



Ultra-Light Hybrid Composite Door Design, Manufacturing, and Demonstration

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2017 DOE Vehicle Technologies Office Review Presentation

TPI Composites Inc.

7 June 2017



Project ID#: LM119

Overview

Timeline

- Project start date : Dec 2015
- Project end date : Nov 2018
- Percent complete: 50%

Budget

- Total project funding \$5,974,519
 - DOE share \$2,969,194
 - Contractor share \$3,005,325
- Funding received in FY 2016
 - DOE share \$593,269
 - Contractor share \$757,387
- Funding for FY 2017
 - DOE share \$1,984,199
 - Contractor share \$1,159,220

Barriers

- **Cycle time** - standard composite manufacturing processes can process these parts at a cycle time of about 1 hour per part. New injection technologies and resin formulations have opened the possibility of faster cycle times.
- **Mass** - current materials and methods utilize steel as the main structural component, adding mass to the overall structure, thereby reducing the vehicle fuel efficiency
- **Cost** - one of the major light-weighting materials at our disposal, carbon fiber, is upwards of \$10-15/lb. This material must be used judiciously in order to meet cost targets

Partners

- TPI Composites – Project Lead
- University of Delaware
- US Automotive OEM
- Hexion
- Saertex
- Creative Foam
- Krauss-Maffei

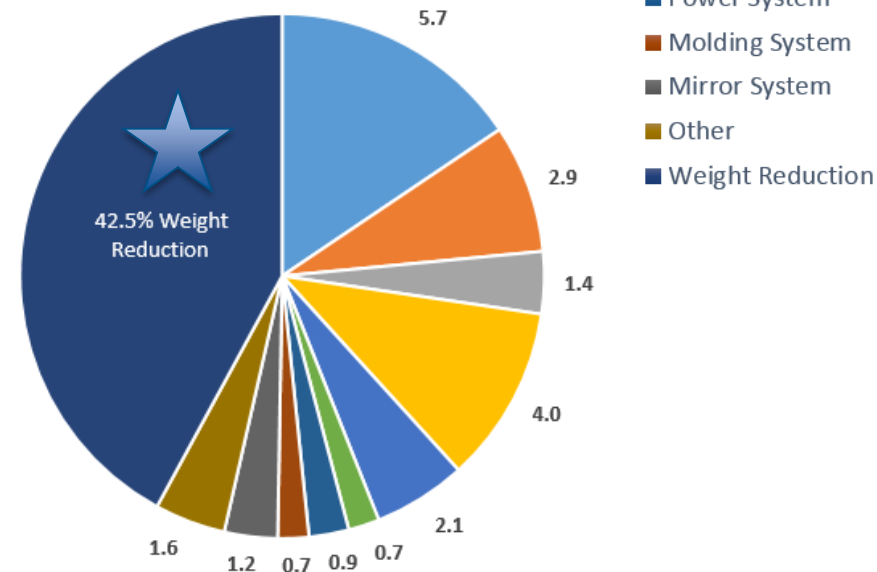
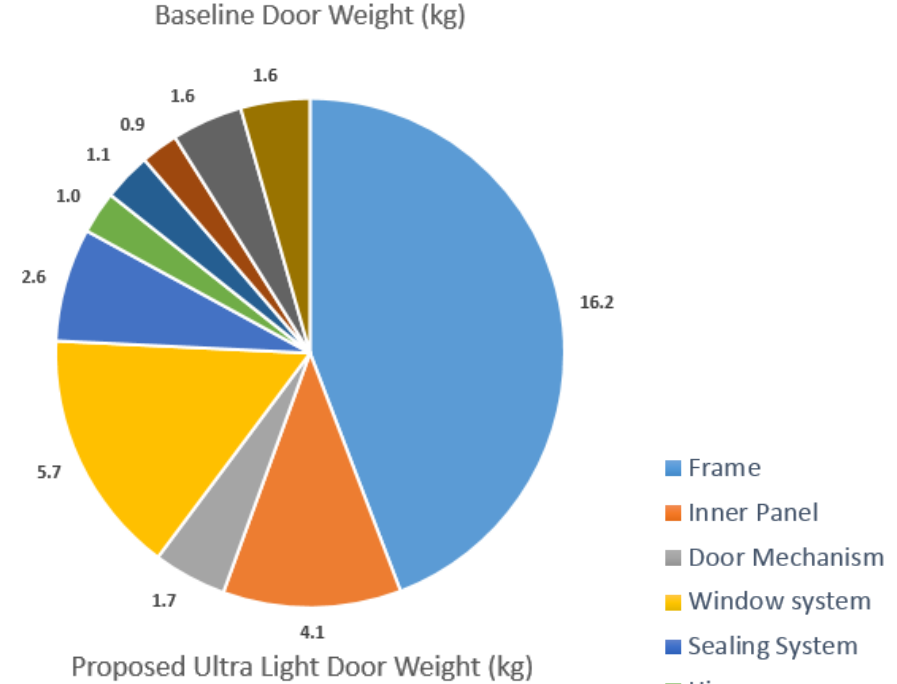
Relevance - Objective

- Project Objectives
 - Reduce the full system weight of a car door by 42.5%
 - Cost target – less than a \$5 increased for every pound of weight saved
 - To meet DOE-VTO Multi-Year Program Plan (MYPP) light weighting goals
- Objectives this period
 - Identify requirements
 - Develop concept designs
 - Materials characterization
 - Begin Detailed Design began
- Impact
 - Advance the composite manufacturing processes to a point where an automotive part can be created in a matter of minutes rather than hours
 - Allow composites to be competitive in the automotive space
 - Realize VTO goals of improving automotive efficiency and reducing emissions

Relevance - Objective

- 42.5% reduction in weight
- Less than \$5 cost increase for each pound saved

	Current Baseline Door Door	Proposed Ultralight Composite Door	Weight reduction	Reduction
	(kg)	(kg)	(kg)	%
Frame	16.2	5.7	10.5	65%
Inner Panel	4.1	2.9	1.2	30%
Door Mechanism	1.7	1.4	0.3	18%
Window system	5.7	4	1.7	30%
Sealing System	2.6	2.1	0.5	20%
Hinges	1.0	0.7	0.3	29%
Power System	1.1	0.9	0.2	19%
Molding System	0.9	0.7	0.2	20%
Mirror System	1.6	1.2	0.4	27%
Other	1.6	1.6	0.0	0%
Totals	36.5	21.2	15.3	



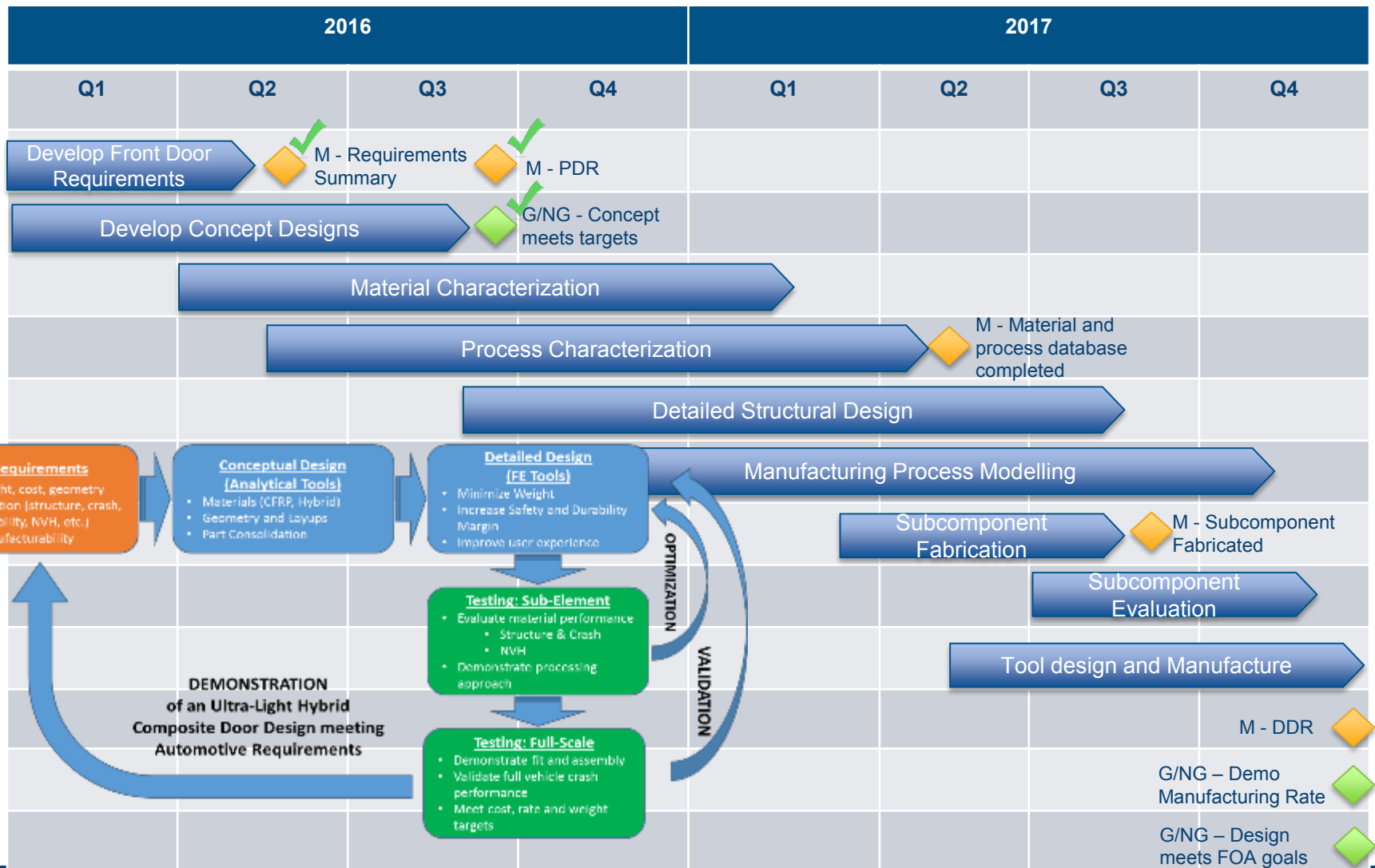
MILESTONES

	Task Title	Type	Description	Verification Process	Planned Date	Status
2016	Conceptual Design	M	Front Door Requirement Summary	Identify All Door Requirements GM,DOE Approvals	M3/Q1	Complete
2016	Conceptual Design	M	Preliminary Design Review	Meeting Reviewing Proposed Concepts	M6/Q2	Complete
2016	Conceptual Design	GO/ NO- GO	Concept Meets Requirement Targets	Concept Meets FOA Goals, 42.3% weight reduction and <\$5 per pound saved DOE Review	M6/Q2	Complete
2016	Develop/Implement/Validate Door Design using Predictive Engineering Environment	M	Material and Process Test Protocol Established	Test Protocol Provided DOE Review	M9/Q3	Complete
2016	Develop/Implement/Validate Door Design using Predictive Engineering Environment	M	Predictive Engineering Environment Implemented	Demo PE Environment on Sub-Component DOE Review	M12/Q4	Complete
2017	Develop/Implement/Validate Door Design using Predictive Engineering Environment	M	Material and Process Database Completed	Database Defined and Completed DOE Review	M15/Q5	Ongoing

MILESTONES

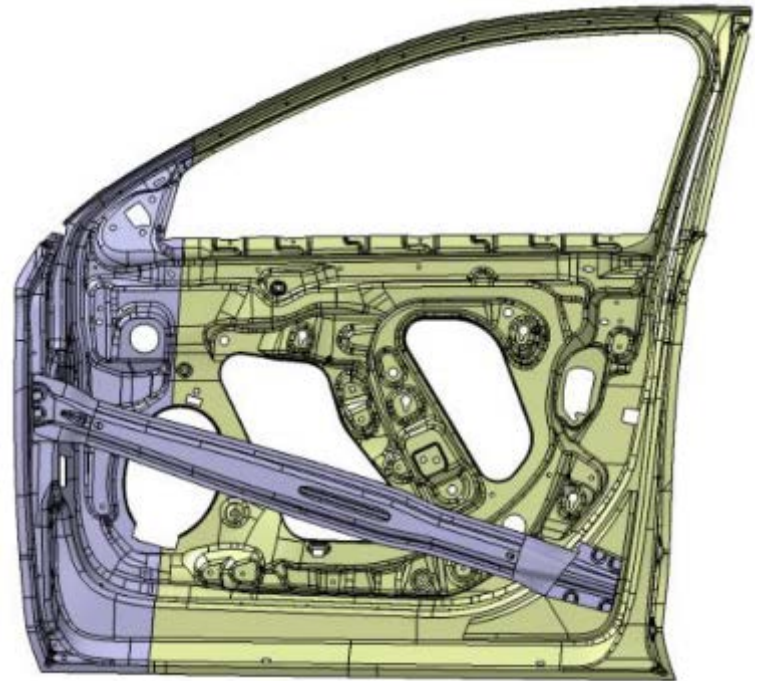
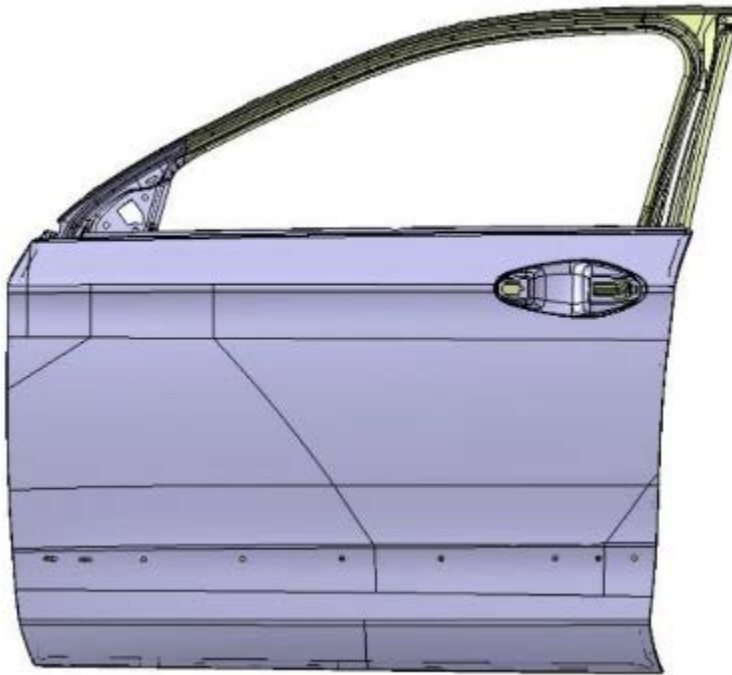
	Task Title	Type	Description	Verification Process	Planned Date	Status
2017	Develop/Implement/Validate Door Design using Predictive Engineering Environment	M	Sub-Component Fabricated	Component Process and Data Provided DOE Review	M18/Q6	Ongoing
2017	Develop/Implement/Validate Door Design using Predictive Engineering Environment	M	Detailed Design Review	Meeting Reviewing Full Door Design GM,DOE Approval	M21/Q7	
2017	Develop/Implement/Validate Door Design using Predictive Engineering Environment	GO/NO-GO	Demo Manufacturing Rate	Sub-Component infusion and cure time below 3 minutes DOE Review	M18/Q6	
2017	Develop/Implement/Validate Door Design using Predictive Engineering Environment	GO/NO-GO	Demo Design Meets FOA goals using Predictive Engineering Environment	Full Door Design Meets Task 1.1 Requirements GM and DOE Approvals	M21/Q7	

Approach & Milestones



Technical Accomplishment – Door CAD Geometry Transferred from OEM

- Three main structural parts
 - Door Inner
 - Door Outer
 - Intrusion Beam



Technical Accomplishments – Material characterization conducted

Coupons manufactured via HP-RTM process by Hexion

Ultrasonically reviewed by University of Delaware for voids & fiber direction

University of Delaware and TPI conducted simultaneous tests to confirm material properties



Technical Accomplishments – Material characterization conducted

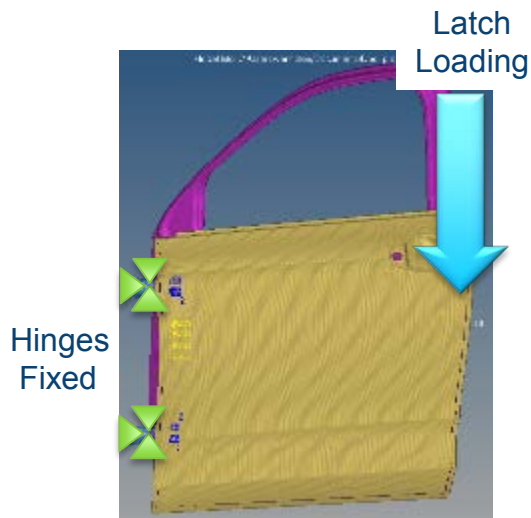
Material Properties

- Mechanical properties in panels were on the lower side of the 45-55% range of parts manufacture for HP-RTM process
- If the fiber volume could be increased in an optimal layup the material properties would increase
- Creating a lighter part through the use of less material

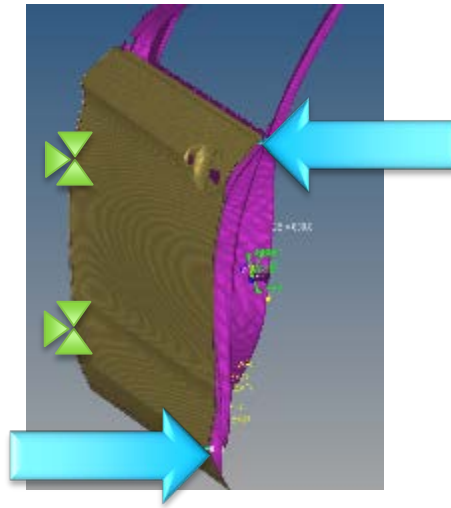
Property		T300/3501-6 Epoxy @ 50%Fv	E-Glass 3501-6 Epoxy @ 50%Fv	Saertex, Carbon, Zoltek Panex 35, Hexion @ ~45%Fv	Saertex, Glass, PPG 2002, Hexion @ ~45%Fv
Longitudinal	Tensile Modulus [GPa]	117	38.2	101	34.3
	Tensile Strength [Mpa]	1765	1075	1222	723.0
	Tensile Strain-to-Failure [%]	1.50	2.80	1.14	2.30
	Compressive Modulus [GPa]	-	-	92.80	36.68
	Compressive Strength [Mpa]	1090	725	740	616
	Compressive Strain-to-Failure [%]	0.93	1.90	0.82	1.46
Transverse	Tensile Modulus [GPa]	7.9	11.0	8.1	12.8
	Tensile Strength [Mpa]	59	56	50	49
	Tensile Strain-to-Failure [%]	-	-	0.65	0.41
	Compressive Modulus [GPa]	-	-	7.72	12.07
	Compressive Strength [Mpa]	213	201	143	137
	Compressive Strain-to-Failure [%]	-	-	2.78	1.51
Shear	In-Plane Poissons Ratio	0.27	0.26	0.36	0.27
	In-plane Shear Modulus [GPa]	3.70	4.14	2.90	2.90
	In-plane Shear Strength [Mpa]	-	-	86.3	81.8

Technical Accomplishment – Critical static requirements agreed upon

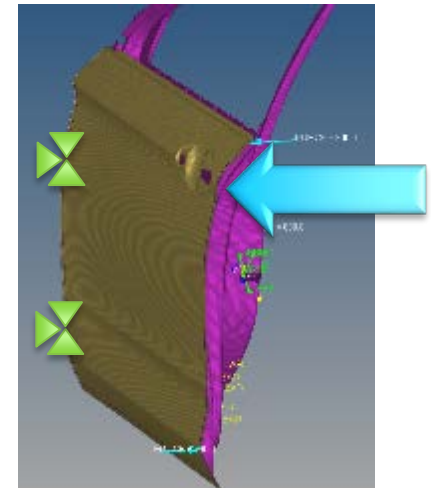
- Critical Static Door Loading Defined with OEM
 - DIW Vertical rigidity
 - DIR Torsional rigidity (point & distributed)
 - Check Load rigidity (Full Open)



Vertical



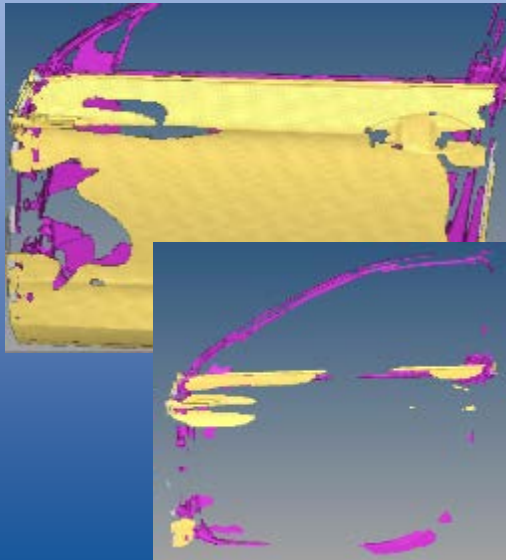
Torsional



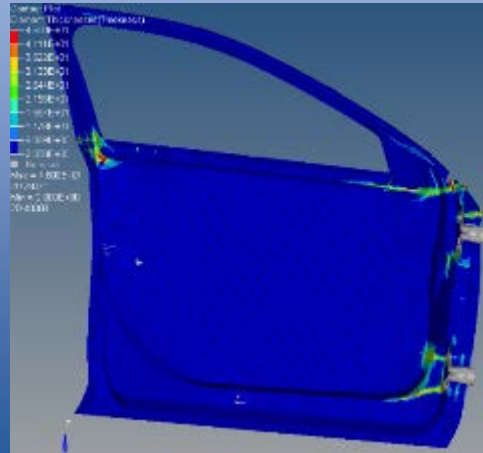
Check Load
Full open

Technical Accomplishments – Door laminate optimization conducted

Free size optimization
thicknesses of plies where
needed



Discrete size optimization
Calculates number of plies
and shape



Ply Shuffling
Optimizes Ply stack

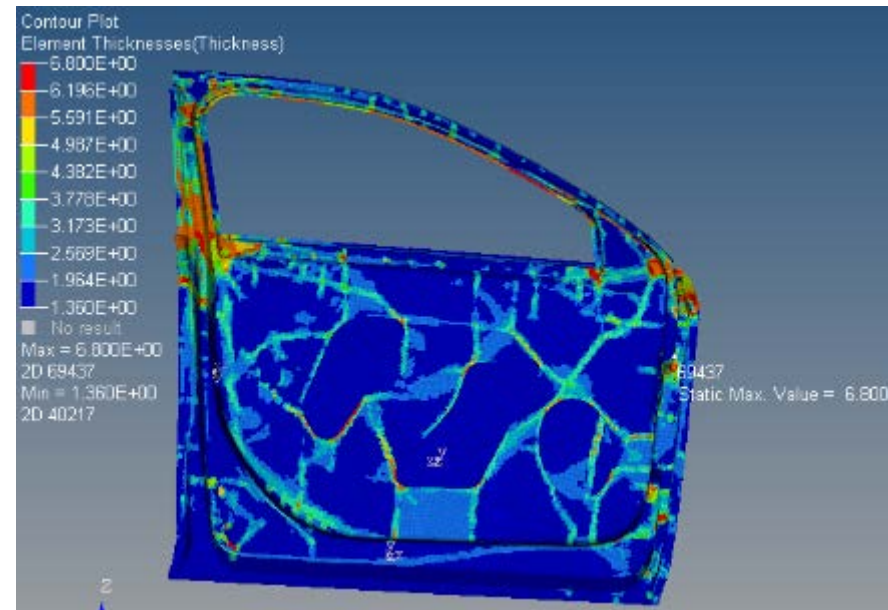
Stacking sequence for STACK 1

Iteration 0	Iteration 1	Iteration 2	Legend
11101	14101	14101	50.0%Kevlar
11102	11102	11102	40.0%Kevlar
11103	11103	11103	10.0%Kevlar
12101	12101	12101	50.0%Kevlar
12102	12102	12102	40.0%Kevlar
12103	12103	12103	10.0%Kevlar
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18103	18103	18103	10.0%Kevlar
19101	19101	19101	50.0%Kevlar
19102	19102	19102	40.0%Kevlar
19103	19103	19103	10.0%Kevlar
20101	20101	20101	50.0%Kevlar
20102	20102	20102	40.0%Kevlar
20103	20103	20103	10.0%Kevlar
21101	21101	21101	50.0%Kevlar
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40102	40102	40102	40.0%Kevlar
40103	40103	40103	10.0%Kevlar
41101	41101	41101	50.0%Kevlar
41102	41102	41102	40.0%Kevlar
41103	41103	41103	10.0%Kevlar
42101	42101	42101	50.0%Kevlar
42102	42102	42102	40.0%Kevlar
42103	42103	42103	10.0%Kevlar
43101	43101	43101	50.0%Kevlar
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46103	46103	46103	10.0%Kevlar
47101	47101	47101	50.0%Kevlar
47102	47102	47102	40.0%Kevlar
47103	47103	47103	10.0%Kevlar
48101	48101	48101	50.0%Kevlar
48102	48102	48102	40.0%Kevlar
48103	48103	48103	10.0%Kevlar
49101	49101	49101	50.0%Kevlar
49102	49102	49102	40.0%Kevlar
49103	49103	49103	10.0%Kevlar
50101	50101	50101	50.0%Kevlar
50102	50102	50102	40.0%Kevlar
50103	50103	50103	10.0%Kevlar

Technical Accomplishments – Door laminate optimization completed

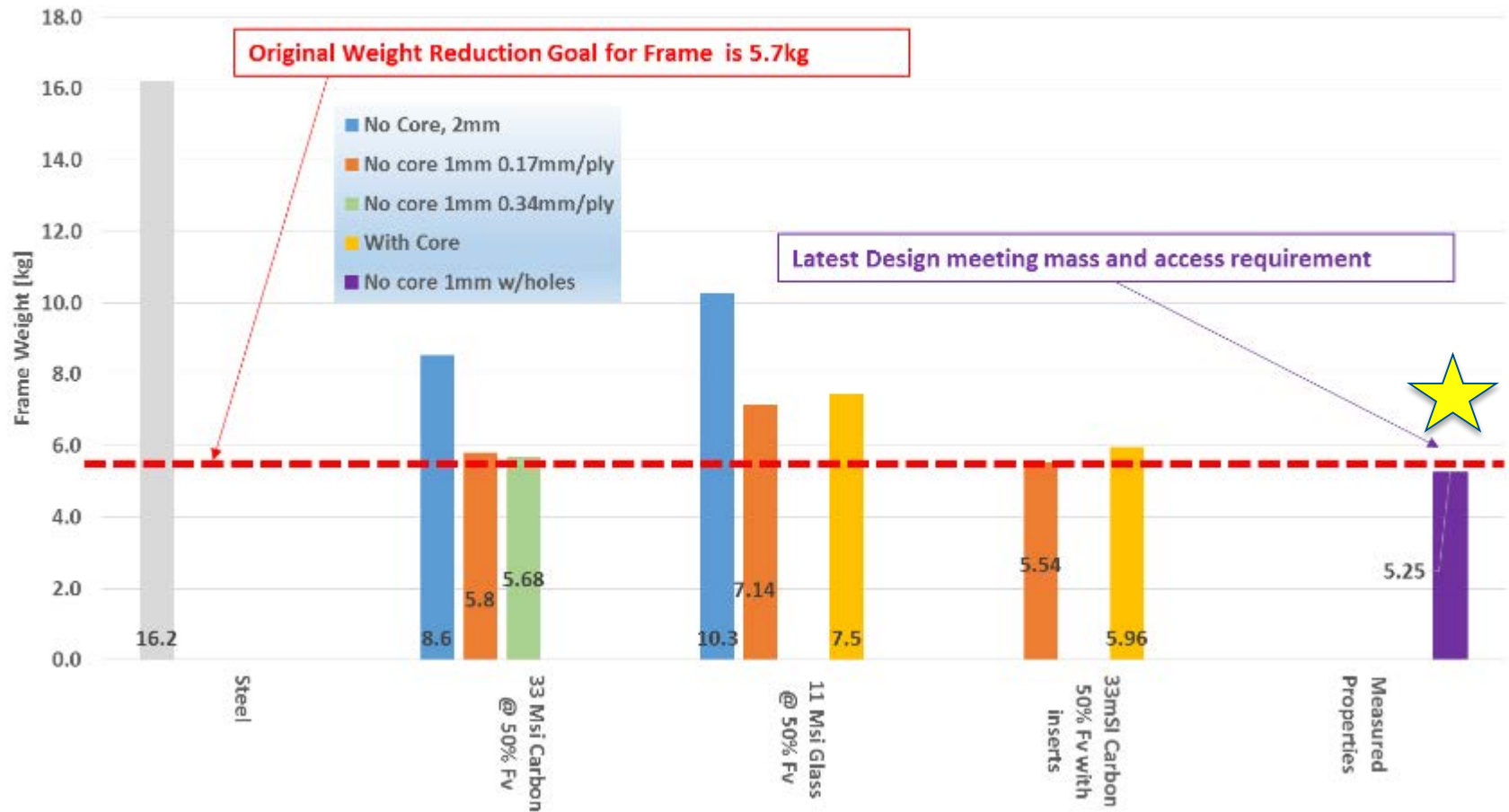
- Ply laminate optimization to match existing door stiffness
 - Objective minimize mass
 - Under the following constraints:
 - Max Displacement for Vertical Load case
 - Max Displacement for Torsional Load case
 - Max Displacement for Check Load case
 - Balanced plies
 - Min laminate thickness ≥ 1 mm
 - Max Tensile strain
 - Max Compressive strain

Total Mass of inner panel = 5.25 kg



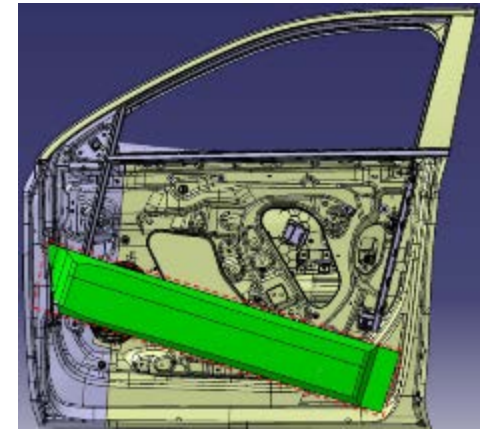
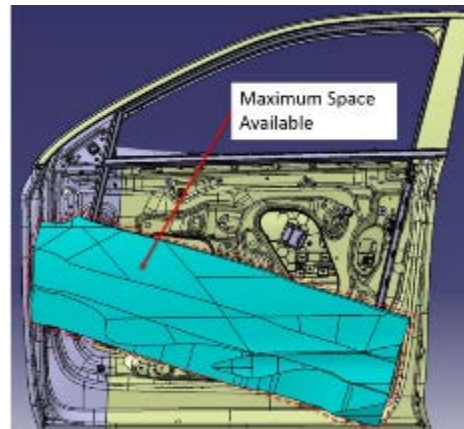
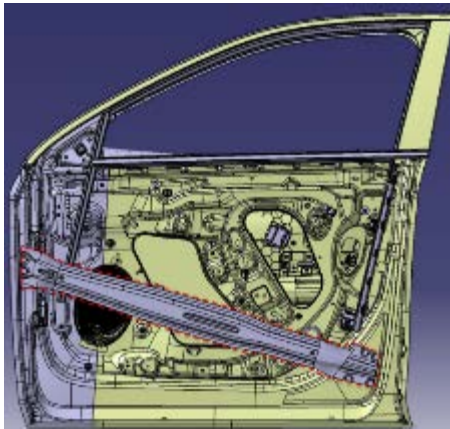
Technical Accomplishments – Weight targets

Design Study Mass Results



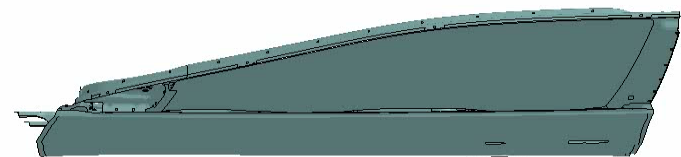
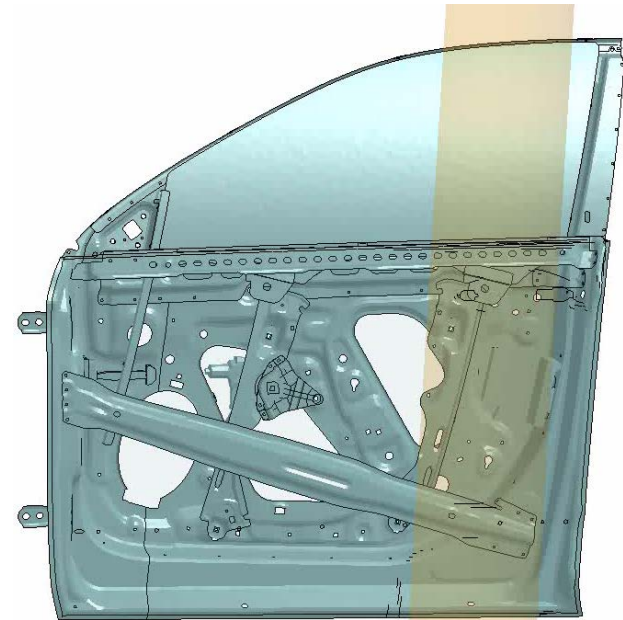
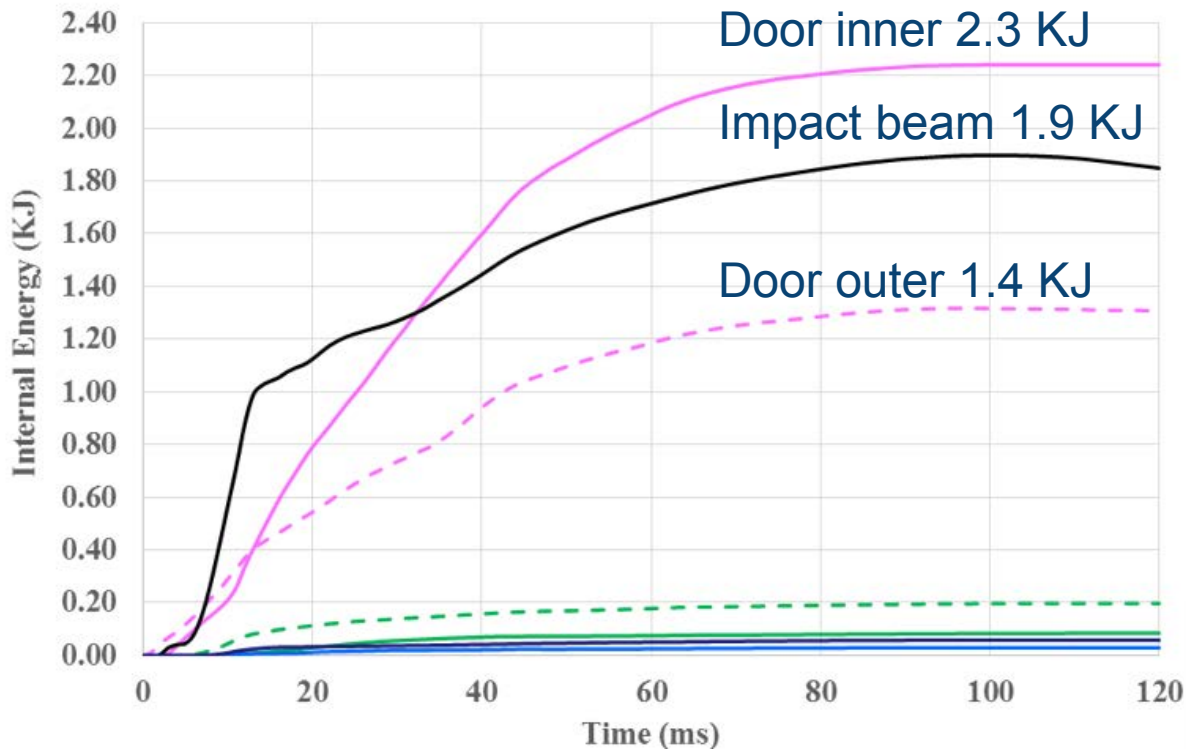
Technical Accomplishments – Intrusion Beam

- Design Allowance Volume
 - Must accommodate existing door internals
 - Window track, motor, latches, hinges
- Three Candidate designs
 - Over-braided foam
 - Hat-Spine design
 - Integrated with door outer



Technical Accomplishments – Baseline impact performance of steel door

Energy absorbed by steel door



Baseline energy absorbed by steel components sets the bar for composite replacements

Technical Accomplishments – Baseline impact performance of steel door

A new material model for NCF composites in the framework of LS-DYNA will be developed in this project

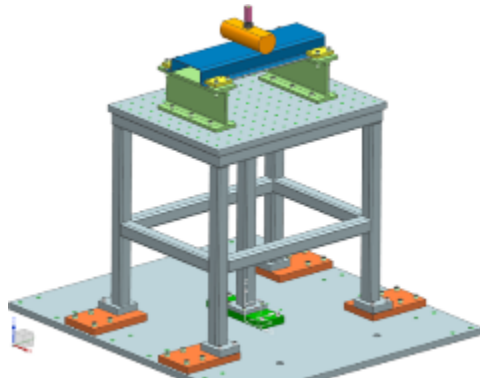
Orthotropic continuum damage model (MAT261 of LS-DYNA)

- Growth of damage is modeled based on fracture toughness:

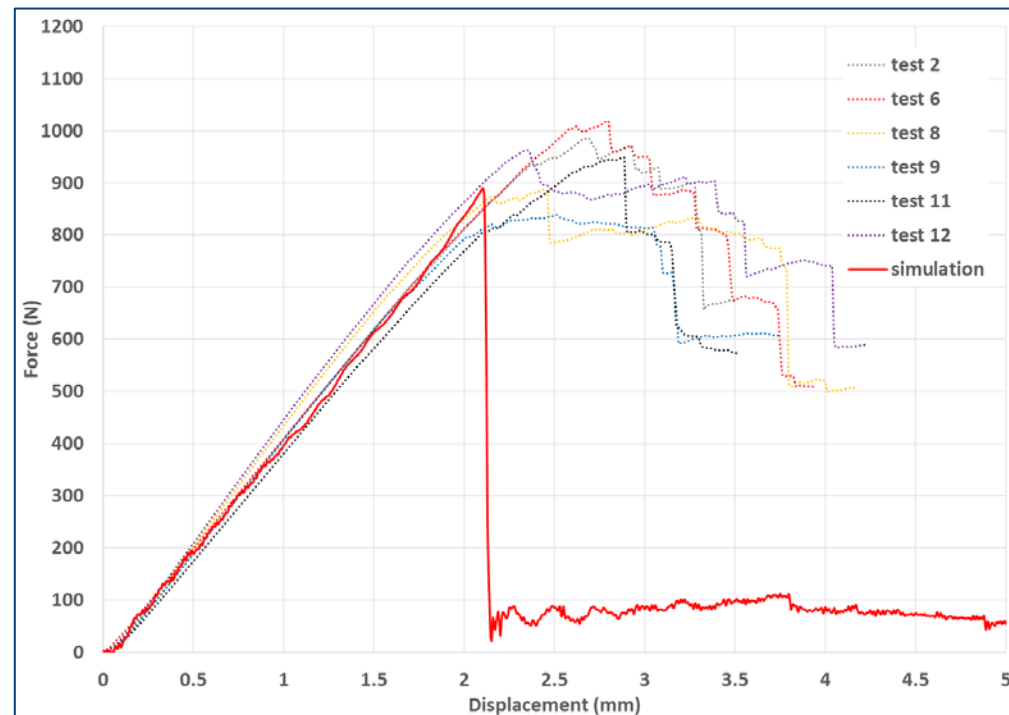
- Longitudinal tensile
- Longitudinal compressive
- Intralaminar matrix tensile
- Intralaminar matrix longitudinal shear
- Intralaminar matrix transverse shear

- Non-linear shear behavior

- Strain rate



Impact tower test setup



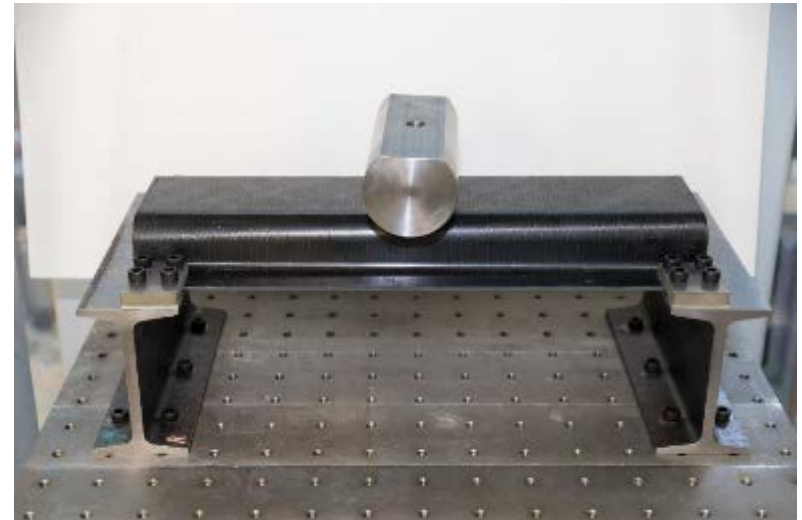
3-PT Bend Tests

Technical Accomplishments – OEM partner creating dynamic impact models

Conducting quasi static and dynamic tests to obtain the strain rate constants for the dynamic material card definition



Quasi Static



Drop tower

Technical Accomplishment – Current status to targets

- Mass reduction target- **42.5%**
- Cost added/pound saved target- **<\$5**

100% Carbon	
Weight Reduction [lb]	29.20
% Reduction	36%
Cost increase	\$ 222.44
Dollars/pound saved	\$ 7.62

50/50 Carbon/Glass	
Weight Reduction [lb]	24.26
% Reduction	30%
Cost increase	\$ 168.28
Dollars/pound saved	\$ 6.94

Carbon cost is driving the dollars per pound saved

Reduction Opportunities to investigate

- Further reduction in component thickness (optimization)
- Cost of inputs (Carbon/Glass)

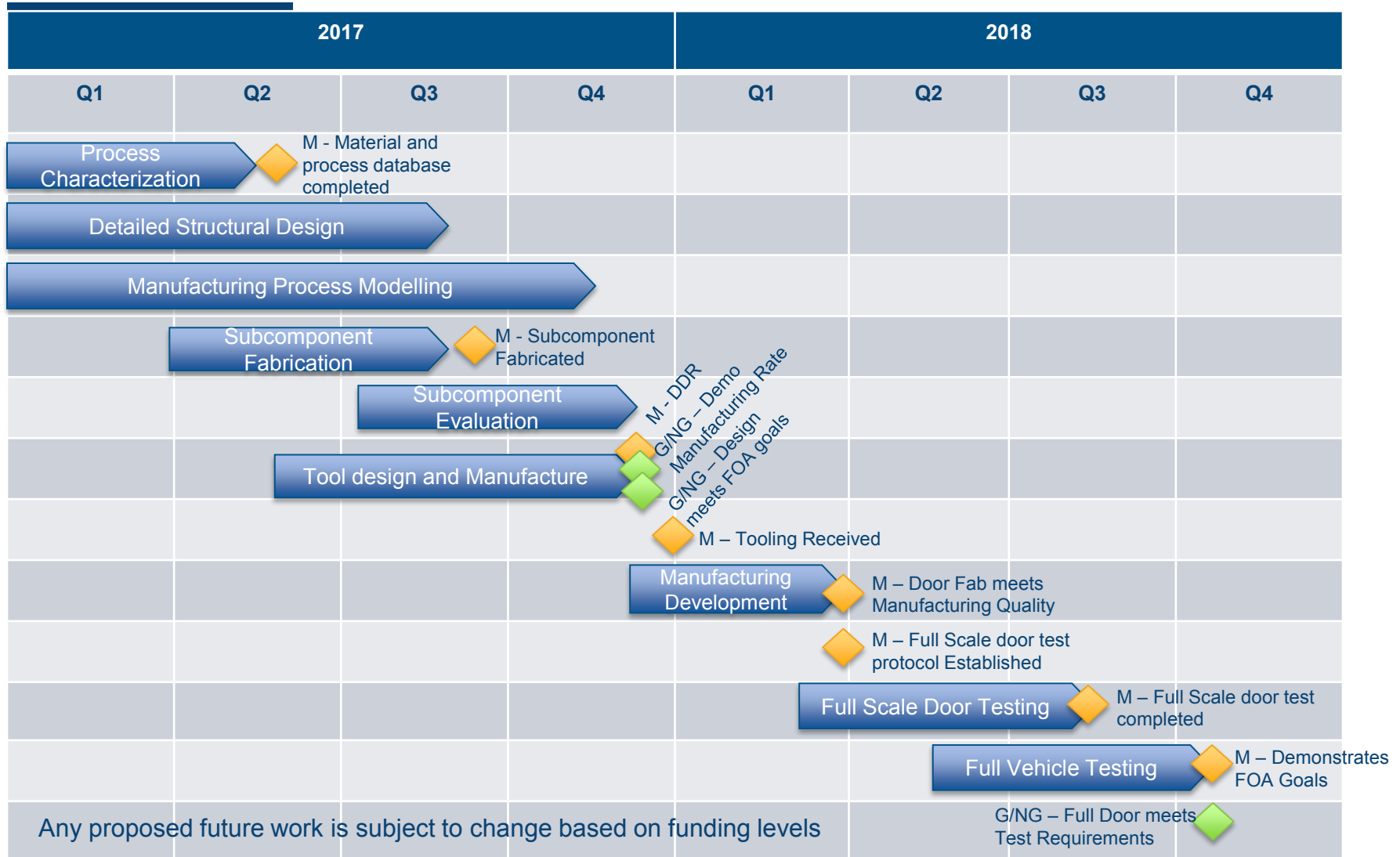
Collaboration with other institutions

TPI Collaborators	
Global Automotive OEM	Sub Contractor, Provide geometry, requirements, Dynamic impact simulation and testing
	Sub Contractor, Composite Modelling, static simulation / optimization, material characterization, Testing Coupons Subcomponents
	Sub Contractor, Snap Cure resins, process guidance
	Sub Contractor, Non-Crimp Fabrics, Preform Technology to the program
	Sub Contractor, Structural Foams
	Sub Contractor, Resin Handling Equipment and process guidance
	Vendor, HP-RTM tooling manufacture and process guidance

Remaining Challenges and Barriers

- The mass saved through the light weighting of the OEM door internals saved less mass and cost more than originally thought
- More mass will need to be saved through the structure light weighting to meet goals
- Validation of the availability thinner plies for manufacture
- Additional optimization will need to be run
- Tooling will also have to be designed in parallel to meet the 6 month tooling lead time

Proposed Future Research



Proposed Future Research

- Planned Future Work
 - Finalize laminate
 - Tooling design and fabrication
 - Component joining techniques
 - Door fabrication
 - Full scale door testing
 - Full vehicle testing
- Potential Future work
 - Creating parts with Low cost Carbon Fiber (ONRL) for cost reduction
 - Future work on Preforming for an HP-RTM part to minimize fiber waste, reducing cost.

Any proposed future work is subject to change based on funding levels

Summary

- **Relevance**

- Cycle time reductions
- 42.5% weight savings
- <\$5/lb cost increase

- **Approach**

- Systems Approach
- Requirements
- Conceptual design
 - Material properties
- Detailed design
 - Optimization
- Sub Element Testing
 - Evaluate
 - Redesign if needed
 - Full scale testing
 - Door
 - Vehicle

- **Technical Accomplishments**

- Requirements defined
- Material characterizations complete
- Preliminary design complete
 - First optimization completed
 - Door laminate defined
- Intrusion beam redesigned
- Dynamic Analysis conducted
 - Baseline complete
 - Creating material models for dynamic analysis
 - Qusai static and dynamic testing

- **Future work**

- Prototype creation
- Tooling design and fabrication
- Door fabrication
- Door testing