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

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2018 DOE Vehicle Technologies Office Review Presentation

TPI Composites Inc.

19 June 2018

tpi COMPOSITES

Project ID#: mat119

Overview

Timeline

- Project start date : Dec 2015
- Project end date : Mar 2019
- Percent complete: 66%

Budget

- Total project funding $5,974,519
  - DOE share $2,969,194
  - Contractor share $3,005,325
- Funding received in 2016-17
  - DOE share $1,769,476
  - Contractor share $1,731,475
- Funding for 2017-18
  - DOE share $1,199,718
  - Contractor share $1,273,850

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

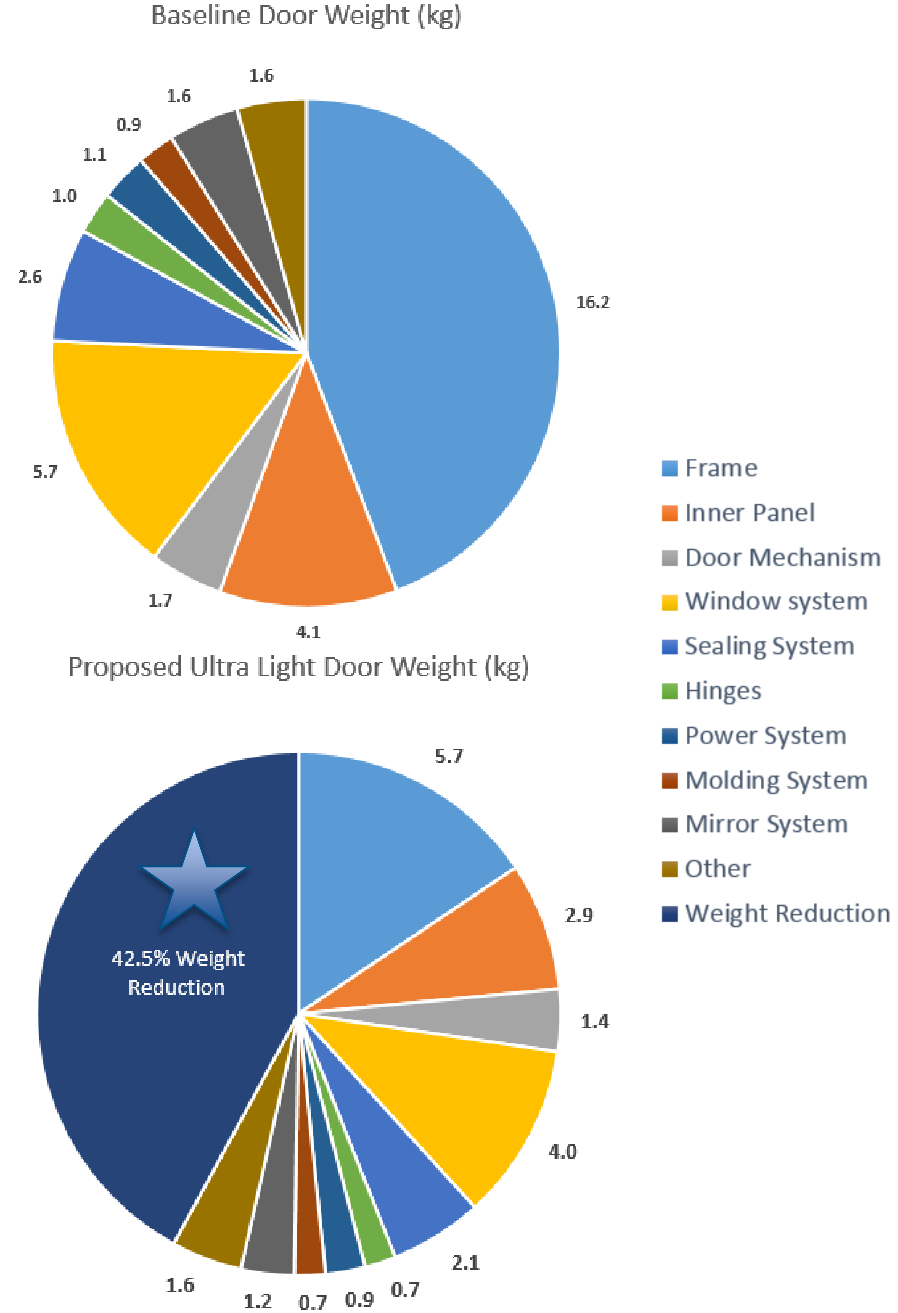
- Objectives this period
  - Finalize materials used
  - Finalize structural design
  - Define tooling
  - Begin tool machining

- 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

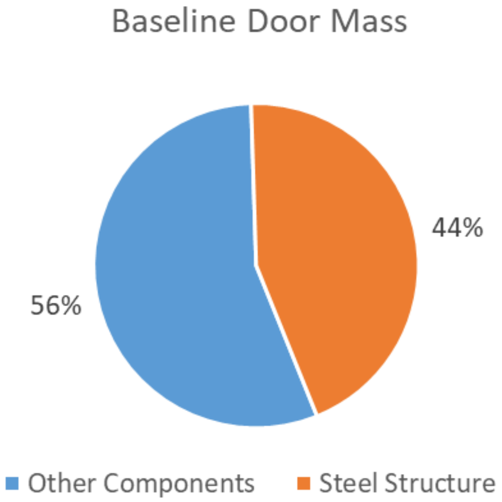
- 42.5% reduction in weight
- Less than $5 cost increase for each pound saved

	Current Baseline Door Door	Proposed Ultralight Composite Door	Weight reduction	Proposed 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

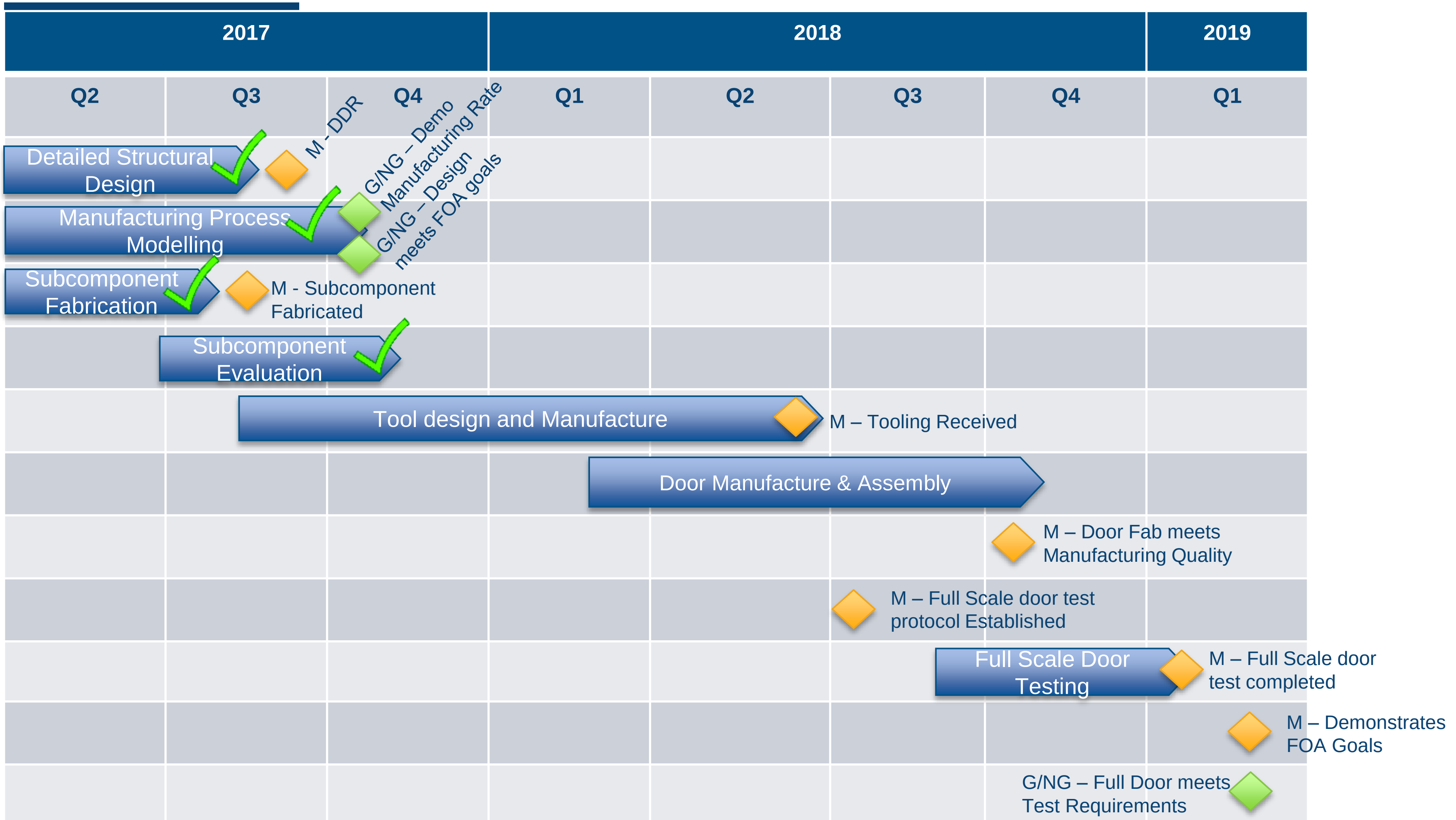


OEM has high confidence that other internals mass can be reduced by 25%

MILESTONES

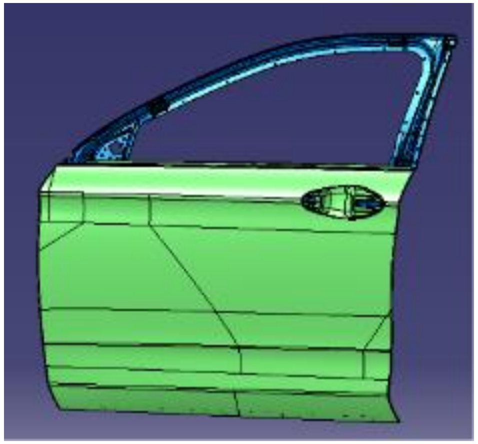
	Task Title	Type	Description	Verification Process	Planned Date	Status
2017	Develop/Implement/Validate Door Design using Predictive Engineering Environment	M	Sub-Component Fabricated	Component Process and Data Provided DOE Review	M18/Q6	Complete
2017	Develop/Implement/Validate Door Design using Predictive 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	
2018	Component Manufacturing and Testing	M	Door Fab Meets Manufacturing Quality	Visual Inspection of Door GM and DOE Approval	M35/Q12	
2018	Component Manufacturing and Testing	M	Full-Scale Door Test Procedure Established	Test Protocol Provided DOE Review	M31/Q11	
2018	Component Manufacturing and Testing	M	Full-Scale Door Testing Completed	Test Report Provided DOE Review	M37/Q13	
2018	Component Manufacturing and Testing	M	Full-Scale Vehicle test demonstrated FOA Goals	Test Report Provided DOE Review	M38/Q13	
2018	Component Manufacturing and Testing	GO/ NO-GO	Full Door Test Meets Requirements	Door test meets weight and other FOA requirements DOE Review	M38/Q13	

Approach & Milestones

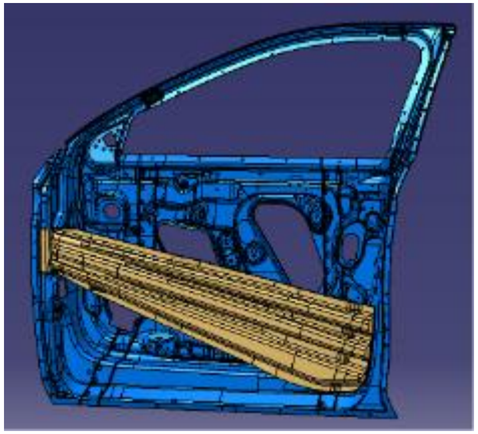


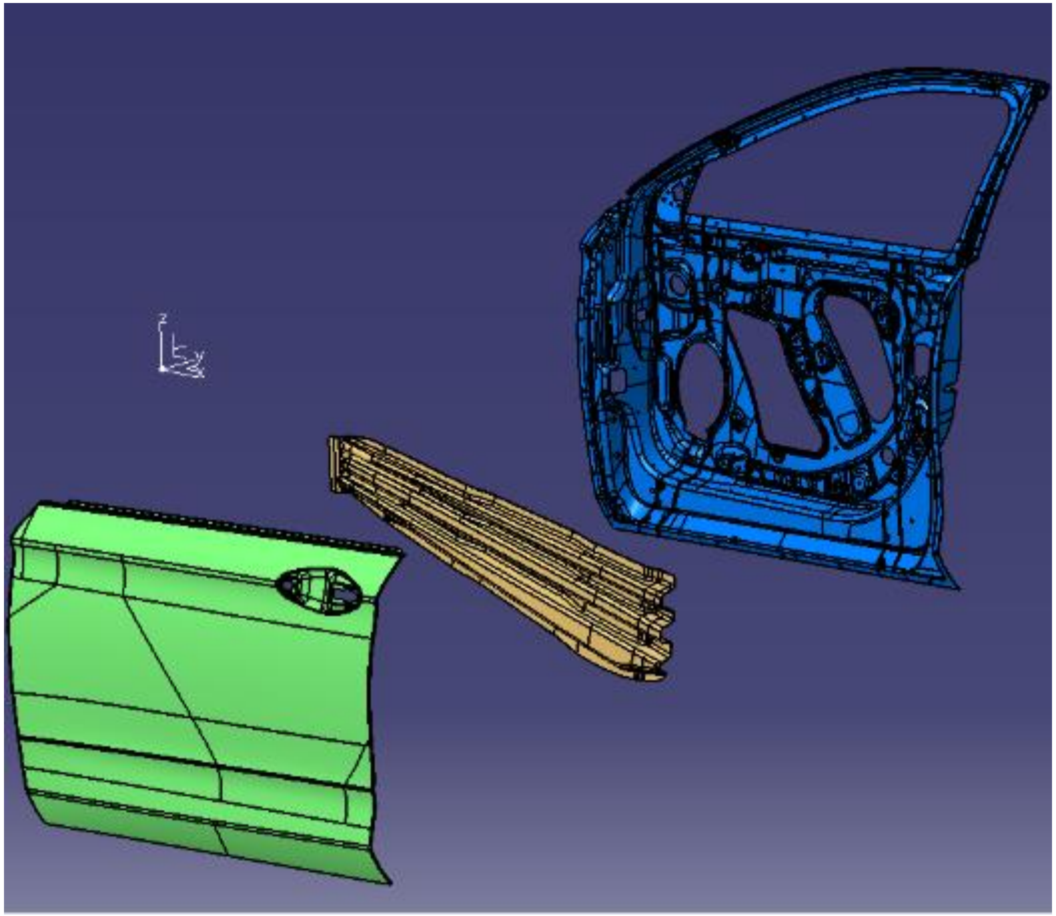
Any proposed future work is subject to change based on funding levels

Composite door components



Door Outer - LCM

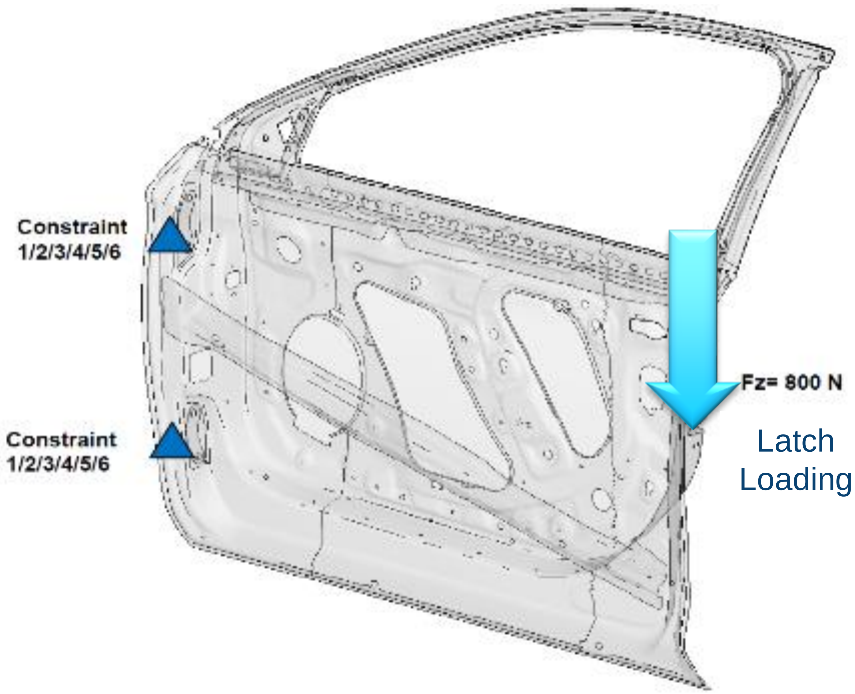




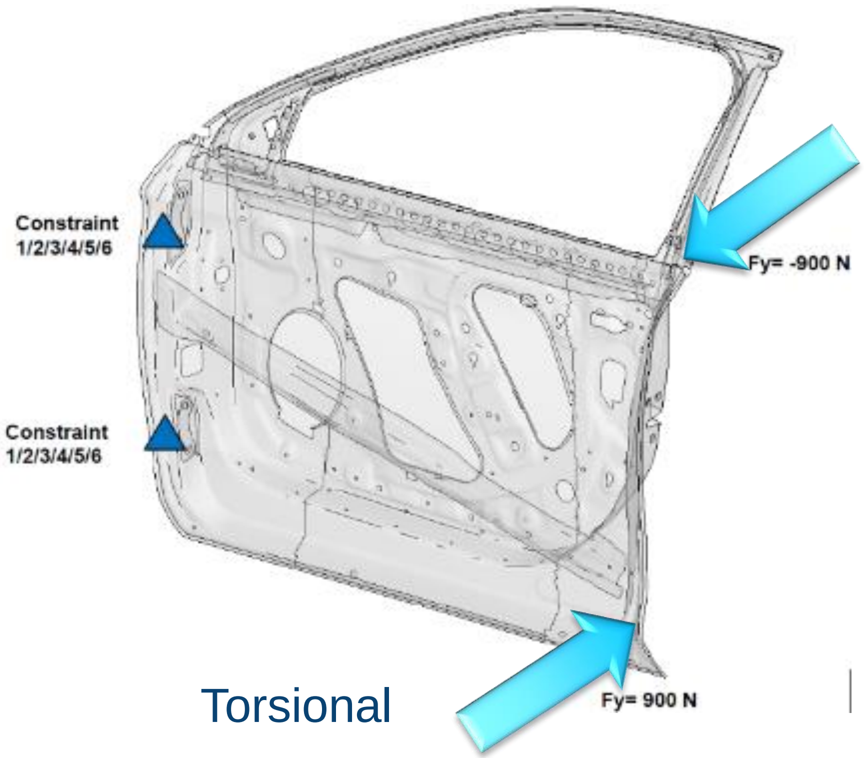
Door Inner & Intrusion Beam - HP-RTM

Static Load Cases - FEA

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



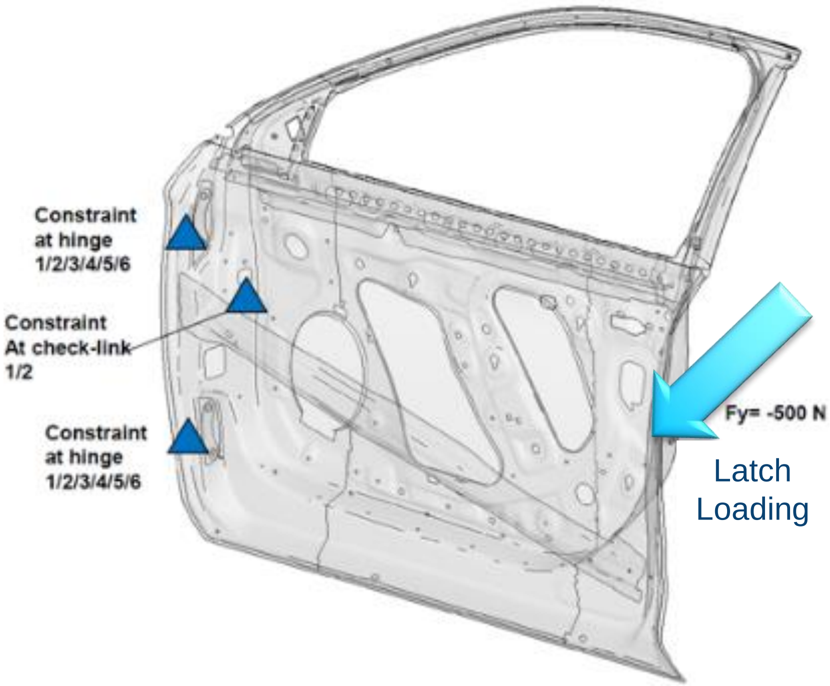
Vertical



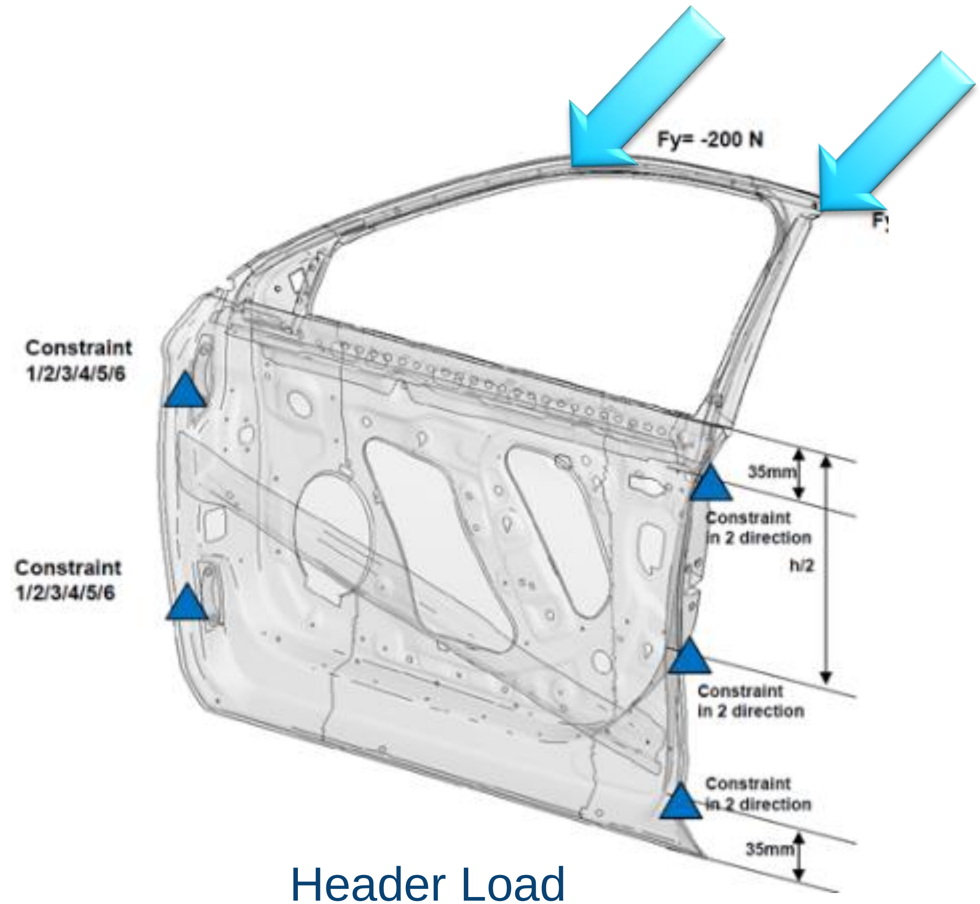
Torsional

Static Load Cases - FEA

- Critical Static Door Loading Defined
  - Check Load rigidity (Full Open)
  - Header Load

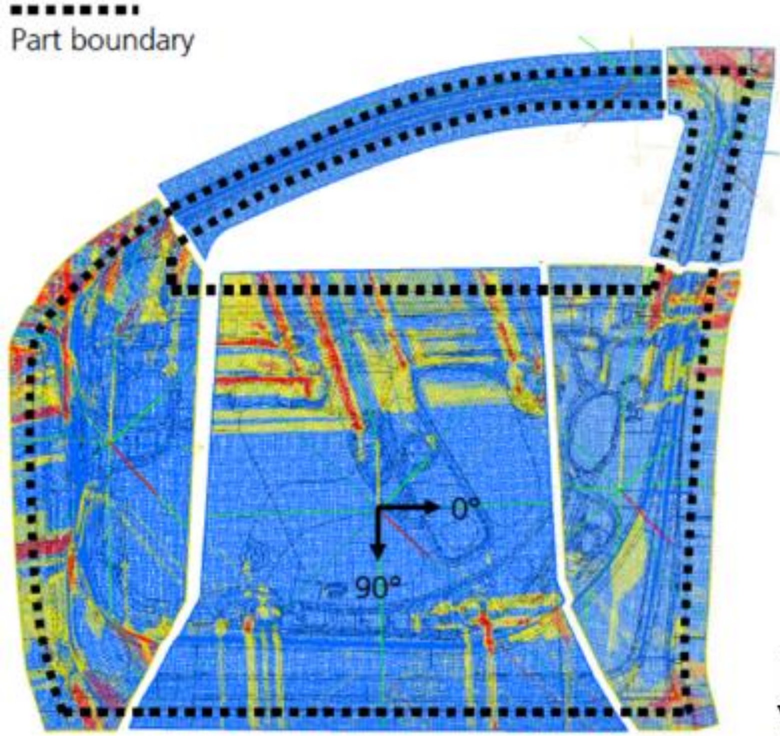


Check Load

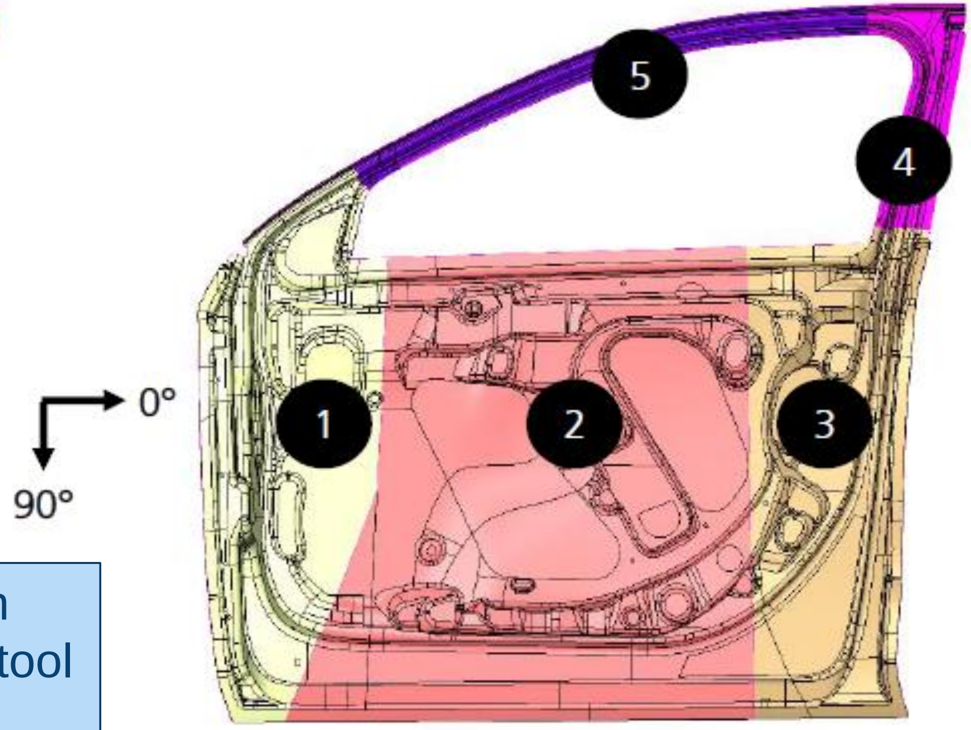


Header Load

Ply breakup locations - Draping



Door Inner is separated in to 5 discrete preforms



Ply shapes are defined through simulation to limit wrinkling in the tool

Iterative process using FiberSIM

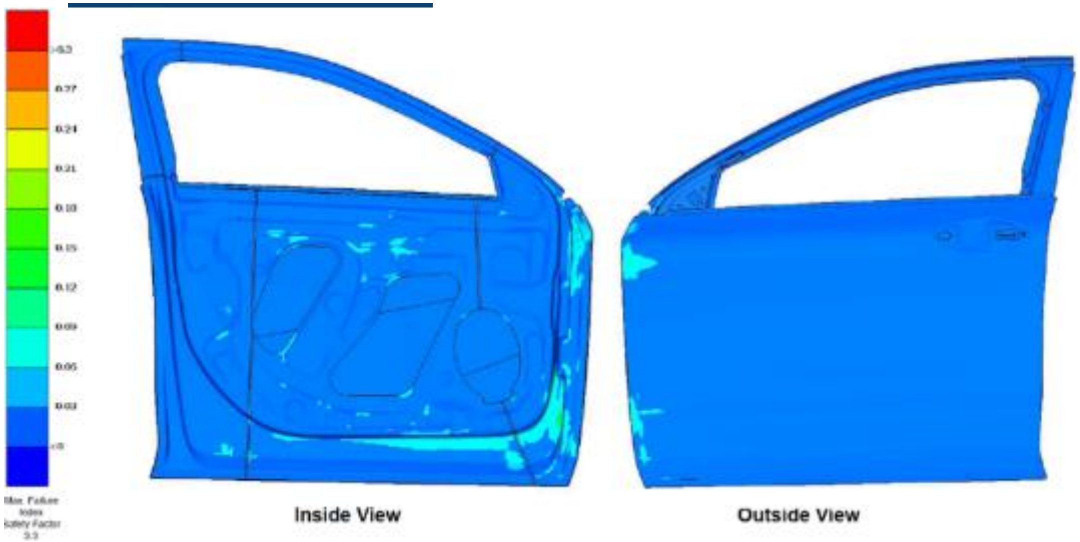
Composite Design Iterations

Load Case	Applied Load (N)	Steel Baseline Deflection 16.2kg	Stiffness Based Design 8.69kg	Strength Based Design 7.3kg
DIW Vertical Rigidity	800N	-3.3mm	-3.1mm	-5.4mm
DIW Torsional Rigidity	900N	-36.6mm	-34.6mm	-69.6mm
Check Load Rigidity	500N	-34.0mm	-34.0mm	-81.4mm
Header Load	250N	-5.2mm	-4.9mm	-12.1mm
	+200N	-5.7mm	-5.5mm	-16.9mm

Stiffness based design - too conservative
Strength based design - too aggressive

design to "split the difference" was sought

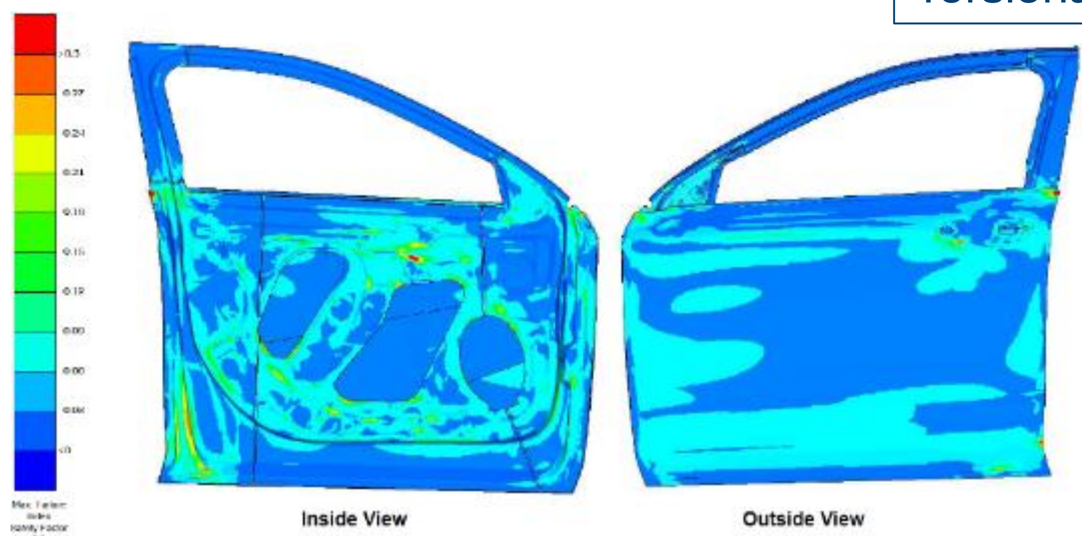
Optimized Results of static FEA



Puck Failure criteria
3x Safety Factor

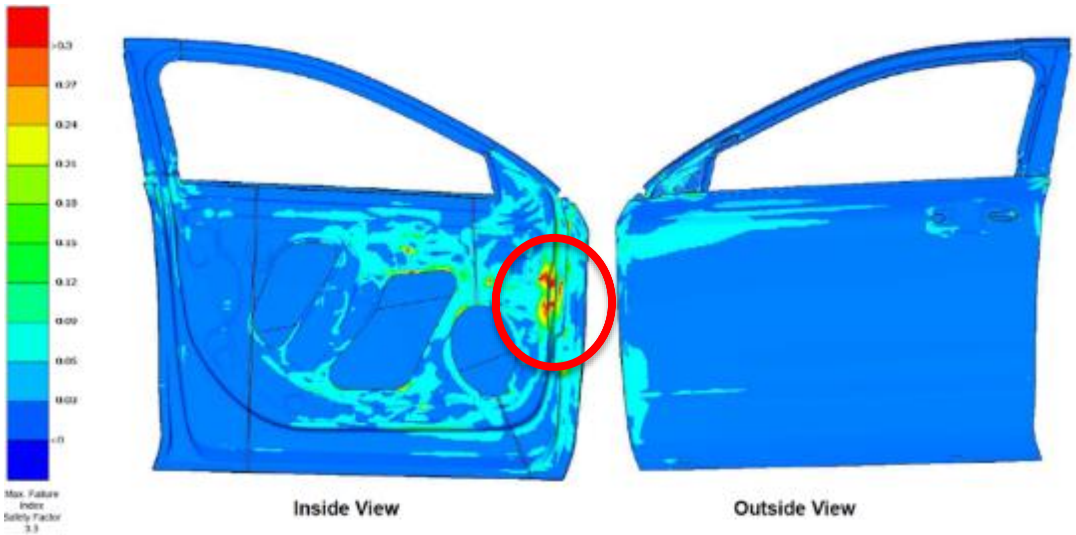
Vertical

Torsional



Torsional load case shows higher stresses, but still well below the 3x safety factor (red color)

Optimized Results of static FEA

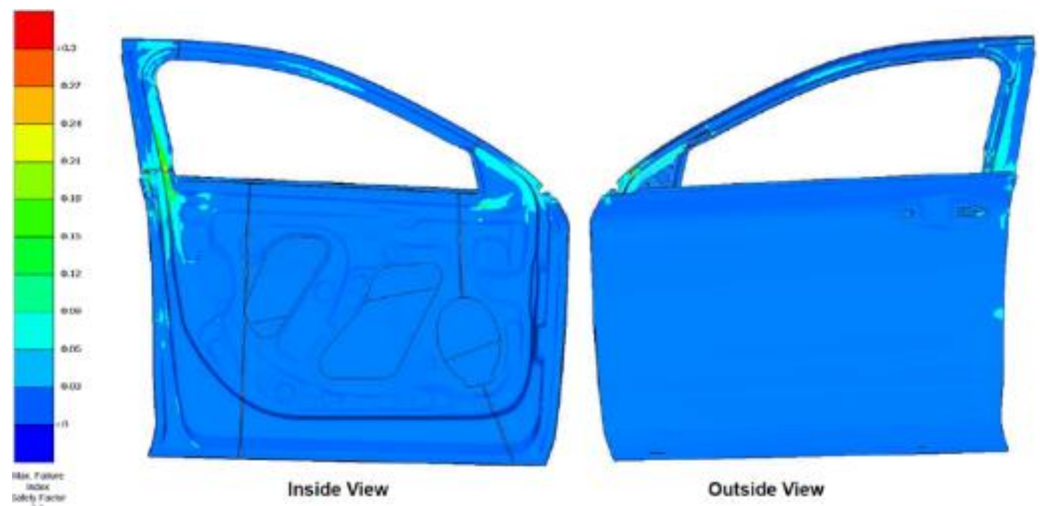


Puck Failure criteria

3x Safety Factor

Check Load

Header load



Check load case shows higher stresses localized at the check link (red). These are at the 3x safety factor.

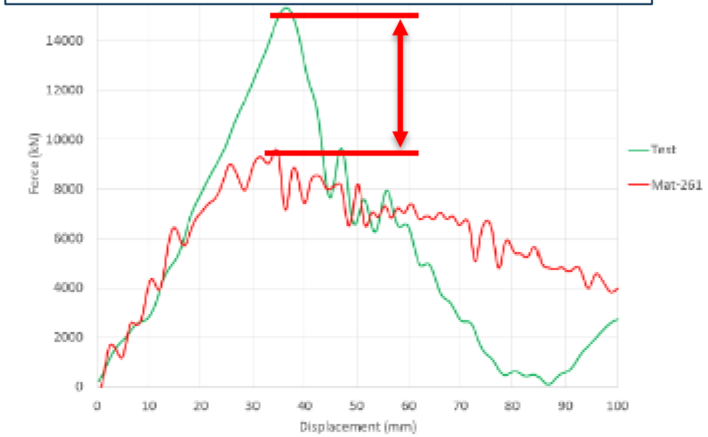
Static FEA Deflection

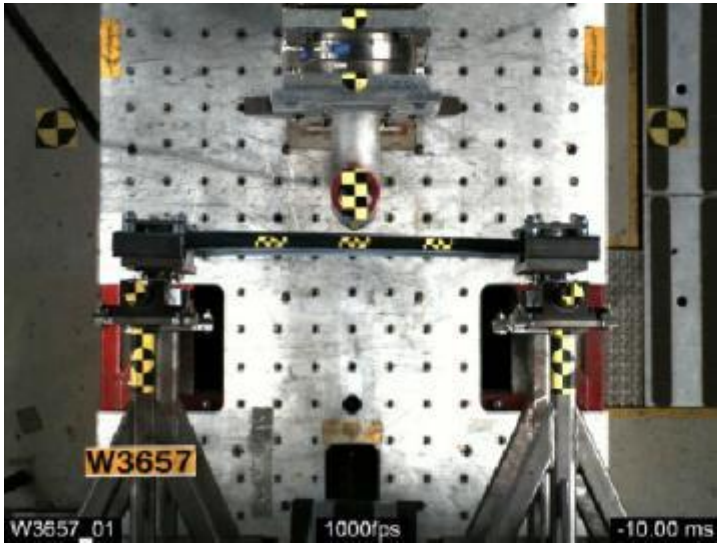
Load Case	Applied Load (N)	Steel Baseline Deflection 16.2 kg	Optimized Design 8.2 kg	Change 49%
DIW Vertical Rigidity	800N	-3.3mm	-3.2mm	3%
DIW Torsional Rigidity	900N	-36.6mm	-39.1mm	6.8%
Check Load Rigidity	500N	-34.0mm	-32.4mm	4.7%
Header Load	250N	-5.2mm	-4.4mm	15%
	+200N	-5.7mm	-5.5mm	3.6%

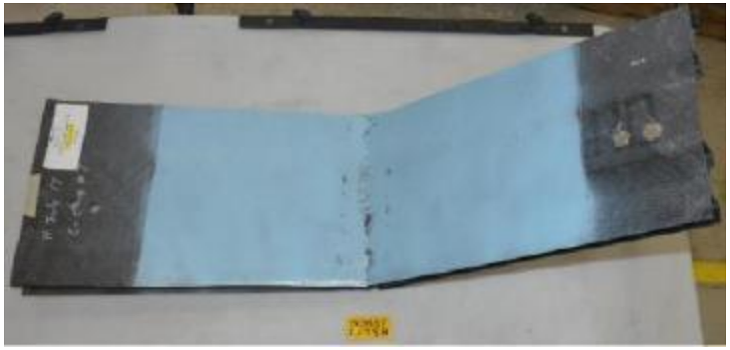
Optimized Composite door matches the static performance of the Steel Door

Improving Dynamic FEA Correlation with tests

Dynamic composite material model currently under predicts peak force

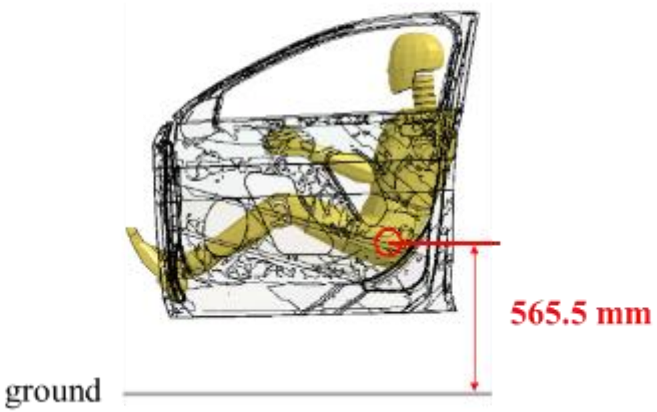


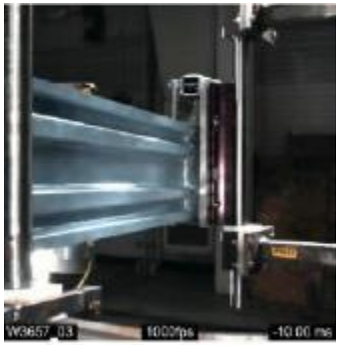


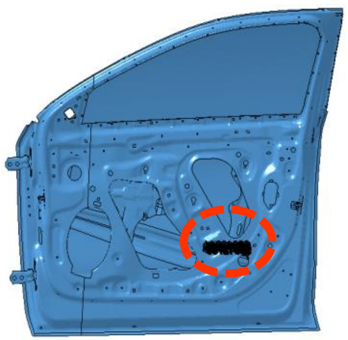


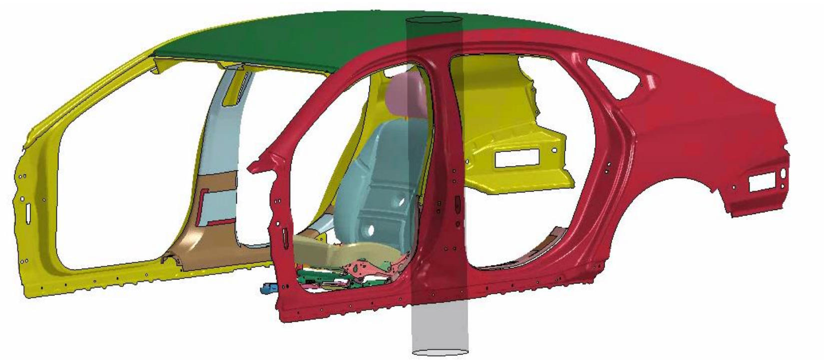
Additional tests required for model refinement (2018)

Results of Dynamic FEA







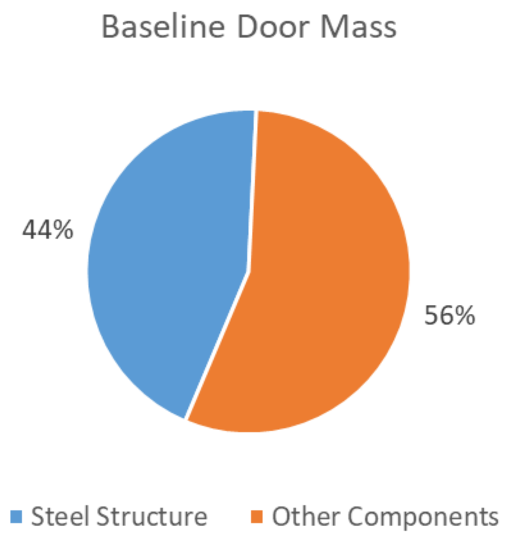


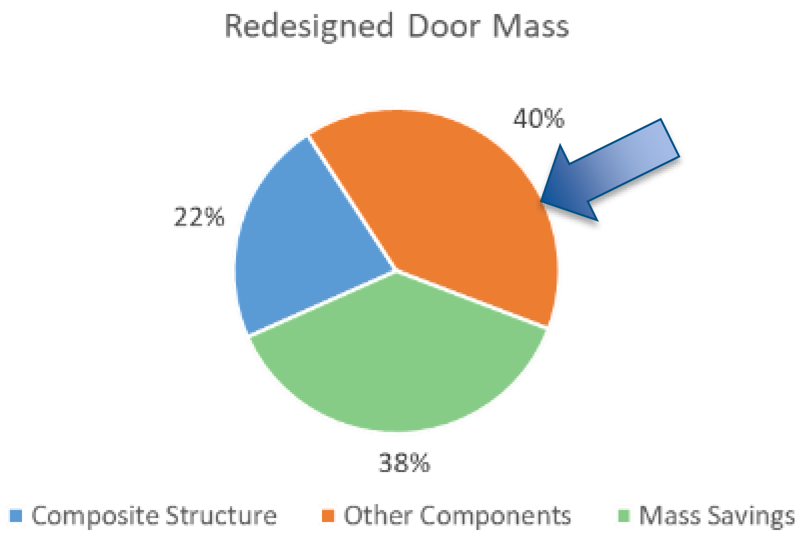
Composite door intrusion closely matches cabin deflection

Cabin Intrusion [mm]	
Steel Door	Composite Door
x	+5%

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 carbon fiber cost: $7.75/lb

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

Input carbon 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

Oak Ridge National Laboratory

The use of Oak Ridge LCCF with projected pricing meets targets

Response to previous years comments

The project is well-designed, feasible, and integrated with other efforts.

Comment: The approach to meet the target vehicle weight of 42.5% based only on composites limits the cost-effective vehicle light-weighting opportunities. However, the reviewer added it will demonstrate at least what can be achieved if light-weighting is limited only to composites.

Response: After further discussion with the OEM they were able to provide visibility to internal light-weighting efforts for the non structural door components which make up more than half the mass of the door. Components such as the glass and guidance system, mirror, check link, hinges and molding system. We did take credit for these numbers to achieve the 39% total door mass reduction.

Technical accomplishments and progress toward overall project and DOE goals

Comment: After 50% project completion to date, an actual approximately 15% versus planned 42.5% weight reduction has been demonstrated. The reviewer said there was no indication given to how close to the final mass reduction while meeting the DOE target of cost of mass saving will be achieved. The reviewer stated that it is important that a multi-material composite-intensive design be considered in order to achieve both DOE mass reduction and savings targets. The reviewer noted, though, that some validation activities such as material characterization and door laminate design optimization have not been completed.

Response: Although the first 1/3 of the program did only yield an approximate mass savings of 13% the reviewer did not adequately state that the design investigation would continue to be scrutinized until a more reasonable answer was found. This investigation included broadening the materials used and potential ply schedules for reach a total mass savings of 39%

Proposed future research

Comment: The plan for future work includes full scale door and vehicle testing which indicates that no alternative designs will be considered to meet the DOE technical targets.

Response: A clarification to the statement “no alternative designs will be considered”. This statement was directed towards the geometric design as the effort is constrained by the existing car design. Through the course of the laminate design there were many iterations of internal structure and ply schedule for mass optimization to reach a solution deemed acceptable to pass static and dynamic testing.

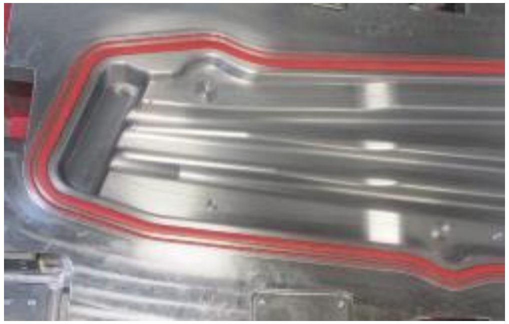
Collaboration with other institutions

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

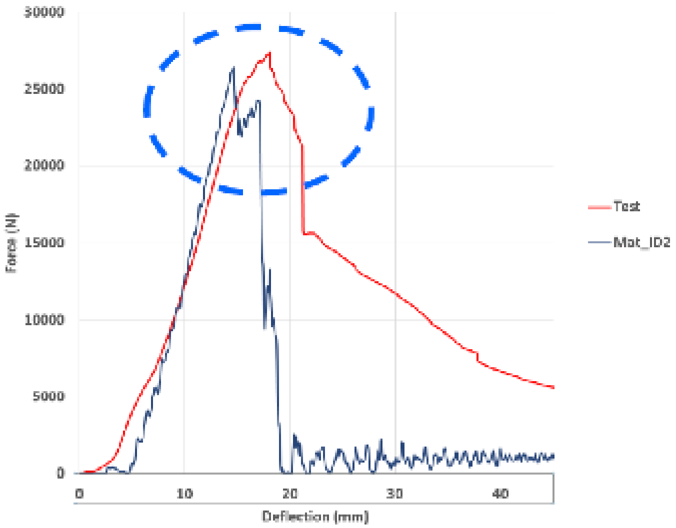
- Manufacture of Door Parts in remote locations
  - Create preforms
  - Ship all necessary parts to location
  - Develop filling/curing process
- Assembly of Door
  - Trimming
  - Bonding
  - Assembly of internal parts
- Define Static tests
  - Create test fixtures
  - Coordinate test with OEM
- Define Dynamic tests
  - Create test fixtures
  - Coordinate test with OEM
- Improve material models

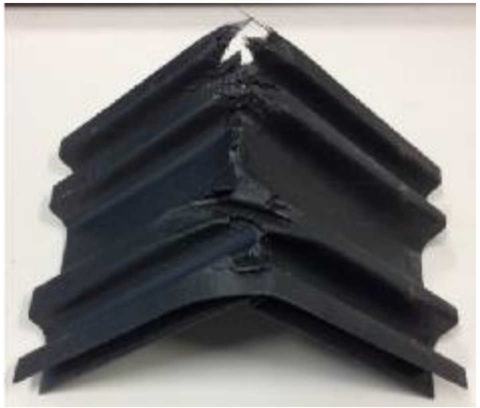
Planned Future Work - Tooling for 2018 build

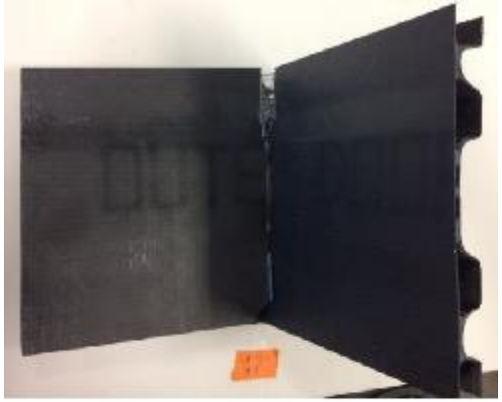


Planned Future Work - Improved material model alignment

- Additional testing
- New modelling techniques
- New material model cards







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**
  - Material characterizations complete
  - Detailed design complete
    - optimization completed
    - door laminate optimized
  - Intrusion beam redesigned
  - Dynamic Analysis conducted
    - Baseline complete
    - Creating material models for dynamic analysis
      - Qusai static and dynamic testing
- **Future work**
  - Tooling fabrication
  - Door fabrication
  - Door testing