High Performance Composite Bikes: Laminate Optimization When Every Ounce Lighter Matters

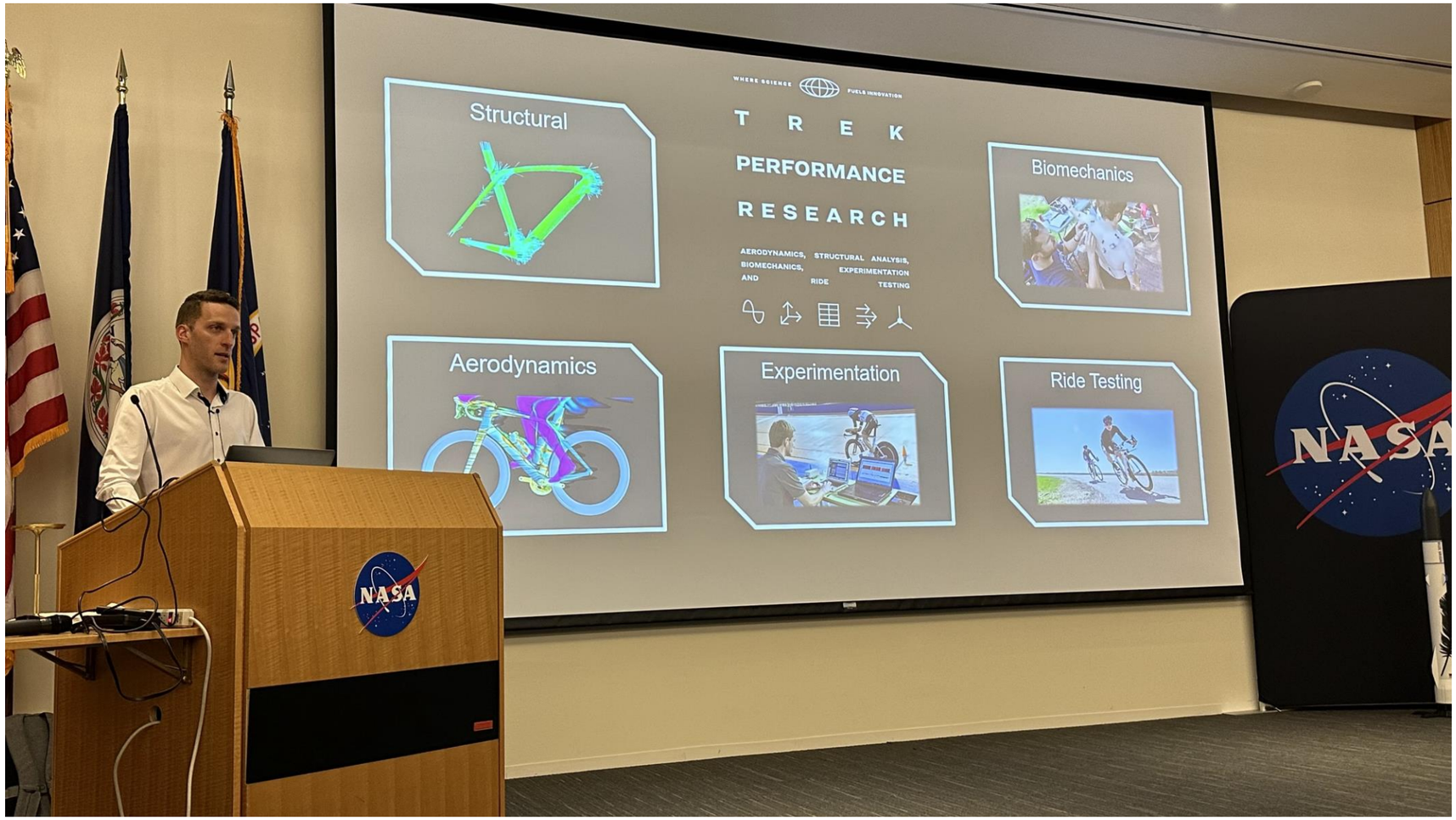
Ryan McLoughlin

Johannes Schwingel

Bertram Stier

Contact us: www.collieraerospace.com

Where We've Been



Meet the Team

Ryan McLoughlin

Structural Engineer
Collier Aerospace - Raleigh

Johannes Schwingel

Research Engineer
Collier Aerospace GmbH

Bertram Stier

Director, Advanced Composites
Collier Aerospace GmbH

The Challenge

Aerospace Parts

Single/Simple Curvature

High-Performance Parts

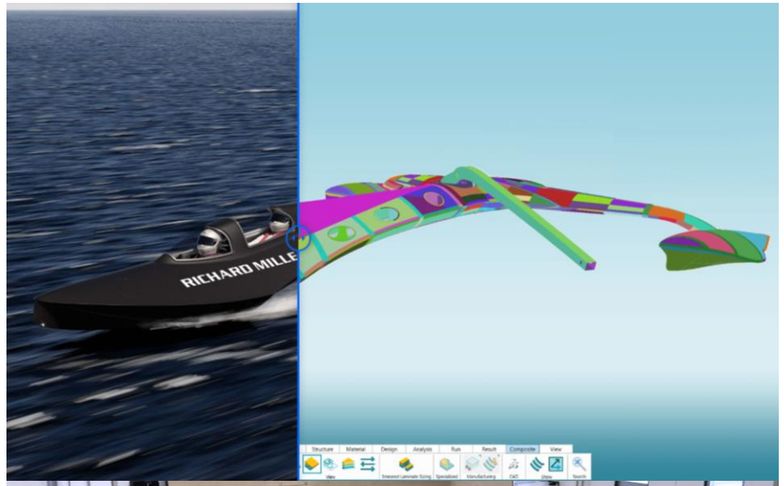
Complex Curvature

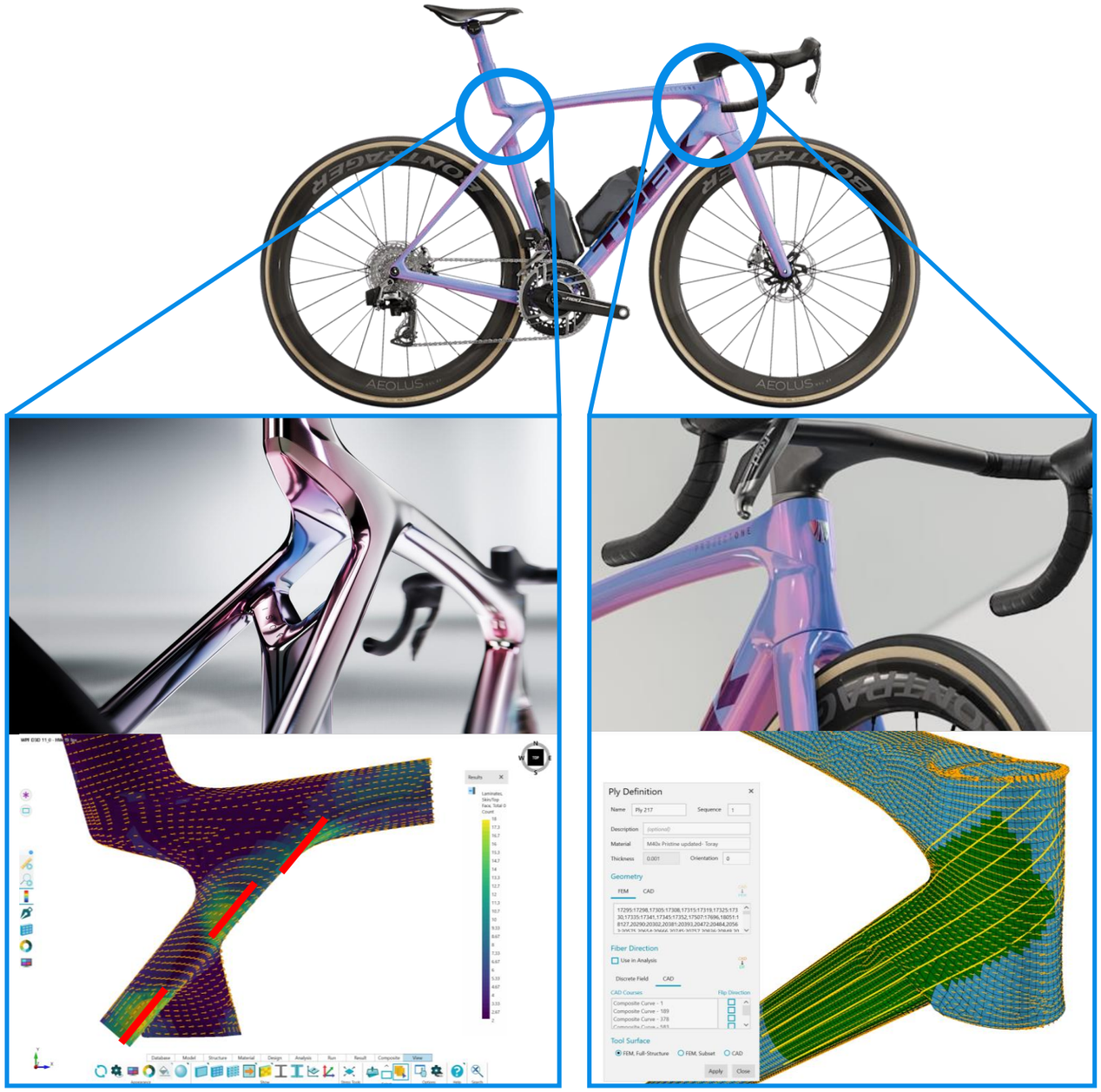
The Challenge

Case Study: Road Bike Barstem

- Doubly-Curved
- Stiffness Critical
- High Load Transfer Area
- High Part Complexity

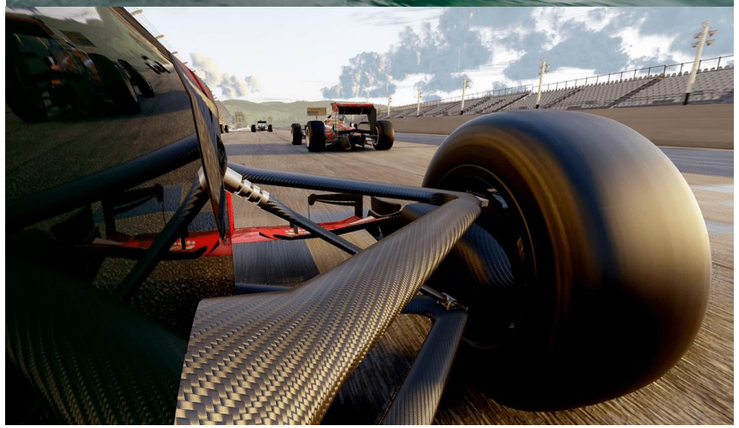
Applicability





Potential Applications

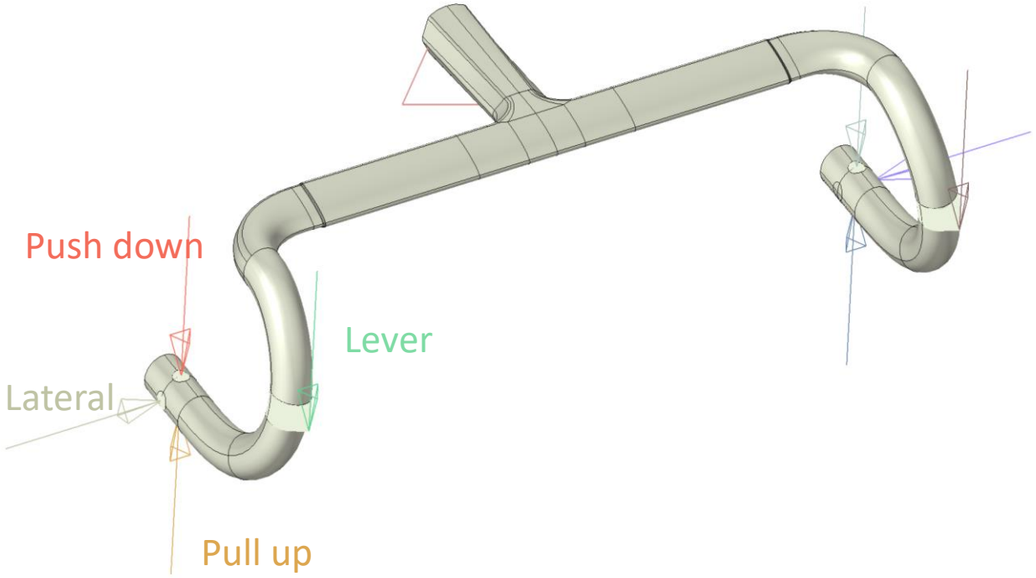
- High Part Curvature
- Complex Geometry
- Extremely Lightweight (grams)
- Complex Stiffness Requirements



Handlebar Barstem Case Study

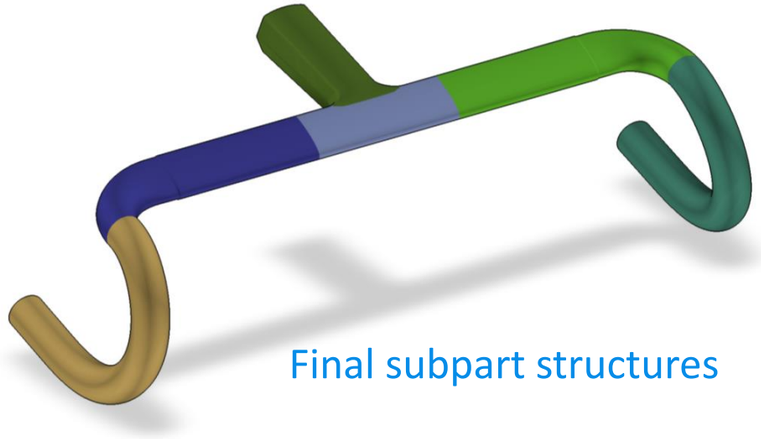
HyperX Initial Setup

Symmetric load cases applied to left and right side

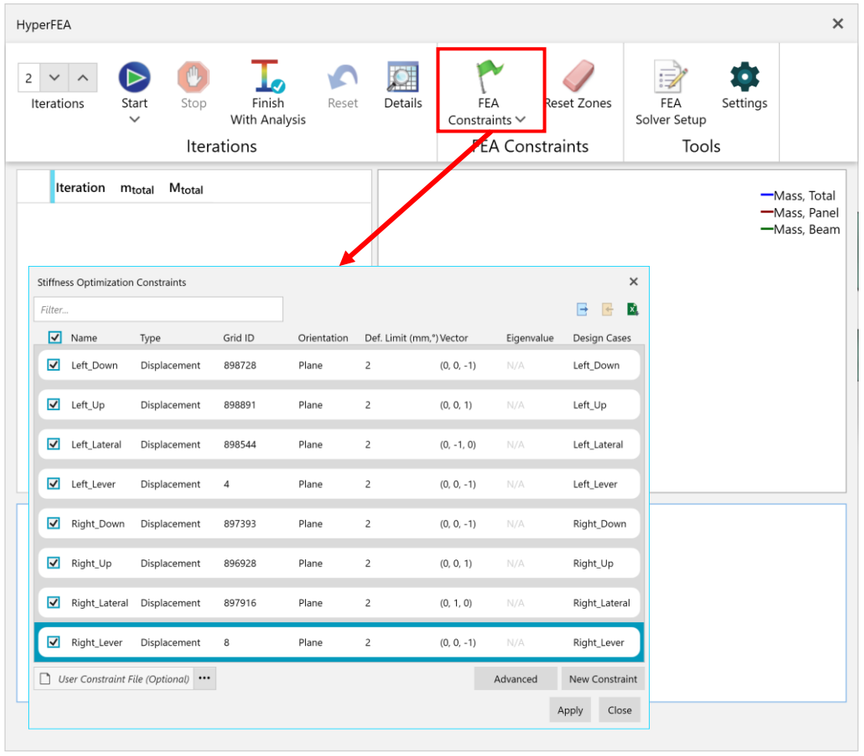


Load case	FEM load [N]	Load case multiplier
L/R Push down	100	12
L/R Pull up	100	12
L/R Lever	100	4.8
L/R Lateral	100	12

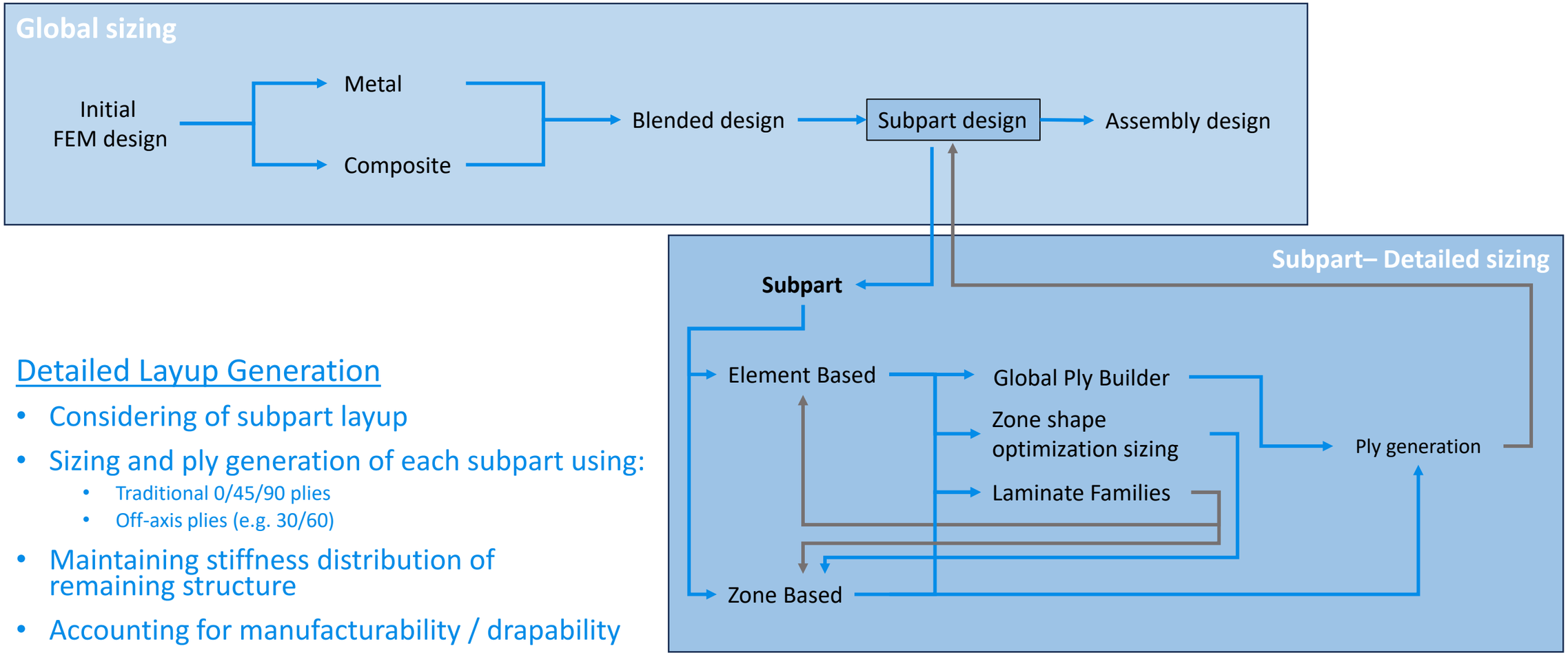
Load cases according to BS EN ISO 4210-5:2014



Final subpart structures



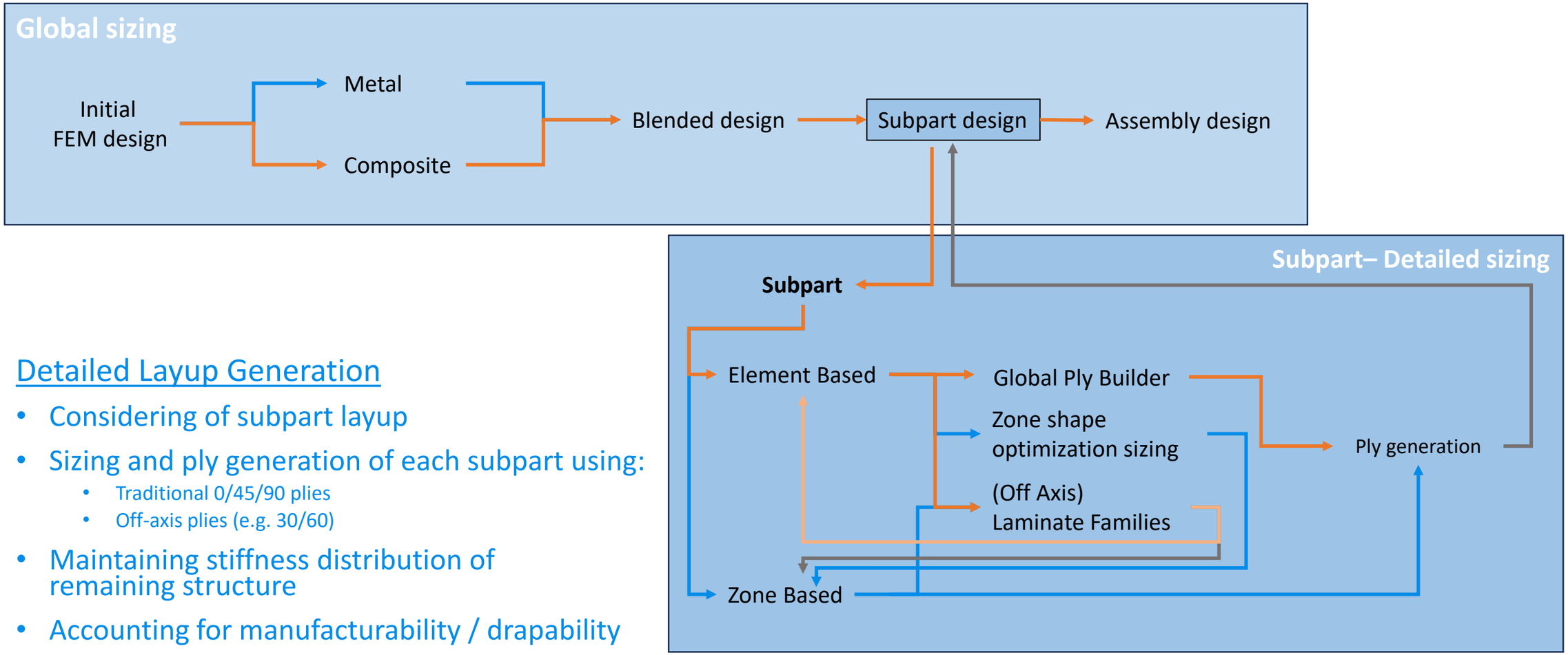
General composites – Sizing workflows



Detailed Layup Generation

- Considering of subpart layup
- Sizing and ply generation of each subpart using:
  - Traditional 0/45/90 plies
  - Off-axis plies (e.g. 30/60)
- Maintaining stiffness distribution of remaining structure
- Accounting for manufacturability / drapability

General composites – Sizing workflows



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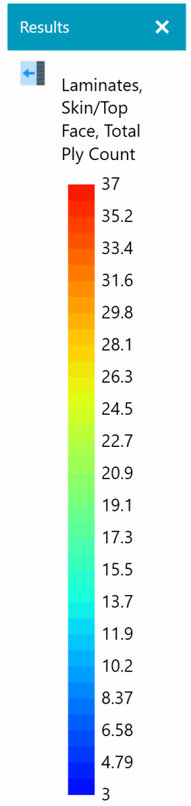
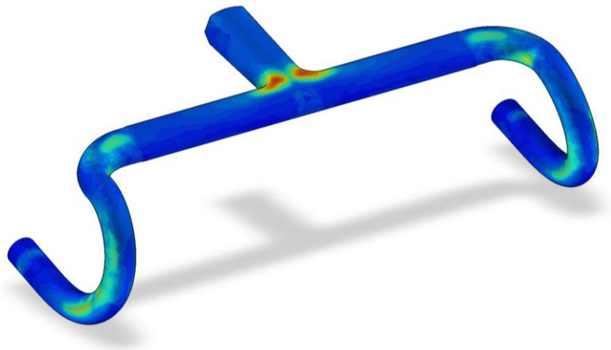
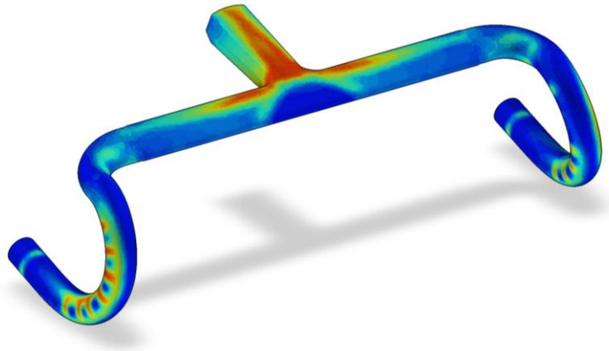
Comparison of constraint combinations



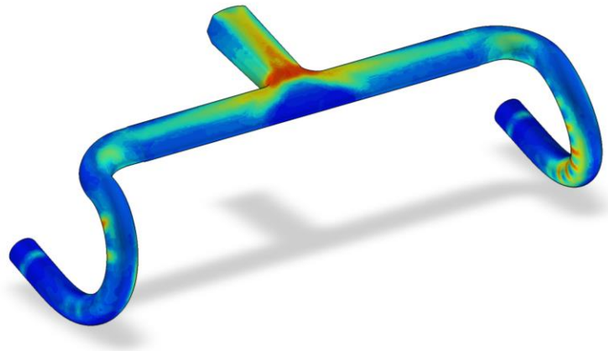
Strength



Stiffness



Stiffness and strength



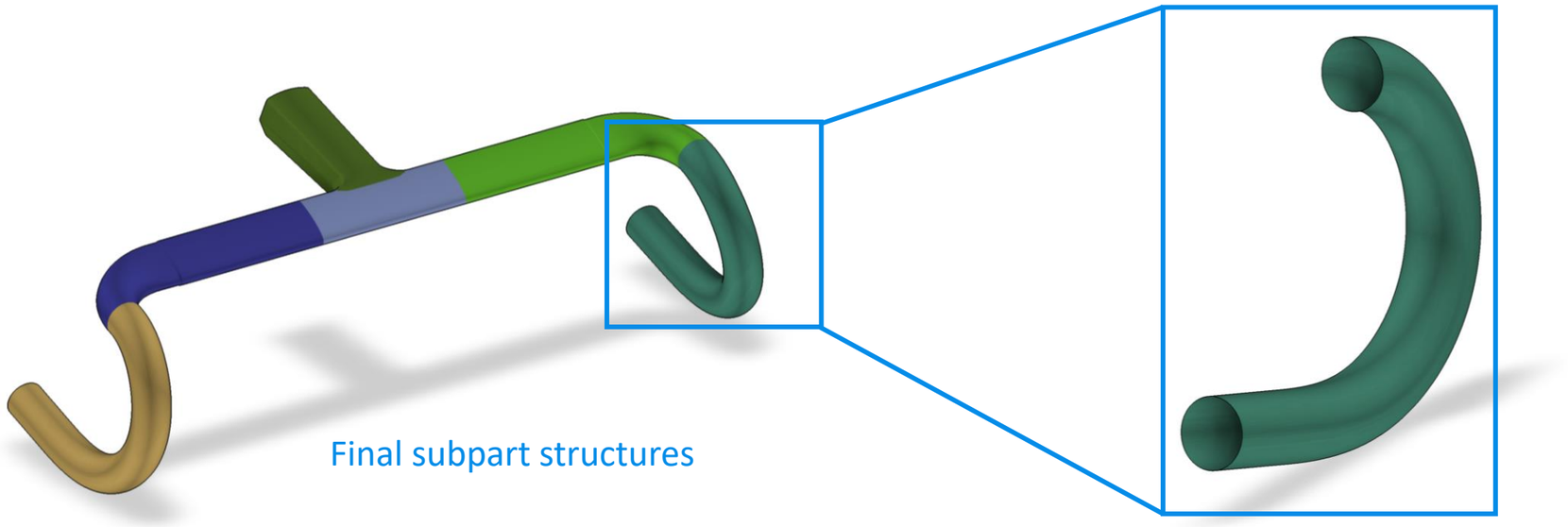
Comparison: Stiffness/Mass [N/mm/kg]

	Strength	Stiffness	Strength / Stiffness
Design Case (Push down)	180.7	195.8	205.7

Subpart Focus: Left drop

HyperX setup changes

- Only drop remains in a HyperX structure to keep rest of the model constant during HyperFEA process.
- Design property is adapted to contain the drop specific maximum ply count.
- Use Iterated FEM to retain piecewise stiffness contributions from sized structures



Final subpart structures

Isolation of drop structure to remain in HyperX

Manufacturability considerations with Catia V5

HyperX <-> Catia Integration

HYPERX → DS CATIA → HYPERX → DS CATIA

- Part Sizing
- Laminate Family Generation
- Initial Virtual Ply Generation

Ply Boundary Generation

Ply Sequence

- Ply Producibility
- Ply Cut Pieces

Draping Simulation
CAD curves

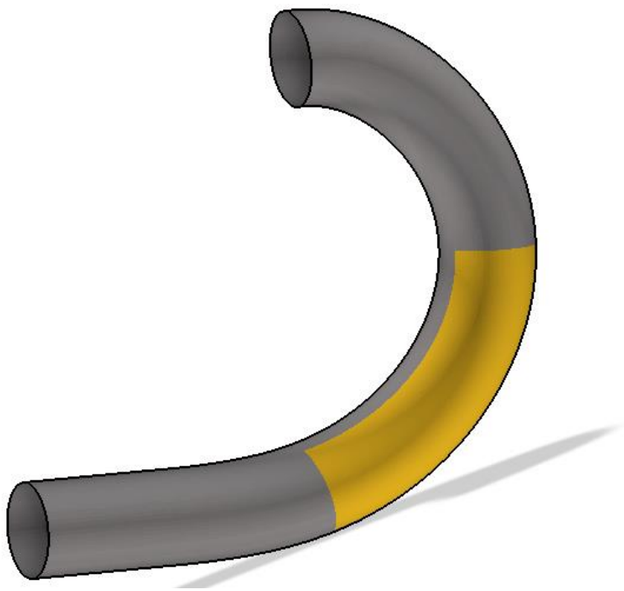
- Variable Fiber Direction (From CAD Curves)
- Catia-Informed Ply Modification
- Margin Reassessment (From VFD)

Adjusted Ply Boundaries & Sequence

- Flat Patterning
- Plybook Generation

HyperX <-> Catia Integration

Ply Boundary Generation in HyperX



Ply definition in HyperX

FEM
CAD

Ply boundary extraction in HyperX

Ply data transfer to Catia:

- Producibility checks
- Variable fiber definition
- Ply book generation

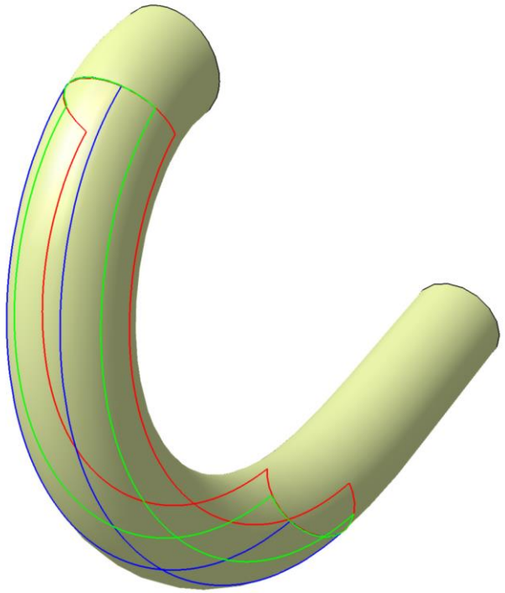
HyperX <-> Catia Integration

Initial Ply Sizing Results

Sequence	Ply Name	Orientation	Thickness	Material
1	Ply 1	0	0.1397	Collier Tape
2	Ply 2	0	0.1397	Collier Tape
3	Ply 3	0	0.1397	Collier Tape
4	Ply 4	0	0.1397	Collier Tape
5	Ply 5	45	0.1397	Collier Tape
6	Ply 6	-45	0.1397	Collier Tape
7	Ply 7	0	0.1397	Collier Tape
	Ply 8	0	0.1397	Collier Tape
8	Ply 9	45	0.1397	Collier Tape
9	Ply 10	-45	0.1397	Collier Tape
10	Ply 11	0	0.1397	Collier Tape
	Ply 12	0	0.1397	Collier Tape
11	Ply 13	45	0.1397	Collier Tape
12	Ply 14	-45	0.1397	Collier Tape
13	Ply 15	0	0.1397	Collier Tape
14	Ply 16	0	0.1397	Collier Tape
	Ply 17	90	0.1397	Collier Tape
15	Ply 18	0	0.1397	Collier Tape
16	Ply 19	45	0.1397	Collier Tape
17	Ply 20	-45	0.1397	Collier Tape
18	Ply 21	0	0.1397	Collier Tape
19	Ply 22	90	0.1397	Collier Tape
	Ply 23	90	0.1397	Collier Tape

Initial Global Ply Builder Output

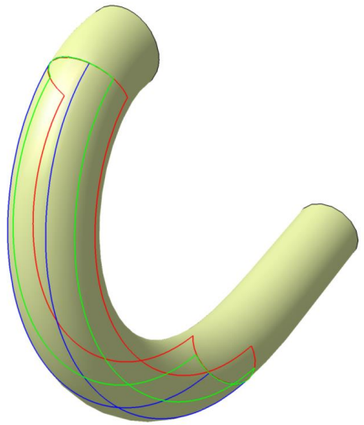
Ply	Width [mm]
1	45
2	30
3	15



Representative Large Structure Plies

Producibility check

0° ply orientation



Plies in Catia V5

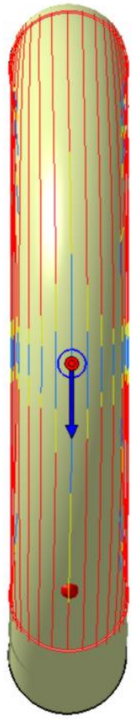
Shearing angle:

Normal	< 3°
Warn	< 6°
Limit	> 6°

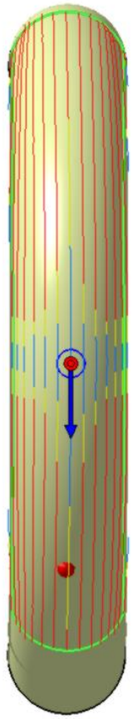
Ply	Width [mm]
1	45
2	30
3	15

Smallest width 0° ply not manufacturable!

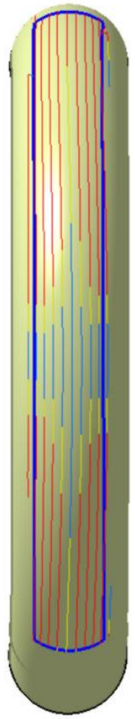
Ply 1



Ply 2



Ply 3



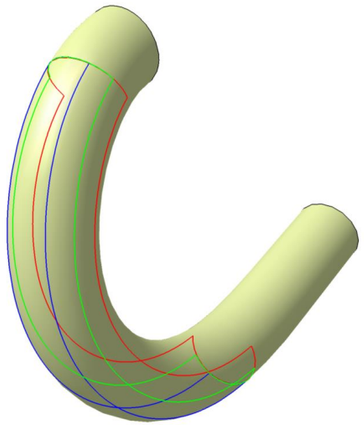
Producibility check

30° ply orientation

- Off-Axis ply orientations are manufacturable with smaller ply widths

→ Design space limitation based on draping results

→ Decrease in ply width leads to better drapability



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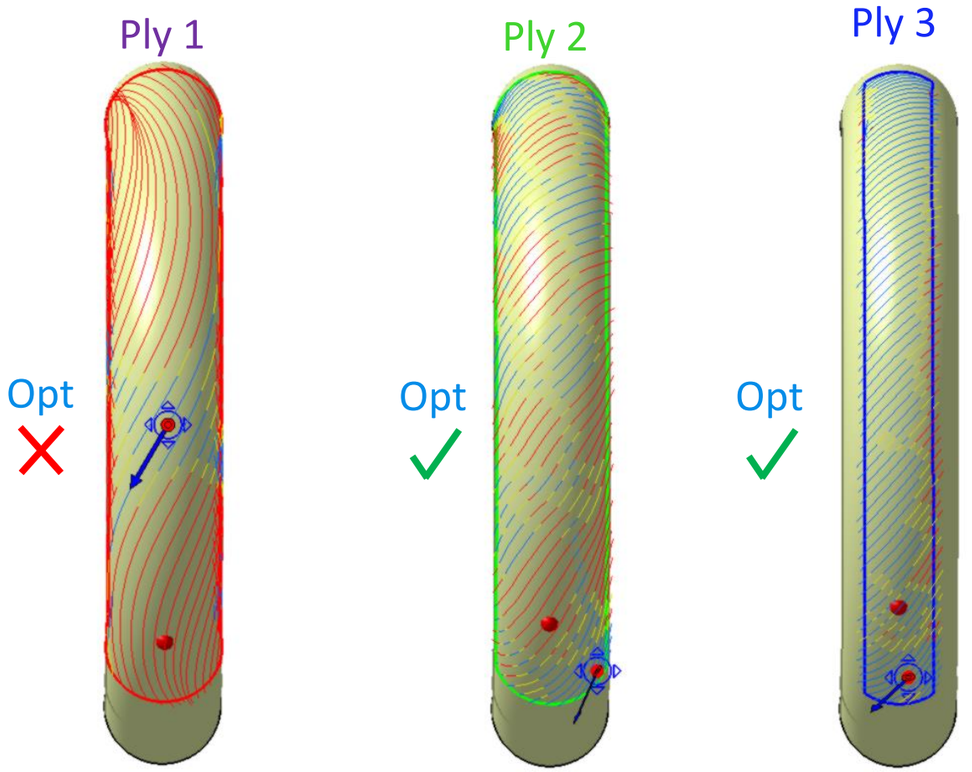
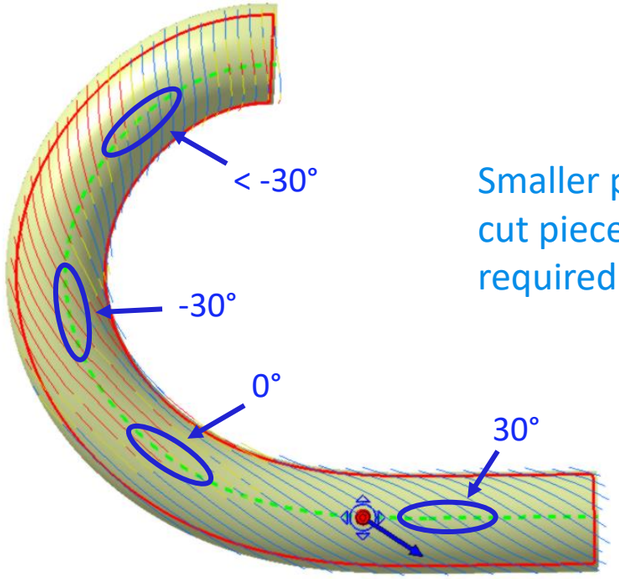


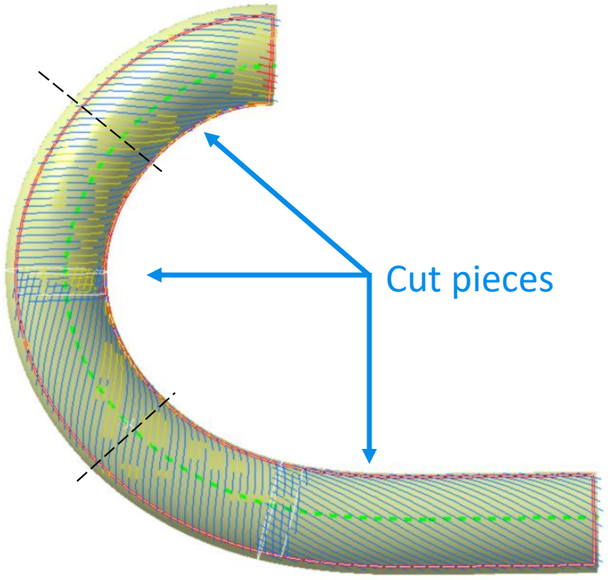
Producibility check

Comparing: Full ply vs. cut pieces

- Full plies are often hard to manufacture
- Areas with high curvatures result in high fiber angle deviations.
- Splicing into more cut pieces decreases fiber angle deviations and accounts for overlaps.



Smaller plies or cut pieces required!



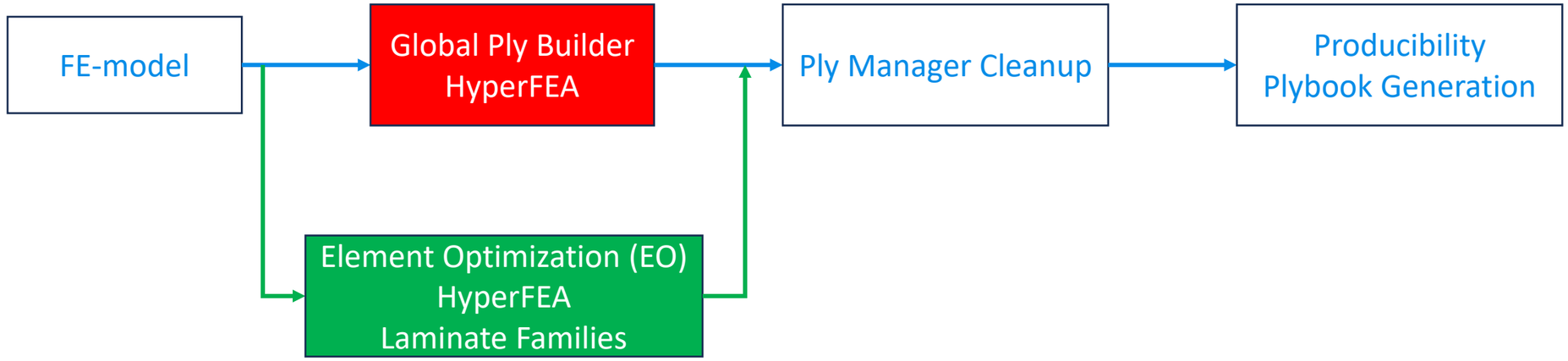
Finer discretization possible
→ Better results
→ Higher manufacturing effort

- Desired ply orientation: 30°
- Actual full ply fiber orientations with respect to reference line – –

Full ply divided into three cut pieces with overlaps
→ Enhanced producibility for each cut piece

Off-Axis Ply Optimization

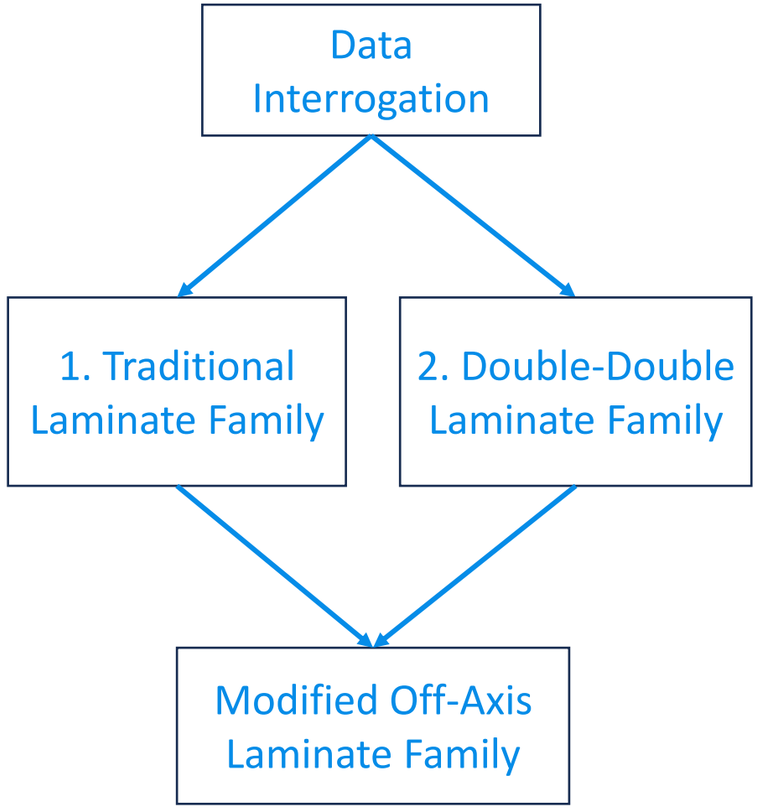
Drops Off-Axis Workflow



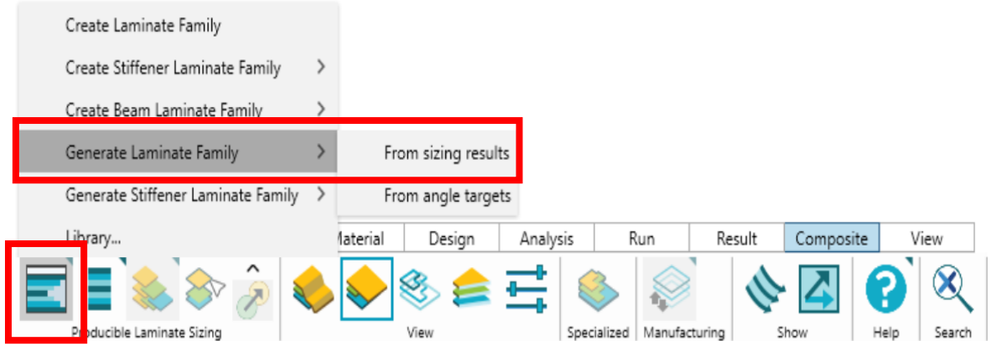
- Producibility checks show 0° plies are not manufacturable → Off-axis plies necessary
- Global Ply Builder is restricted to “Traditional” laminates (0s, +/-45s, 90s)
- New workflow leverages laminate family capabilities as intermediate step to Ply Manager
- HyperX suite of data acquisition tools allows user to identify optimal off-axis angles
  - Laminate family trade studies
  - Automated Double-Double laminate family generation from ply angle targets
  - “Traditional” laminate family generation from element optimization sizing

Trade Studies

Laminate Family (LF) Generation



1.



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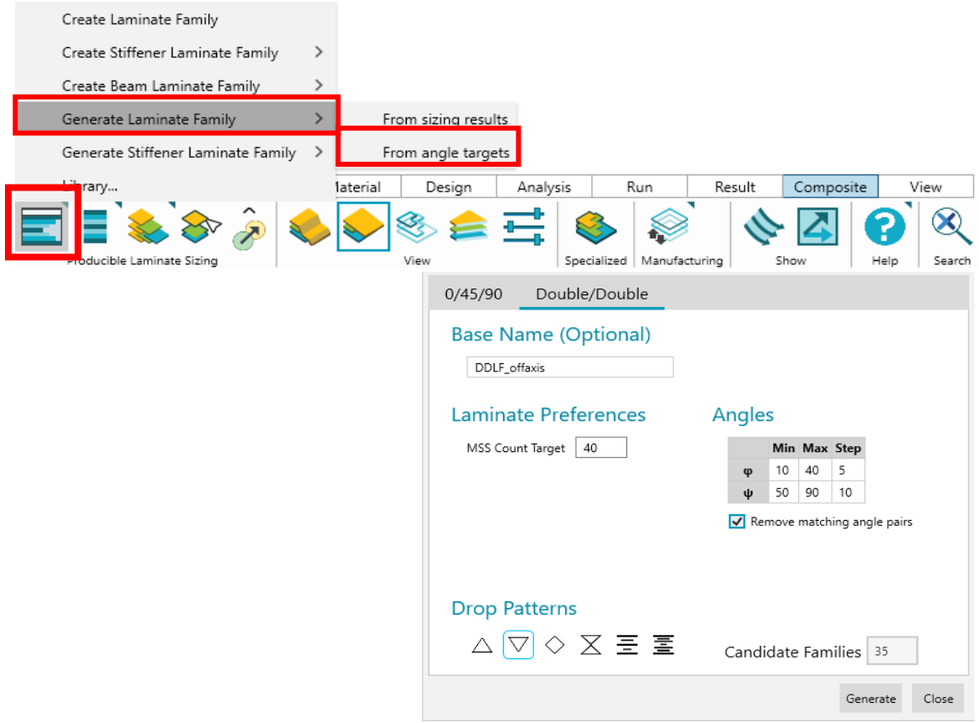


Trade Studies – Laminate Family Down-Selection

LF Trades – Modified Composite EO Master Stacking Sequence (MSS)

Laminate Family Design Study

Input Selection

Zones: 2:33

Designs: Zone_Based_Trial (2)

Input Laminate Families

Drop_Trad_UpsideDownTriangle (33)
Drop_Trad_UpsideDownTriangle - more 20s (33)
Drop_Trad_UpsideDownTriangle - more 22s (33)

Trials to run: 6

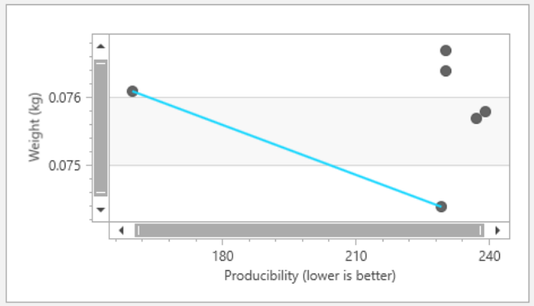
Run Trials

Always use Detail Sizing

Output

Producibility Complexity: AFP and Tape | Hand Fabric and Uni's

Tri	Inputs: FamilyName	Weight	Producibility (lower is better): Metric A	Metric	Metric B	Plies	Ply Cuts
1	Drop_Trad_UpsideDownTriangle	0.0761	159.8268	297.9195	5.7802	60	418
2	Drop_Trad_UpsideDownTriangle - more 20s	0.0757	237.1565	305.1337	5.7229	59	442
3	Drop_Trad_UpsideDownTriangle - more 22s	0.0758	239.2974	315.302	7.2779	60	446
4	Drop_Trad_UpsideDownTriangle - more 25s	0.0744	229.3723	314.8579	2.8641	60	444
5	Drop_Trad_UpsideDownTriangle - more 27s	0.0764	230.4178	298.0228	2.5918	57	442
6	Drop_Trad_UpsideDownTriangle - more 30s	0.0767	230.397	299.7167	2.5918	57	442



Selected Trial

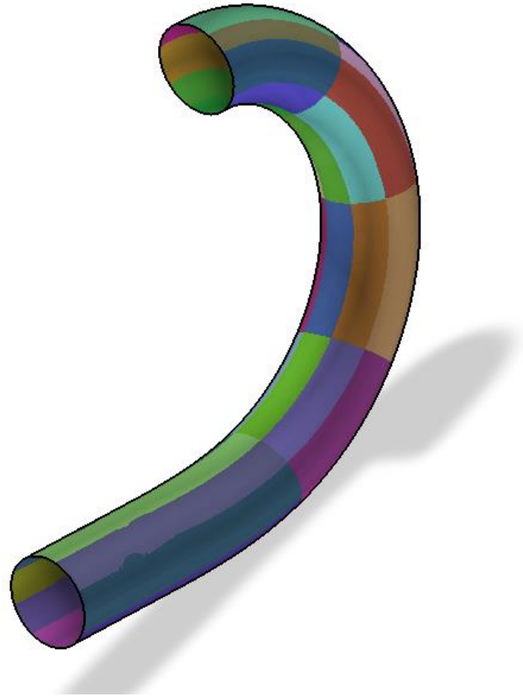
General	
Family	
Weight (kg)	
Producibility (lower is better)	

Critical Margins of Safety	
Criteria	
Zone	
Margin	

Laminate Statistics	
Plies	
Sequences	
Ply Cuts	

Producibility (lower is better)	Laminate	Avg Ply
Metric A		
Metric B		

Make Design | Update Design | Close



Coarse Zoning

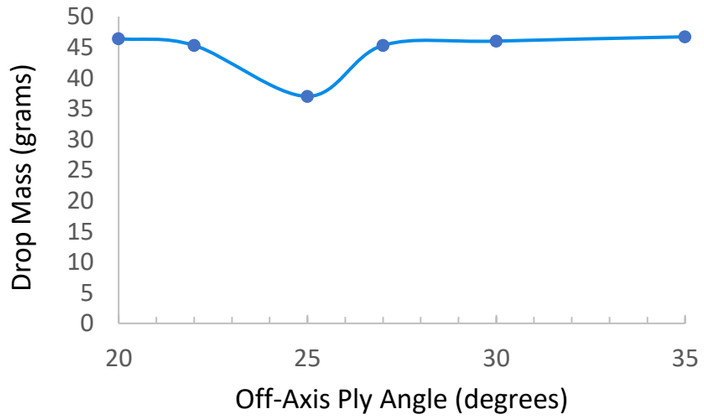
Traditional MSS generated from Composite EO (0/45s/90) → Modified MSS with MFG. considerations, angle targets from Double-Double trades → Fine sensitivity study on tight angle range for laminate family down-selection

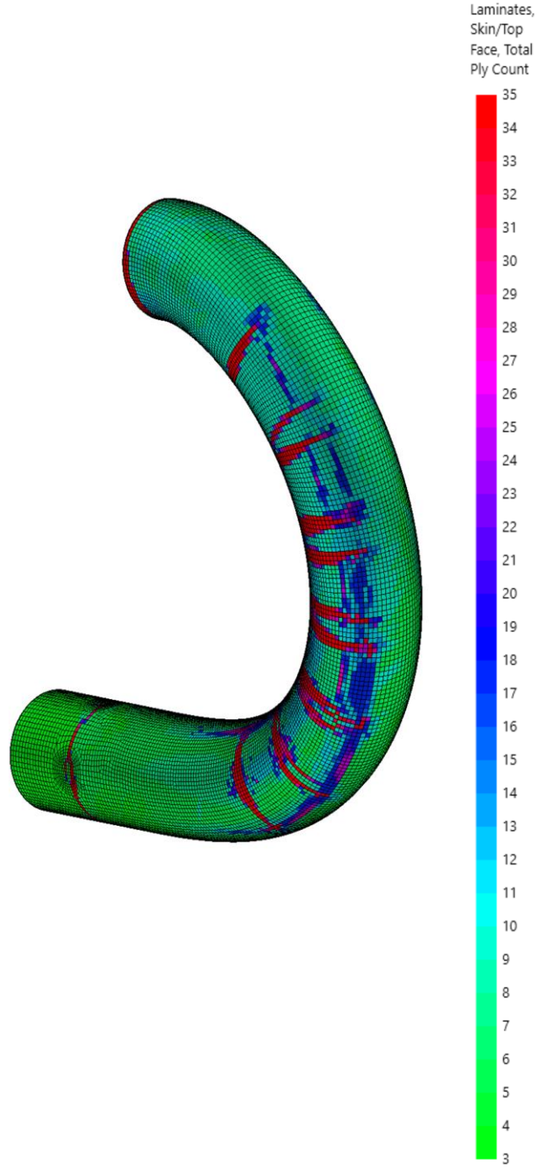
Laminate Family Down-Selection

Composite EO with Modified Off-Axis Laminate Families

Laminate Family	Weight (g)	Max Deflection (mm)	Weight Delta
Baseline [0/45/90]	40.1	2.43	--
Modified 20°	46.4	2.42	+14.7%
Modified 22°	45.3	2.44	+12.9%
Modified 25°	35.9	2.43	-10.5%
Modified 27°	45.3	2.44	+12.9%
Modified 30°	46.0	2.46	+15.7%

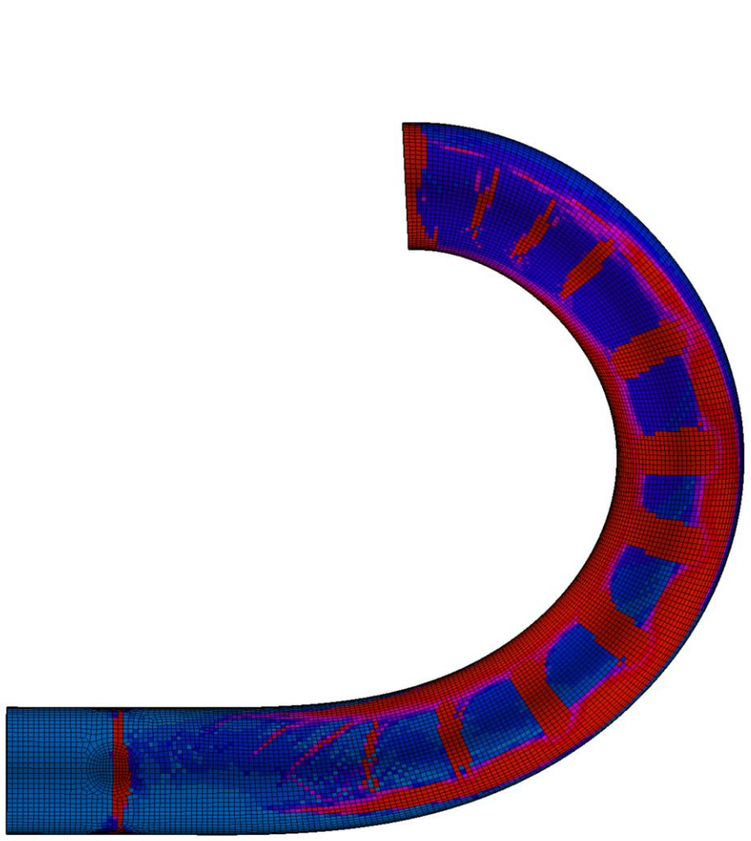
- LF Composite has no Global Ply Builder
- Highly optimized ply placement (Non-manufacturable plies)
- Next Step: Further laminate family modifications to reduce non-manufacturable high ply count regions (stiffness-driven reinforcement)



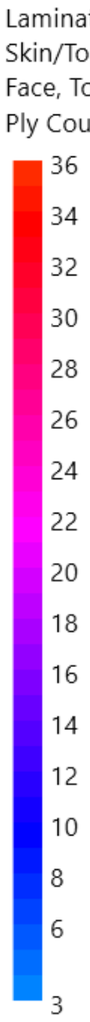


Ply Generation

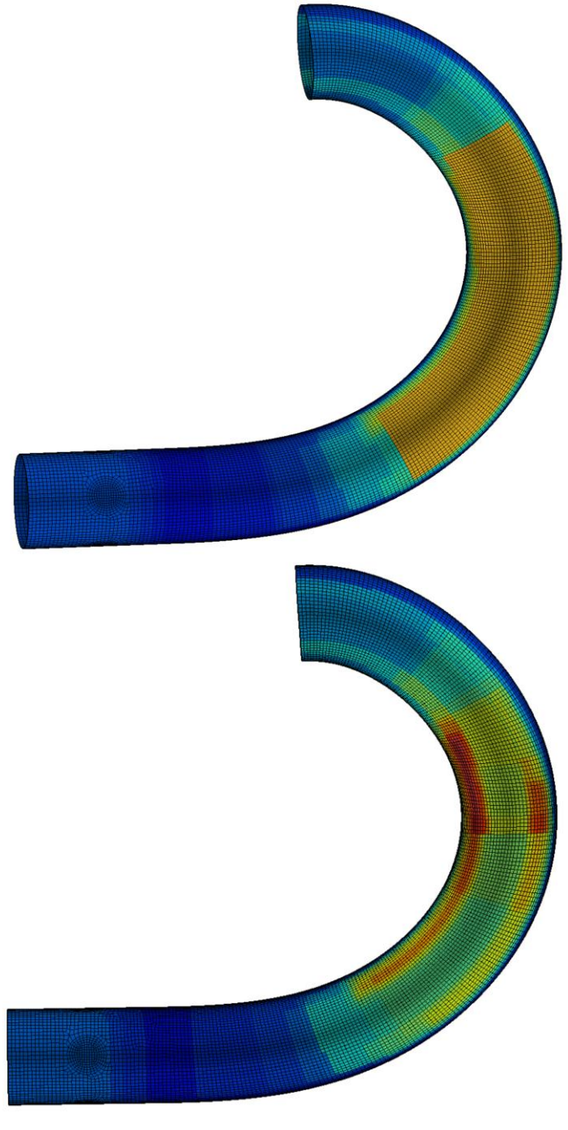
Composite EO -> Ply Manager

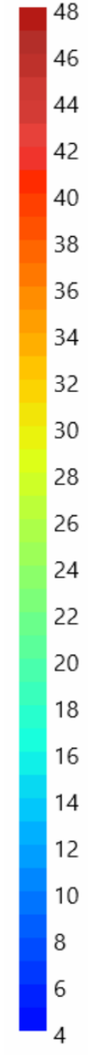


Composite EO Results



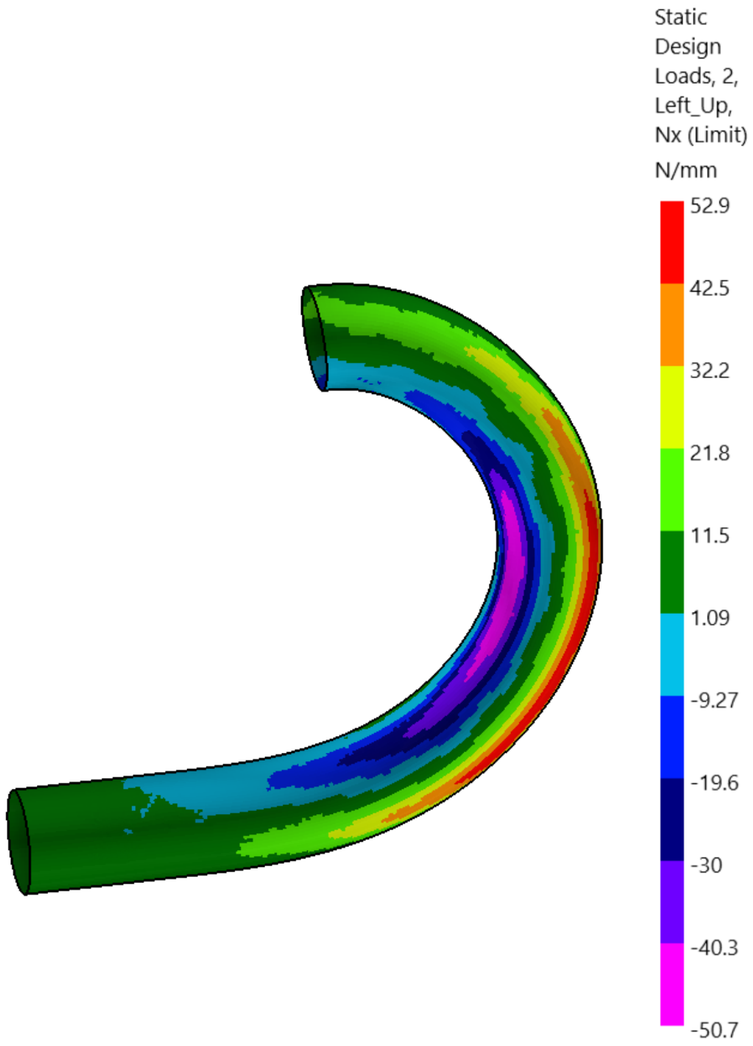
Ply clean-up

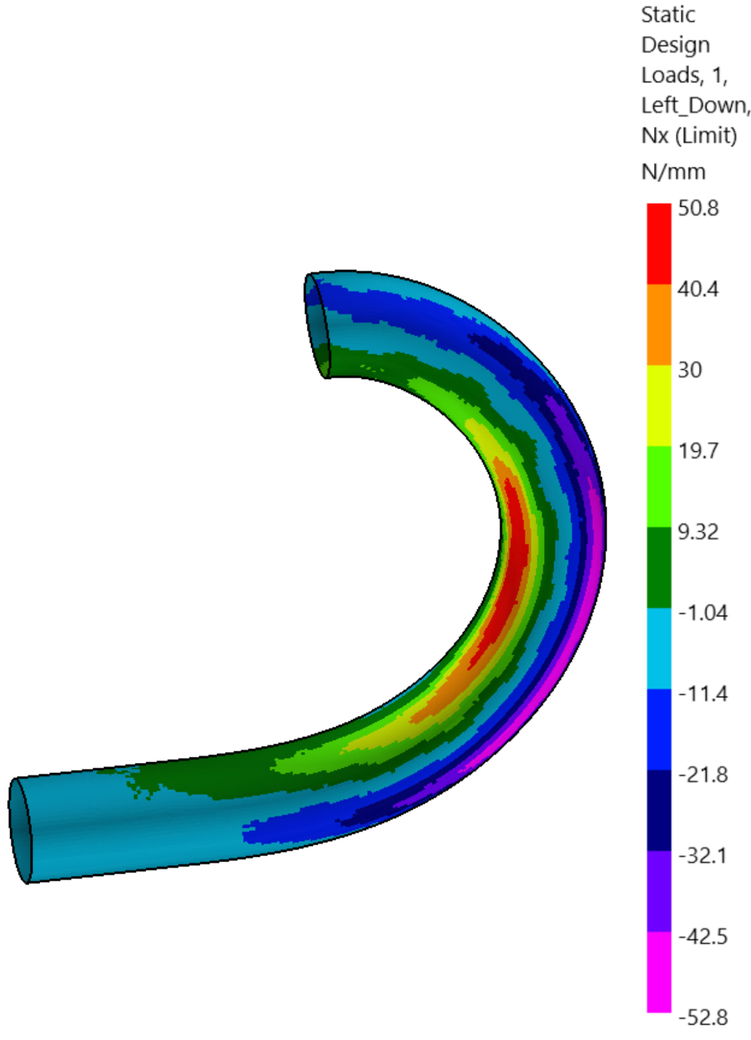




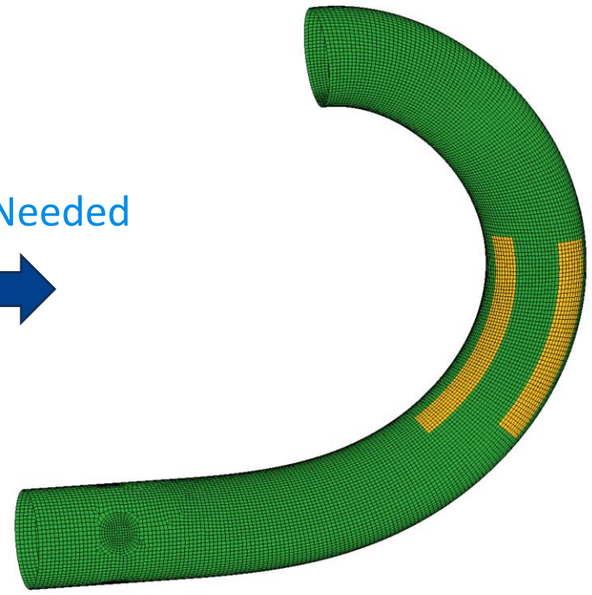
Ply Generation

Stiffness Refinement





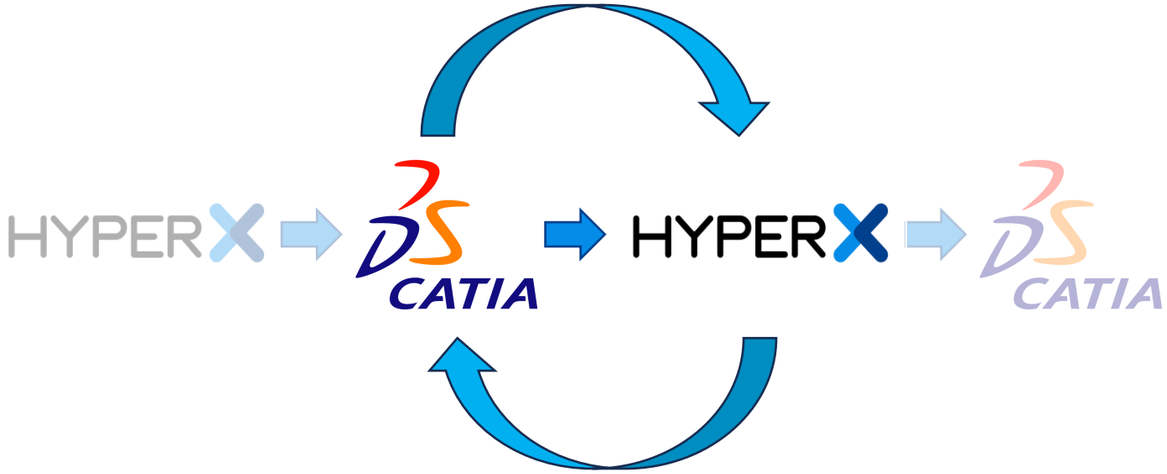
Local Stiffeners Needed

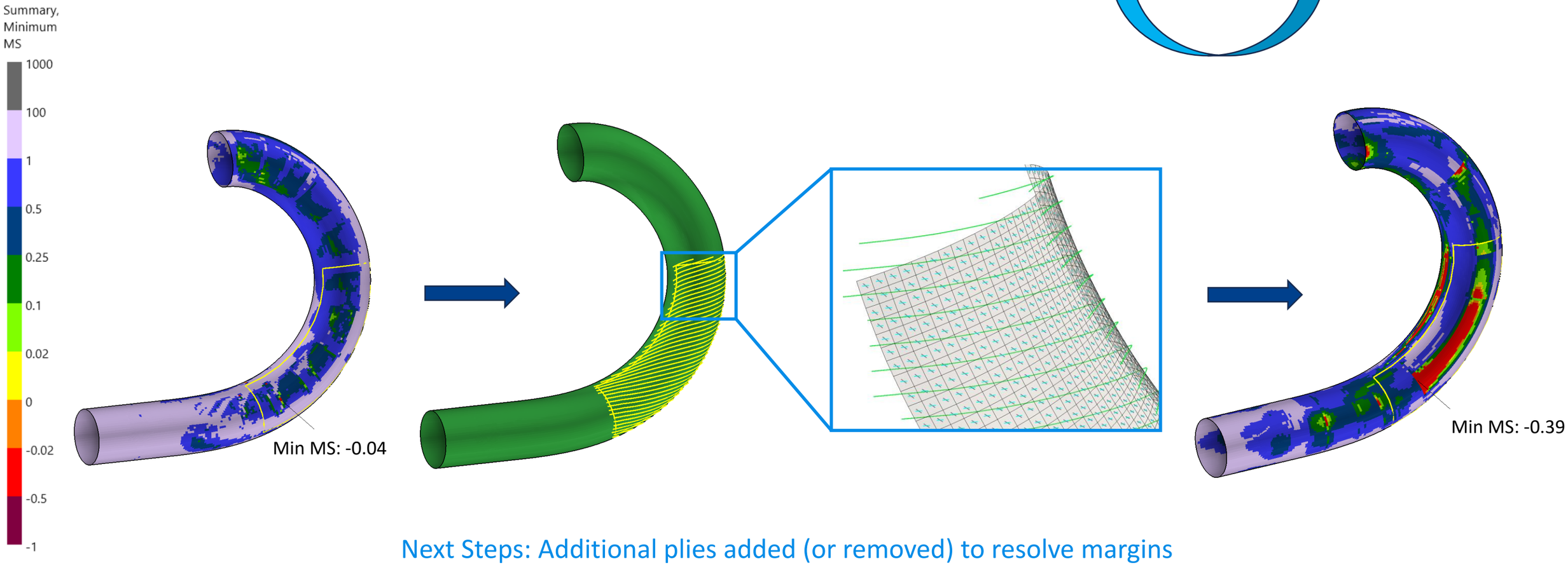


0° plies added

Ply Generation

Variable Fiber Direction Update

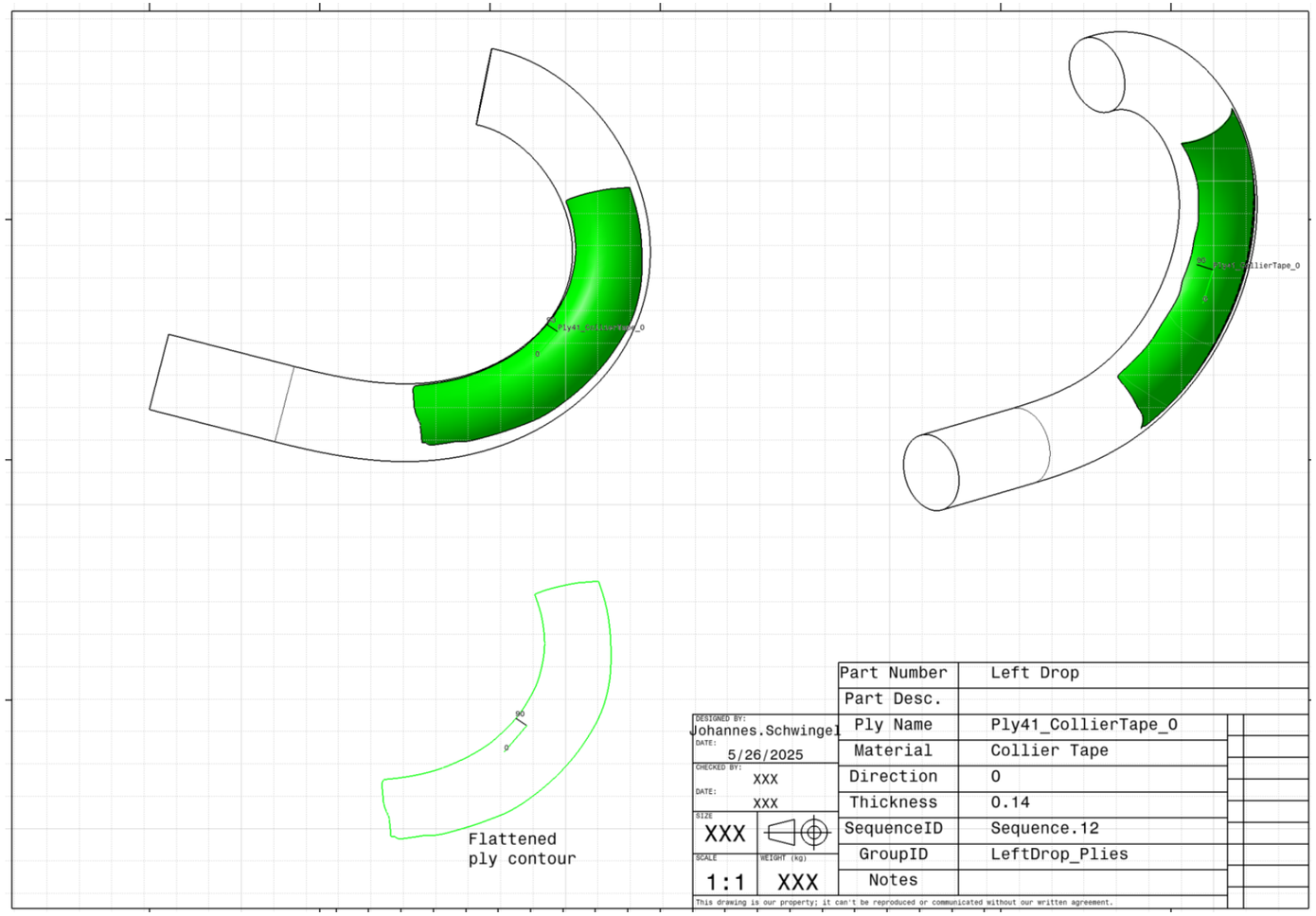




Next Steps: Additional plies added (or removed) to resolve margins

Ply Generation

Catia Flat Patterning – Plybook Generation



Conclusions

Weight

- 10% lighter than initial subpart design
- 2.5% lighter than a traditional laminate design
- 6% reduction in ply cut pieces vs. traditional laminate
- Nominal average stiffness change (~-1%)

Schedule

- HyperFEA strength and stiffness iterations
  - Usually: Make and break, MONTHS at a vendor
  - **1 week in HyperX**
- Design trades
  - Easily compare different design concepts
- Variable Fiber Direction margin update
  - Troubleshoot design intent vs as-manufactured virtually
- Quickly perform follow-up iterations

Producibility

- Laminate Family generated from sizing results
- Draping analysis in Catia
- Manufacturing guidance
- Clear plybook generation

Contact us: www.collieraerospace.com