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

- Nathan P Gravelle – Principal Investigator

- 2019 DOE Vehicle Technologies Office Review Presentation

- TPI Composites Inc.

- 11 June 2019

Project ID#: mat119

Overview

Timeline

- Project start date : Dec 2015
- Project end date : Dec 2019
- Percent complete: 80%

Budget

- Total project funding $5,974,519
  - DOE share $2,969,194
  - Contractor share $3,005,325

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

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

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

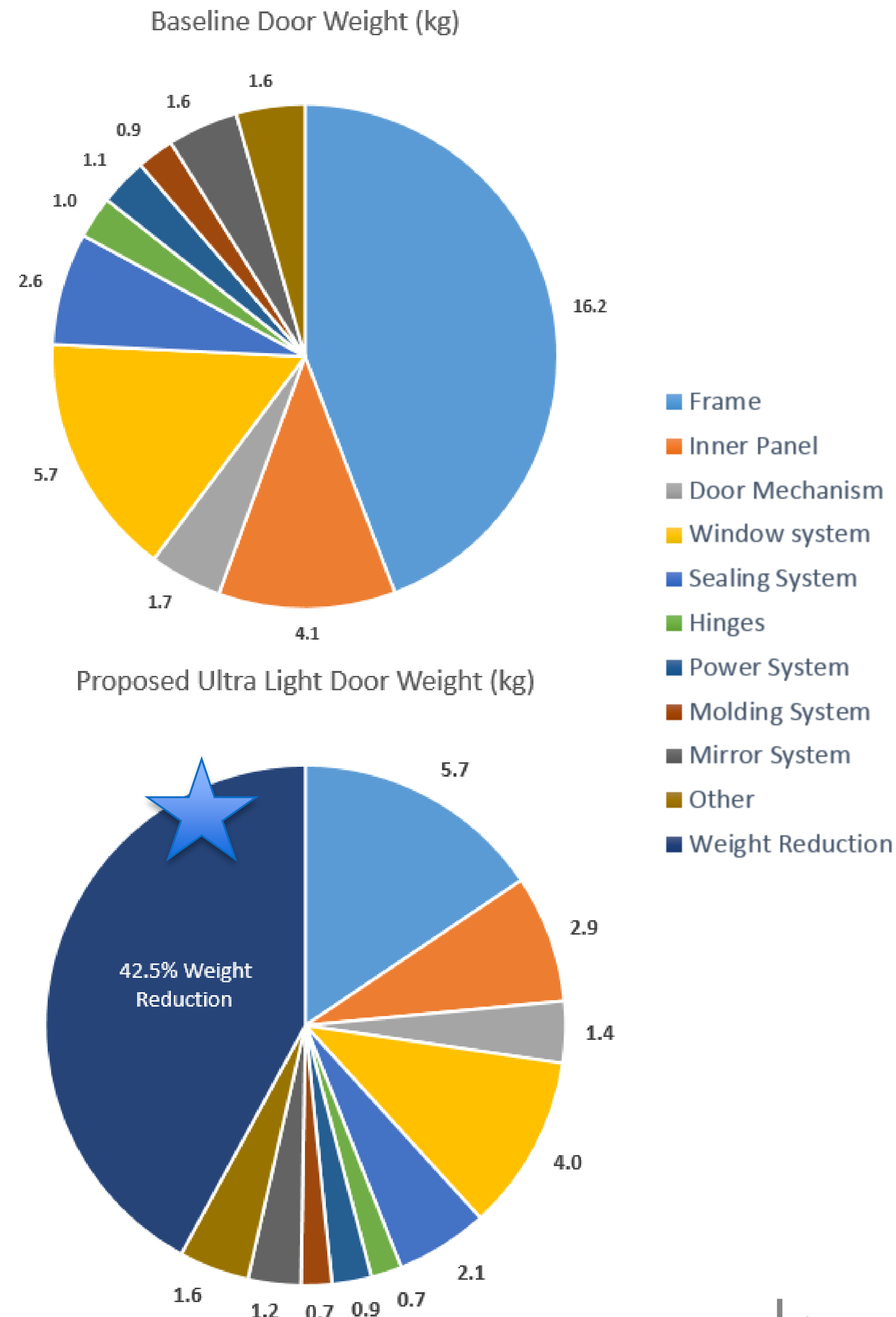
- Objectives this Period
  - Fabricate major door components
    - Door Inner
    - Door Outer
    - Intrusion Beam
  - Assemble Doors
  - Begin Testing

- 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 and technical targets described in the 2017 U.S DRIVE MTT Roadmap report, section 5.1

Relevance - Objective

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

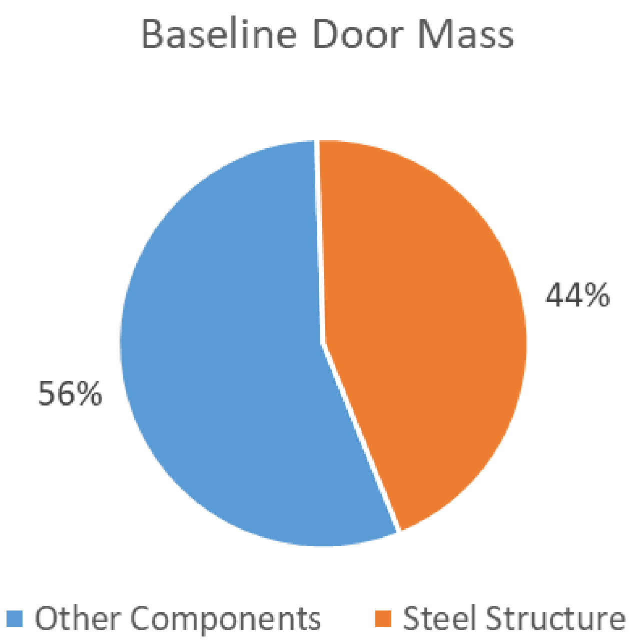
	Current Baseline Door Door	Proposed Ultralight Composite Door	Weight reduction	Reduction
	(kg)	(kg)	(kg)	%
Frame	16.2	5.7	10.5	65%
Inner Panel	4.1	2.9	1.2	30%
Door Mechanism	1.7	1.4	0.3	18%
Window system	5.7	4	1.7	30%
Sealing System	2.6	2.1	0.5	20%
Hinges	1.0	0.7	0.3	29%
Power System	1.1	0.9	0.2	19%
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	



tpi

Discussion on door internals- OEM design mass

- 56% of door mass are non structural components

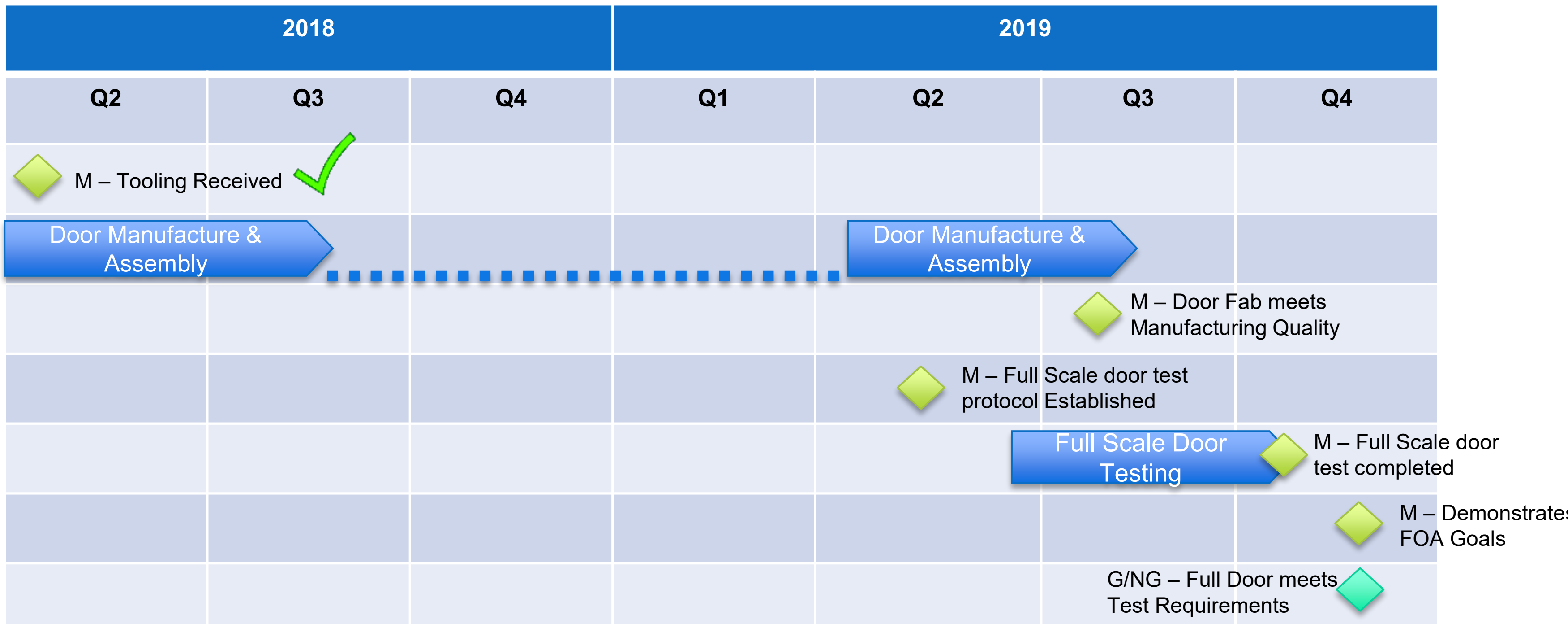


OEM has high confidence that other internals mass can be reduced by 25%

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	
2019	Component Manufacturing and Testing	M	Full-Scale Door Test Procedure Established	Test Protocol Provided DOE Review	M44/Q15	
2019	Component Manufacturing and Testing	M	Full-Scale Door Testing Completed	Test Report Provided DOE Review	M45/Q15	
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	

Approach & Milestones



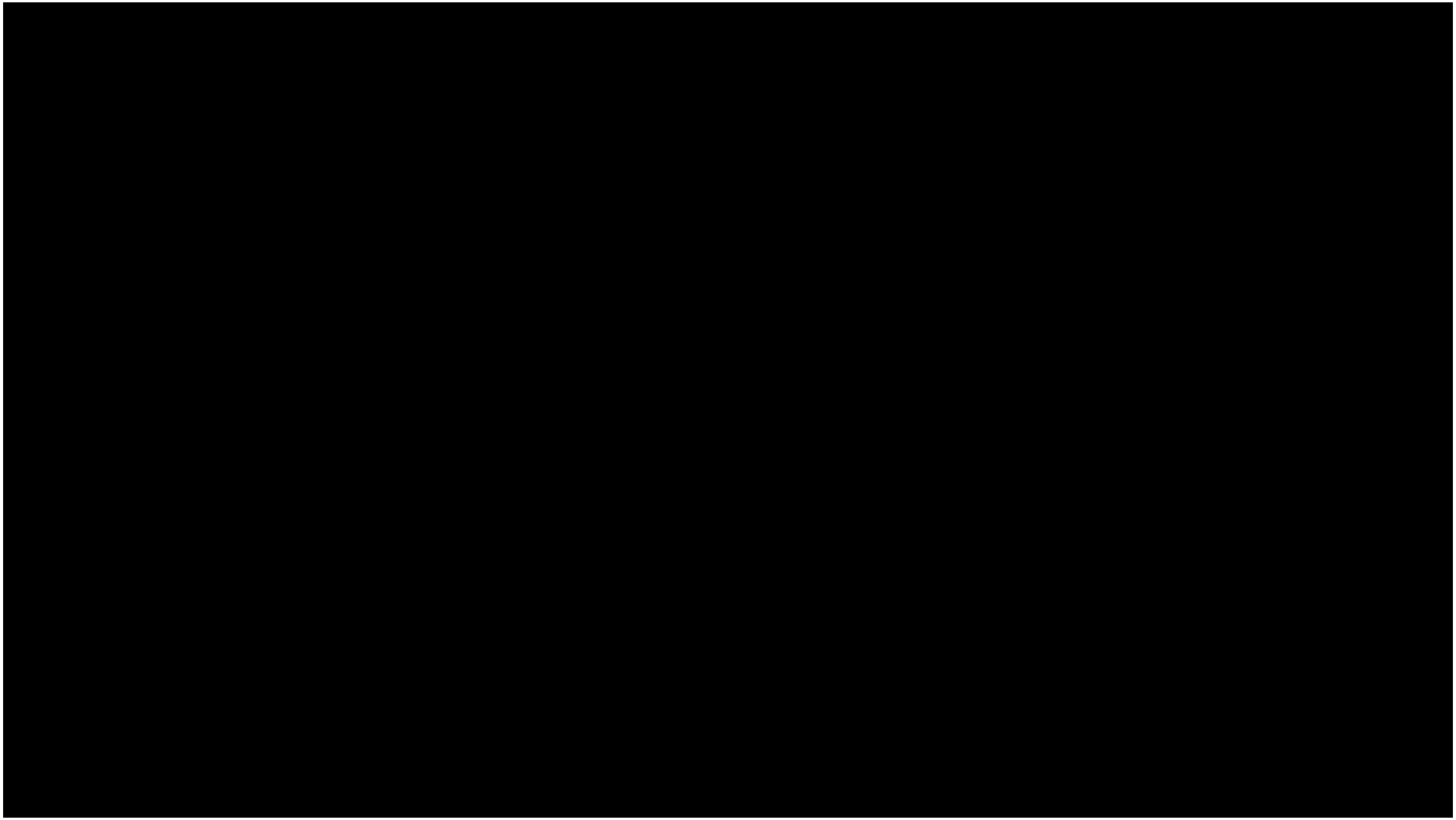
Any proposed future work is subject to change based on funding levels

Accomplishments - Liquid Compression Molding (LCM) Door Outer

- 4.2 minutes molded part to part demonstrated
- 2 minute cure epoxy resin from Hexion
- Capable of molding 75,000 units per year

tpi

Accomplishments -
LCM Door Outer Manufacturing Demonstration



Accomplishments - High Pressure Resin Transfer Molding (HP-RTM) Door Inner

- Preforming
  - Prebinderized fabric
  - Single sided heated tool
  - 1 ATM pressure
  - Draping characteristics were over predicted in FiberSIM
  - Wrinkles as a result

Drapeability of preform needs to be improved

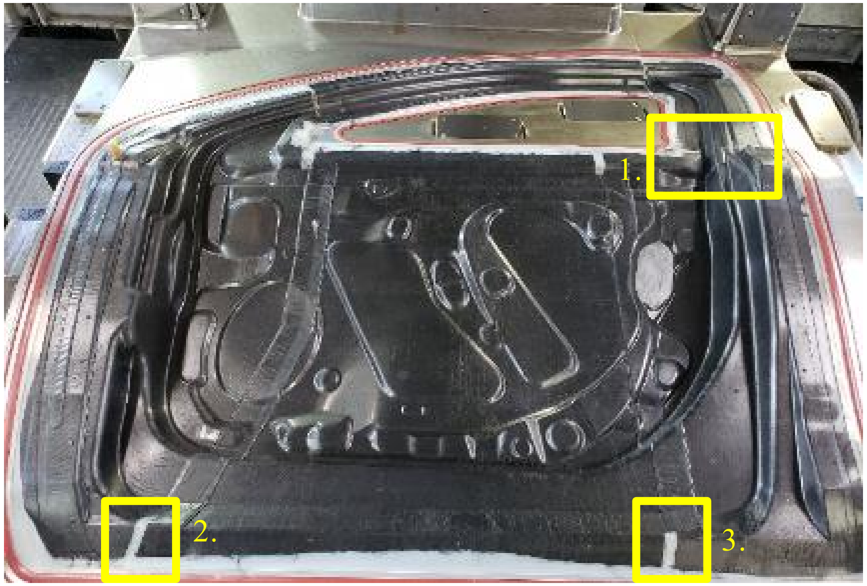
Accomplishments - HP-RTM - Door Inner

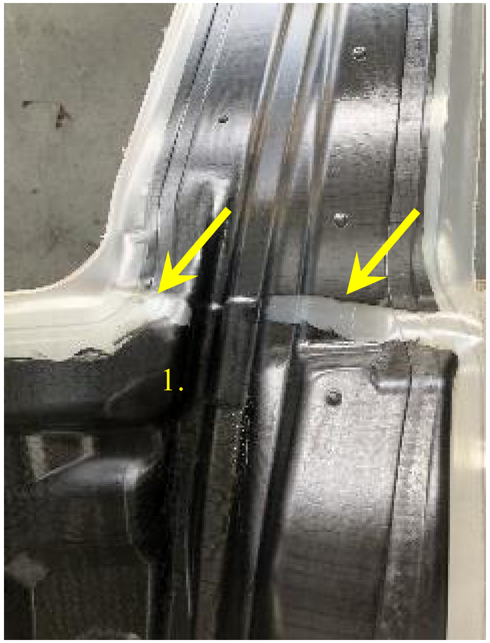
- Molding

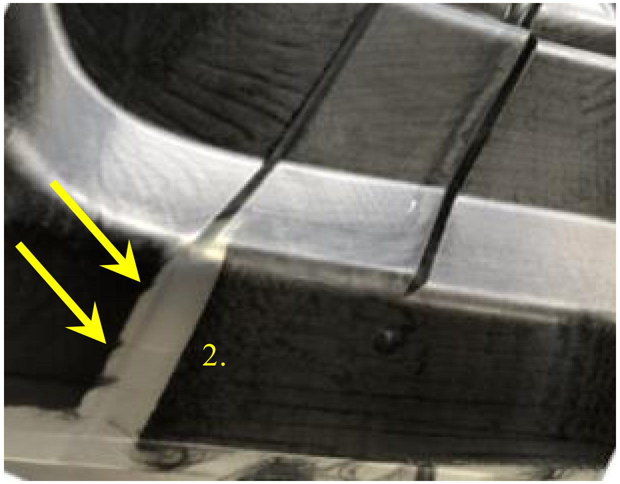
Preform shaped needs improvement, due to separation in mold

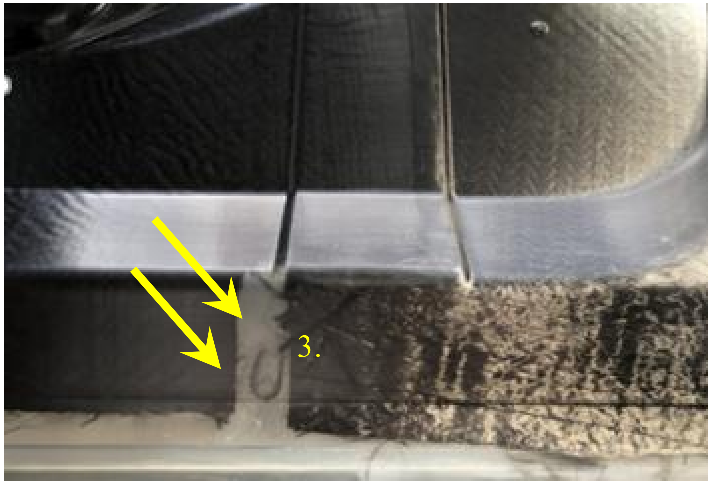
Accomplishments - HP-RTM – Door Inner Issues

- Preforms separated during molding
- Redesign using overlap joint for round two of preforms









Accomplishments -
New Fabrics to improve drapeability

- Additional reinforcement materials identified to improve preform wrinkling
  - Chomarat NCF with a tricot stitch
    - chain stitch previously
  - A&P braided broadgood – Qiso fabric

Chain Stitch

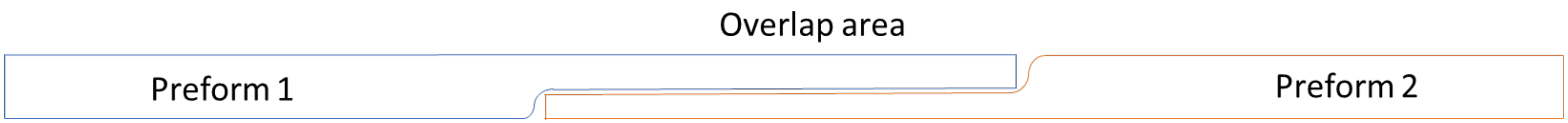
Tricot Stitch

Braided Broadgood

These new material forms should improve drapability and contouring and reduce the amount of wrinkling seen

Accomplishments - Updated Preforms

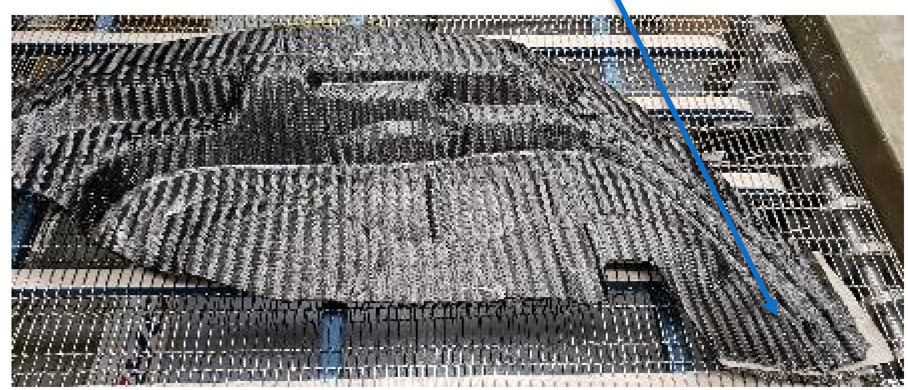
- New preforms are being constructed which will allow a “full” overlap joint rather than the “tab” overlap which was previously employed
- This technique should vastly improve the structural performance as well as the visual aspects of the door



Tab Overlap Design

Original Preform

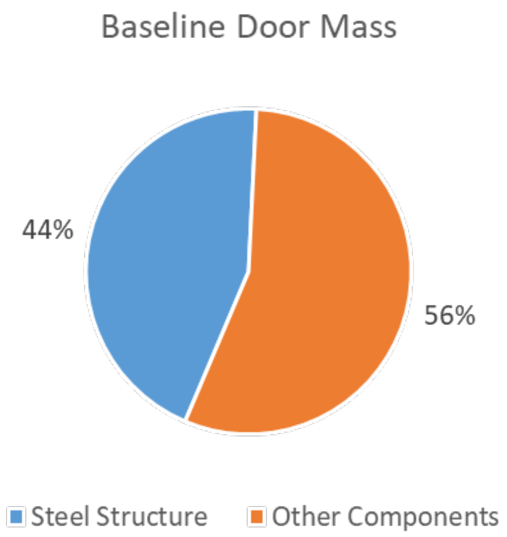
Full Overlap Design

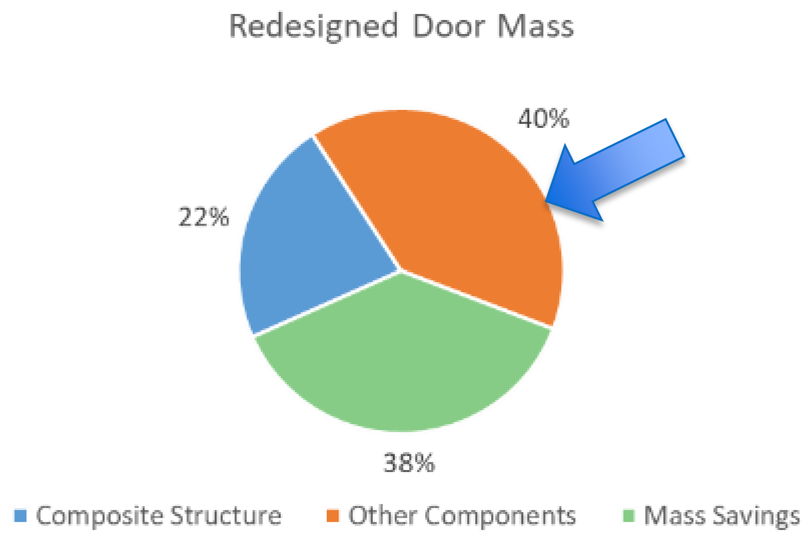


Updated Preform

Accomplishments - 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

OAK RIDGE National Laboratory

The use of Oak Ridge LCCF with projected pricing meets targets

Response to previous years comments

Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.

Comment: The reviewer said that the overall technical barriers are being addressed very well. The reviewer was unclear how the materials were being characterized for HP-RTM where the resin is injected at 1,500 psi and above. The reviewer asked how the characterization work will translate to the HP-RTM process.

Response: The material properties of the resin are not affected by the injection pressure of the process. The team used the average tested material properties for the analysis at a 50% fiber volume ratio

Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule

Comment: The reviewer said that there is little information on the technical accomplishments other than the CAE design. The reviewer was unclear if the load case of dent and ding damage to the outer panel was addressed in the CAE. The lack of information on the material properties is disappointing. The reviewer said there is little information on the materials or the processing conditions. The reviewer was perplexed that the design fails to meet the torsional rigidity requirement, yet is deemed okay. This reviewer expected to see information on the manufacturing process to yield the cycle time that is stated to be a major objective of the project. Additionally, there is little information on the testing to prove the design and correlate the CAE. With the failure to meet torsional stiffness, the reviewer expected failures in the wind, noise, and water leak tests for this design. Also, the Class A surface finish is a requirement for the door, and the reviewer said that this project ignores this performance requirement

Response: The load case of dent/ding was not reviewed as it was not one of the driving load cases as defined by the OEM. Torsion, check load, header load, vertical load. The design as presented does not fail torsional rigidity requirement. The cycle times were not discusses in this report as this was not investigated during this period. Class A surface finish was deemed out of scope for this effort at the beginning of the program and was agreed upon by both the OEM and the government.

Collaboration and Coordination Across Project Team.

Comment: The reviewer stated that while the listed subcontractors are appropriate for this project, the collaboration and cooperation are not clearly defined. For next year, the reviewer recommended that the project please include a matrix of when different groups meet and cooperate on aspects of the project. The reviewer acknowledged this is likely okay, but there is little evidence in the presentation.

Response: All the groups meet on a bi weekly basis to discuss the design and results. All collaborators had representatives at each process trial.

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

Remaining Challenges and Barriers

- Manufacture of Remaining Door Parts
  - Re-Create preforms
  - Ship all necessary parts to location (Fraunhofer, London, Ontario)
- Assembly of Door
  - 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

Proposed Future Research

- Potential Future Work
  - Creating parts with Low Cost Carbon Fiber (LCCF) (ORNL) 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**
  - Door Outer parts fabricated
    - Manufacturing process defined
  - Door Inner parts fabricated
    - Preform drapability issue discovered
    - Preform overlap issue identified

- **Future work**
  - Door Inner fabrication
  - Door assembly
  - Door testing

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