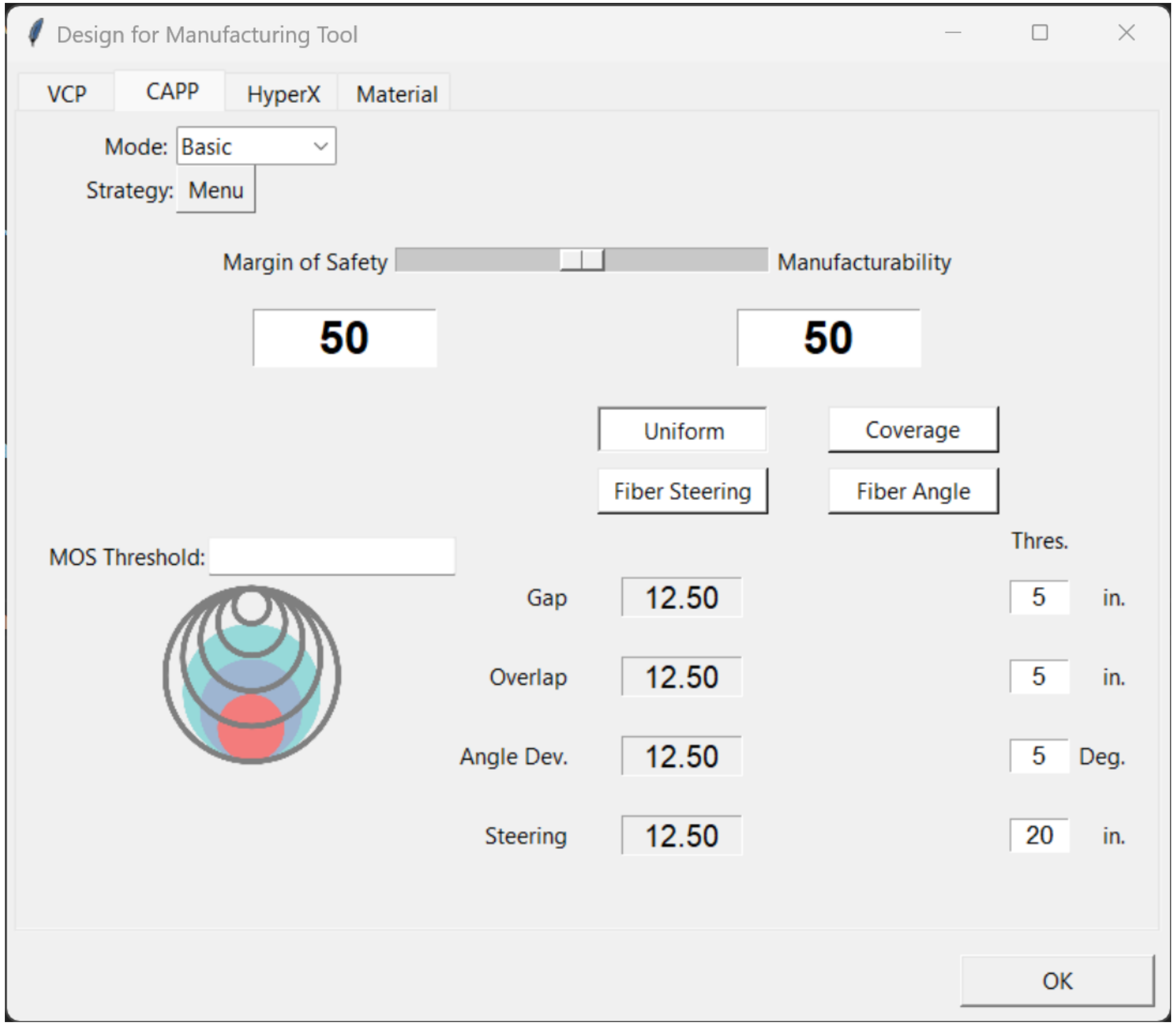


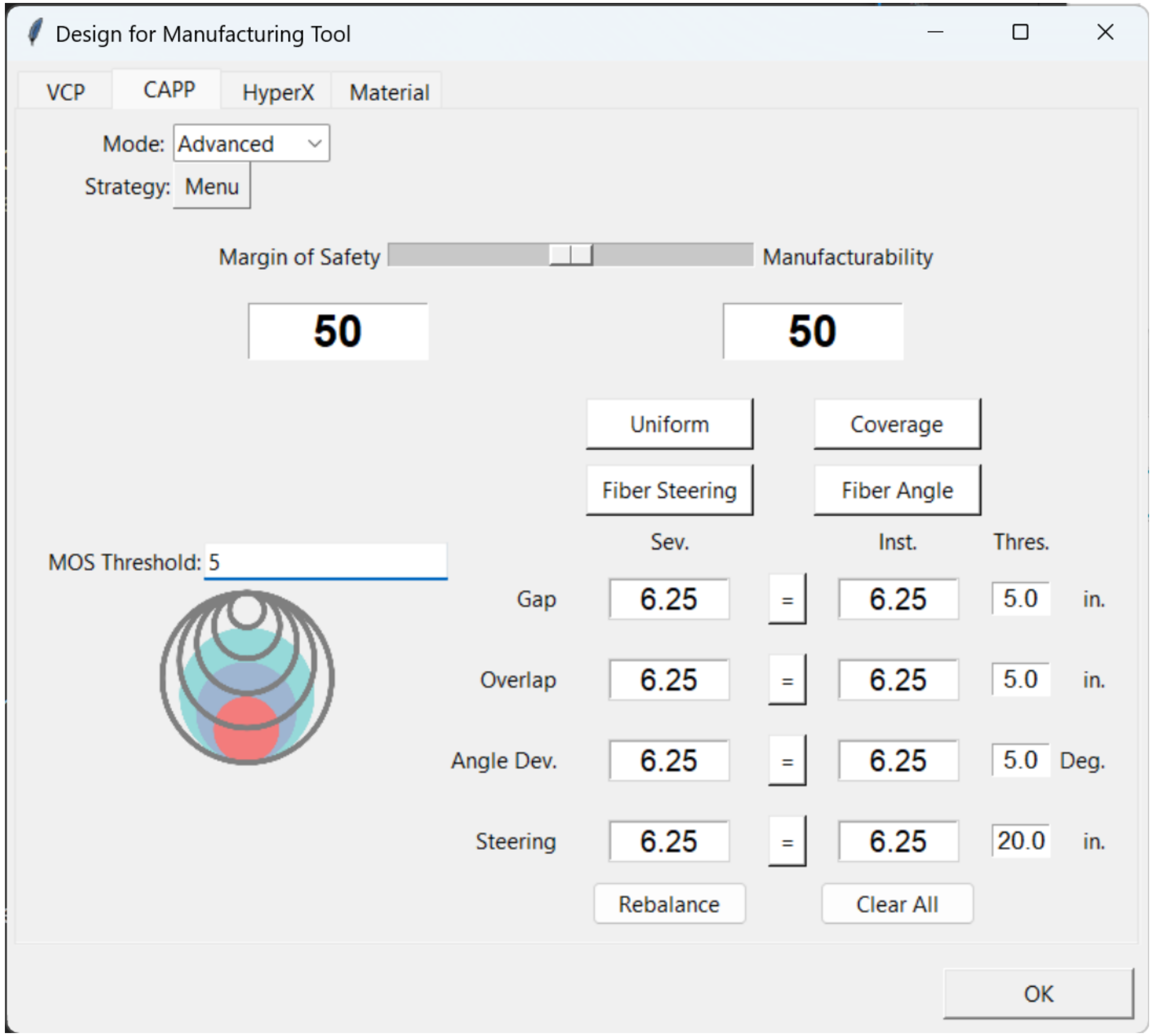
CAPP Software Interface



- The principal functions are starting point, layup strategy and laminate-level optimizations.

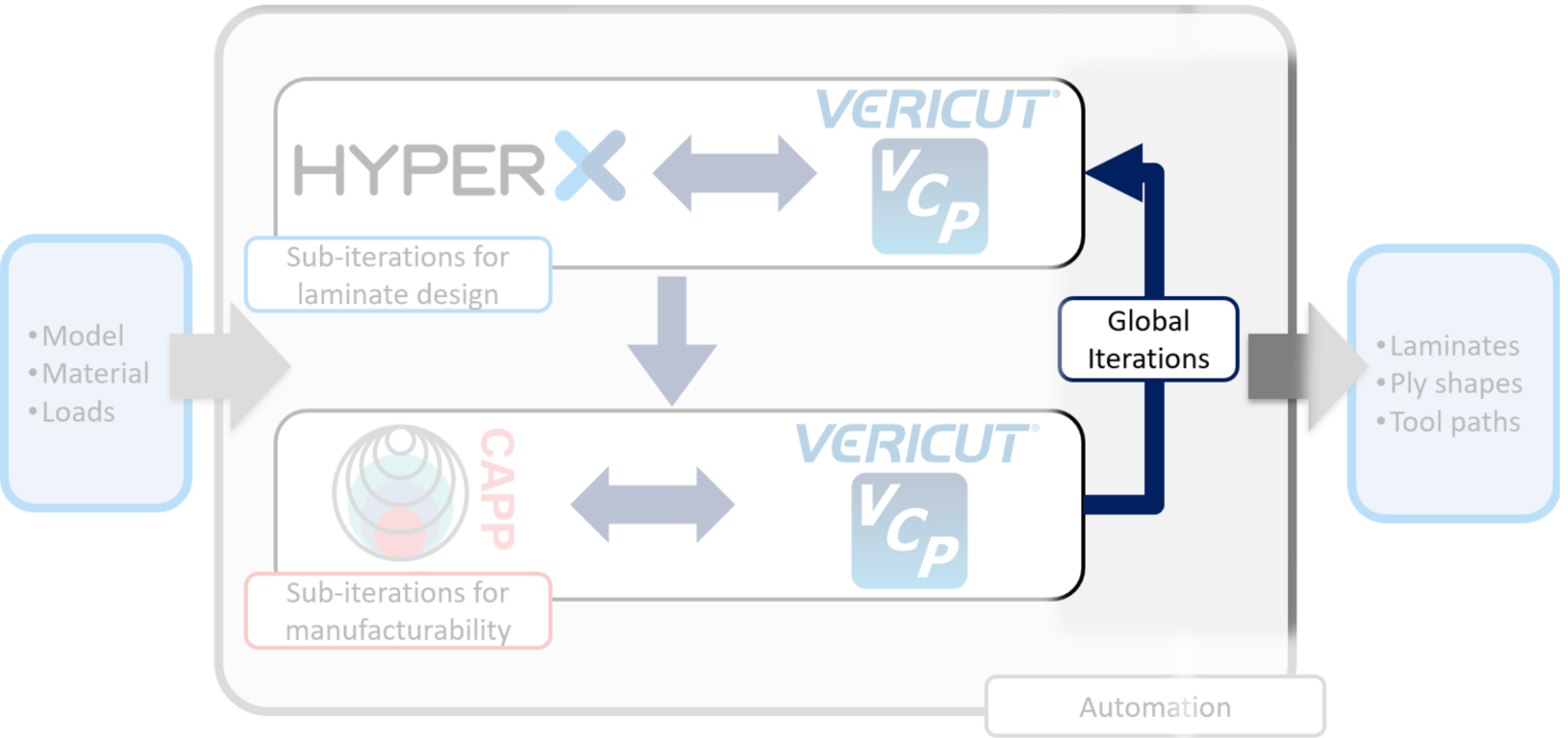
CAPP Integration with HyperX

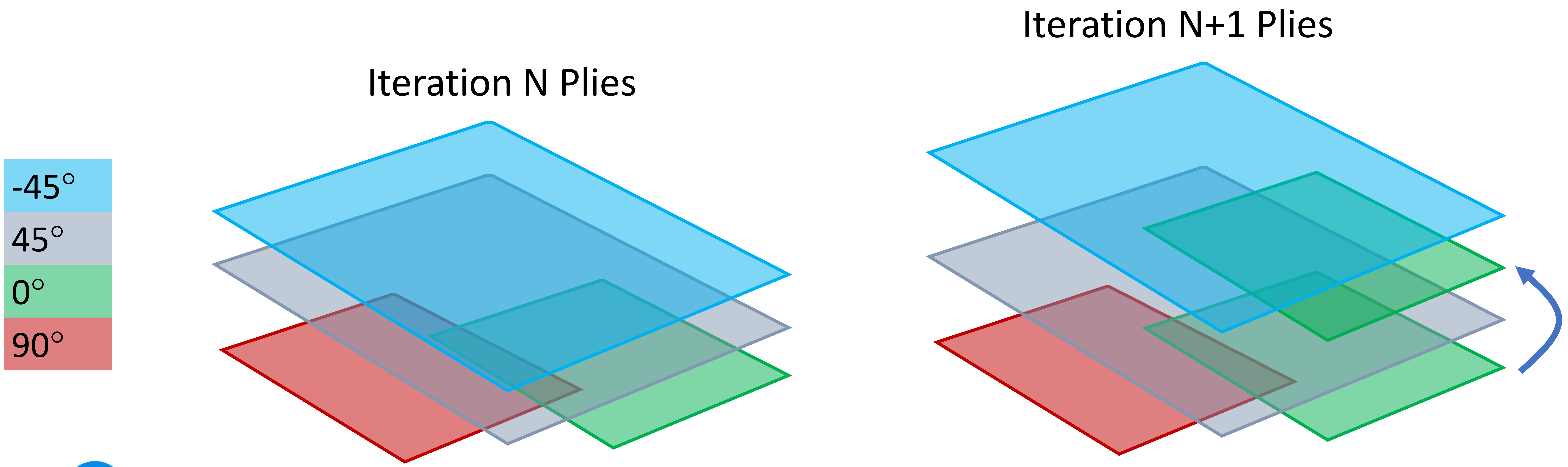




Overall Optimization Approach: Global Iterations

- HyperX or CAPP can make changes to the plies that the other software does not know about
- Global level iterations needed to converge the HyperX-VCP and CAPP-VCP sub-iterations
- After each sub-iteration, the global optimizer can insert new manufacturing-optimized plies to resolve negative stress margins, as needed





Ply 3 duplicated (preserving manufacturability) and inserted between 1 and 2

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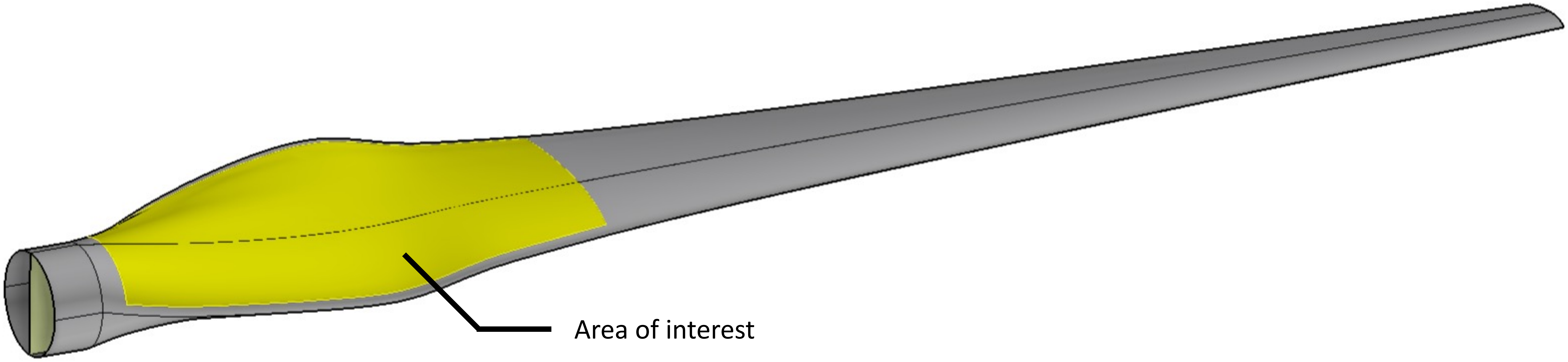
Verification Example Introduction

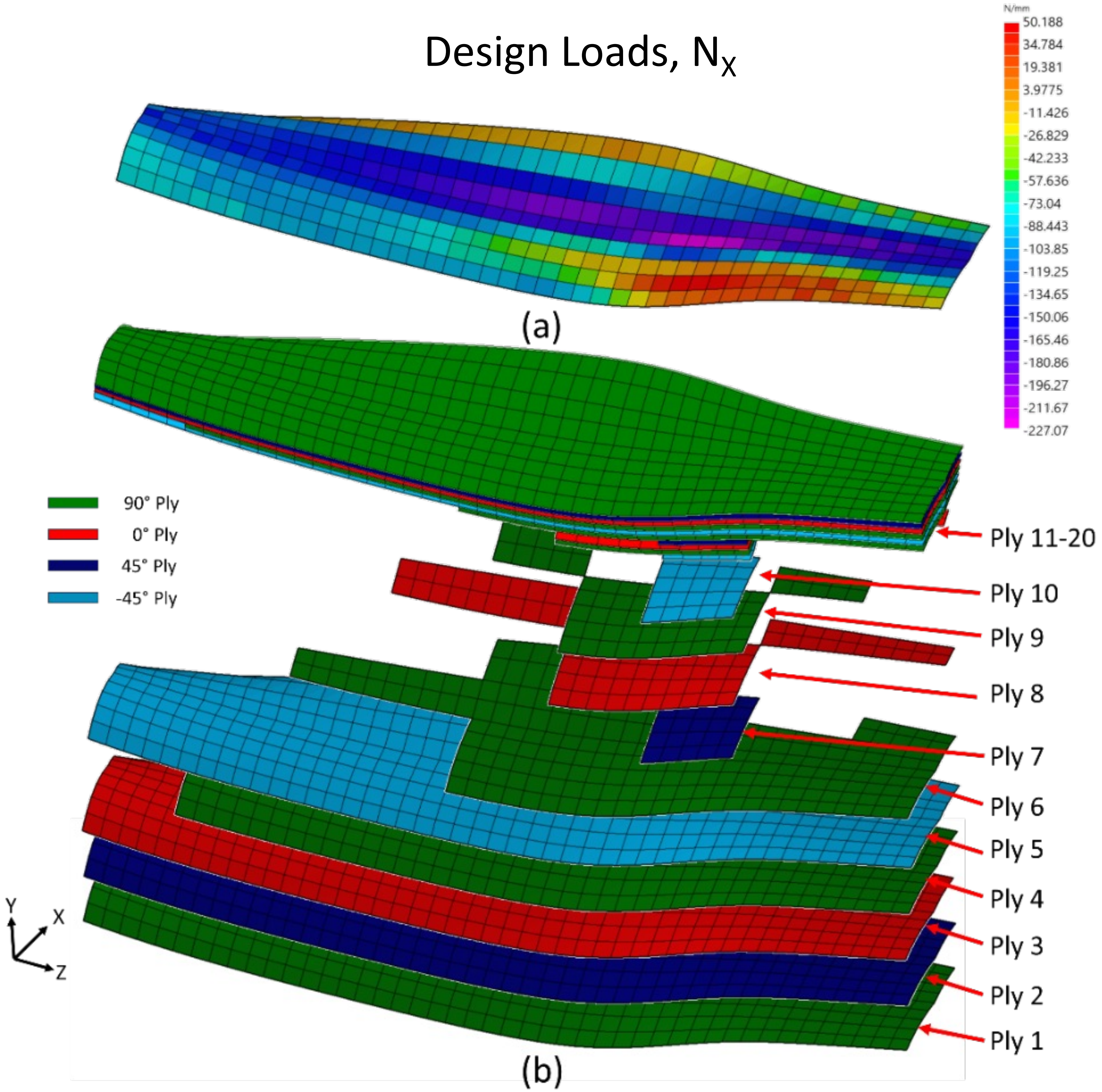
- Example demonstrates the HyperX-VCP iteration (CAPP-HyperX iteration still in work)
- 3m wind blade
- 1 load case (pressure distribution)
- High contour region selected as a good challenge problem



Wind Turbine Blade Laminate

- Plies generated in HyperX
  - 20 Plies in total
  - Symmetrical Plies
- The internal stresses of the wind turbine blade
  - Stress concentrations at bottom right
  - Results on a thicker laminate in the stress concentrations
- Margin of safety, delta, and % differences was measured in the full plies.

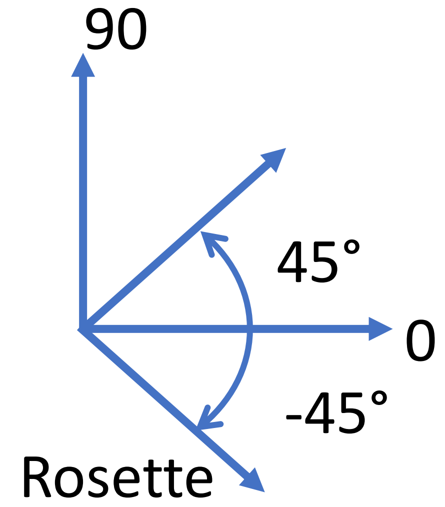
Design Loads, N_X



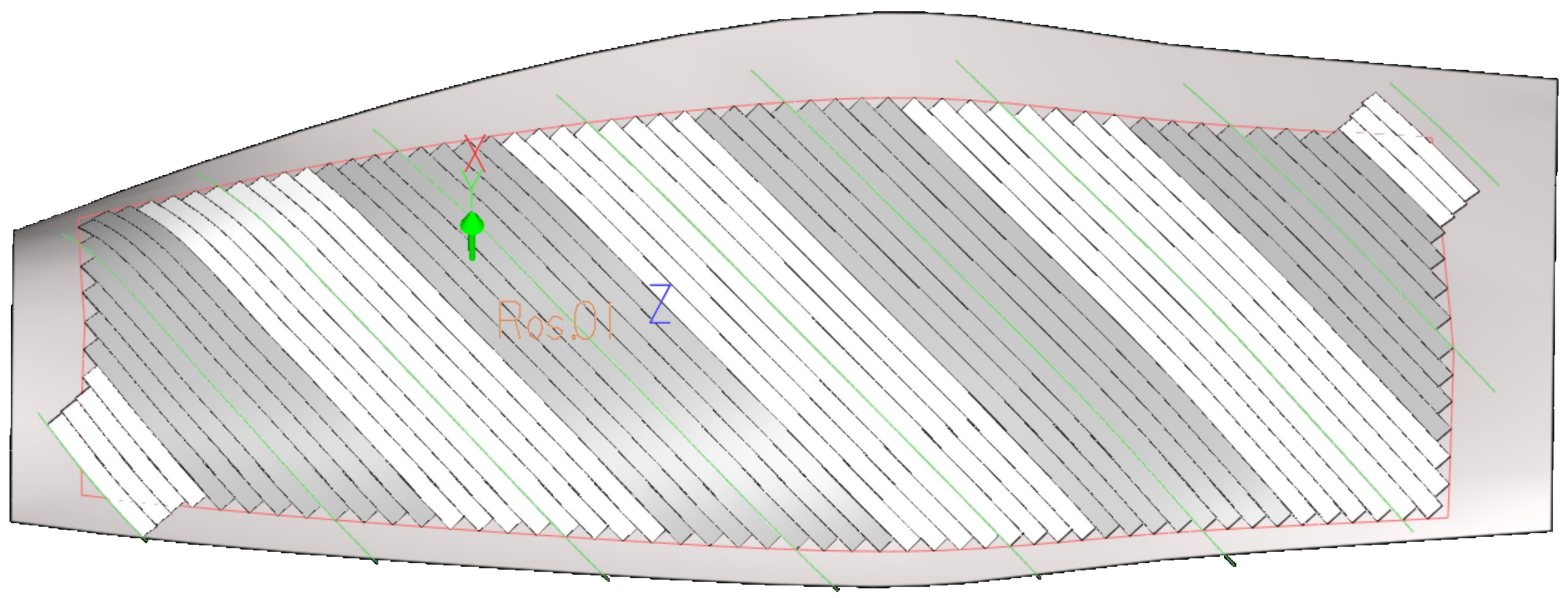
Angle Deviation

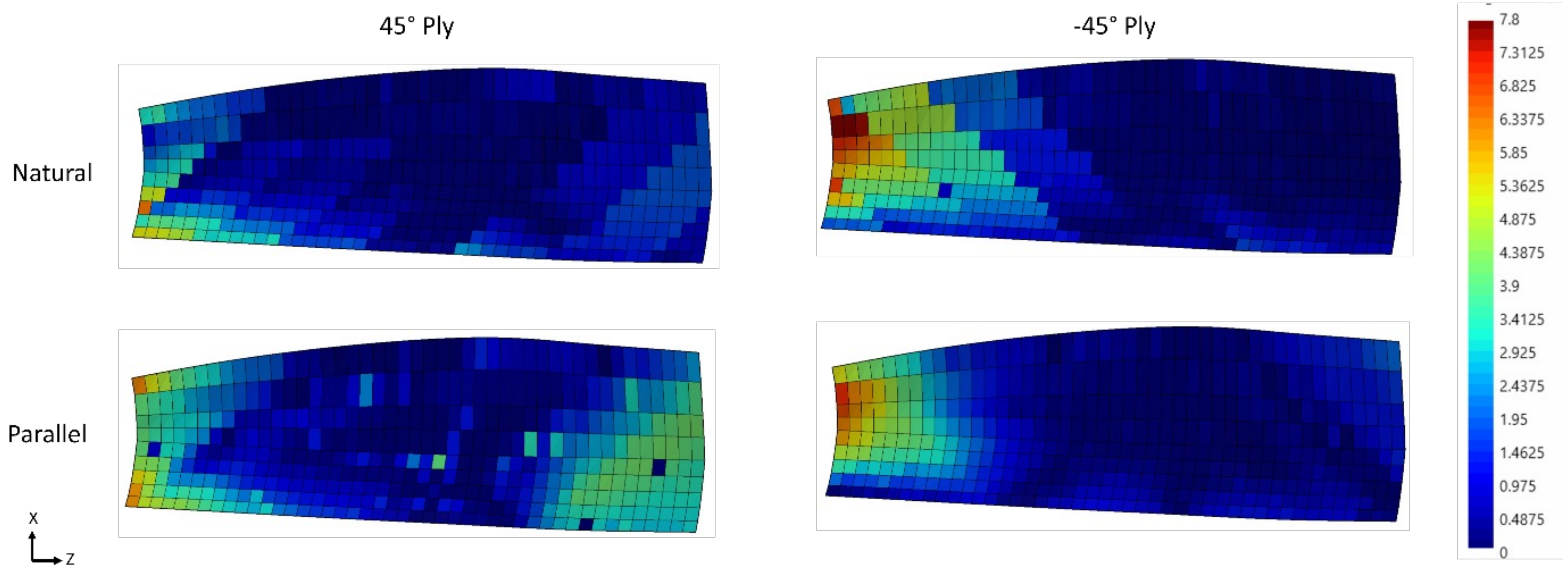
- Angle deviation in the complete plies shows a deviation between 0° to 7°.
- Average deviation - 1.0 ° – 1.6° in the 45 and -45 deg
- Large Deviations in:
  - Left hand side of the model
  - minor deviation in the bottom right

Tow path	Angle	Ply Number	Average Deviation	Maximum Deviation
Natural	45	2,19	1.52	6.28
	-45	5,16	1.03	7.14
	90	3,18	0.52	3.3
	0	1,20	1.04	7.18
Parallel	45	2,19	1.67	6.47
	-45	5,16	1.25	7.75
	90	3,18	0.98	5.9
	0	1,20	0.68	4.61



VCP Paths





Margin of safety

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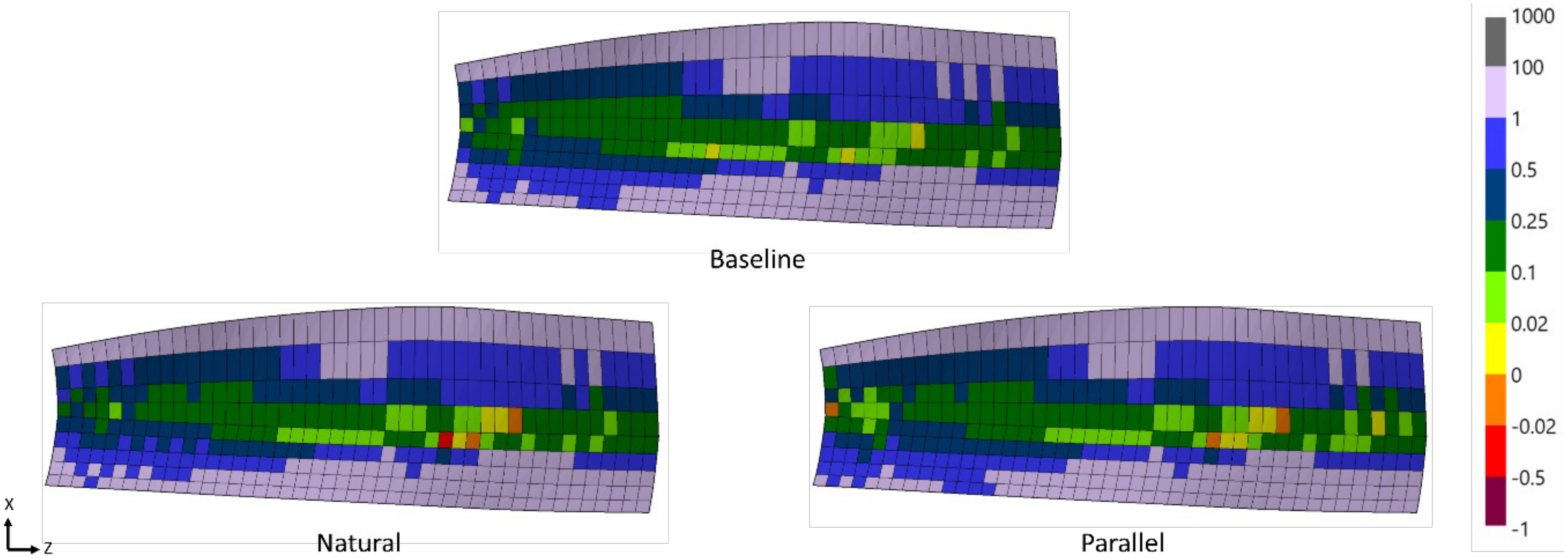
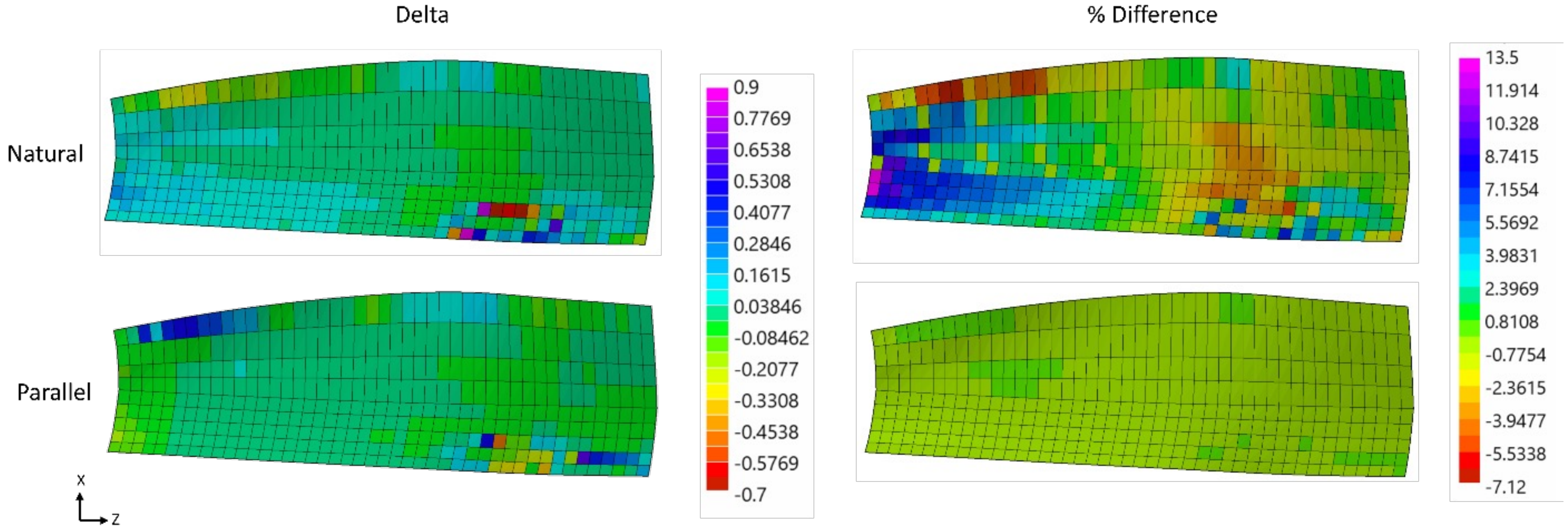
- The baseline of the wind turbine blade shows no negative margins of safety
- Negative margins are produced by both the natural and parallel tow path strategies
  - The natural paths produced negative margins at the center right
  - The parallel tow paths produced negative margins at the center left and right of the wind blade

Margin of Safety



Differences

- For the "as-manufactured" fiber directions, the delta for some elements does not show a large decrease or increase in MS.
- The % difference shows that the change of MS was significant in certain places but did not significantly impact the resulting MS.
- The negative MS experienced relatively small changes in MS.
  - Small changes in misalignment can affect the overall safety of the composite laminate.



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- Presented approach for integration of stress analysis/optimization (HyperX) with AFP manufacturing process planning (CAPP), including iteration with AFP path generation (CGTech)
- Optimization results in laminates that are weight-optimum and also optimized for manufacturability
- Demonstrated the approach on a section of a 3m wind blade. Automated iterations used to:
  - Generate AFP paths on structure
  - Automatically update stress analysis
  - Add plies to structure to alleviate negative margins caused by fiber deviations

Thank You!

Questions?

Acknowledgements

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