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

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2020 DOE Vehicle Technologies Office
Project ID - Mat119
TPI Composites Inc.
3 June 2020

Overview

Timeline

- Project start date : Dec 2015
- Project end date : March 2020
- Percent complete: 100%

Budget

Total project funding $5,974,519

- DOE share $2,969,194
- Contractor share $3,005,325

Project Funding	2016	2017	2018	2019	2020
DoE Share	555,745	1,213,732	831,552	368,165	165,060
Contractor Share	692,779	1,038,695	1,095,955	177,896	-51,704

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
- Krauss Maffei
- Chomarat
- Atkins & Pearce
- Ashland

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

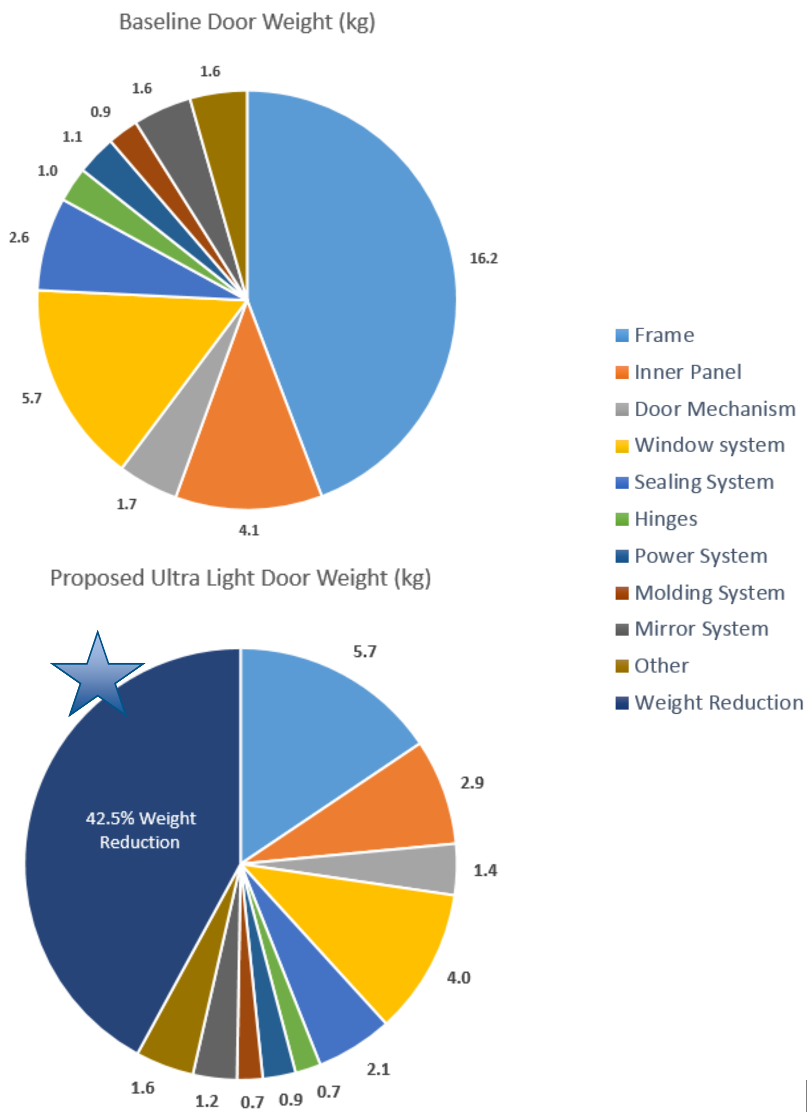
- Objectives this Period
  - Assemble Doors
  - Complete Testing
    - Static Testing
    - Dynamic testing

- 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

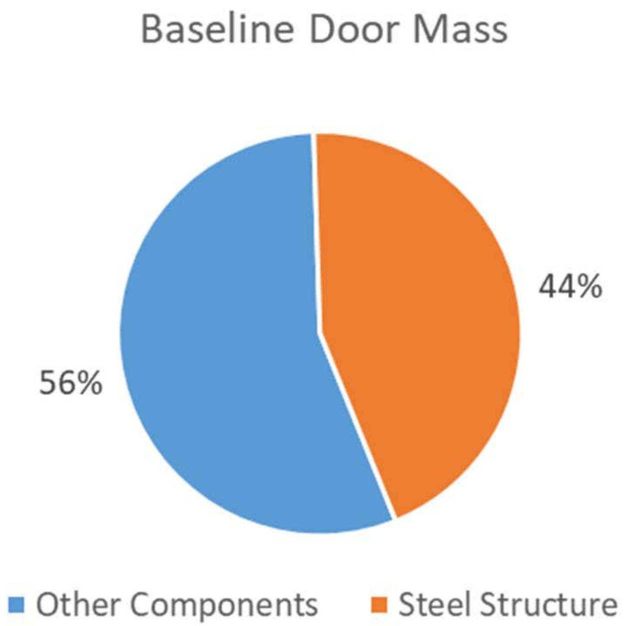
- 42.5% reduction in weight
- Less than $5 cost increase for each pound saved

	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	



Discussion on door internals- OEM design mass

- 56% of door mass are non structural components



OEM has high confidence that other internals mass can be reduced by 25%

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	Complete
2017	Develop/Implement/Validate Door Design using Predictive Engineering Environment	M	Detailed Design Review	Meeting Reviewing Full Door Design GM,DOE Approval	M21/Q7	Complete
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	M23/Q8	Complete
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	M23/Q8	Complete
2018	Component Manufacturing and Testing	M	Tooling For Full Door Received	Tool received at TPI	M30/Q10	Complete
2019	Component Manufacturing and Testing	M	Door Fab Meets Manufacturing Quality	Visual Inspection of Door GM and DOE Approval	M42/Q14	Complete
2019	Component Manufacturing and Testing	M	Full-Scale Door Test Procedure Established	Test Protocol Provided DOE Review	M44/Q15	Complete
2019	Component Manufacturing and Testing	M	Full-Scale Door Testing Completed	Test Report Provided DOE Review	M45/Q15	Complete
2019	Component Manufacturing and Testing	M	Full-Scale Vehicle test demonstrated FOA Goals	Test Report Provided DOE Review	M45/Q15	
2019	Component Manufacturing and Testing	GO/ NO-GO	Full Door Test Meets Requirements	Door test meets weight and other FOA requirements DOE Review	M45/Q15	Complete

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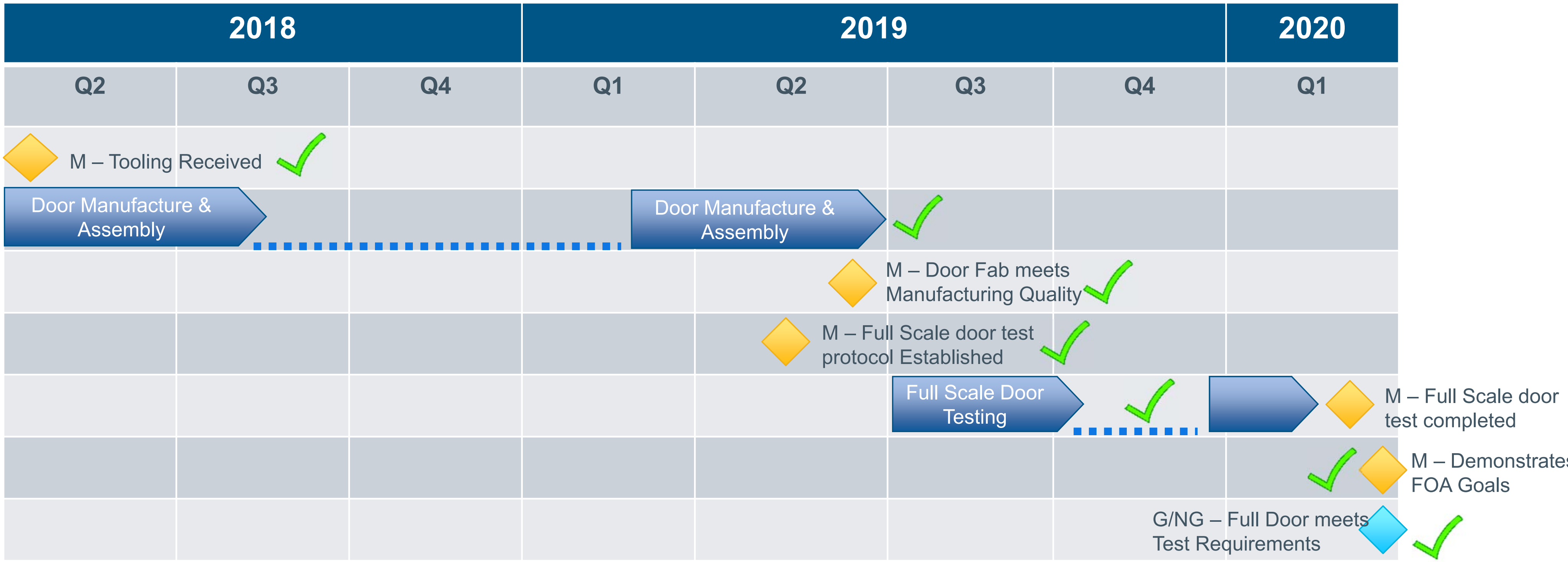
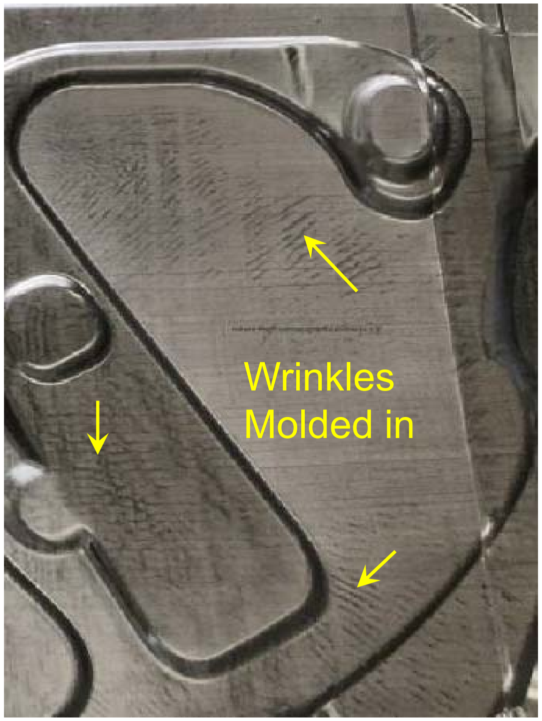
Approach & Milestones



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

Door Manufacture – Improved Preforms

- Wrinkling Issues
  - Independent of Binder Type Thermoplastic veil or Thermoset powder
  - NCF not as drapable as Braided Qiso product



NCF Preform

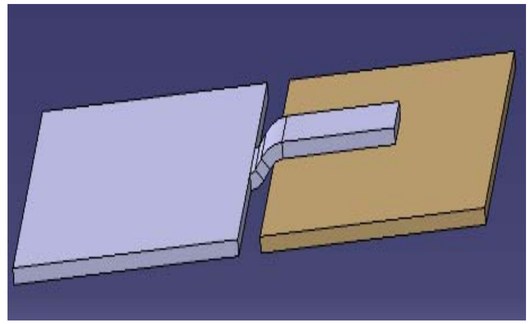
Qiso Preform

Door Manufacture – Improved Preforms

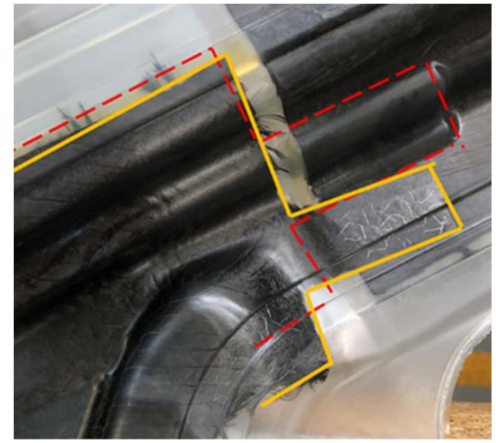
Tab Overlap Design

Original Preform

Tab Overlap Design



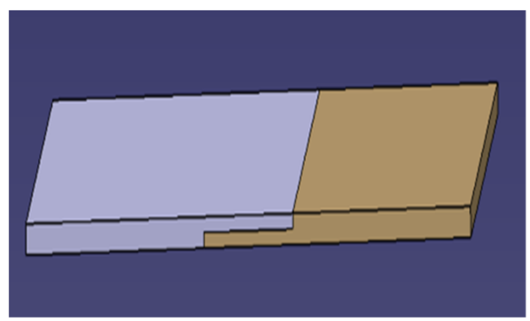
No structural tie between preforms



Full Overlap Design

Updated Preform

Full Overlap Design

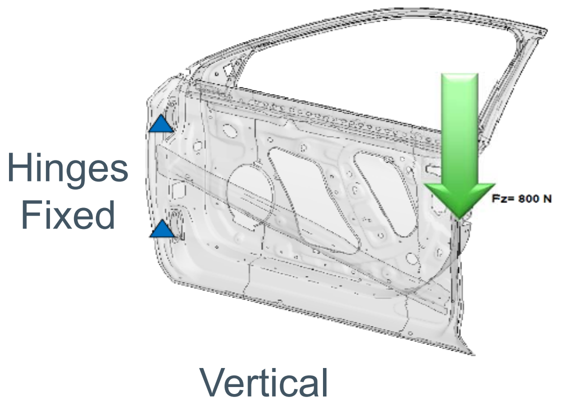


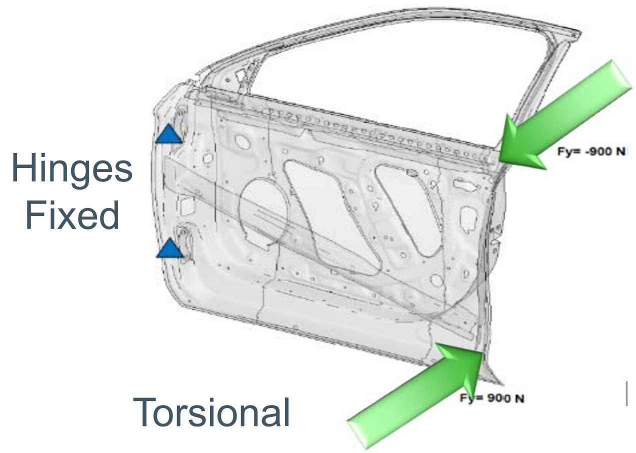
Structural Integrity

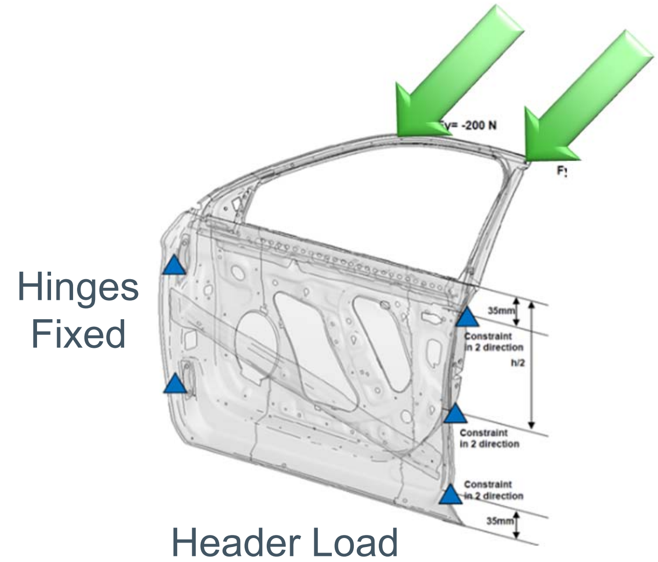
Door Manufacture – Test Preparation

- CNC Trimmed
- Bonded with Ashland Polyurethane Adhesive
  - Door Inner
  - Door Outer
  - Intrusion beam

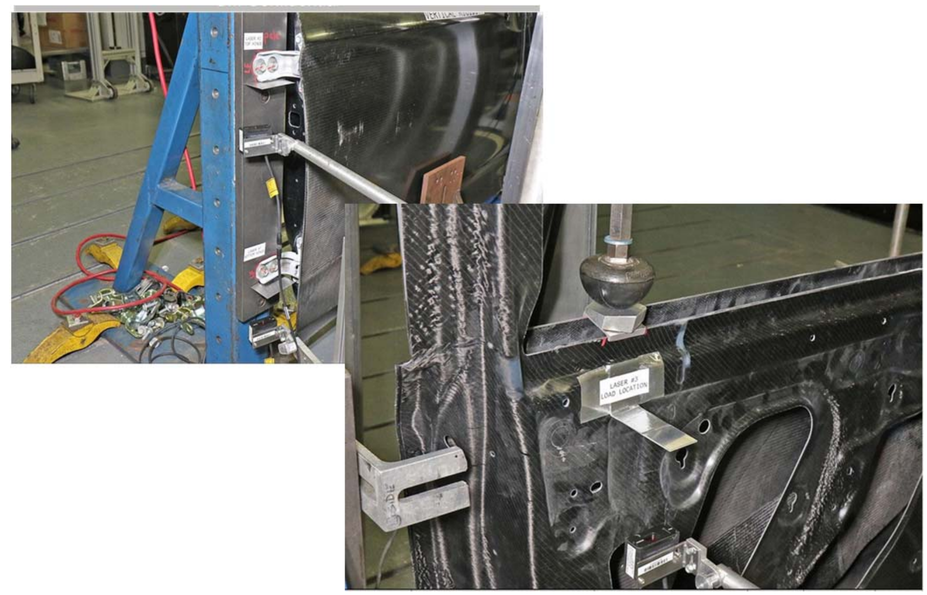
Door Testing – Static Loading







Door Testing – Static Stiffness Results



Test	Steel (kN/mm)	Composite (kN/mm)	Composite % Difference
Vertical	150.91	146.42	-3
Torsional 1	75.4	84.4	+12
Torsional 2	88.2	100.5	+14
Header @ B Pillar Load	48.8	46.8	-4.1
Header Offset Load	30.91	34.5	+11.6

Carbon fiber doors with 45% weight savings over the steel doors are statistically same as steel doors

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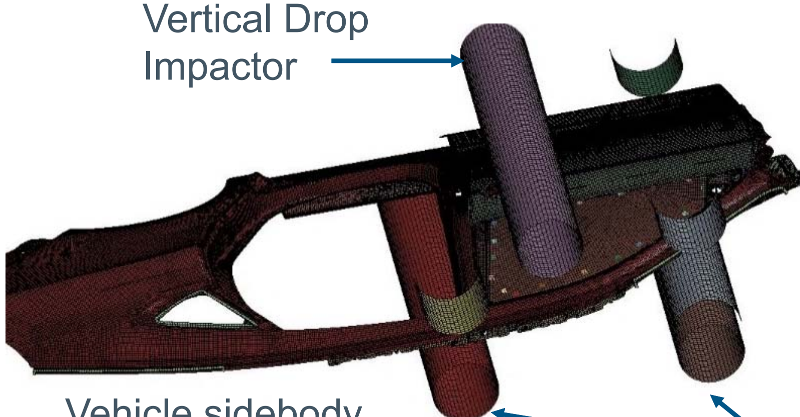
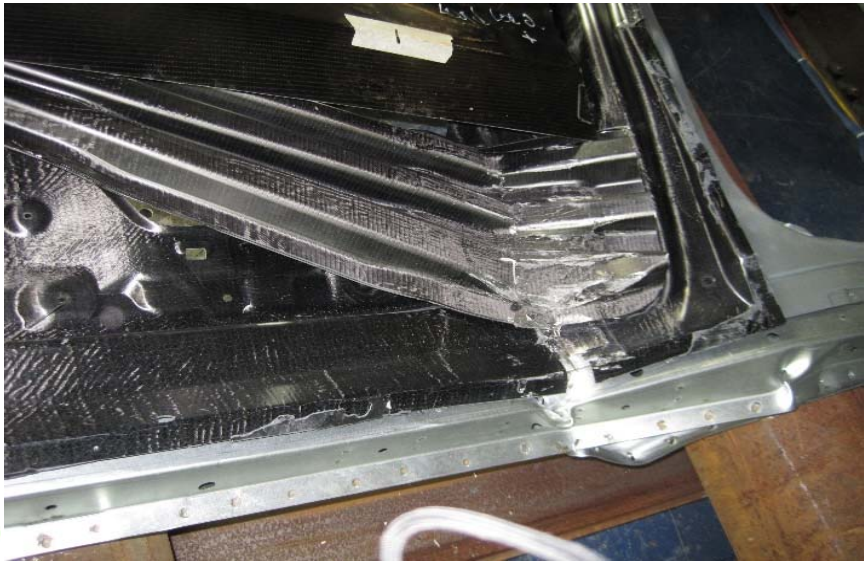
Door Testing – Dynamic

- Simply Supported
  - 12” diameter supports
  - Sidebody of vehicle
- 3000lb vertical drop impactor
  - 12” diameter impactor
- Dropped from a height of 24”



Door Testing – Dynamic

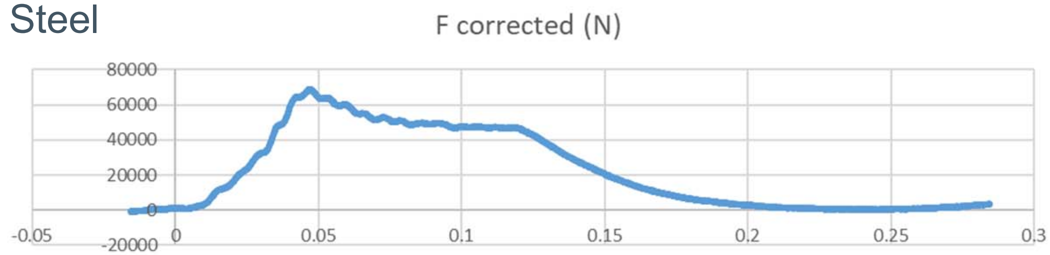
- Tested three steel doors a baseline
- Outer Panel disbond occurred at end of impact event
- Energy absorption similar to that of steel



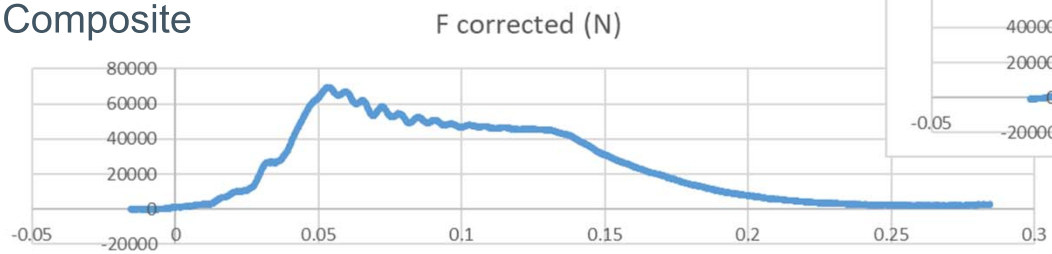
Door Testing – Dynamic

Force - Deflection

Steel

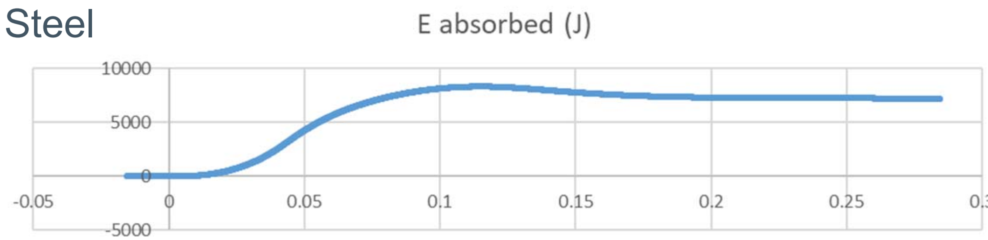


Composite

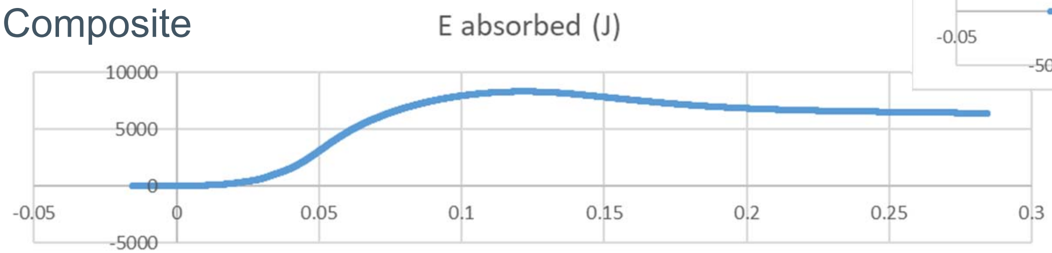


Energy Absorbed

Steel



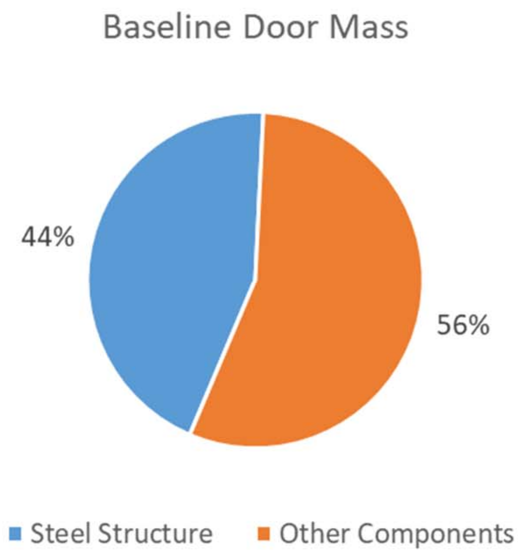
Composite

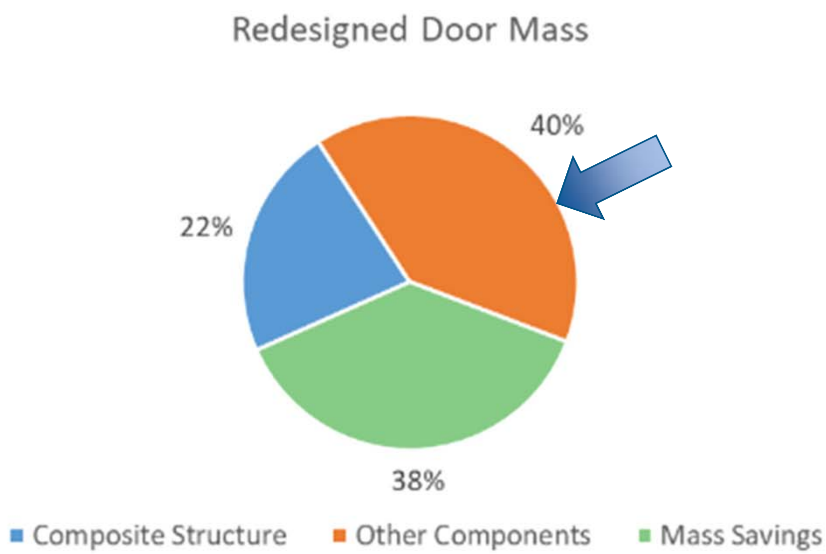


The Carbon and Steel doors behave similarly in the impact tests
The test result is assumed to be driven by the sidebody performance

Summary of Mass Improvements

- Redesigned Door Reductions:
  - 49% mass reduction of steel door frame mass
  - 25% mass reduction of other door components





38% Reduction in total door mass
More aggressive approach for door internals would help reach 42.5% target

Technical Accomplishment – Status to targets

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

Input fiber cost: $7.75/lb

Optimized Design		
Weight Reduction [lb]		30.3
% Reduction		38%
Cost Increase	$	165.72
Dollars/pound saved	$	5.47

Input fiber cost: $4.75/lb

Oak Ridge LCCF Design		
Weight Reduction [lb]		30.3
% Reduction		38%
Cost Increase	$	131.13
Dollars/pound saved	$	4.33

calculations include 10% waste

The use of Oak Ridge LCCF with projected pricing meets targets

Response to previous years comments

Comment: Regarding mass, the team has indicated a weight savings of 38% over the incumbent solution, and the weight reduction target is 42.5%. The reviewer was not fully clear what steps would be taken to further reduce the weight, without compromising performance.

Response: TPI composites focused on the steel structural components for light weighting with Carbon Fiber. The OEM would need to invest more time and effort into the other door components to get over the 42.5% light weighting challenge.

Comment: The cost analysis considers two types of fibers—a $7.75/lb. version and a $4.75/lb. version. The basis or which specific fiber was used to benchmark the $7.75/lb was not fully clear to this reviewer, who also highlighted that the Oak Ridge fiber is still not a commercially available fiber. Hence, the latter is mainly a paper exercise to simulate a "what if" scenario.

Response: The $7.75 input fiber was based on the commercially available industrial grade carbon fiber on the market today. TPI Composites agrees that the use of the $4.75 ORNL LCCF as an input fiber is purely a paper study, showing that these lofty targets could be hit only if the cost of carbon fiber could come down.

Comment: Regarding future work on preforming for an HP-RTM part to minimize fiber waste and reduce cost, the reviewer asked how and what methodology will be used to minimize fiber waste, and about the costs incurred in preparing the preform.

Response: Future work will include material categorization and simulate the draping and forming of the fabric will allow efficient nesting to a near net shape preform in the mold. For these trials we did more of a brute force manual prediction of the initial ply shape. We did not have time to investigate the ply draping prediction tools.

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
KraussMaffei	Sub Contractor, Resin Handling Equipment and process guidance
CHOMARAT	Partner, Non-Crimp Fabrics, Preform Technology to the program
A&P Technology	Partner, Non-Crimp Fabrics, Preform Technology to the program
Ashland always solving	Partner, Polyurethane Adhesive Technology to the program

Remaining Challenges and Barriers

- Final Report

Proposed Future Research

- 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.
  - Specific efforts to reduce mass of door internals
    - Window glass
    - Window guidance system
    - Mirror
    - Check link
    - Hinges
    - Molding system

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 door testing
- **Technical Accomplishments**
  - Dorr Assembled
  - Door Tested
    - Static
    - Dynamic
- **Future work**
  - Final Report