

A CASE FOR REPLACING STEEL WITH GLASS-MAT THERMOPLASTIC COMPOSITES IN SPARE-WHEEL WELL APPLICATIONS

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Abstract

This paper will discuss the use of glass-mat-thermoplastic (GMT) composite to replace steel in spare-wheel wells (SWW) by European automakers and tier suppliers. Although this application has been successfully translated across multiple OEMs and platforms in this geography for 10 years, it is still little known and less understood in the Americas and Asia/Pacific despite its numerous advantages. In an attempt to help automakers and tier suppliers in other parts of the world understand the benefits of this technology, the paper will discuss OEM performance criteria, design requirements, tooling and manufacturing of the part, as well as requirements for finished assembly into the vehicle vs. traditional steel systems.

Background and Requirements

The spare-wheel well is a common component on most passenger vehicles with a trunk or rear hatch (back door). This round or square pan is mounted into the trunk opening, where it holds an extra wheel, tire iron, and jack. A loadfloor made from particleboard, natural-fiber composite sheet, a honeycomb-polypropylene-sheet sandwich construction, or straight GMT usually covers it. The loadfloor may also be carpeted, to provide an integral surface inside the floor of the trunk.

This component must pass a number of tests. Spare-wheel wells mounted into the vehicle must meet impact requirements. The wheel well must stay attached to the vehicle frame after a crash. Impact performance is influenced not only by the structure of the well itself, but also by the amount of energy that is absorbed by the steel or aluminum wheel hub. This test is considered to be the most important requirement for any SWW design to pass by all European OEMs.

SWW components are also subjected to tests that evaluate resistance to noise/vibration/harshness (NVH), hot and cold climates, flammability, common automotive chemicals, and long-term heat aging. Additional tests include drivability over rough roads, a test simulating driving up over a curb and scraping the bottom of the vehicle, and various standard mechanical tests conducted on complete parts for impact, tensile strength, elongation, etc.

Table I provides a short summary of test requirements for the spare wheel well used by European OEMs for all SWW systems, regardless of material used. Since the types of spare wheels carried by different classes of vehicles vary so much, as do the test methods used by each OEM, the tests are described generically.

Traditional Steel Systems

Steel is the incumbent material for SWW applications worldwide.

Steel Assembly Sequence

A steel SWW is welded to the body-in-white (BIW) prior to e-coat and it travels with the frame throughout the entire assembly process.

The typical assembly sequence is as follows:

1. OEM stamps part (2-3 stamping tools typically required to achieve shape; cycle time is very fast, producing a part roughly every 10 sec).
2. Holes are punched into the part for e coat drainage.
3. Part is shipped to vehicle assembly plant.
4. Part is robotically welded to the BIW to achieve a watertight seal.
5. Vehicle frame is e-coated with SWW in place.
6. Vehicle travels through paint and assembly process.
7. Holes in SWW (to allow e-coat chemicals to drip out) are plugged during assembly.
8. Trunk carpet and loadfloors are installed toward end of assembly line.

Benefits and Issues with Steel

Both material and process are familiar. Performance of the steel system is more than adequate. But there are opportunities to improve weight and cost by considering other materials for the system.

Although steel prices have generally been lower than composites on a piece price basis, in North America, recent raw-material price increases have raised piece- and systems costs dramatically for both this metal and its tooling. Typically, the deep draw design of spare-wheel wells requires at least 2-3 stamping tools to create. At an average cost of \$2-4-million USD per set of steel stamping tools, economics favor high-volume vehicles with long production runs. Vehicles with large wheels may require more tools, leading to even higher tooling costs. Furthermore, these very large wheel wells can lead to drapability issues for sheets of steel, requiring the use of thicker steel and modified tooling. Additionally, as has been learned with the design of other vehicle components, it is difficult to stamp a deep radius in steel cost effectively, without using a large number of tools. Hence, steel parts are generally not radiused as steeply as those in plastics and often require more packaging space.

Of course, the usual issues with steel also apply here, including the material's high specific gravity, which leads to heavier parts (albeit thinner ones, due to this metal's high stiffness and strength), and the potential for corrosion, requiring numerous secondary-finishing operations. One additional issue is that holes must be punched into the steel wheel well so e-coat chemicals can drain out after dipping the body in white. These holes must later be closed out with plastic plugs during vehicle assembly, adding an additional on-line step. A summary of the benefits and issues related to steel SWWs is provided in Table II.

Switching from Steel to Composites

Although steel is the long-time incumbent in SWWs, for the past decade, European OEMs has been using increasing amounts of composite materials for this application to reduce weight and costs. By virtue of their lower specific gravity, polymer composites have generally had the advantage of lighter weight parts vs. metals. Now, steel's price increases can often provide composites with an advantage in terms of systems costs too, especially for shorter production-run vehicles where the high cost of steel tooling takes longer to amortize.

Typical Composite Options

The most common polymer composites in use in conventional passenger vehicles include:

- **Glass-mat thermoplastic (GMT)** – a sheet-form composite comprised of a thermoplastic matrix (typically polypropylene, but theoretically may be virtually any thermoplastic) with various types of glass mat (continuous strand, randomly oriented for high stiffness & impact strength; short chopped fiber for better surface finish and filling of deep design details; unidirectional for selective addition of higher strength in a given axis; or a woven glass cloth for very-high strength in 2 axes) cut to size and subsequently compression molded or thermostamped. Various types of GMT composite can be stacked in the mold to tune a part without changing the tool. GMT offers better preservation of glass fiber length (30 - 50 mm or greater) for higher impact and stiffness vs. LFT and SMC.
- **Long-fiber thermoplastic (LFT)** – a direct, in-line compounding process that combines a thermoplastic matrix (typically polypropylene, but theoretically may be virtually any thermoplastic), with additives, then uses the melt to wet-out and impregnate long glass fiber rovings, which are subsequently cut to size to form a reinforced sheet that can subsequently be molded by compression or compression-transfer molding. Fibers, after molding, typically have an average length of 5 - 20 mm.
- **Sheet-molding compound (SMC)** – a precompounded sheet-form prepreg of thermosetting polyester resin and chopped glass fiber (25 or 50 mm) that is processed by injection or compression molding; must be kept refrigerated prior to processing and has shelf-life constraints.

GMT and LFT are thermoplastic materials that can be melt-reprocessed, whereas SMC is a thermoset. Use of thermoplastic components facilitates recycling both in-plant scrap and post-consumer components – an important feature in Europe where all vehicle components must be able to be recycled. GMT and LFT have polypropylene resin matrices, offering lower specific gravity than polyester-based SMC for lighter weight parts at comparable wall thicknesses. Additionally, SMC is known to be brittle, so is not well suited for applications subject to impact. SMC is also characterized by relatively long cycle times, on average 2-3 min for a part like a spare-wheel well.

As sold, GMT is a finished product ready to mold. Its use does not require a molder to make an additional investment in an extruder, or take responsibility for raw material inputs. Since LFT is both produced and molded by the processor, the processor bears all responsibility for the product recipe, quality control of glass, and the molding itself. While LFT is more tailorable on the fly, it also can be prone to greater quality variations.

Another important difference between these technologies is that GMT materials are able to achieve higher stiffness, impact, and strength values than LFT owing to greater preservation of glass fiber length after molding. It is well known in plastic design that maintaining glass fiber length is critical to achieving high mechanical properties in parts. For the grades used in SWW applications, GMT tends to maintain fiber lengths of 30 - 50 mm vs. 5 - 20 mm for LFT after molding. In SWW applications, that enables GMT parts to withstand rear collisions and maintain part integrity (holding the wheel in place inside the vehicle). Finally, GMT's as-molded cost tends to be lower than that of LFT.

The Move to Composites

The earliest composite SWW developments tended to be molded from either sheet-molding compound (SMC) or glass-mat thermoplastic (GMT) composite, depending on the capacity, familiarity, and capability of a given tier supplier in composite fabrication. Regardless of which material system was used, the switch from steel to polymer composites reduced weight and systems costs, lowered the number of tools required (which especially benefited lower volume vehicles), and offered the opportunity to mold in ergonomic features at no additional costs.

Although there are still a few SMC wheel wells in production, the general experience has been that SMC has issues of brittle failure in impact events, and tends to be heavier than other composite options. Additionally, SMC wheel wells were not always able to hold the wheel in the vehicle during the crash test.

While several tier suppliers have explored LFT as a possible technology for SWW applications, there are currently no exclusively LFT parts in production because this technology failed to pass the impact tests. Some processors are now exploring hybrid composites that combine LFT with other technologies, such as GMT.

Over time, GMT has emerged as the dominant composite technology for this application. This is because it offered the same types of benefits as SMC – lower weight, lower systems costs, lower tooling costs, and design flexibility – while also providing faster cycle times, lighter weight parts, and avoiding the brittle-failure problems.

GMT materials perform well in crash situations and have been used in many different vehicle applications that require energy management during a crash, such as rear hatchback doors, door hardware modules, bumper beams, and instrument panel carriers [3,5,6]. Trial and error has shown that the best combination of mat technology for a GMT spare-wheel well application combines 2 products: a chopped fiber sheet that fills complex design features like ribs and bosses well, plus a woven-glass mat that provides high toughness and strength in 2 axes¹. (The use ratio for each material is dependent on a given design.) This combination creates knitline integrity and therefore overall part integrity, and the best cost/performance ratio. Use of the woven fabric mat also has proven to be key for successfully passing crash tests.

¹ This composite, comprised of continuous-strand, woven glass cloth and PP matrix, is called GMTex[®] by the manufacturer, Quadrant Plastic Composites. The woven glass cloth is called TwinTex[®] by its manufacturer, Vetrotex, a division of St. Gobain.

Overall Composite Benefits

Polymer composites provide:

- Reduced weight and systems costs.
- Smaller package space required for stowing the tire.
- Better sound damping vs. steel for a quieter vehicle.
- Opportunity to add additional ergonomic features, stowage, and other space- and parts-consolidation at no additional processing costs.
- Lower tooling costs – especially attractive for lower build vehicles.
- Reduced assembly-line space and cost via eliminating the station used to close out e-coat drip holes in the steel wheel well.
- Improved worker ergonomics and efficiency attained by maintaining an open trunk through the manufacturing line, since workers can stand in the trunk opening to install lighting and assemble wiring and harnesses with greater ease.
- Better NVH due to plastics' inherently better sound damping properties.
- No corrosion issues.
- The same robot is used to apply adhesive for both the windshield and the spare-wheel well, reducing assembly costs.

A summary of key benefits and challenges of composite SWWs is provided in Table II. With all these advantages, it is natural to ask why composites have not been used in SWW applications outside of Europe. Switching materials does necessitate making changes. For instance, on the assembly line, the SWW is installed after e-coat – ideally, late in the assembly process. Additionally, changing the way tooling costs are amortized – not just piece price based on total vehicle build, but equations that also factor in a total reduction in tooling costs for a given program – also makes composite wheel wells more attractive. Finally, at least in the case of North American OEMs, switching to composite SWW components involves moving work currently done by unionized autoworkers out to tier suppliers.

Implications to North American assembly operations of moving to a GMT composite SWW are as follow:

- The fuel tank can now be put into position from behind or above (through the trunk lid opening). This allows the tank assembly to take place when the vehicle is being worked on at the “ground level.”
- The same robot that applies the windshield adhesive/sealant carries out application of the adhesive/sealant that connects the composite wheel well to the body. This provides more utilization of the same resource. Although, the SWW work increases the amount of work (and therefore time) for the robot, it eliminates operations elsewhere in the vehicle that take longer. Hence, no increase in overall assembly time or investment has been seen on European vehicles.
- The adhesive/sealant used to glue the SWW to the BIW is the same 2-part urethane used to attach the windshield.
- In Europe, the trunk is considered a separate component from the chassis. Dedicated engineers examine it for opportunities to reduce cost and weight, increase functionality, and consolidate components. In North America, the trunk is not “owned” by one particular design group but rather is considered to be part of the frame, making it harder to find an internal champion for the conversion.

Table III provides a list of current and pending applications of GMT spare-wheel wells. These vehicles share specific attributes that made them good candidates for a conversion to composites, including:

- New model with flexibility in assembly-line design;
- Desire for molded in features like storage compartments, battery trays, etc.;
- Accounting advantage given for cost-effective tooling (\$500,000 USD or less);
- Build volume of 100,000 - 300,000 vehicle²,
- Design requirement to protect spare wheel from heat and environment by storing them internally, without also impeding on passenger space.

Composite Design Options

Designing spare-wheel wells in composites instead of steel can provide a number of advantages. First, tooling is simplified and less costly. Although it takes 2-3 (or more) steel stamping tools to make the deep draw shape of the wheel well, the shape can easily be created via composites in a single tool in a single pass. Costs for a set of steel stamping tools can run \$2-3-million USD, whereas a typical compression-molding tool for GMT is only \$250,000-500,000 USD. Parts are generally molded in 45 sec vs. 20 sec for steel. The time difference is made up in assembly by shortening the e-coat drip-off cycle, eliminating welding of the SWW to the BIW, eliminating plugging the holes in the steel SWW, and easier assembly of other trunk-area components. Molding SWW parts in GMT typically requires a press sized to approximately 1,500 to 2,000 t.

As would be expected, weight reduction is achieved. Typically, GMT parts are 30% lighter than comparable designs in steel. Wall thicknesses are 2.5 - 3.0 mm. On a SWW for a full-size passenger vehicle with a build volume of 150,000 units, switching from steel to GMT reduced a comparable part from 8.7 to 4.2 kg – in this case a 52% reduction in weight. The steel part was also 20% more expensive than the GMT part when all tooling and processing costs were added together. In a study published several years ago [4,5], German company, Rütgers performed a cost analysis by comparing different material concepts for a spare wheel well (Table IV). Factors such as weight, material costs, process investment, and assembly costs were considered in this study. The least expensive solution for the SWW part was calculated to be a combination of GMT and the woven glass-cloth mat, which provides very high 2D mechanical properties. This material has become the standard for composite spare-wheel wells in Europe.

Because it is easier to pull a tighter radius (sharper corner) in a composite part than a steel part, use of composites also can reduce packaging space an average of 13%, freeing up valuable trunk space for additional features or more storage. This higher design freedom provides the ability to incorporate functionality such as rear battery trays, storage for jacks, emergency roadside kits, lockdown features, and more in the extra space freed up with the composite SWW. Although it is possible to add such features with a steel SWW, this requires additional separate tooling and assembly fixtures, which increases tooling costs. There is no additional cost with the composite SWWs, and the design can be accomplished in less space.

² Initially, European OEMs assumed that composite SWW applications would only make sense on platforms with low build volumes, on the order of 100,000 - 150,000 units. However, continuing experience shows that any platform where it is desirable to reduce ultimate tooling costs can be a good candidate. There are now composite SWWs on platforms in the 300,000 build-volume range and the application shows promise of proliferating further.

The interior of a composite SWW may be left as molded plastic or in-mold decorated with carpeting. With the steel system, carpeting cannot be molded in at the same time the SWW is created to finish off the trunk area in a single step as it can be with composites and insert-molding techniques. Furthermore, composite parts can be designed to include molded-in flanges that help the consumer lift the spare tire out of the trunk easier and more ergonomically – again, without incurring additional tooling costs and assembly steps. In fact, the SWW can be reconceived as a multifunctional box, as shown in Figures 1-7. Covering the top of the SWW can be accomplished with GMT decorated with carpet, left black with a grained surface for aesthetics, or covered with alternative load-floor materials, like natural-fiber or glass-mat composites.

Additional benefits gained by switching to composites include improvements in vehicle acoustics. Because plastics are “softer” than metals, they have better sound damping properties, so noise is reduced. Further, they do not corrode, nor are they at risk of causing a galvanic reaction with the steel frame to which they are attached.

One area of potential challenge for the use of composite wheel wells placed near the exhaust system – that of heat – can be addressed by using an inexpensive, insert-molded aluminum heat shield. Depending on size of the SWW involved, typical costs for the heat shield run between \$0.50-1.00 / vehicle in the volume builds that have been discussed.

Composite Assembly Sequence

From a vehicle-assembly standpoint, there are some changes vs. steel. A vehicle with a composite SWW requires a build sequence that enables the body-in-white to move through e-coat without the wheel well in place, since the temperature of the solution is too high for the polymers typically used. The SWW is installed after e-coat – generally after trunk wiring and lighting is installed, which can provide some assembly advantages for closing out the trunk.

In Europe the typical assembly sequence using a GMT composite SWW looks like this:

1. Tier 1 molds GMT part and flame treats after molding to prepare for primer.
2. Primer is applied.
3. Part is shipped to vehicle assembly plant.
4. Primer is refreshed (optional and varies by the OEM).
5. Adhesive bonding system is applied robotically to BIW after e-coat. The same adhesive/sealant is used as that which attaches the windshield to the body. Additionally, the same robot that dispenses the sealant on the windshield and attaches it to the BIW attaches the SWW to the body.
6. Part is assembled into vehicle.
7. A 10-kg weight is placed on the part to hold it in place while the bond cures (approximately 30 min) during the rest of the assembly process.
8. Weight is removed from vehicle when the tire is put into trunk.

Attachment to Vehicle Frame

Instead of being riveted to the BIW, composite wheel wells are elastomerically bonded, generally with the same urethane adhesive system used to bond glass windshields to the frame. To ensure the part stays flat and cures properly against the steel frame, a 10-kg weight is set inside the well for approximately 30 min during assembly. It is removed when the spare tire is placed inside the well.

Two different primer systems are currently being used in Europe, as follows.

System 1: Short-Term Primer

1. Primer is readily available from all major adhesive/sealant suppliers (Henkel, Dow, Sika, etc.).
2. Primer is compatible with urethane adhesive/sealant used for windshield assembly.
3. Primer is available in the aftermarket for dealers and repair shops.
4. Depending on system used, primer reactivation by OEM may be required prior to application of the adhesive/sealant.

System 2: Long-Term Primer

1. Primer is readily available from all major adhesive/sealant suppliers (Henkel, Dow, Sika, etc.).
2. Primer is compatible with urethane adhesive/sealant used for windshield assembly.
3. Primer is available in the aftermarket for dealers and repair shops.
4. No primer reactivation by OEM is required prior to application of the adhesive/sealant if part is assembled within 3 months of having the primer applied.

Decade of Success in Europe

Composite spare wheel wells (SWW) have been used successfully in Europe for more than a decade on at least 10 platforms produced by 5 different OEMs, as noted in Table III. Several additional vehicles are currently in the pre-production phase and should be commercial before year's end.

As noted previously, composite SWWs were initially targeted at low-volume vehicles of 150,000 units or less. However, experience has confirmed that this change can be beneficial to any program where it is desirable to reduce overall tooling costs, regardless of build volume and amortization schedule. Hence, newer programs that are making use of composite SWWs include platforms with 300,000 or greater production capacity per year.

The composite technology of choice has been glass-mat thermoplastics manufactured by Quadrant Plastic Composites, AG. These materials use a PP matrix and a 40% by weight chopped fiber mat, with selective reinforcement of a high-strength woven glass mat to improve crash performance and stiffen the floor of the part so it does not move or vibrate. Use of the woven mat has proven to be critical for passing tough high-speed impact tests.

Summary and Next Steps

Composite SWWs will be most attractive to North American OEMs on vehicles where it is desirable to reduce overall tooling costs (not just component costs) on the platform upfront. It will also be attractive where opportunities to add functionality and reduce components and weight are seen as a value add that is attractive to customers, such as the opportunity to create a “multifunctional box” as shown in Figures 1-7.

To date, no composite SWW application has been introduced on an existing vehicle during regular production. The real benefit of making the switch involves all the design opportunities that plastics offer over steel – something that can best be realized on a total redesign during a new or updated vehicle launch.

References

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Data

Table I: General testing requirements for SWW applications in Europe regardless of material system used

Type of Test		
Impact Tests	Standard Mechanical Tests for Tensile Strength, Elongation, etc.	Noise, Vibration, Harshness (NVH)
Resistance to Common Automotive Chemicals	Resistance to Flammability	Long-Term Heat Aging
Hot & Cold Climate Test	Curb Damage Simulation	Drivability Over Rough Roads

Table II: Comparison of select benefits & issues with various metal and GMT composite spare-wheel well systems

Type of Spare-Wheel Pan	Benefits of System	Issues with System
<i>Steel</i>	Well-characterized material model	Rising steel prices in North America
	High stiffness & strength; broad thermal & chemical performance	Potential for high tooling cost based on number of tools required to create shape
	Well-known crash performance	Possible drapability issues for large wheel designs
	Readily available material & tooling	More packaging space required
	Mounted to BIW; travels with vehicle during entire build sequence	Heavy; potential for corrosion
<i>GMT Composites</i>	Acceptable strength with lower weight (ability to tailor stiffness based on lay-up of mat)	Requires change in assembly sequence
	Good crash performance without brittle failure (provides ductile failure even at low temperatures)	In North America, causes production of SWW to move out of unionized OEM assembly plants & to Tier Suppliers
	Lower tooling costs; attractive any platform where it is desirable to reduce ultimate tooling costs, regardless of amortization schedule	Requires flame treating & primer coat prior to addition of adhesive used to bond to metal frame
	Takes up less packaging space	If placed close to exhaust system, may require addition of aluminum heat shield
	Offers ability to mold in hand grips, pockets to stow tools, & other functionality at no additional cost	In North America, the trunk is not "owned" by one particular design group, so harder to find internal champion for conversion.

Table III: Current & pending composite spare wheel wells on European vehicles

OEM	Commercial on Platform	Type of Composite
<i>DCX</i>	Mercedes A Class	GMT [§]
	Mercedes C Class	GMT + GMTex ^{§§}
	Mercedes S Class	GMT + GMTex
	Mercedes E Class	GMT + GMTex
	Mercedes C Class Coupe	GMT + GMTex
<i>Audi</i>	A2	GMT
	A8	Steel overmolded with GMT
<i>Volkswagen</i>	D1 (Phaeton)	GMT + GMTex
<i>BMW</i>	X5 ^{§§§}	GMT
	Series 1	LFT + GMTex

[§] GMT = PP matrix with 30-50 mm chopped glass fiber mat (after molding).

^{§§} GMTex = PP matrix with glass mat and continuous-strand woven fabric for high strength in 2 axes.

^{§§§} Related application with similar impact requirements. Part is a multifunctional box with battery tray, but no spare wheel well.

Table IV: Cost analysis of various material options for a spare wheel well design [4,5]

Material	Thickness (mm)	Weight (kg)	Material Cost / Part	Investment	Total Cost Assembled	Functional Integration
Steel	0.8	8.7	0.8	1.6	1.2	Low
Aluminum	1.5	5.9	1.0	2.0	1.4	Low
Magnesium	2.0	5.2	1.8	2.4	2.1	Low
GMT+ GMTex [§]	2.5 -3.5	4.5	1.0	1.0	1.0	High

[§] GMTex = a glass mat composite comprised of a PP matrix plus woven glass cloth mat, produced by Quadrant Plastic Composites.

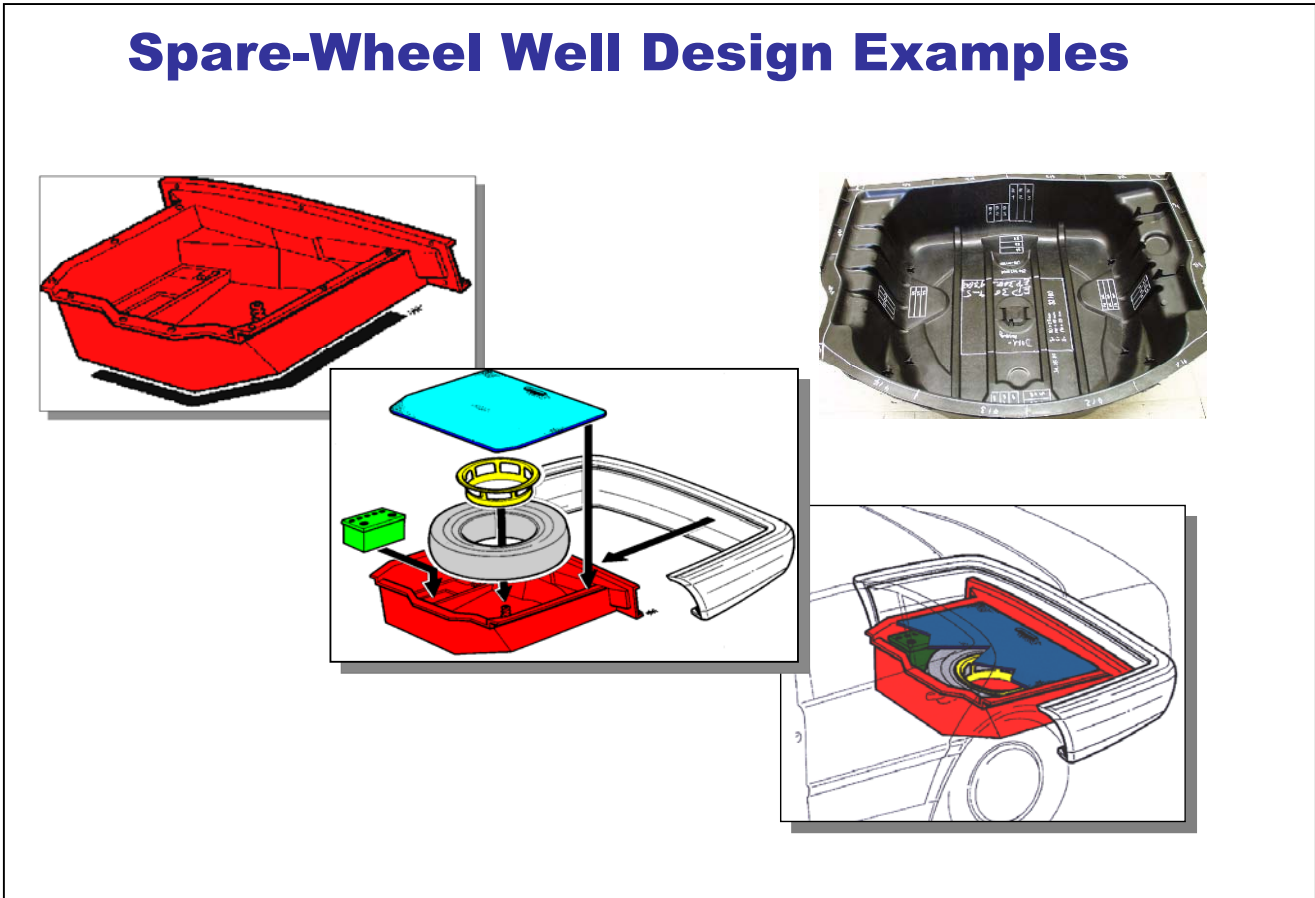
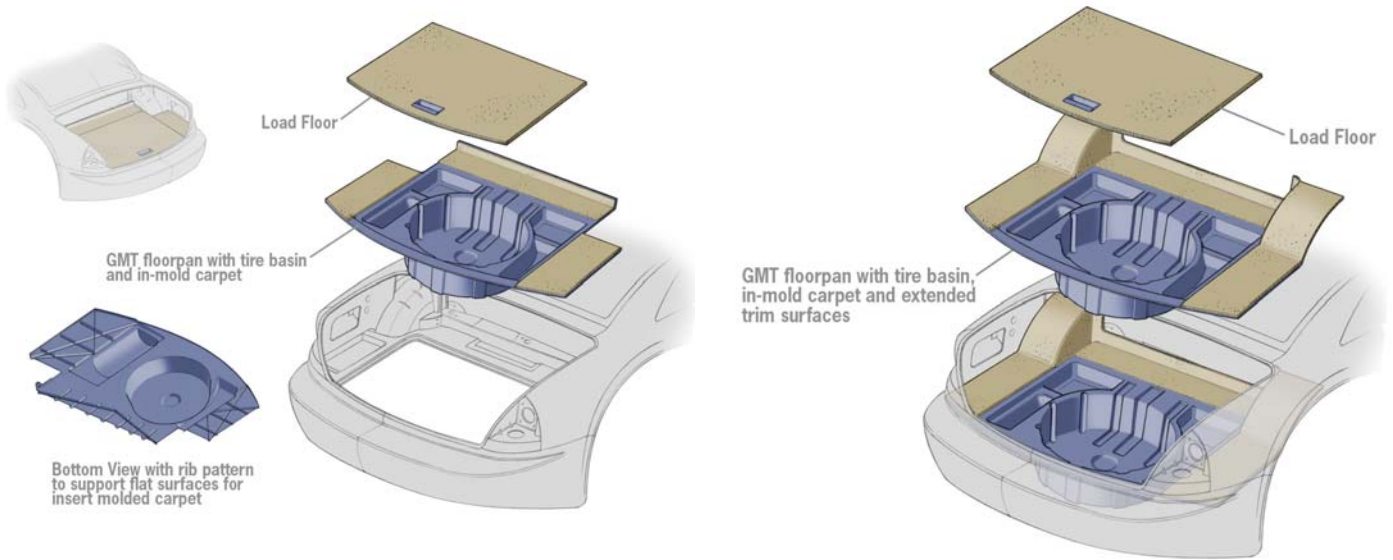
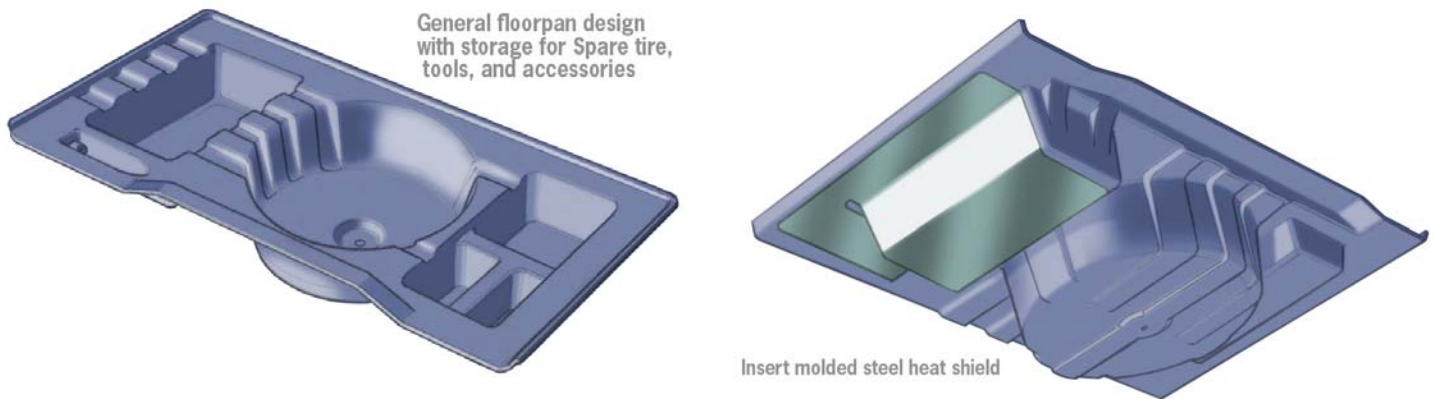


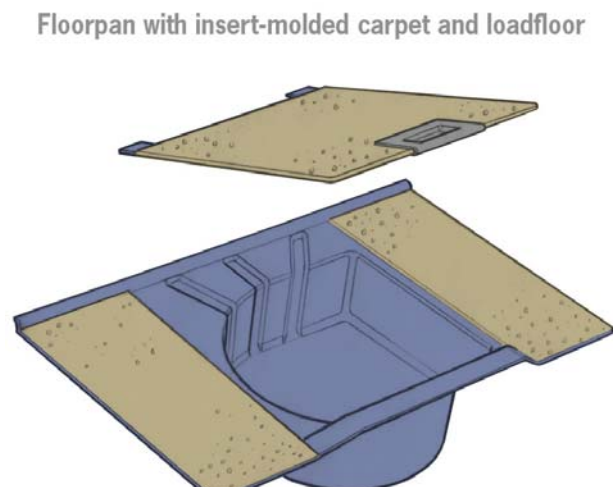
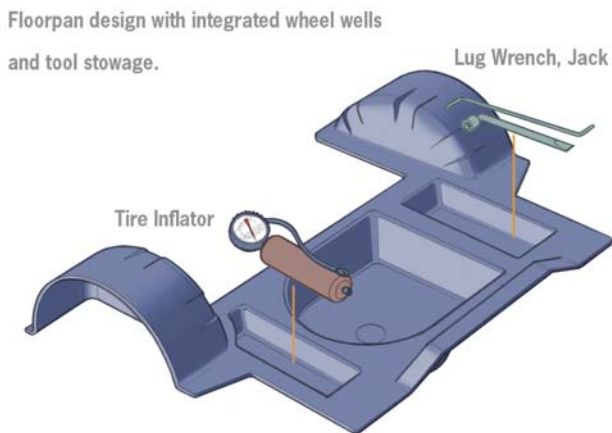
Figure 1: Spare-wheel well designs showing opportunities for parts consolidation (image courtesy of Aksys)



Figures 2-3: (left to right) Design concepts for composite SWW with extended trim surfaces, loadfloor, and stowage bins for jacks, tire inflators, etc.



Figures 4-5: SWW concept incorporating various features for stowage shown from top (left) and bottom (right) view. Image on right shows use of integral aluminum heat shield.



Figures 6-7: SWW designs incorporating wheel wells plus stowage for jacks, tools, and tire inflator (left) and with insert-molded carpet and loadfloor (right).