

Design of a Composite Structural Panel for High Volume Production

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ABSTRACT

As CAFE requirements increase, automotive OEMs are pursuing innovative methods to lightweight their Body In Whites (BIWs). Within FCA US, this lightweighting research and development activity often occurs through Decoupled Innovation projects. A Decoupled Innovation team comprised of engineers from the BIW Structures Group, in collaboration with Tier 1 supplier Magna Exteriors, sought to re-design a loadbearing component on the BIW that would offer significant weight savings when the current steel component was replaced with a carbon fiber composite. This paper describes the design, development, physical validation and partnership that resulted in a composite Rear Package Shelf Assembly solution for a high-volume production vehicle. As the CAFE requirements loom closer and closer, these innovation-driven engineering activities are imperative to the successful lightweighting of FCA US vehicles.

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INTRODUCTION

The Federal Government's CAFE (Corporate Average Fuel Economy) ruling requires that FCA US and other automotive OEMs (Original Equipment Manufacturer) meet a 54.5 miles per gallon fuel efficiency requirement by 2025. While powertrain technologies evolve to meet the challenge, the lightweighting of the body structure reduces the load that these new powertrains have to manage. To develop the technology required to address this significant lightweighting challenge, FCA US uses a well-defined process of Decoupled Innovation. *Decoupled* means that the research, design and engineering of new technologies are completed separately, or decoupled, from the normal FCA US Product Development Process and associated timelines. *Innovation* represents the idea that new, novel and applicable technologies are intelligently applied to the intentional lightweighting of FCA US vehicles and Body In Whites (BIWs). Upon completion of a successful Decoupled Innovation Project, the technology can be made available to engineers and designers for implementation on up-coming vehicles.

As part of the Decoupled Innovation process, FCA US can leverage the experience, expertise and design capabilities of its suppliers. The Decoupled Innovation team for this project was comprised of engineers from the BIW Structures Group and Magna Exteriors. Magna has previous experience in composite design, development and manufacturing capability through the Magna-NRC Composites Centre of Excellence located in Concord, Ontario, Canada. By combining FCA US's ability to build, retrofit and test an actual production vehicle with Magna's composite manufacturing expertise, the collaboration strategy was complete and could be mutually beneficial to both companies.

While composite panels have been used extensively in the past for automotive exterior panels and storage tubs (hoods, roof panels, spare tire tubs, etc.), the complexity involved in developing a load-bearing structural BIW panel at high-volume production quantities has limited its application. The primary objective of this project was to define a *structural* component on the BIW that would offer significant weight savings when the current steel component was replaced with a carbon fiber composite. The secondary objective of this project was to identify a composite manufacturing process that would be capable to support high-volume vehicle quantities. In this case, that means production volumes of at least 150,000 vehicles per year. To meet these project objectives, the Rear Package Shelf Assembly of a current production high-volume BIW was selected as the subject assembly and focus of the Decoupled Innovation project.

The Steel Rear Package Shelf Assembly

The Rear Package Shelf Assembly is currently produced as a steel panel attached to a steel BIW by traditional resistance spot welding. The Rear Package Shelf Assembly consists of the rear shelf panel, front cross member reinforcement and a rear cross member reinforcement, with provisions for the attaching points for the rear seat center occupant seat belt retractor and three child tether attaching points (FIGURE 1). Since this panel provides the attaching locations for the seat belt retractor and the child tethers, engineering validation and safety testing is required to certify the vehicle. The rear package shelf also contributes to the driving performance of the vehicle by adding torsional stiffness to resist twisting under dynamic handling maneuvers.

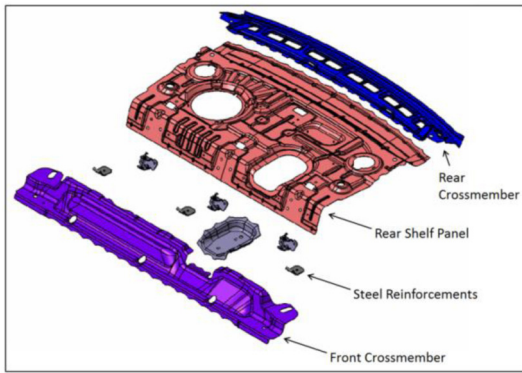


Figure 1. Steel Rear Package Shelf Assembly

The primary safety function of the Rear Package Shelf Assembly is to meet the FMVSS (Federal Motor Vehicle Safety Standards) load conditions of the rear seat belt anchors and the rear seat child tether retention mounts. Other secondary functions include providing a panel behind the rear seat back to close out the trunk, mount the rear seatback striker and other electrical receiver modules, and support the audio system's sub-woofer speaker. During the initial phase of the project, stress evaluations and design optimization studies were conducted to address the primary loadcases applied to the shelf panel at the seat belt retractor and child tether anchorages. Additionally, in this early phase of the project, cross-mobility analysis was used to meet the vibration criteria as it relates to the vehicle's sub-woofer speaker performance. Finally, torsional stiffness was evaluated to measure the contribution of the Rear Package Shelf Assembly to the overall performance of the BIW.

DESIGN AND ENGINEERING PROCESS / DEVELOPMENT

The Rear Package Shelf Assembly is essentially a large, relatively flat steel stamped component, with front and rear crossmembers that support the significant vehicle and passenger loading requirements, predominantly from impact and Noise, Vibration and Harshness (NVH) load inputs. The design strategy of the Composite Rear Shelf Assembly looked to balance both of these performance attributes and ensure that the current production performance of the steel shelf assembly could be achieved, all while reducing mass.

NVH & Stiffness Loadcase Development

A key challenge when lightweighting a body component is the change in NVH characteristics due to the loss of structural damping from the lighter material. The lighter design therefore must have higher stiffness to maintain similar NVH performance. On the steel package shelf assembly, the sub-woofer is mounted directly to the shelf. The low frequency vibrations caused from the sub-woofer can excite the shelf and are a potential cause for buzz, squeak and rattle (BSR) in the package shelf region.

Through the development of the Composite Rear Shelf Assembly, the engineering team constantly monitored the mobility of key points on

the package shelf assembly through critical frequency ranges to ensure that the BSR requirements for the shelf could be met.

The torsional stiffness of the assembly was also monitored throughout the development against a baseline target. The shelf sub-assembly stiffness was later validated in a sub-system test fixture, to ensure the lightweight design did not change the torsional attributes of the rear end of the body structure, and would not affect the dynamic handling characteristics of the car.

Safety Loadcase Development

In the FMVSS 207/210 loadcase, both seat belt retractor loading and child tether loading forces are applied directly onto the Rear Package Shelf Assembly, so this assembly fit the project objective to design a load-bearing BIW composite solution. It is normal to see relatively large displacements in the body structure at the outboard seat belt mountings. The high strains resulting from these displacements would need to be addressed and mitigated for in the development and implementation of the carbon fiber reinforced composite solution, which would have lower elongation limits. The decision was made to segment the package tray inboard of the exterior belt mounts to eliminate this area from the project scope. This decision was also critical in developing the trim line and interfacing section within the existing steel structure and rear window opening for body shop assembly and the retrofitting of the composite design solution into an existing BIW for testing (FIGURE 2).

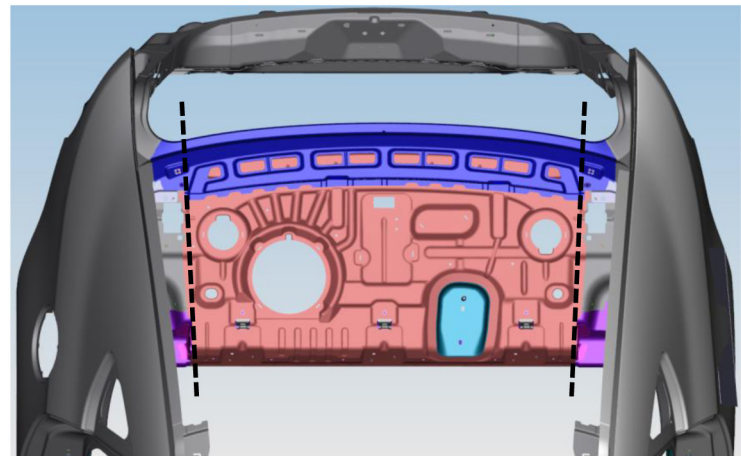


Figure 2. Rear Package Shelf Assembly boundary trim line

To speed up engineering development and improve simulation time, a virtual CAE (Computer Aided Engineering) buck model was created. This virtual buck model represented the rear of the vehicle, including the Rear Package Shelf Assembly, the seat back panel and the rear floor. A loadcase was developed for the virtual buck model to simulate the FMVSS 207/210 load inputs into the BIW structure (FIGURE 3). The load levels and magnitudes at each attachment point were extracted from a simulation model of the steel body. It was reasonable to assume that if the composite shelf assembly virtual buck could manage the same loads as the steel structure, then the design could be considered validated in the full-BIW model.

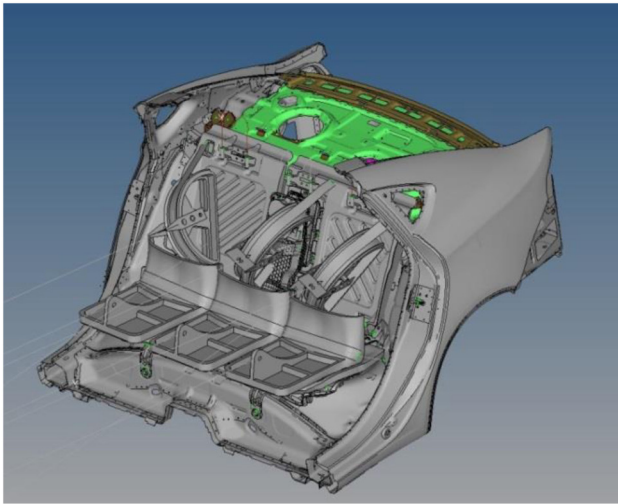


Figure 3. Virtual Buck Model for CAE Analysis

The full body level seatbelt and child tether loads were applied to the virtual buck model of the Composite Rear Package Shelf Assembly. Since these two load cases are of a relatively high magnitude, they were quickly identified as the most challenging load cases for this Decoupled Innovation project. Significant design and engineering analysis was performed at each of the seat belt retractor and child tether attachment locations. It was determined that steel reinforcement plates sandwiched between the composite panel would be most effective at eliminating local point loads and distributing the attachment forces through the surrounding composite. The use of steel reinforcements is a commonly used method in composite design to distribute high forces. It allows for better leveraging of the matrix composition of the composite material, which gets its strength and robustness by distributing loads through the resin to neighboring fibers, which are also stabilized by the resin and cross-directional plies. The steel reinforcement cup used to mount the center seat belt retractor in the steel version of the assembly was carried over and subsequently bonded into the composite rear package shelf panel assembly solution. This enabled local, higher deformation in the steel material and mitigated the need for the composite parts to manage the higher deformation and associated local strains. FIGURE 4 shows the loading conditions for the seat belt retractor and child tether anchorage locations.

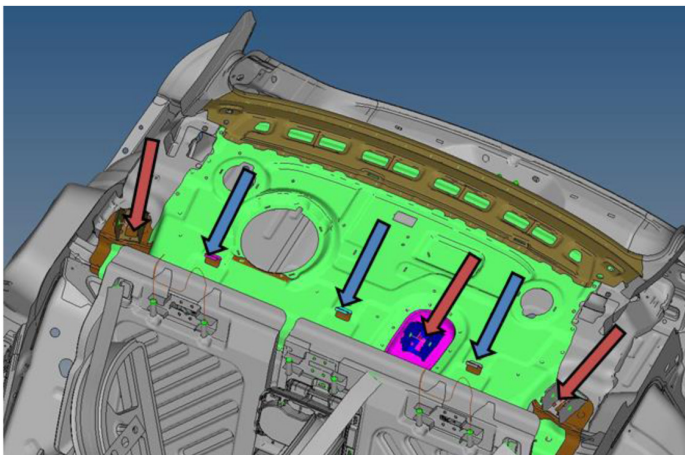


Figure 4. Loading conditions used to represent FMVSS 207/210. Red arrows at retractor attach points, blue arrows at child tether attach points.

Both component-level and BIW-level loading conditions were evaluated in parallel during the engineering design. The load transfer into the steel structure was an important part of ensuring the bonding and interfacing locations were stable enough to distribute the loads effectively. Additional component level analysis was performed on the rear shelf panel and child tethers to ensure that the stand alone components would also be able to manage the localized forces (FIGURE 5).



Figure 5. Component level set-up for CAE

Ply Orientation / Geometry Development

The composite analysis was based on classic laminate theory, where both on-axis and off-axis material properties are used to develop the laminate material properties of a multi-ply component. The fiber angle variations caused by the fabrication of the part is a critical learning process as it affects both the structure's load carrying capability and the parameters optimized for the manufacturing process. Fiber angles were evaluated using a specialized software technology to review the draping of each ply and the resulting fiber angle variation (FIGURE 6). Often the orientation of the primary material axis is affected by the geometry of the part itself; geometry such as beads, formations, or curvature can change the ply direction in the completed part. The ability to properly capture these slight variations in material direction was very important in correctly evaluating the load carrying capacity of each ply stack.

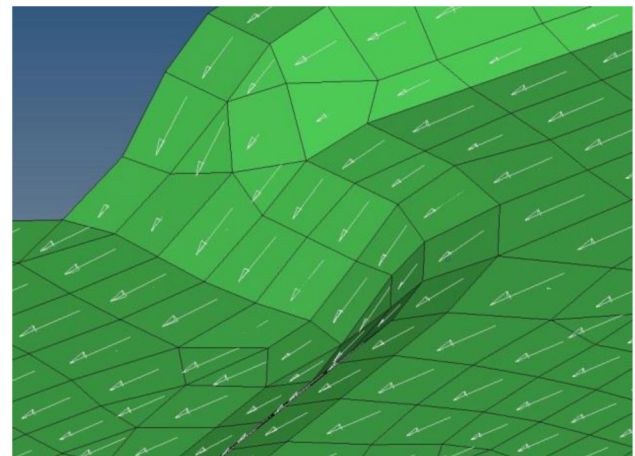


Figure 6. Visualization of ply angle variations for FEA development