DEVELOPMENT AND BUILD OF THE FORD FOCUS FCV LIGHTWEIGHT CARBON FIBER DECKLID

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Abstract

Ford Motor Company contracted Multimatic to develop and supply a niche volume, low investment cost, and lightweight decklid for the Focus Fuel Cell Vehicle (FCV) program. An aluminum solution was considered by the program, however dedicated stamping tools would have been required and thus was considered infeasible. A carbon fiber solution was proposed as it would offer low investment cost at very low weight, however, a fully production ready North American OEM Class A carbon composite closure had never been attempted at the time of this program. The decklid would not only be required to meet the Class A surface finish requirements, but would also have to be fully engineered to accept all carry-over components and hardware, including seals, meet all production component engineering requirements, and then be certified to meet the Production Part Approval Process (PPAP) requirements, all while providing significant mass savings. This paper will describe the methodology used to conduct the decklid engineering and development which includes the design and CAE assessment, prototype fabrication, physical testing, and production build. The decklid assemblies were manufactured using carbon fiber / epoxy prepreg materials and aramid honeycomb core materials and were autoclave cured using single-sided tooling. Having met all PPAP requirements, the completed assemblies became the first North American OEM production carbon fiber decklids and were shipped to the Ford assembly site primed and ready for paint and final assembly. The final composite decklid assembly mass reduction was 60% compared to the baseline production Focus steel decklid, resulting in a mass saving of approximately 6.3kg.

Background

Ford Motor Company produced a fleet of 30 Focus Fuel Cell Vehicles (FCV) for model year 2004 [1-4]. The FCV vehicles, an example of which is shown in Figure 1, were deployed to various city governments and research organizations. The vehicles are based on a heavily modified version of the production Ford Focus and feature an underbody mounted 85kW fuel cell stack and system module. Due to the addition of the fuel cell system, several mass saving technologies were implemented to offset the increased mass. One of these technologies was the carbon fiber decklid, which is the subject of this paper. Other examples of mass saving technologies that were integrated into the FCV included an aluminum hood, aluminum front fenders and wheels, lighter-weight stainless steel body panels, titanium suspension springs, aluminum suspension components, lightweight front and rear glass, and polycarbonate side windows [2]. Other lightweight components engineered and/or produced by Multimatic in support of the FCV program can also be seen in Figure 1.

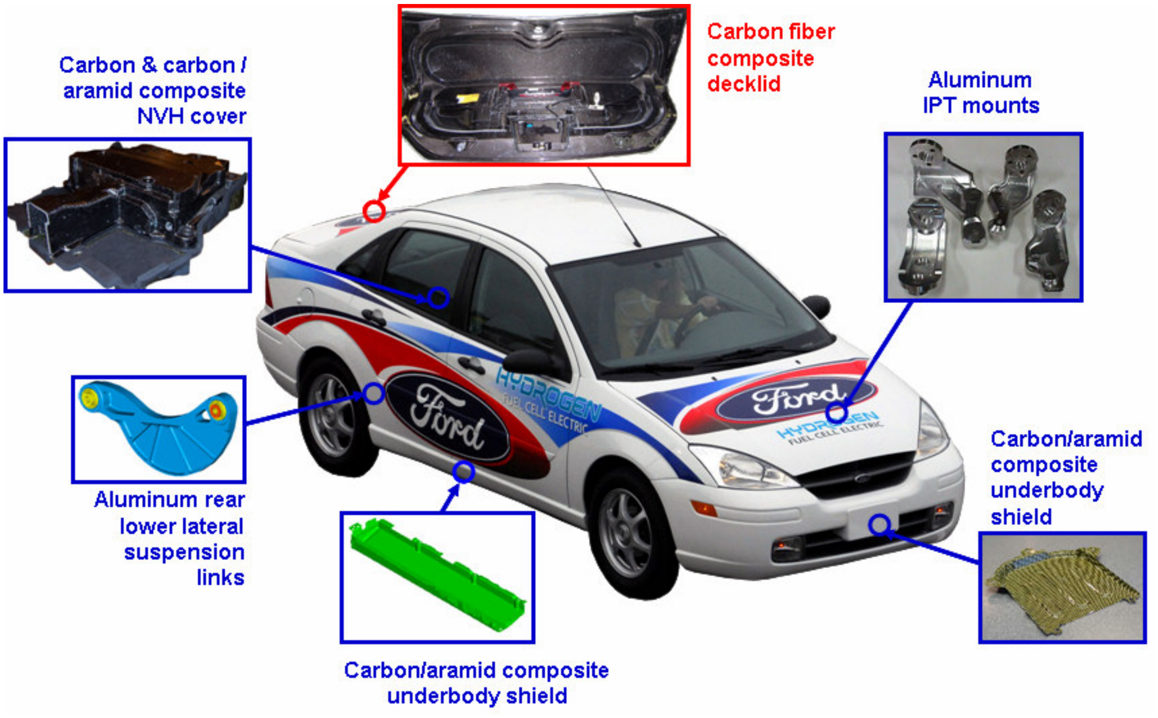
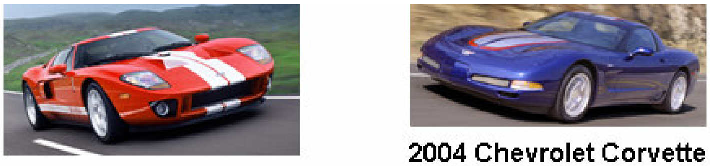


Figure 1: 2004 Ford Focus FCV

Several recent examples of automotive carbon fiber closure applications are illustrated in Figure 2. At the time of the FCV program (2002 to 2004), automotive OEM experience with carbon fiber composite closures was very limited in North America, with first partial carbon fiber panel applications just starting to appear in the market place in 2004 [5] and 2005 [6]. In contrast, OEM experience in Europe has been more extensive with several niche volume "super car" applications featuring fully carbon fiber composite closure applications [7, 8, 9]. Carbon closures in super car applications are generally driven by styling, ultimate performance, and low investment cost considerations.



2005-06 Ford GT
Decklid inner panel

2004 Chevrolet Corvette Commemorative Edition Z06
Hood outer panel

2004 Porsche Carrera GT
Hood, rear hatch, roof panel, & doors

2003-07 McLaren-Mercedes SLR
Hood, decklid, and doors

2003 Ferrari Enzo
Hood, rear hatch, and doors

Figure 2: Recent Examples of US-Spec Vehicles with Carbon Fiber Composite Closures

Given the need for mass reduction in the Focus FCV program, the production volume requirements, and the potential of carbon fiber closures demonstrated by some of the European OEMs, Ford contracted Multimatic to develop and supply a niche volume, low investment cost, and lightweight production decklid.

Ford Motor Company's responsibilities included management of the overall vehicle program, all vehicle level testing, final decklid assembly, vehicle assembly, and topcoat paint. Multimatic's responsibilities included packaging of all carry-over decklid hardware & trim, conducting structural design and engineering, CAE performance assessment, design release, component testing, prototype and production build, and demonstrating compliance with the Production Part Approval Process (PPAP) requirements.

Objectives

The objective of the FCV decklid program was to design, engineer, prototype, validate, and manufacture a low production volume, and low investment decklid that would meet all OEM production decklid performance and appearance requirements at a mass of less than 4.75 kg. Although the production vehicle decklid could be altered, the styling surface, and all mating surfaces and carry-over hardware and trim would need to be integrated in the design.

Design

In order to meet the program objectives and to establish a feasible composite design, several requirements needed to be satisfied, including:

- Design Verification (DV) Test requirements
- Mass target of 4.75 kg (~56% reduction vs. 10.8 kg steel decklid)
- Class A appearance requirement
- Deletion of the trunk liner for further mass reduction by providing a visually pleasing decklid interior appearance

A total of 21 DV requirements were identified at the beginning of the program and these are summarized in Table 1. The table also indicates whether the test was conducted as part of the component level CAE evaluation, as part of the component level physical testing, or as part of the vehicle level evaluation. Of these 21 requirements, a total of 18 component level requirements were directly considered in the decklid design in addition to several local fastener and material requirements. A total of 3 requirements were to be evaluated at the vehicle level. A total of 3 of the 18 component tests were conducted for references purposes to help establish the optimum gas strut forces. As indicated in the table, 6 requirements were assessed via component level CAE methods to establish the basic structural performance of the decklid.

Table 1: Decklid Design Verification Test Requirements

ID	Test	Component CAE	Component Testing	Vehicle level testing
1	CANTILEVERED BENDING	YES	YES	NO
2	LATCH LOAD DEFLECTION - OVERBEND CONTOUR	YES	YES	NO
3	MARGINS / FLUSHNESS	NO	YES	NO
4	PALM PRINTING	NO	YES	NO
5	SLAM OPEN CYCLE DURABILITY	NO	YES	NO
6	LATERAL & VERTICAL STABILITY	YES	YES	NO
7	OPERATING EFFORTS	NO	YES	NO
8	TORSIONAL RIGIDITY	YES	YES	NO
9	STAY OPEN (WIND LOAD)	NO	REFERENCE	NO
10	VEHICLE JACKING	NO	NO	YES
11	ABUSIVE DROP	NO	YES	NO
12	SOUND QUALITY	NO	NO	YES
13	CRASH PERFORMANCE	NO	NO	YES
14	ELBOW DIMPLING	NO	YES	NO
15	SLAM CLOSE CYCLE DURABILITY	NO	YES	NO
16	THERMAL SAG	NO	YES	NO
17	FRONT CORNER DEFLECTION	YES	YES	NO
18	WATERFALL DEFLECTION	YES	YES	NO
19	OIL CANNING	NO	YES	NO
20	LATCH LOAD REQUIREMENT	NO	REFERENCE	NO
21	DECKLID IMPACT ON DOWNSTANDING FLANGE	NO	REFERENCE	NO

Production Steel Decklid Design

The steel design is illustrated in Figure 3. The overall dimensions of the decklid are approximately of 430mm length X 1260mm width X 450mm height. The main components are the Class A outer panel, the inner panel, the latch reinforcement, and the hinge and bumper reinforcements. The inner panel is only connected to the perimeter of the outer panel via hem flanging. “Gum drops” are used to separate the inner panel from outer panel and to inhibit vibration. The outer panel provides the styling surface and provides attachments for various hardware and trim pieces. The inner panel provides the internal structure, latch reinforcement attachment, hardware attachments, and the sealing surface. The latch reinforcement houses the latch hardware while the hinge reinforcements provide local stiffness and strength in the hinge attachments regions on the inner panel. Additional bumper reinforcements provide local strength for the over-slam bumpers on the inner panel. A mass and material gage breakdown for the steel decklid is summarized in Table 2.

Several components and trim items are attached to the decklid. These components were required to be carried-over to the composite decklid design. The inner panel provides attachments to the (a) wiring harness and clips, (b) emergency release and fasteners, (c) latch hardware and fasteners, (d) bump stops, (e) hinges and reinforcements, and (f) interior trunk liner. The outer panel provides attachments to the (a) Center High-Mounted Stop Lamp (CHMSL) and clips, (b) handle and fasteners, and (c) exterior trim.

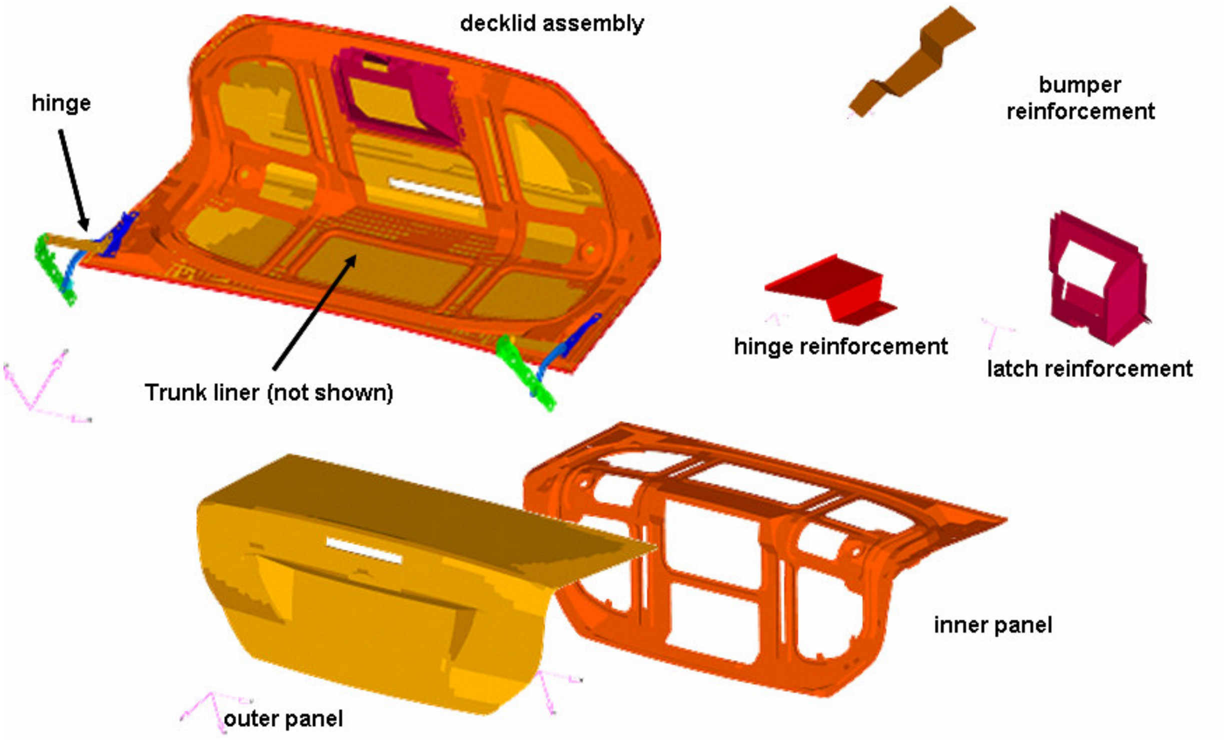


Figure 3: Baseline Steel Decklid Design

Table 2: Steel Decklid Mass & Gage Summary

Component	Thickness [mm]	Material/ Construction	Mass [kg]
Hinge Reinforcements	1.55	Steel stamping	0.22
Outer Panel	0.75	Steel stamping	5.60
Inner Panel	0.70	Steel stamping	4.30
Latch Support	2.0	Steel stamping	0.70
		Total Mass [kg]	**10.8**

Composite Decklid Design Concept

The composite decklid design concept is illustrated in Figure 4. The general construction and component function of the composite decklid is similar to the steel decklid, with some key differences implemented to maximize weight reduction opportunity. A hydrogen vent duct is incorporated into the outer panel which alters the local geometry the seal plane on the inner panel. The vent is comprised of a plastic clip which snaps into the decklid, and a cap designed to vent excess pressure. The Class A outer panel is a structural panel with honeycomb core regions to improve the composite panel stiffness and strength. The inner panel is bonded along the outer perimeter as well as along the interior region for increased stiffness and strength over the steel design. The interior bondline is located only in the cored regions of the outer panel to avoid bondline read-through. The latch reinforcement is bonded to both the inner and outer panel and the geometry was essentially carried-over from the steel design to maintain its functionality. The inner panel geometry was greatly simplified versus to the steel design to simplify manufacturability. The inner panel, the latch reinforcement, and the vent duct were all designed to have a solid laminate construction.

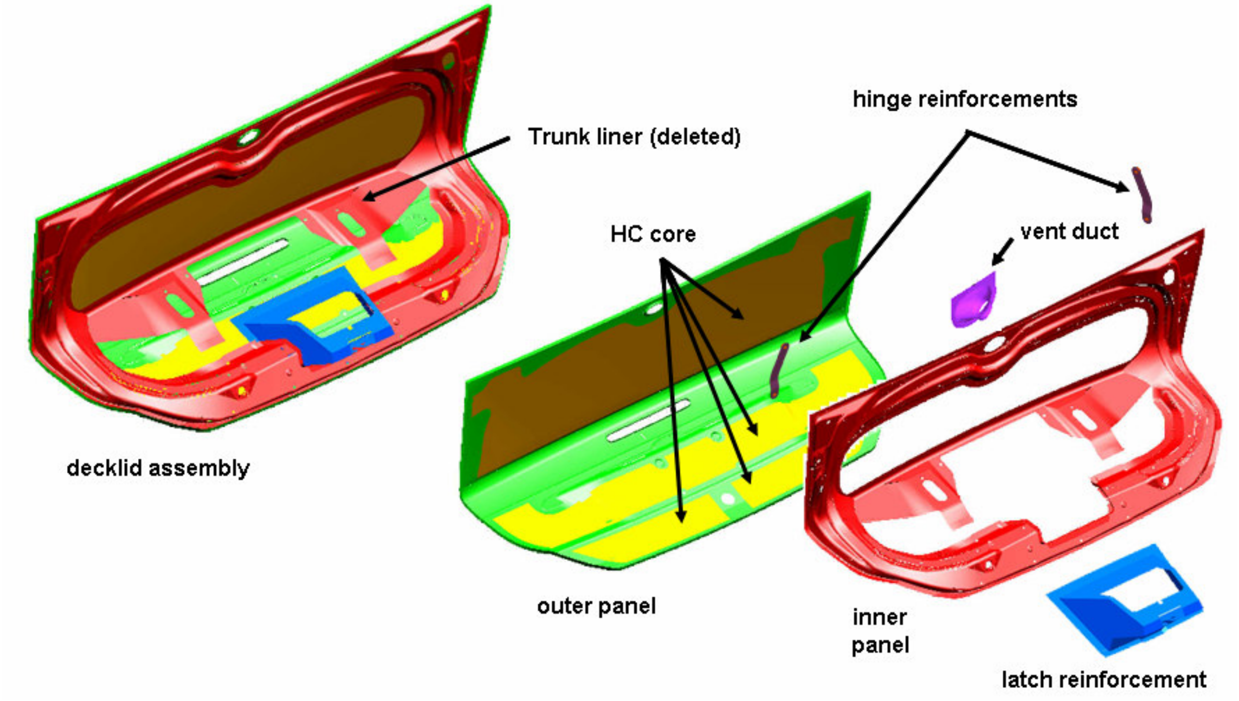


Figure 4: Composite Decklid Design Concept

Materials

Numerous materials and material combinations were evaluated within the autoclave environment to determine their suitability for achieving a Class A surface finish on the complex decklid geometry with a minimum amount of hand-finishing. The following were investigated:

- Carbon fiber prepreg fabric and various resin types
- Carbon fiber semi-pregs
- Various core types and densities
- Various surface veils
- Various in-mold and conventional primers
- Various surface preparation methods

The final Class A surface material selection was based on manufacturability considerations and OEM paint plaque sample evaluations. The following materials were selected for the solid laminate and sandwich constructions (see Figure 5):

- Carbon fiber fabric / epoxy prepreg, 200gsm, ~0.21mm ply thickness
- 3.2mm (1/8”) cell size, 48kg/m^3 (3.0 lb/ft^3) aramid honeycomb core, 6.35mm (¼”) thick
- Fiberglass / epoxy fabric prepreg, 300gsm, ~0.23mm ply thickness for local galvanic corrosion protection
- Epoxy paste and film adhesives
- Mild steel hinge reinforcements, E-coated for galvanic corrosion protection

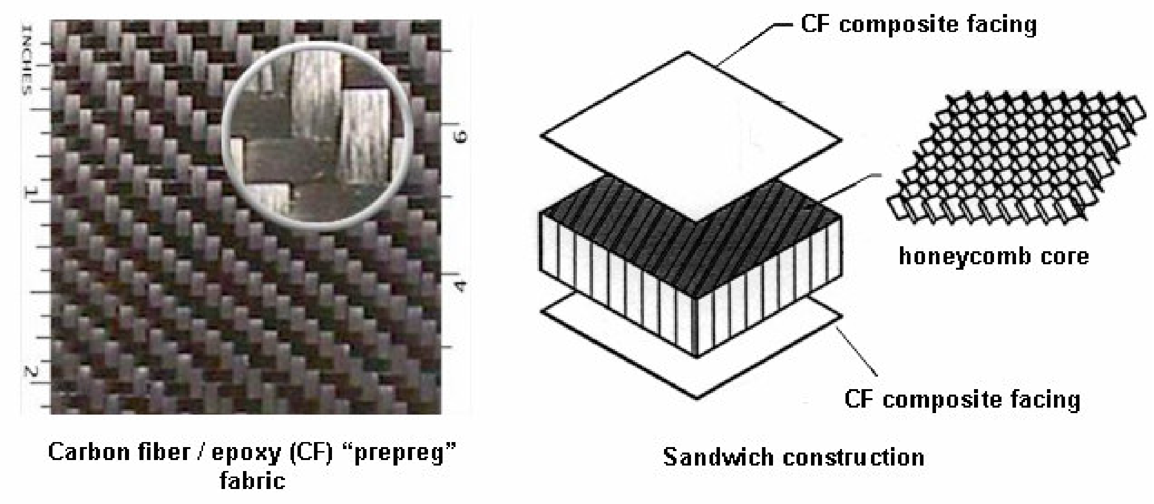


Figure 5: Carbon Fiber Prepreg and Sandwich Construction

Detail Design

Once the general design concept was selected, and the basic materials were determined, the detail design could be conducted. The detail design work entailed determination of the shape of the inner panel, and the packaging of the wiring, attachment and interface engineering for all of the mating components, and the incorporation of the hydrogen vent. Once a 3-dimensional CAD model was developed (see Figure 6), various layups could be evaluated based on the structural performance requirements and CAE assessment (see CAE Performance Assessment section). A key portion of the detail design was the integration of the carry-over hardware which is the subject of the next section.

Interface design

Material thickness and inner panel design differences relative to the baseline steel decklid required considerable attention to detail to ensure correct fitment of all the carry-over components. Composite panel thicknesses are inherently greater than steel panel thicknesses. Therefore, the maximum thickness capability for each mating hardware and trim component had to be evaluated and a workable solution had to be determined. In some cases, the local panel thickness could be decreased to accommodate the hardware item, and in other cases the fastener or clip could accommodate the increase in material thickness. The key sections for each component interface are illustrated in Figure 6 and in the list below. Figure 7 gives an indication of the complexity of the many interface requirements at the Y=0 centerline section.

- CHMSL and clips (Y=0 & 165)
- Wiring harness and clips (X=4950, Y=450)
- Emergency release and fasteners (Y=-240)
- Latch and fasteners (Y=0)
- Handle and fasteners (Y=240)
- Vent and vent retainer clip (Y=0)
- Bump stops (Y=285)
- Hinges and reinforcements (Hinge section)
- Interior trim panel (package protect) (Y=191)
- Backlight (Y=0)

In addition to the thickness considerations, any carbon fiber part of the decklid that was in contact with a steel component (e.g. hinge reinforcement and latch hardware) needed to be isolated for galvanic corrosion. Isolation was accomplished by including a surface ply of fiberglass in the interface regions and by E-coating the hinge reinforcements.

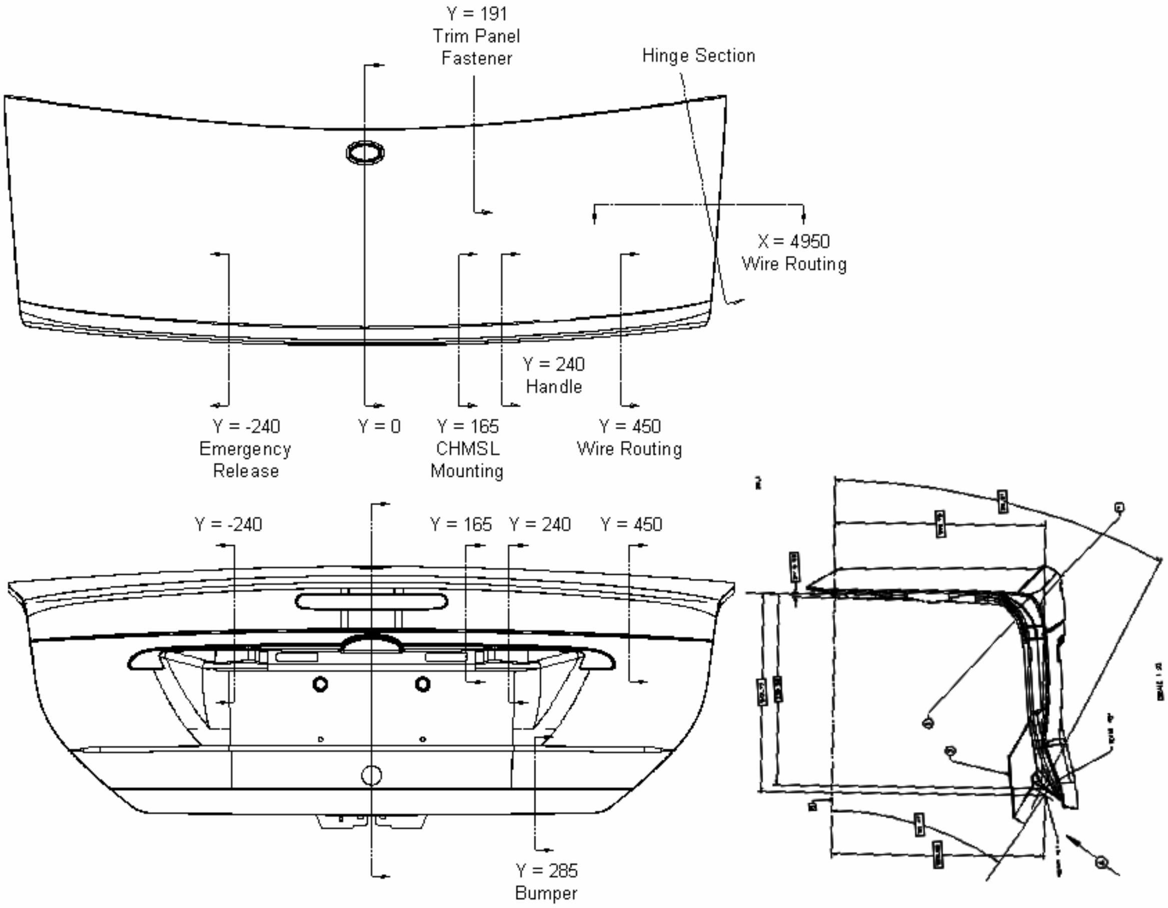
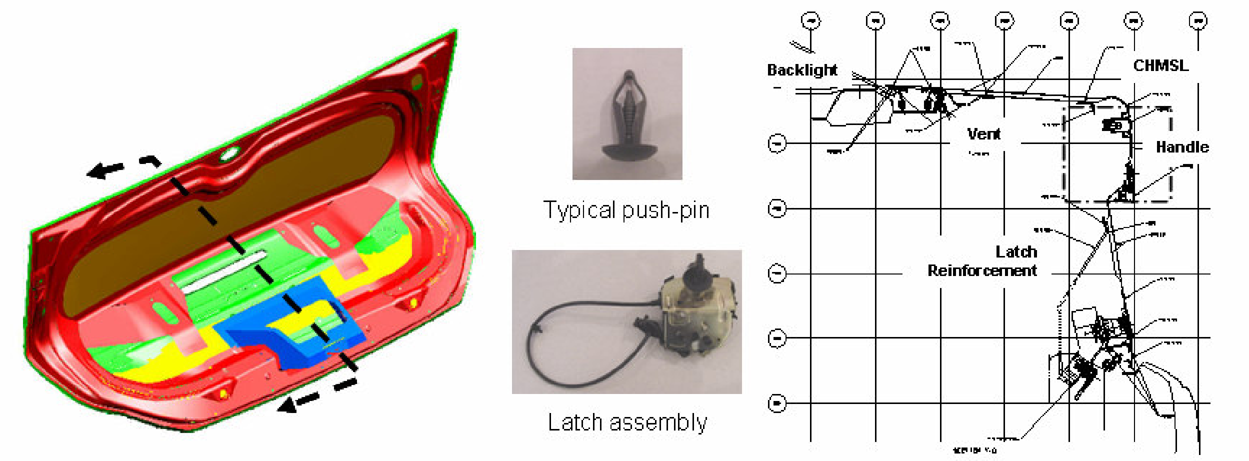


Figure 6: Decklid Detail Design & Key Interface Sections



Typical push-pin

Latch assembly

Figure 7: Sample Hardware and Carry-Over Hardware Interface Requirements

An image of the fully assembled decklid CAD model, including all components and hardware, and attachment features is shown in Figure 8.

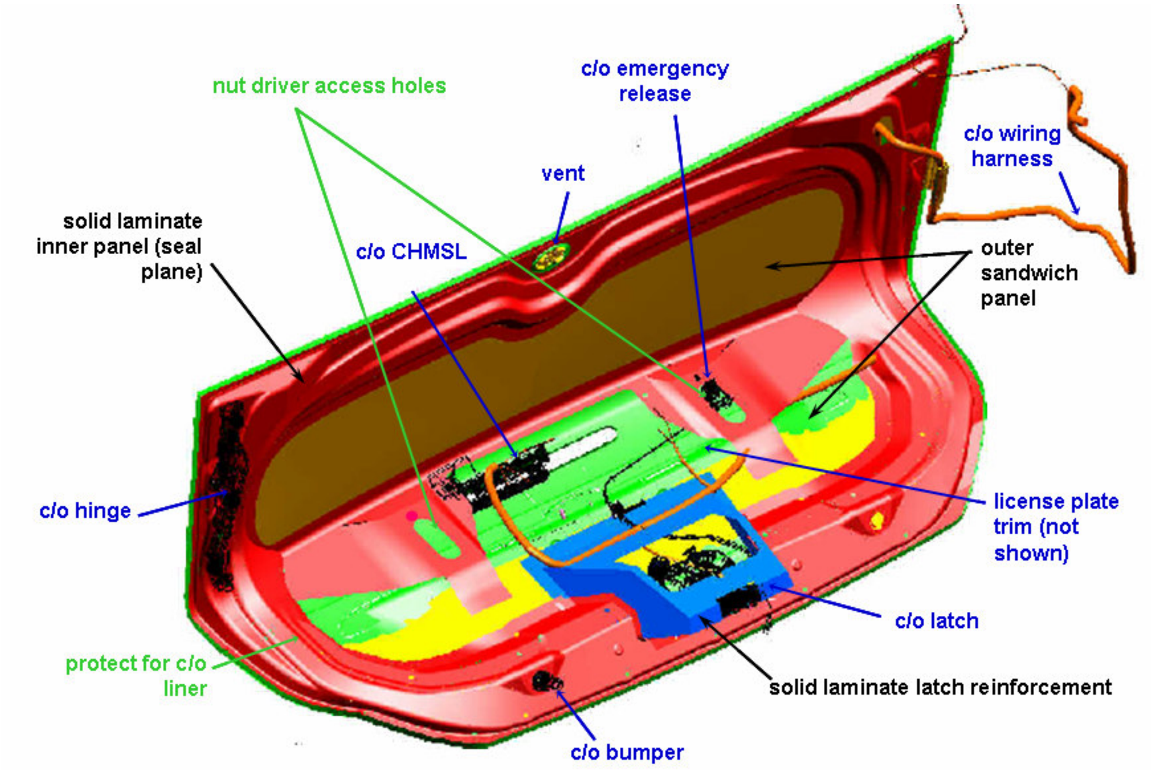


Figure 8: Fully-Assembled Composite Decklid CAD Model

CAE Performance Assessment

A detailed finite element model of the composite decklid design concept was developed and all structural performance assessments were performed using the geometrically nonlinear analysis option in ABAQUS/Standard [10]. The decklid model was subjected to the 6 DV load cases noted in Table 1. Many laminate configurations were evaluated and modified to minimize the mass of the assembly while meeting all structural performance requirements.

As can be seen in Figure 9, the finite element model consisted of six components: the outer panel, inner panel, latch reinforcement, vent duct, and two hinge reinforcements. All components were modeled using fully integrated shell elements. Composite shell section definitions were used to define the layup for the composite components. Local coordinate systems were used to properly define the orientation for the orthotropic composite materials. The honeycomb core was assumed to be a ply within the composite shell section representation of the laminate to facilitate the evaluation of various core thicknesses.

The components of the decklid were assumed to be bonded together using a stiff epoxy structural adhesive. To simulate this in the model, adhesive bonding was simulated using rigid beam multi-point constraints. The bonded areas in the model are shown in Figure 10.

The material properties used in the analyses were assumed to be linear elastic and are listed in Table 3. The material strength was evaluated in some load cases using the Tsai-Wu failure criteria but material failure was not predicted to occur at the applied load levels. As linear material properties were used, permanent set could not be predicted and would have to be evaluated later through physical testing.

Table 3: Material Properties

	Property*									
	Ply Thickness	**Density**	**Tensile Modulus**			**Poisson's Ratio**	**Shear Modulus**			
Material Type	**[mm]**	**[g/cc]**	**E_L [GPa]**	**E_T [GPa]**	**E_Z [GPa]**	**ν_{LT}**	**G_{LT} [GPa]**	**G_{LZ} [GPa]**	**G_{TZ} [GPa]**
Steel	--	7.8	207		--	0.29	--	--	--
Carbon/epoxy prepreg, 2X2 twill weave fabric	0.221	1.55	51	51	--	0.05	3.25	3.02	3.02
Aramid Honeycomb, 3.2 mm cell size, 6.35 mm thick, 48 kg/m^3 density	--	0.048	0.007	0.007	0.138	0.1	0.002	0.045	0.024

CAE Results

The decklid performance was evaluated for all 6 load cases. After evaluating several layup configurations, it was apparent that there were two dominant load cases that would drive the design: (1) Front corner deflection and (2) waterfall deflection. The model setup for both of these load cases is shown in Figure 11. Elastic strain energy and deflection contours are illustrated in Figure 12 for the front corner deflection load case and in Figure 13 for the waterfall deflection load case. Although each case exhibits different deflection contours, it can be seen that the loading induces bending about the waterfall region of the decklid which is indicated by the highlighted elastic strain energies. Increasing the section size in the highlighted region was not an option due to the carry-over sealing surface on the interior of the decklid, so the material thickness had to be increased and the material orientation had to be optimized to satisfy the deflection requirement.

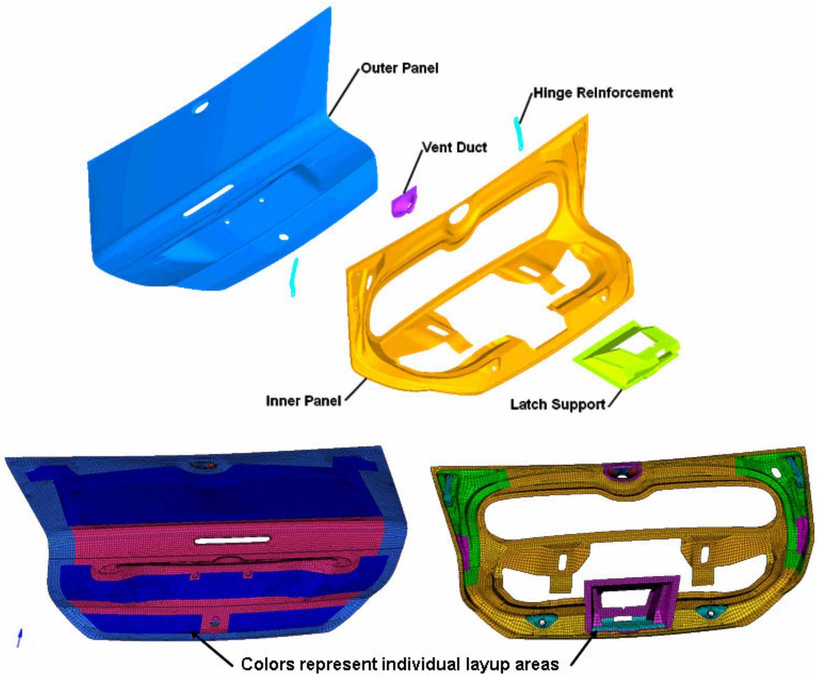


Figure 9: Finite Element Model

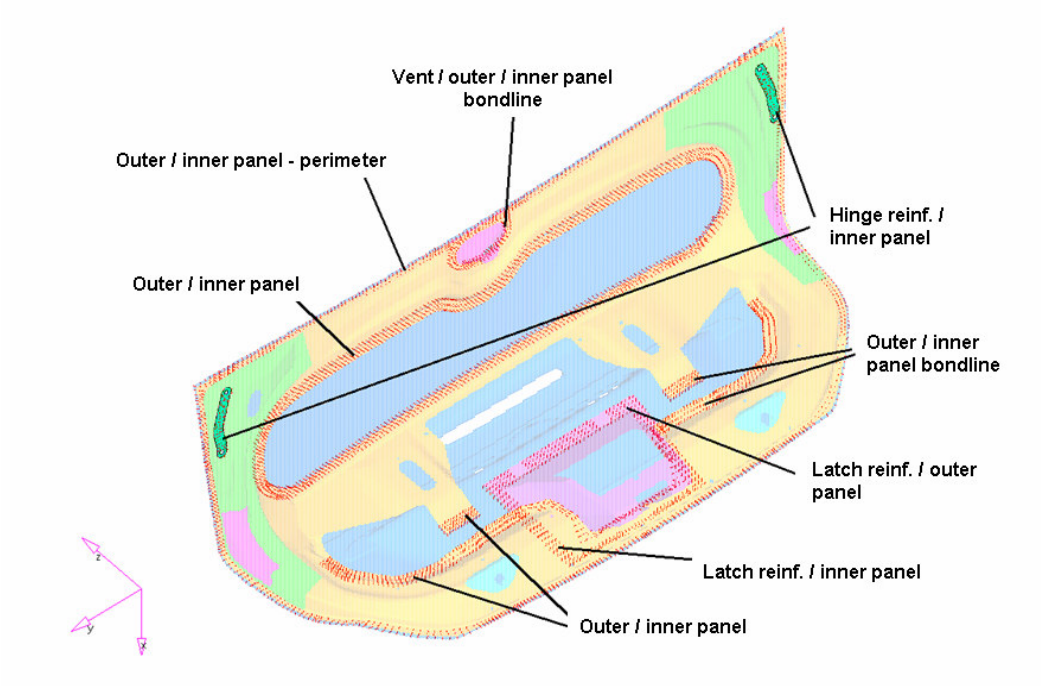
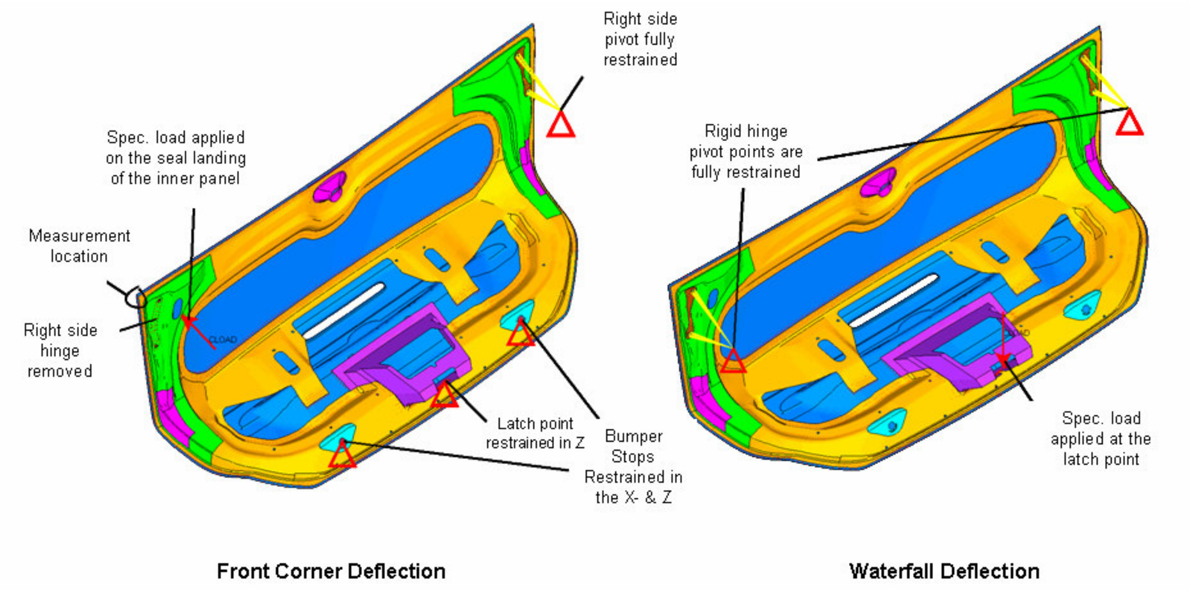


Figure 10: Finite Element Model Bonding Assumptions



Front Corner Deflection

Waterfall Deflection

Figure 11: Front Corner and Waterfall Deflection Model Setup

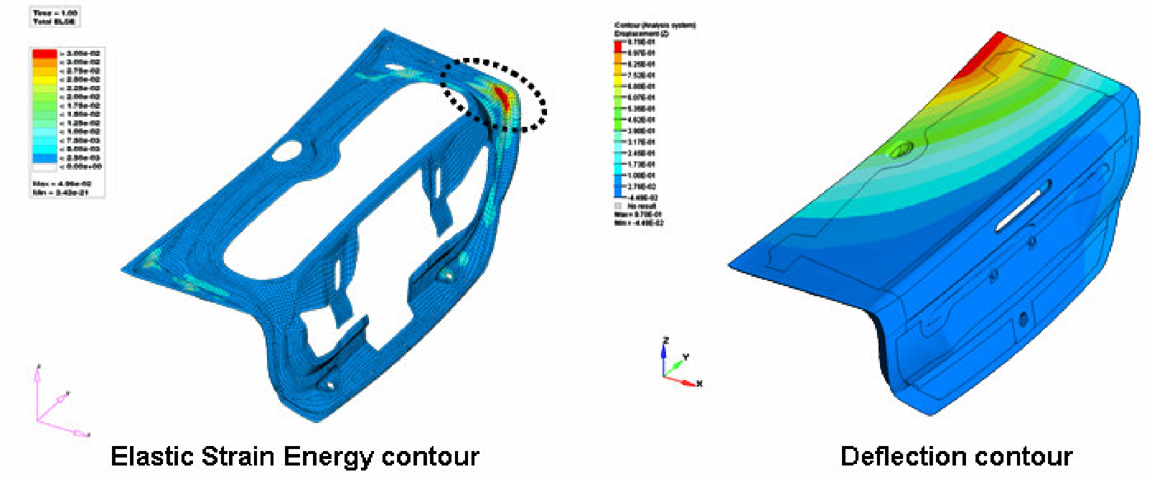


Figure 12: Front Corner Deflection Predicted Strain Energy and Deflection Contours

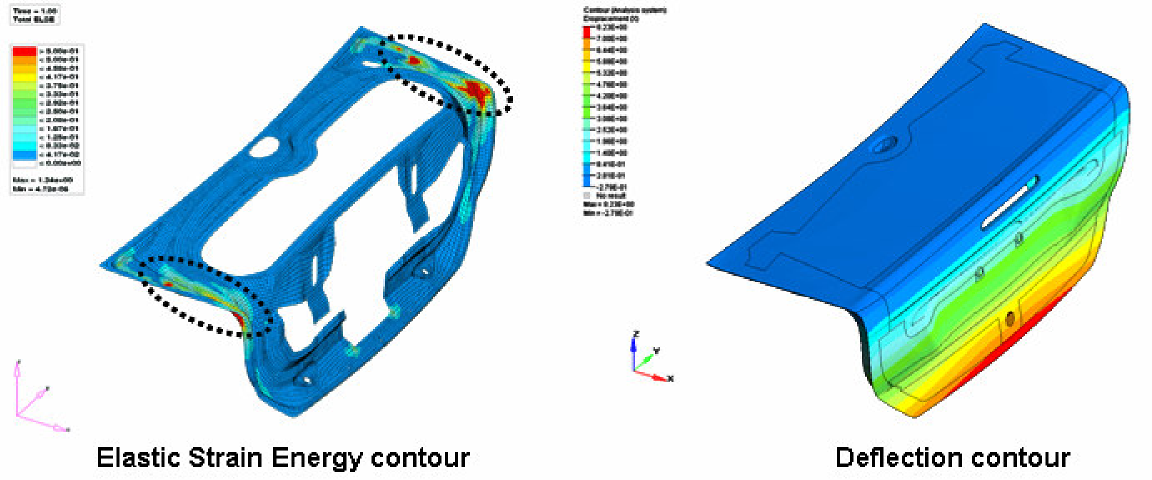


Figure 13: Waterfall Deflection Predicted Strain Energy and Deflection Contours

The predicted results for all 6 load cases are summarized in Table 4. The table indicates the load case name, the displacement requirement for the specified applied load, and the predicted displacement result in terms of % difference relative to the requirement. It can be seen that all deflections are below the requirement. The front corner and waterfall deflections were 4% to 5% below the requirement, respectively, while all other deflection results were 71% to 89% below the requirement.

The resulting material thickness distribution for all decklid components is shown in Figure 14. As can be seen in the figure, the thickness varied from approximately 1.1mm to 2.7mm for the solid laminate regions. The thickness of the sandwich laminate regions was a constant 7.2mm. Material orientations were a combination of $0/90^{\circ}$ and $\pm 45^{\circ}$ ply angles.

Table 4: Predicted Results

Load Cases		Requirement		Results
No.	**Test Name / Source**	**Load Case**	**Value**	**CAE vs. Requirement**
1	**CANTILEVERED BENDING**	deflection due to gravity [mm]	1.0	**-79%**
		deflection at spec. load [mm]	10.0	**-89%**
		set after spec. load [mm]	0.7	**N/A**
2	**LATCH LOAD DEFLECTION - OVERBEND CONTOUR**	deflection at spec. load [mm]	0.5	**-78%**
		set after spec. load [mm]	0.5	**N/A**
		damage after peak load	none	**none**
6	**LATERAL & VERTICAL STABILITY**	vertical stability [mm]	70.0	**-74%**
		lateral stability (avg) [mm]	3.0	**-71%**
8	**TORSIONAL RIGIDITY**	twist [deg/m]	2.0	**-85%**
		set after spec. load [deg/m]	0.4	**N/A**
17	**FRONT CORNER DEFLECTION**	deflection at spec. load [mm]	1.0	**-4%**
18	**WATERFALL DEFLECTION**	deflection @ spec. load [mm]	8.0	**-5%**

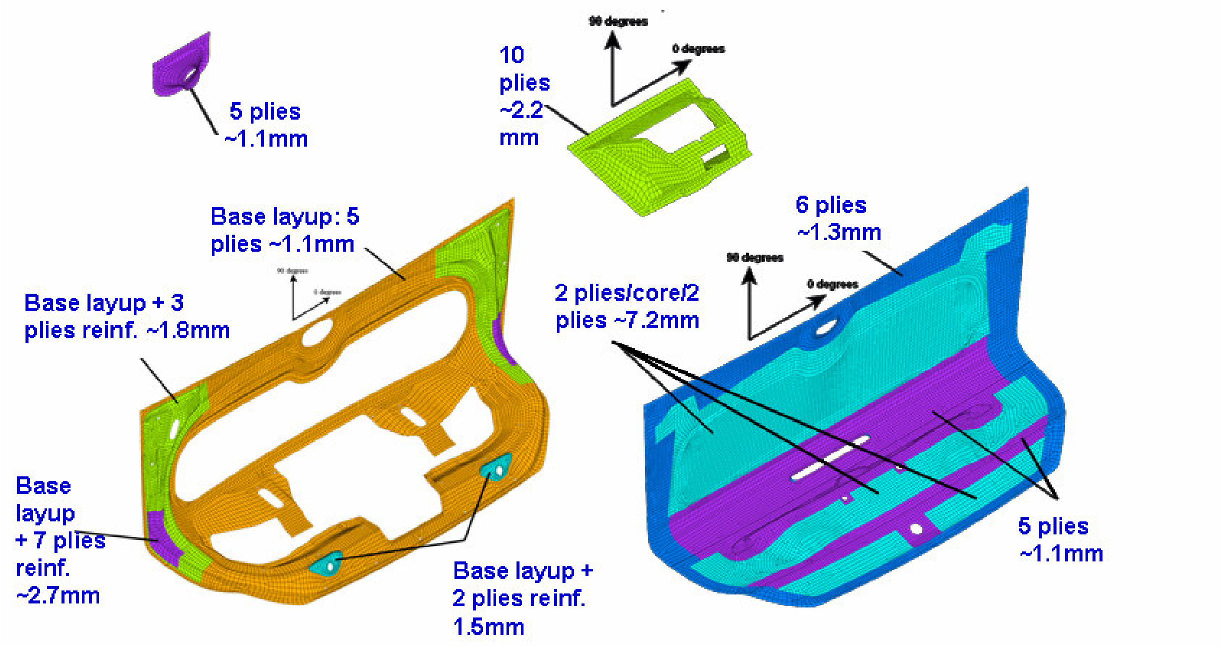


Figure 14: Final Decklid Layup

A breakdown of the predicted 3.90kg decklid mass is provided in Table 5. The predicted mass is 17.9% below the target mass of 4.75kg. The total mass includes the mass of the hinge reinforcements, an estimate of the film adhesive and bond line adhesive, but does not include the mass of paint and primer, or any ply overlaps. Therefore, the mass of an actual finished decklid is expected to be somewhat higher.

Table 5: Predicted Mass Summary

Component	Thickness [mm]	Material/ Construction	Carbon Fabric Mass [kg]	Core Mass [kg]	Total Mass [kg]
Hinge Reinforcements	1.0	SAE J1397 1008 Steel	-	-	0.061
Outer Panel	1.1 / 1.3 (solid) 7.2 (cored)	Carbon/epoxy prepreg 2X2 twill weave fabric, 6.35 mm thick / 3.2 mm cell Nomex honeycomb	1.56	0.13	1.69
Inner Panel	1.1 to 2.7	Carbon/epoxy prepreg 2X2 twill weave fabric	1.22	-	1.22
Latch Support	2.2	Carbon/epoxy prepreg 2X2 twill weave fabric	0.36	-	0.36
Vent Duct	1.1	Carbon/epoxy prepreg 2X2 twill weave fabric	0.02	-	0.02
Film Adhesive (not modelled)	-	Film adhesive	-	-	0.27
Bond Line Adhesive (not modelled)	-	2 Part epoxy paste adhesive	-	-	0.28
				Total Mass [kg]	**3.90**

Manufacture

All decklid components were manufactured on single-sided tooling using a vacuum bag / autoclave process. The inner and outer panel tools were carbon fiber, while the latch reinforcement and vent tools were aluminum to facilitate any late design changes. To minimize program investment, both prototype and production components were made from the same tooling, with only minor modifications required to manufacture the production components, such as adjustments to the bond fixture, hole & slot locations, modifications of detail component features, etc.

Prototype components were used to develop the manufacturing process, verify DV performance, develop all wire routing, evaluate fit and finish, and evaluate vehicle level performance. Once all PPAP requirements (see the below section on PPAP) were met, production components could be delivered to the OEM for top coat paint and final decklid and vehicle assembly.

Autoclave molding

Before laminating components, the prepreg and core materials were NC cut and organized into individual kits to facilitate work flow. All decklid components were laminated according to the layup scheme defined by the analysis. The outer panel differed somewhat from the other panels in that the tool was first coated with an in-mold primer before lamination to minimize hand finishing after cure. After lamination, all components were vacuum-bagged, checked for vacuum integrity, and then cured in the autoclave for a specified time / temperature / pressure cycle. After cure, all components were trimmed using a combination of router fixtures, 5-axis waterjet, and machining. The above processes are illustrated in Figure 15.

Prepreg NC kit cutting

Component lamination

Autoclave cure

Trimming & finishing

Figure 15: Autoclave Molding & Trimming

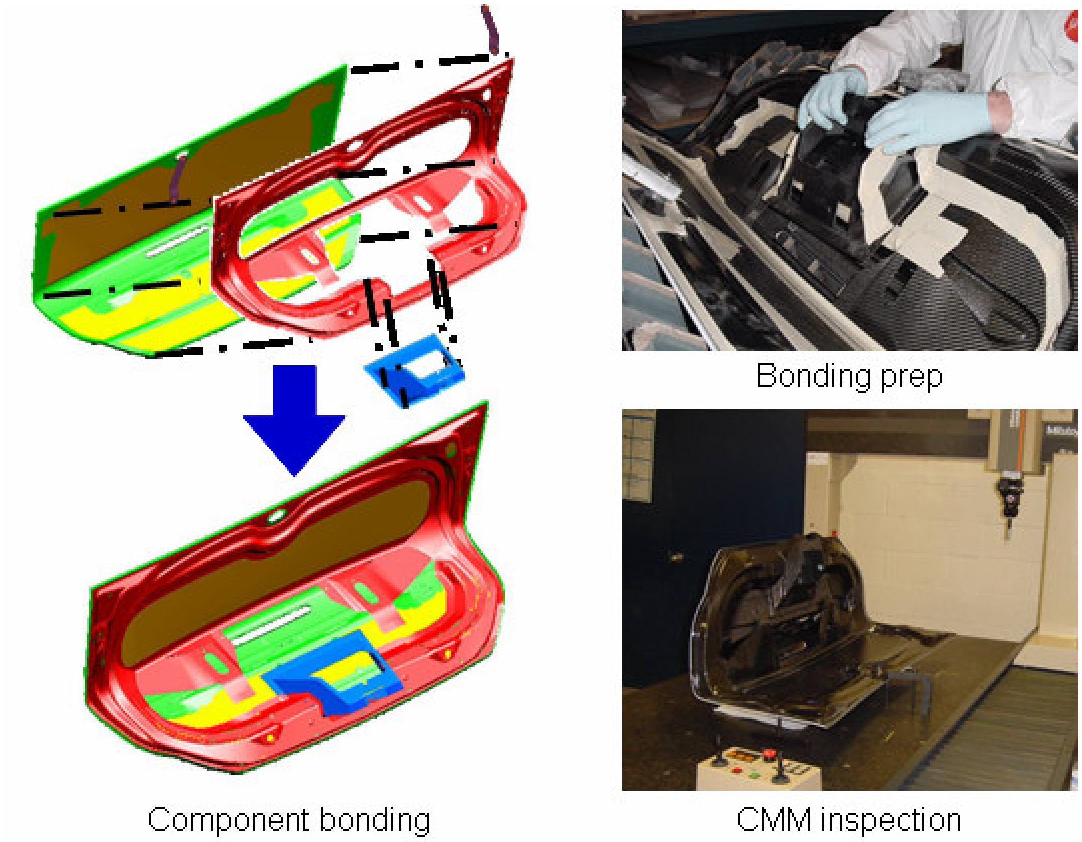
Bonding and Inspection

The next step after completion of the individual components was preparation for bonding. This entailed abrading and wiping the bond areas with acetone before loading each composite component and the hinge reinforcements into the fixture. Epoxy adhesive was pre-applied to each component before loading into the bond fixture. The bond fixture located each component in the correct relative position and a minimum bond gap was defined by micro-spheres mixed into the adhesive. The assembly was then cured at room temperature.

After adhesive cure, each decklid underwent a 100% CMM, surface, and detail inspection to ensure all dimensional and surface finish requirements were met. Upon completion, the decklids were prepared for shipment to the OEM build site. The above steps are illustrated in Figure 16.

Mass

The average mass of the as-molded decklid assemblies was 4.3kg, which was close to the CAE minimum mass prediction of 3.9kg. Completely primed and finished decklids, as shown in Figure 17, had an average mass of 4.5kg.



Bonding prep

Component bonding

CMM inspection

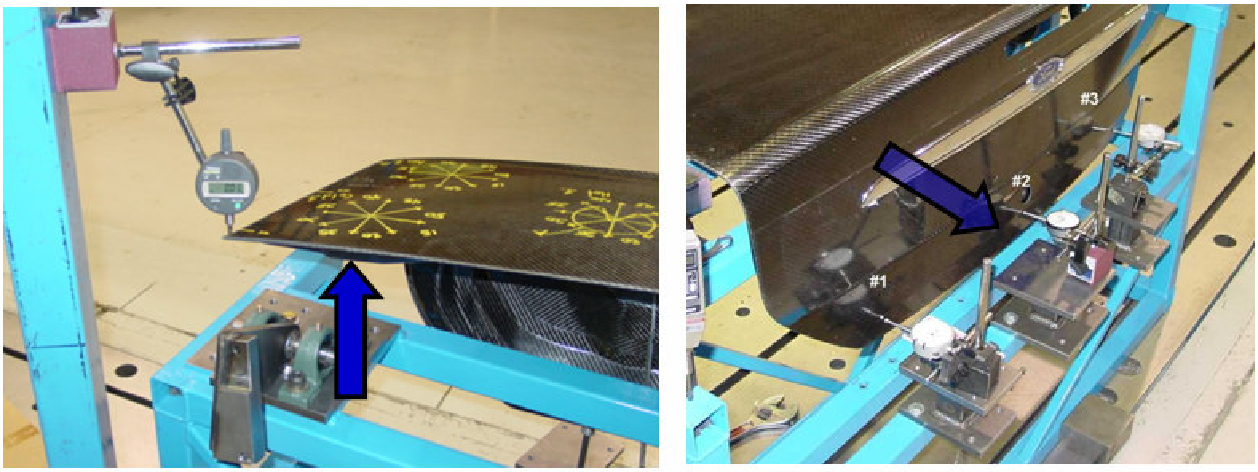
Figure 16: Bonding and CMM Inspection

Figure 17: Completed Decklid

Design Verification Testing

Once the first prototype decklids were completed, physical testing could be conducted to verify the predicted CAE performance and validate the complete list of component level requirements summarized in Table 1. A total of two production-intent carbon decklid assemblies and one production steel decklid were tested for this purpose. As can be seen in Figure 18, a custom test fixture was fabricated so that all boundary conditions and loading could be applied in a manner consistent with the CAE analyses (see Figure 11).

All tests were conducted to OEM test specifications. Deflection profiles were measured with dial gages or displacement transducers, and forces were applied with a force gage. In some cases, the decklid was conditioned in an environmental chamber to evaluate performance at cold and/or hot temperatures.



Front corner deflection

Waterfall deflection

Figure 18: Front Corner Deflection and Waterfall Deflection Test Setups

Design Validation Test Results

The results of the DV testing are summarized in Table 6. The table indicates the load case name, the test requirement, and the test result for the carbon decklid relative to the tested steel decklid. Test results are shown in terms of percent difference or absolute difference relative to the steel decklid. Comments relating to whether the decklid passed the requirement, whether a deviation was permitted, or whether the test was conducted for reference are also included in the table. Note that the steel decklid was not subjected to every loading condition. As can been seen in Table 6, the test performance of the carbon fiber decklids exceeded the test performance of the steel production decklid in all cases except for the latch load deflection and the front corner deflection load cases, in which the steel deflection was exceeded by a small deflection of only 0.11mm and 0.08mm, respectively. In some cases, the requirements were only slightly exceeded and deemed acceptable so a deviation was permitted by the program.

Table 6: Summary of DVP&R Results

Load Cases		Requirement	Carbon vs Steel		Comments
No.	Test Name / Source	Load Case	Test		
			% difference	difference	
1	**CANTILEVERED BENDING**	deflection due to gravity [mm]	-43%	-0.64	**Pass**
		deflection at spec. load [mm]	-52%	-2.18	**Pass**
		set after spec. load [mm]	-65%	-2.20	Slightly exceeded requirement => **deviation permitted** Improved vs. steel baseline
2	**LATCH LOAD DEFLECTION - OVERBEND CONTOUR**	deflection at spec. load [mm]	48%	0.11	**Pass** Slightly exceeded steel baseline
		set after spec. load [mm]	N/A	N/A	**Pass** Steel not evaluated
		damage after peak load	N/A	N/A	**Pass** Steel not evaluated
3	**MARGINS / FLUSHNESS**	margin @ ambient	N/A	N/A	Slight deviation vs. requirement => **deviation permitted** Margin & flushness improved vs steel baseline
		margin @ 49C	N/A	N/A	
		flushness @ ambient	N/A	N/A	
		flushness @ 49C	N/A	N/A	
4	**PALM PRINTING**	spec. palm load	N/A	N/A	**Pass** Steel not evaluated
5	**SLAM OPEN CYCLE DURABILITY**	spec. slam cycles	N/A	N/A	**Pass** Steel not evaluated
6	**LATERAL & VERTICAL STABILITY**	vertical stability [mm]	N/A	N/A	**Pass**
		lateral stability (avg) [mm]	N/A	N/A	**Pass**
7	**OPERATING EFFORTS**	Reference measmts for 2 gas strut force levels, compare w/ steel	N/A	N/A	Reference - used to tune gas struts
8	**TORSIONAL RIGIDITY**	twist [deg/m]	-17%	-0.06	**Pass**
		set after spec. load [deg/m]	-44%	-0.04	**Pass**
9	**STAY OPEN (WIND LOAD)**	Reference measurements for 2 gas strut force levels to compare with baseline steel	N/A	N/A	Reference - used to tune gas struts
11	**ABUSIVE DROP**	1/4 height drop, margin	N/A	N/A	Slightly exceeded requirement => **deviation permitted** Improved vs. steel baseline
		1/2 height drop, margin	N/A	N/A	
		full height drop, margin	N/A	N/A	
		1/4 height drop, flushness	N/A	N/A	
		1/2 height drop, flushness	N/A	N/A	
		full height drop, flushness	N/A	N/A	
14	**ELBOW DIMPLING**	spec. dimple load	N/A	N/A	**Pass** Improved vs. steel baseline
15	**SLAM CLOSE CYCLE DURABILITY**	spec. cycles of slam close	N/A	N/A	Minor deviation after 80% cycle completion => **deviation permitted** Steel baseline not evaluated
16	**THERMAL SAG**	appearance, margin & flush after 1hr @ 180F	N/A	N/A	Minor deviation at 2 points => **deviation permitted** Steel baseline not evaluated
17	**FRONT CORNER DEFLECTION**	deflection at spec. load [mm]	7%	0.08	Slightly exceeded requirement => **deviation permitted** Similar to steel baseline
18	**WATERFALL DEFLECTION**	deflection @ spec. load [mm]	-43%	-4.30	**Pass** Improved vs. steel baseline

Production Part Approval Process (PPAP)

Before production parts could be shipped, it was demonstrated that the decklids were in compliance with the OEM program-specified PPAP requirements. Key elements of the PPAP process included:

- Review and approval of all design records, engineering changes, and CAD data
- Review and approval of the design robustness analysis through the Design Failure Mode Effects Analysis (DFMEA)
- Review and approval of the manufacturing process analysis through the Process Failure Mode Effects Analysis (PFMEA)
- Acceptance of 100% dimensional results for all assemblies
- Review and approval of all performance requirements through the Design Verification Plan & Report (DVP&R)
- Acceptance of the Appearance Approval Report (AAR)

Upon completion of all requirements, a Part Submission Warrant (PSW) was issued by the program and shipment of production components could officially begin.

Summary

The effort involved to engineer (design, conduct CAE assessments and physical testing) and manufacture the first North American OEM production lightweight carbon fiber decklid was described. The completed decklid met all engineering criteria and Class A finish requirements with an as-molded mass of 4.3kg, and a primed and finished mass of 4.5kg, which was below the program mass target of 4.75kg. The resulting mass savings was approximately 60% relative to the 10.8kg production steel decklid. Upon demonstrating compliance with OEM PPAP requirements, primed and ready-to-paint production decklids were shipped to the OEM build facility for production paint and final assembly (see Figure 19 and Figure 20).

Figure 19: Installed Decklid Assembly (Ford Motor Company)

Figure 20: Fully Trimmed Decklid (Ford Motor Company)

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