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

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2017 DOE Vehicle Technologies Office Review Presentation

TPI Composites Inc.

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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

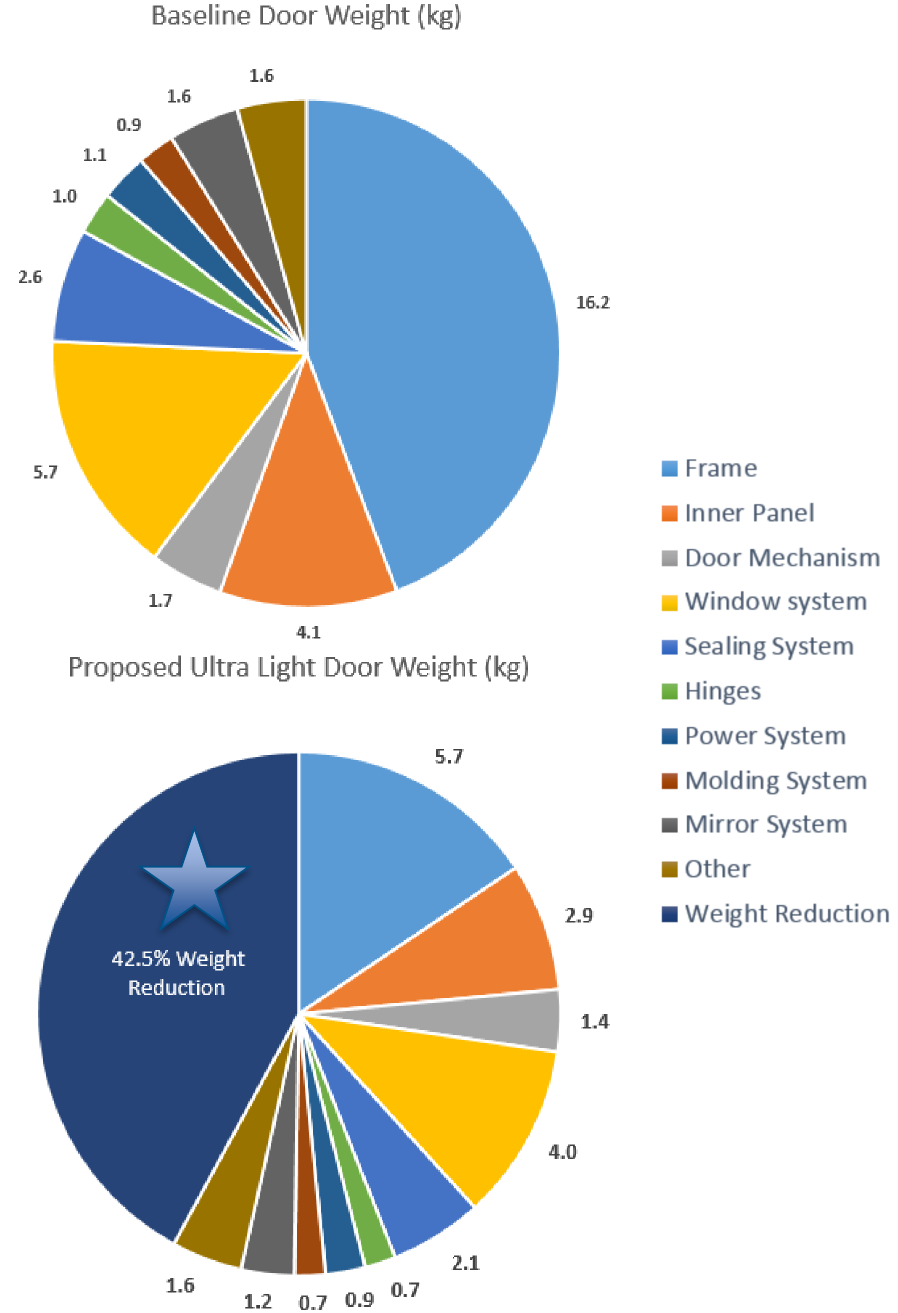
- Objectives this period
  - Identify requirements
  - Develop concept designs
  - Materials characterization
  - Begin Detailed Design began

- 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	



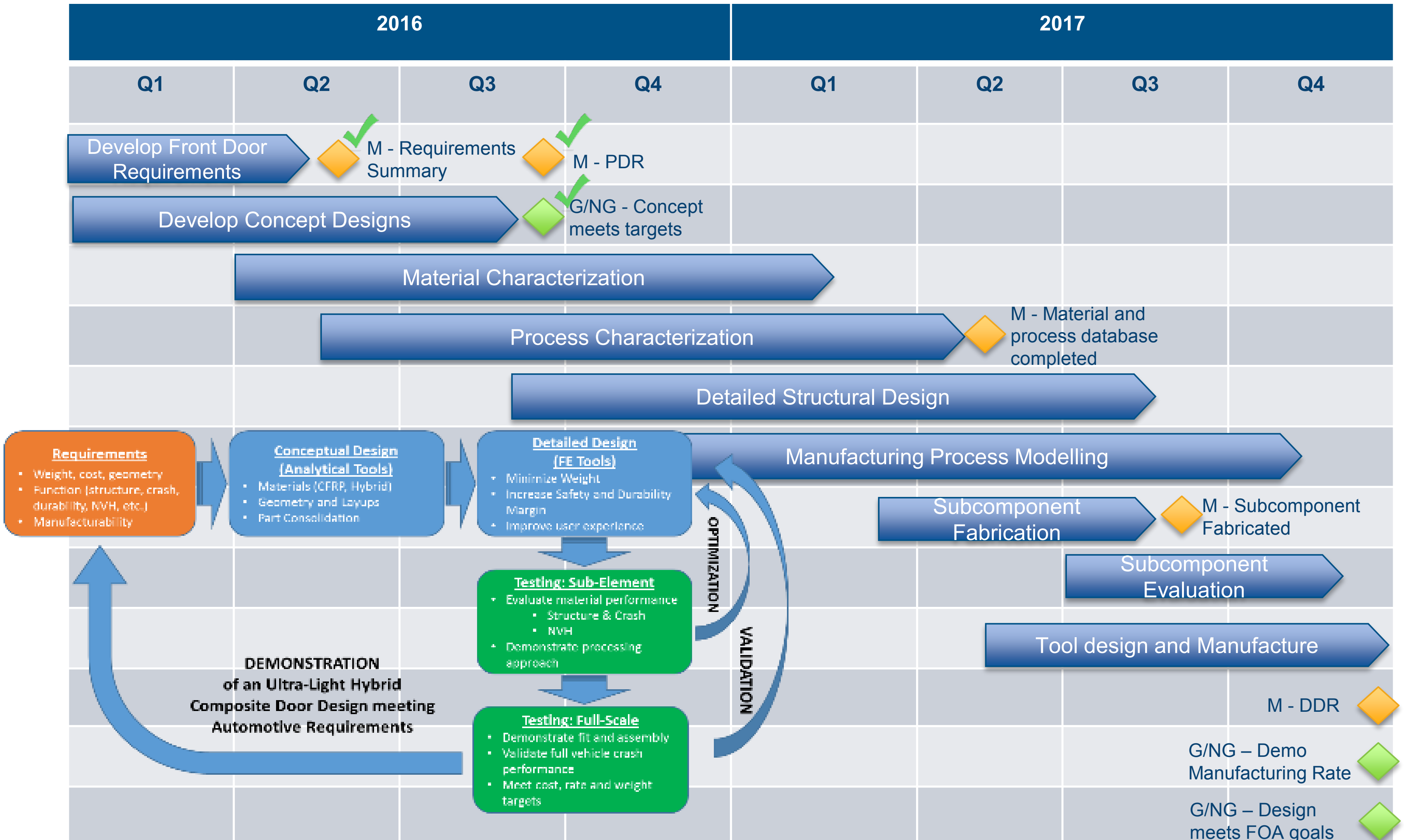
MILESTONES

	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	

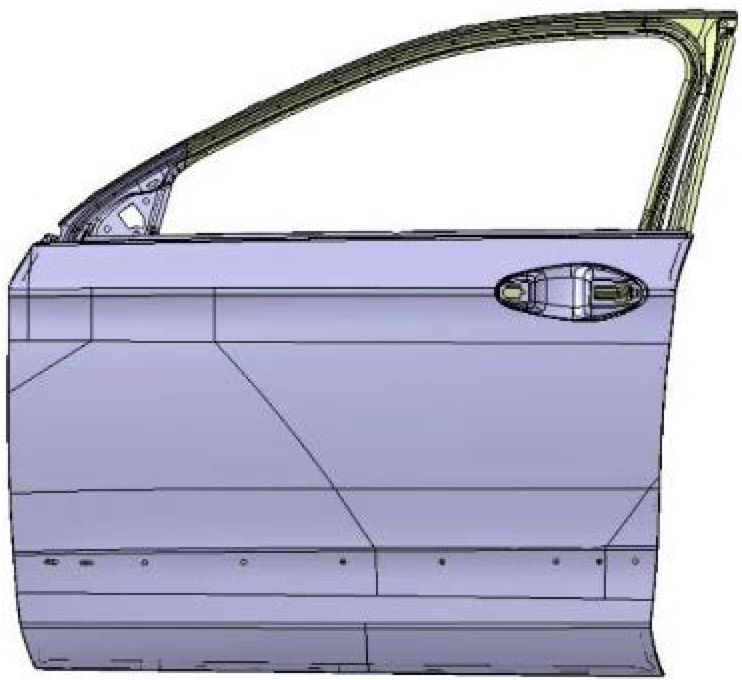
Approach & Milestones

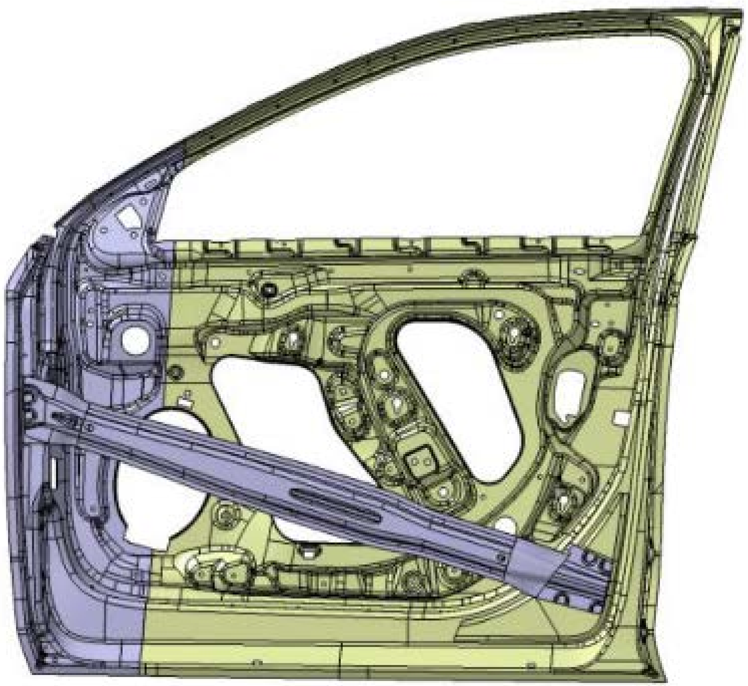


tpi COMPOSITES

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

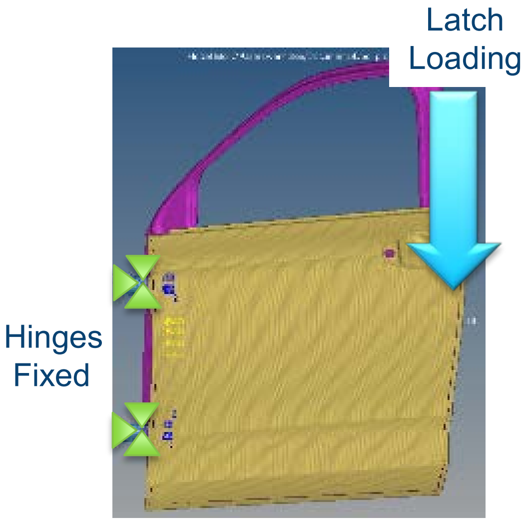
Material Properties

- 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

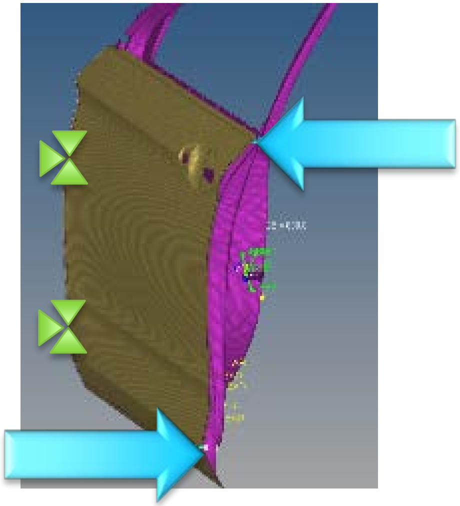
	Property	T300/3501-6 Epoxy @ 50%Fv	E-Glass 3501-6 Epoxy @ 50%Fv	Saertex, Carbon, Zoltek Panex 35, Hexion @ ~45%Fv	Saertex, Glass, PPG 2002, Hexion @ ~45%Fv
Longitudinal	Tensile Modulus [GPa]	117	38.2	101	34.3
	Tensile Strength [Mpa]	1765	1075	1222	723.0
	Tensile Strain-to-Failure [%]	1.50	2.80	1.14	2.30
	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

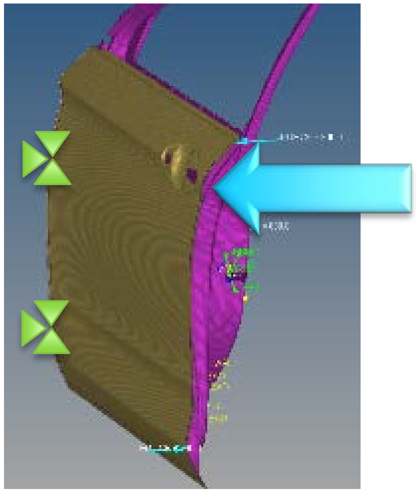
- Critical Static Door Loading Defined with OEM
  - DIW Vertical rigidity
  - DIR Torsional rigidity (point & distributed)
  - Check Load rigidity (Full Open)



Vertical



Torsional

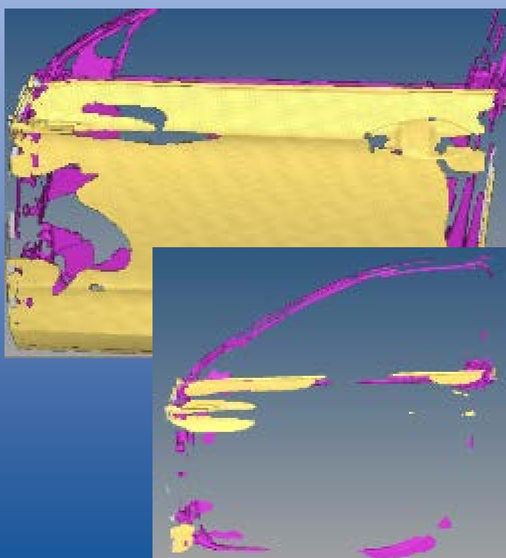


Check Load
Full open

Technical Accomplishments – Door laminate optimization conducted

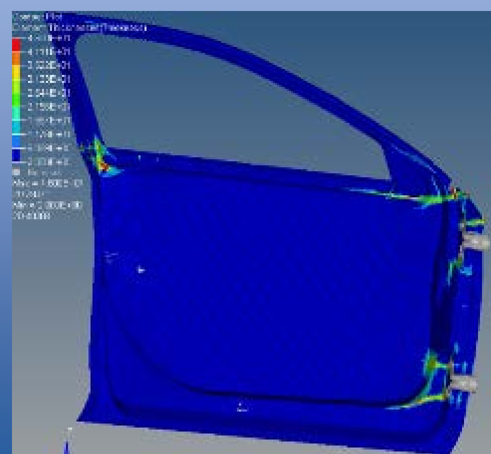
Free size optimization

thicknesses of plies where needed



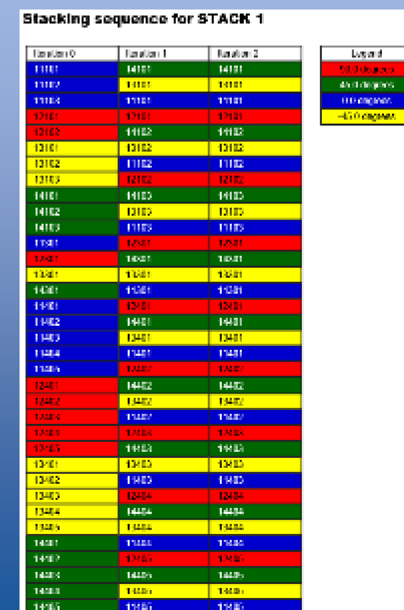
Discrete size optimization

Calculates number of plies and shape



Ply Shuffling

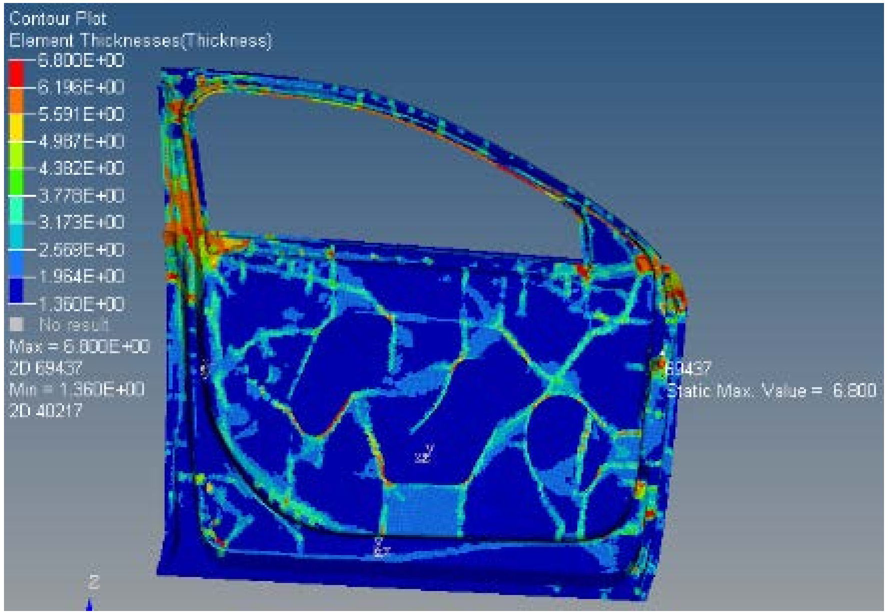
Optimizes Ply stack



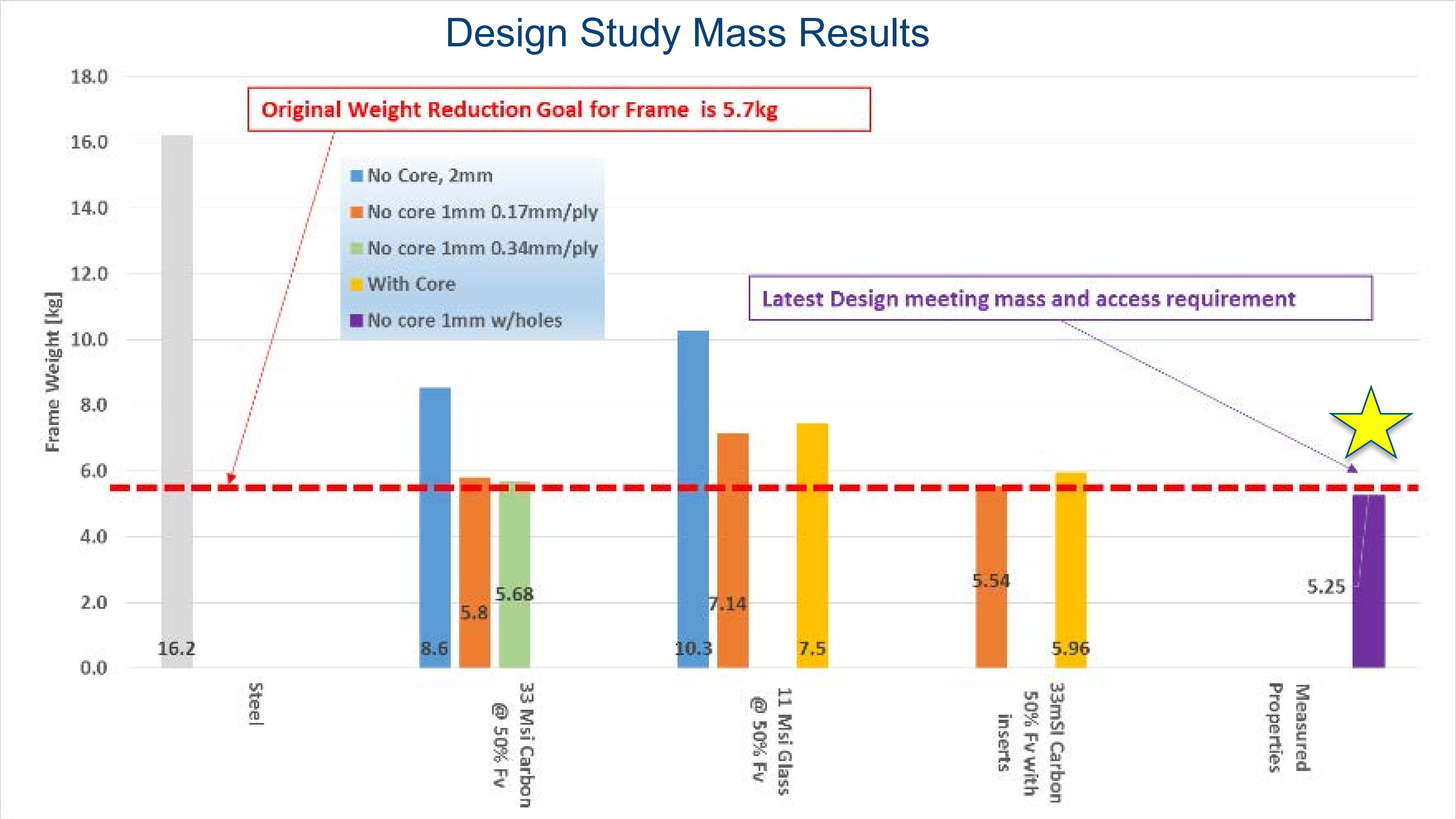
Technical Accomplishments –
Door laminate optimization completed

- 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



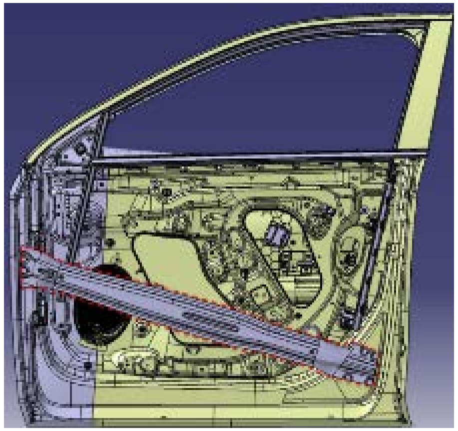
Technical Accomplishments – Weight targets

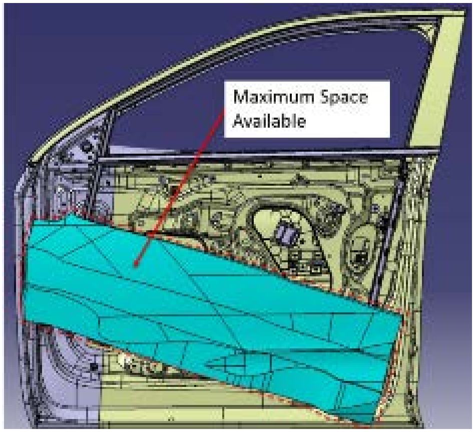


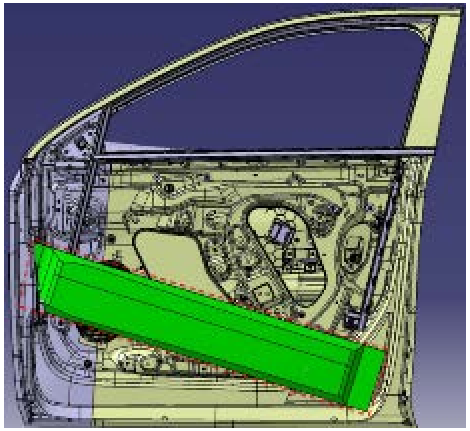
Technical Accomplishments – Intrusion Beam

- 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

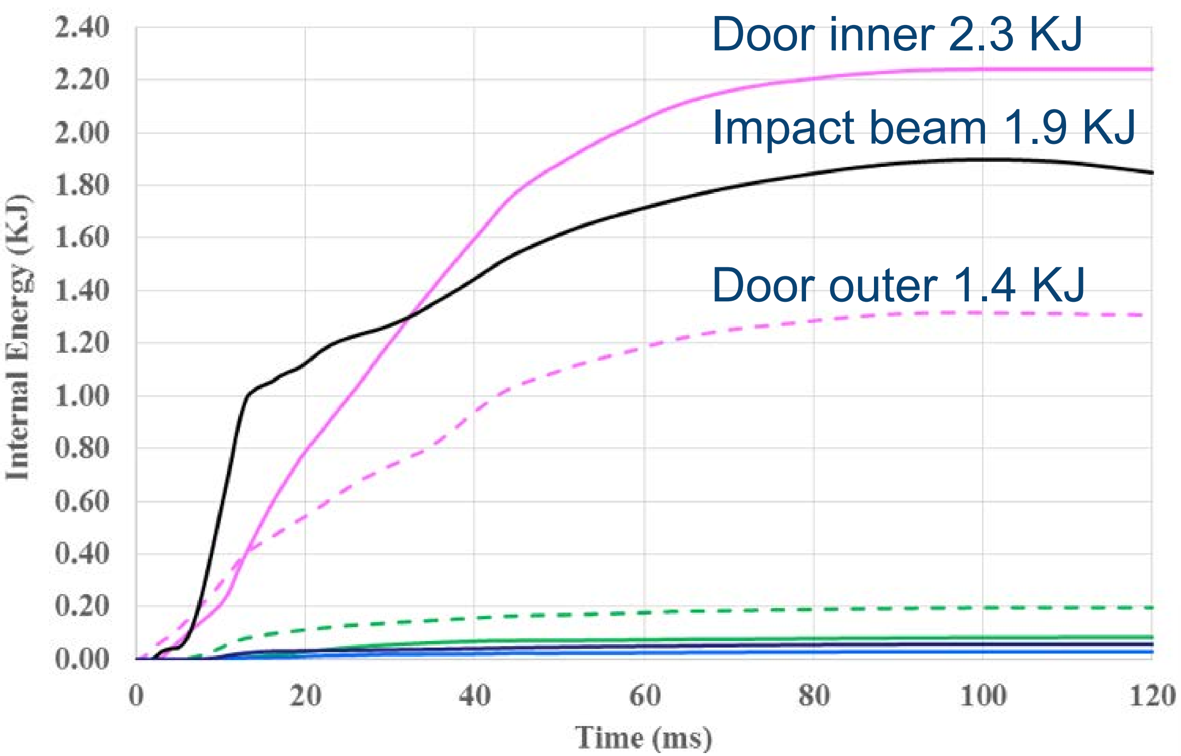


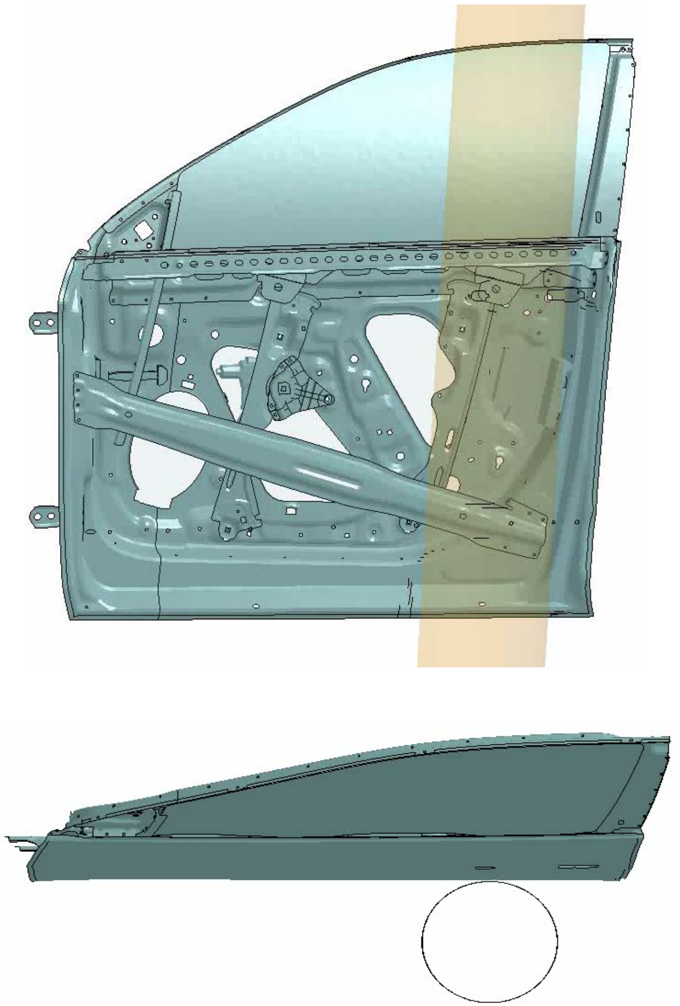




Technical Accomplishments – Baseline impact performance of steel door

Energy absorbed by steel door





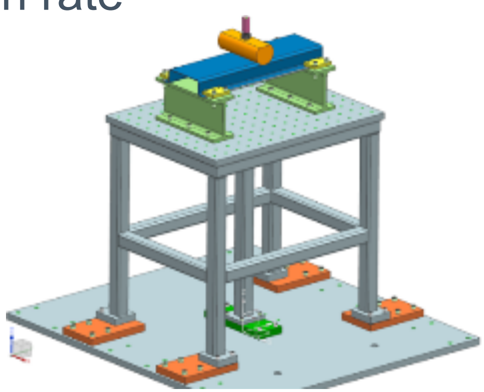
Baseline energy absorbed by steel components sets the bar for composite replacements

Technical Accomplishments –
Baseline impact performance of steel door

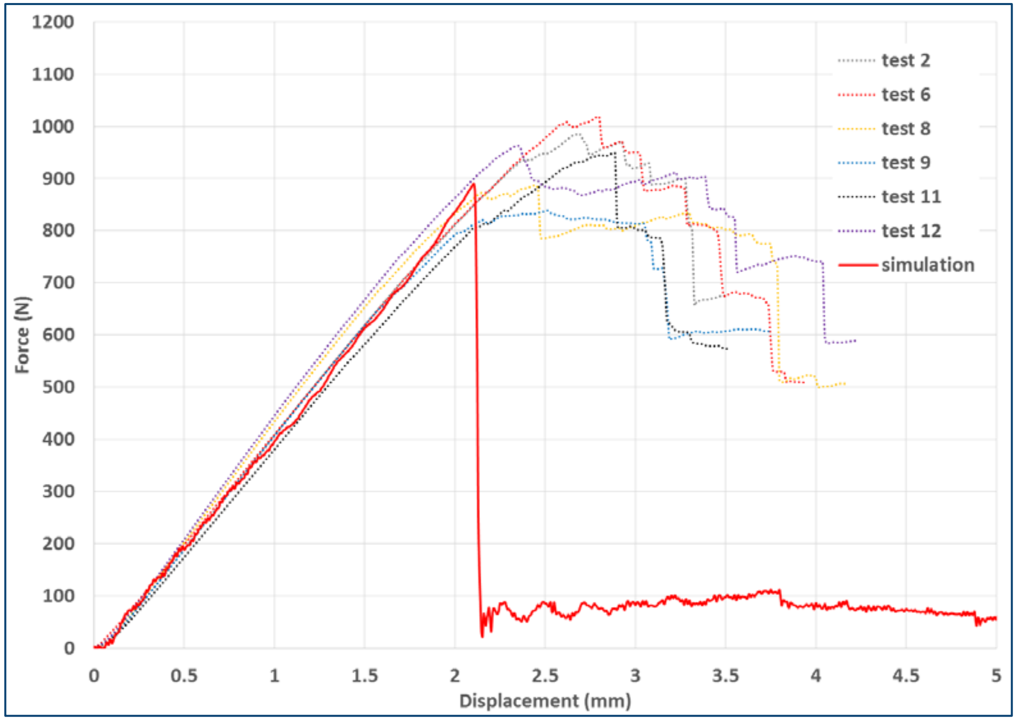
A new material model for NCF composites in the framework of LS-DYNA will be developed in this project

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



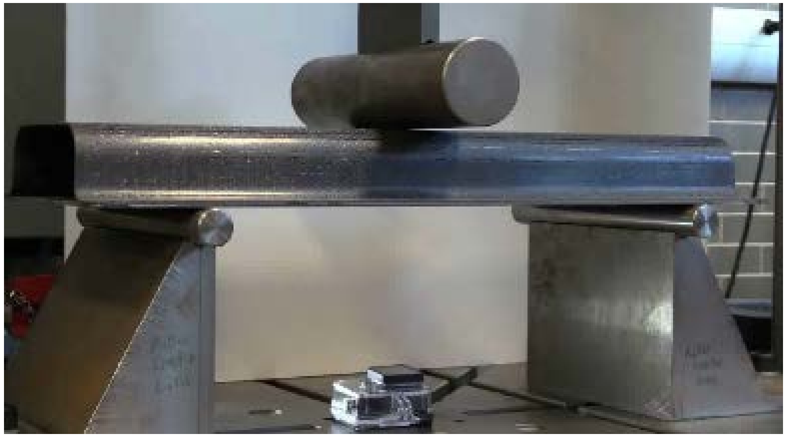
Impact tower test setup



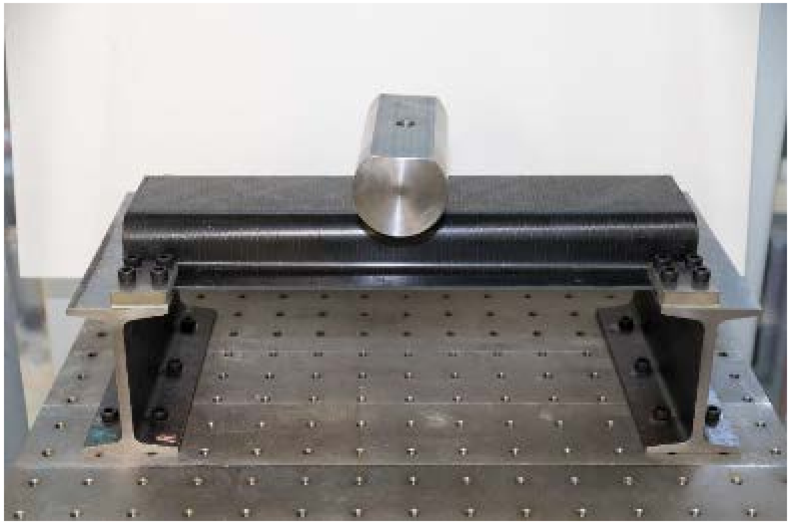
3-PT Bend Tests

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)

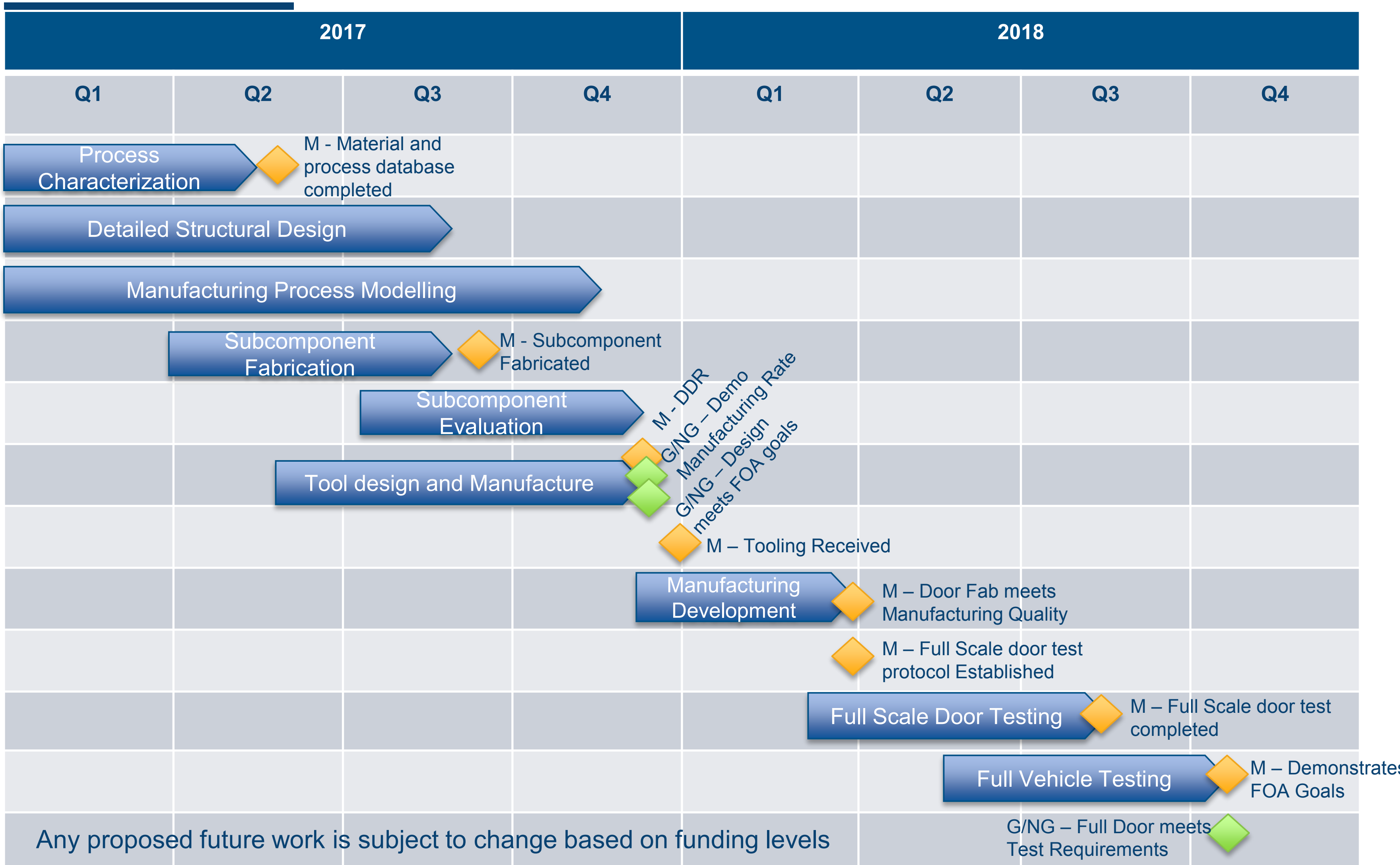
Collaboration with other institutions

TPI Collaborators	
Global Automotive OEM	Sub Contractor, Provide geometry, requirements, Dynamic impact simulation and testing
University of Delaware Center for Composite Materials	Sub Contractor, Composite Modelling, static simulation / optimization, material characterization, Testing Coupons Subcomponents
HEXION	Sub Contractor, Snap Cure resins, process guidance
SAERTEX	Sub Contractor, Non-Crimp Fabrics, Preform Technology to the program
Creative Foam Corporation	Sub Contractor, Structural Foams
KraussMaffei	Sub Contractor, Resin Handling Equipment and process guidance
ALPEX	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