ARCHITECTING NEXT GENERATION LIGHTWEIGHT VEHICLES

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There are a number of approaches manufacturers can take to meet government-mandated fuel economy and carbon dioxide targets, but the most promising is substituting lighter materials in place of steel. With so many material options available, for example, Advanced High Strength Steel, aluminum and carbon fiber, as well as new design and manufacturing techniques, how do original equipment manufacturers and their supply chain partners determine the best route forward?

Tata Technologies has developed an innovative methodology to drive the lightweighting process by evaluating a series of material configurations against a wide range of attributes and benchmarks. This approach enables manufacturers to identify the optimal mix of materials, design options, manufacturing processes, and transformation costs that support them, to design, engineer and produce a world class product delivering the performance the market and regulators demand - at a price the consumer is willing to pay.

This paper discusses federal fuel economy regulations, the environmental and consumer benefits of lightweighting, new and improved materials on the market, along with insights into how manufacturers can optimize their vehicle designs to deliver the right mix of performance and economy for their particular market segment - using Tata Technologies’ innovative lightweighting methodology.
ABOUT THE AUTHORS

Dr. Steve Simplay is part of the strategy team at Tata Technologies, focused on the automotive market. He has more than 12 years of automotive experience with a number of global OEMs such as Toyota, BMW and Jaguar Land Rover and Tier 1 Suppliers, where he held a variety of Product and Project Engineering roles.

Steve has worked on a number of multi-million dollar complete vehicle programs from initial design to full production which have included lightweight materials.

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Steve Haywood is the Executive Vice President and Technical Director of Tata Technologies’ Vehicle Programs and Development Group. He is responsible for delivering complete vehicle programs from concept design to full series production, including supply chain optimization and value management.

Steve has a proven track record of managing multibillion-dollar programs on a global basis, including the creation of the all-new Range Rover vehicle platform, constructed from high-tech, lightweight materials. During his time at Jaguar Land Rover (JLR) he was responsible for the delivery of the T5 platform and the first complete vehicle off that platform, the Discovery - from concept through volume production and commercial launch, into sales in market. Over the course of his 40-year career, he has also worked with companies such as BMW, Ford Motor Company, Lotus, Proton, Ricardo, and Tata Motors, as well as international consultancies and major global OEMs and Tier 1 suppliers.
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FUEL ECONOMY IMPROVEMENTS – THE PRESSURE’S ON

The automotive industry has advanced significantly over the past decade with materials, geometries and manufacturing processes evolving to meet increasing mileage and emissions requirements. However, there are new challenges on the horizon creating even further pressure on manufacturers. The National Program for greenhouse gas emissions (GHG) and fuel economy standards, developed jointly by the Environmental Protection Agency (EPA) and the National Highway Traffic Safety Administration, mandates the average fuel economy of U.S. light duty cars and trucks to increase from 34.1 miles per gallon in 2016, to 54.5 mpg in 2025.¹

This program is projected to:

- Cut six billion metric tons of GHG over the lifetimes of the vehicles sold in model years 2012-2025
- Save consumers more than $1.7 trillion in fuel costs
- Reduce America’s dependence on oil by more than two million barrels per day in 2025

These program requirements must be met in spite of the fact that consumers have demonstrated they are neither willing to sacrifice other vehicle attributes (in fact, they are demanding more) nor pay a significantly greater price for higher mileage and lower emissions.

In Europe, the average emissions of each OEMs fleet needs to drop from about 130 g of carbon dioxide (CO₂) per km in 2015 to 95 g in 2020, and 75 g or possibly lower in 2025.² The penalties for exceeding these targets start at 95 € per gram from the fourth gram onwards per car sold and may increase to 190 € per gram in the coming decades.

There are a number of approaches manufacturers can use to reach fuel economy and CO₂ targets, such as reducing aerodynamic drag, driveline and transmission losses, tire rolling resistance, electrical parasitics and vehicle weight. Given these options, reducing vehicle weight is the most cost-efficient; it has been estimated that a 25% improvement in mass delivers a 10% reduction in fuel consumption and CO₂ emissions. The second best option is reducing aerodynamic drag, which provides only an ~5.5 percent reduction for an ~25 percent reduction in drag. In addition, reducing vehicle weight offers secondary mass reduction benefits, meaning OEMs can downsize the powertrain, brakes, tires, suspension, etc.

Before embarking on a vehicle lightweighting program, manufacturers need to evaluate material options and overcome a variety of technical challenges associated with the transition to lighter materials. However, despite the number of approaches available this is still a challenge for many manufacturers.

VEHICLE LIGHTWEIGHTING – THE BENEFITS

Consumers benefit from lighter weight vehicles too as lower energy demands require less fuel and Lighter weight vehicles are clearly better for the environment. According to the U.S. Department of Energy, the United States consumed nearly 20 million barrels of petroleum per day in 2010. The transportation sector accounted for ~28 percent of total U.S. energy use and two-thirds of the nation’s petroleum consumption, the second-largest source after electricity generation. It’s estimated that 75 percent of fuel consumption directly relates to vehicle weight. With everything else remaining the same and considering weight compounding, an average 10 percent increase in fuel economy can be realized for every 25 percent reduction in vehicle weight.

2010
THE U.S. CONSUMED
20 MILLION BARRELS OF PETROLEUM DAILY

THE U.S TRANSPORTATION SECTOR ACCOUNTS FOR ROUGHLY:

28% OF TOTAL ENERGY USE
2/3 OF PETROLEUM CONSUMPTION

75% OF FUEL CONSUMPTION RELATES TO VEHICLE WEIGHT

25% REDUCTION IN VEHICLE WEIGHT
10% INCREASE IN FUEL ECONOMY

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the overall cost of running the vehicle is cheaper. While the EPA has predicted that meeting new fuel economy standards will add an average of $1,800 to the price of a new light-duty vehicle in 2025, it also estimates that these vehicles will save consumers $5,700 to $7,400 in fuel over their lifetimes.6 A lighter vehicle boasts improved road handling and shorter braking distance over its heavier predecessors and should motivate manufacturers to fully exploit this area. Structural weight saving frees up room to add luxury, technology, and safety accessories that today’s consumer’s demand and develops new competition in the market.

THE MOVE TO NEW AND IMPROVED MATERIALS

Over the last two decades vehicles have expanded in volume and weight, in part due to customer demand but also to meet federal safety standards. However, adding additional weight to a vehicle has a detrimental effect on the fuel economy where these vehicles are slower than, and not as nimble as, their lighter counterparts.

Some OEMs have been successful in shaving 700 to 800 pounds off vehicles, such as the 2015 Ford F-150 pickup and the 2016 Cadillac CT6. To reduce weight, engineers at Ford completely redesigned the F-150 with an "aluminum-intensive" body. The CT6 uses a mix of aluminum, steel and other materials, and weighs less than the CTS, Cadillac’s own midsize luxury sedan. Range Rover reduced the weight of its 2013 model by 420 kg, of which 180 kg can be attributed to changing from a steel to an aluminum monocoque body in white (BIW).

The amount of aluminum – which is more expensive but a third of the weight of conventional steel – in vehicles has shot up, tripling in North America and Europe over the past two to three decades.7 Steel has long dominated the industry as the material of choice, and manufacturers are fighting to retain their share of the market by developing higher strength grades that are thinner than conventional steel but up to six times as durable. Cutting one pound of vehicle weight with Advanced High Strength Steel (AHSS) costs around 50 cents while the cost of aluminum is fourfold of AHSS.

The vast majority of vehicles produced in the world today are built with a main structure consisting of a steel BIW due to its wide range of yield strength, high modulus, low cost, and ease of manufacture. The BIW typically constitutes approximately 20 percent of the vehicle’s weight and other traditionally ferrous components such as the closures (doors, hood and hatch), engine, transmission, driveline, and suspension, bringing the total amount of ferrous metals to above 60 percent of a traditional vehicle. However, the amount of steel and cast iron used in the typical vehicle has declined in recent years due to relatively simple lightweighting measures such as replacing iron castings used in the engine, transmission, wheels, and some suspension components with aluminum, and increasing the use of plastic components, especially under the hood.

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The past decade has witnessed increased use of AHSS as well as other improved varieties of steel. AHSS can cost up to 50 percent more than traditional mild steel but its higher yield strength and other improved mechanical properties make it possible to use lower thicknesses to achieve the same performance characteristics. The result is that the weight of the BIW can be reduced by 20 to 30 percent at an incremental cost per vehicle of well under $1,000. Staying in the steel family minimizes the need to overhaul existing designs and manufacturing methods while giving engineers the freedom to choose from among the wide range of available grades. Volkswagen was able to reduce the weight of the 2013 Golf MK7 by approximately 100 kg (as compared to the previous model) with a 100 percent BIW produced from high strength steel and an AHSS mix, allowing a reduction in the sheet metal thickness. It must be noted that other areas of the vehicle also contributed to the weight reduction.

Aluminum offers opportunities for substantial reductions in vehicle weight beyond its already widespread applications in engine and transmission castings. The greatest potential benefit lies in substituting aluminum for steel in the BIW. Aluminum sheet delivers performance equivalent to steel at an increase in thickness of 40 percent, yielding a weight reduction of approximately 50 percent. Design and manufacturing principles similar to those used for steel bodies can be applied to aluminum vehicle bodies, but even higher weight reductions can be achieved by optimizing the design to take advantage of the different properties of aluminum. For example, the use of extruded profiles with complex cross sections and intricately shaped castings can improve load carrying and stiffening properties and also serve as joining elements. Aluminum body panels can be used in today’s popular stamped unibody construction, as well as in tubular space frame chassis that employ tubes, castings and stampings welded together.

Carbon fiber reinforced polymer (CFRP) offers the potential for even greater weight reductions and also offers considerable advantages in design freedom. But the cost of carbon fiber today is approximately five times higher than steel, which currently restricts its use to the supercar market, while there are a limited number of applications in the premium market. As the automobile industry moves towards the electrification of vehicles, CFRP will become more important and more utilized in full electric vehicles due to the lightweight properties it can offer.

The cost of carbon fiber is projected to fall due to development of less expensive precursor materials, as well as reductions in processing costs. This will most likely lead to increased use of this versatile material in the coming decades.

Increased costs, material property variances, design and manufacturing implications - they are all part of the complexity OEMs are faced with when embarking on a lightweighting program, but let’s not forget another critical issue – safety. The basic laws of physics state that if two otherwise identical vehicles collide, the lighter one will sustain the greater damage. That said, while aluminum and CFRP may be lighter than steel, they’re usually a lot stronger. Engineers must consider how to best absorb and control crash forces so that the crumple zone does not impede into the occupant zone, even with advanced passive safety systems.
Architecting the next generation of lightweight vehicles will require OEMs to undergo a series of compromises. What’s the best way to substantially reduce vehicle weight while improving attributes such as car body stiffness, at a price that the market is willing to pay? Tata Technologies has played a key role in how manufacturers around the world approach lightweighting with its 5R Rightweighting methodology; a tried and tested formula that delivers the Right Performance at the Right Price, by applying the Right Amount of the Right Material in the Right Place.

The choice of specific materials and material combinations is to a significant degree dependent upon the market segment of the vehicle and particularly on its cost target. Tata Technologies forecasts that non-premium vehicle makers will increase their use of AHSS and move to aluminum closures to achieve a moderate degree of weight reduction. The premium market will utilize more intensive use of non-ferrous materials, including all-aluminum BIWs involving both unibody and space frame construction, along with a gradual increase of carbon fiber composites being used. Supercars, including electric vehicles, will increasingly be developed solely from carbon fiber in order to maximize weight savings and deliver the ultimate in performance.

Utilizing the 5R Rightweighting methodology, Tata Technologies has developed three material approaches that offer a robust opening for many vehicle development programs by delivering the right mix of performance and economy for a particular market segment.

- **Mixed Material** – This approach employs a steel unibody frame with AHSS and Ultra-High Strength Steel at critical points, combined with an aluminum roof, tailgate and hood to reduce overall vehicle weight.
- **Mixed Intensive** – This approach achieves incremental weight savings relative to the mixed materials option by leveraging a steel unibody with AHSS panels, closures built from a combination of aluminum and plastic, and plastic fenders instead of steel.
- **Lightweight Intensive** – This approach goes one step further by using a cast and extruded aluminum unibody frame along with aluminum and carbon fiber body panels.

It’s important to note that these approaches are not designed as one-size-fits-all solutions but rather as a starting point for optimizing the vehicle design to meet the manufacturers required attributes.

Achieving the right material mix is one part of the complex equation, however OEMs and Tata Technologies’ Rightweighting methodology uses the 5Rs shown above to help OEMs deliver lighter vehicles that provide the right performance at the right price.
suppliers face a wide range of other challenges in switching to lighter materials. As part of its 5R Rightweighting methodology, Tata Technologies provides thought leadership and experience to assist with:

- The reduced formability of AHSS
- Fatigue properties, flammability and recycling of plastics and composites
- Reduced tensile strength and wear resistance of aluminum relative to steel
- Performing full vehicle lifecycle assessments for each material in multi-material vehicles
- Keeping repair costs low
- Training service technicians in multi-material joining
- Increasing material competency throughout the value chain
- Transformation costs for OEMs when migrating to lightweight materials including manufacturing plant and supply chain

“The future is the best material at the right place, and as long as all materials continue to take their future in their hands and be innovative, there will be a place for all of them.”

– Bernard Gilmont, Automotive and Transport Director, European Aluminum Association

LIGHTWEIGHTING FOR OFF-ROAD VEHICLES AND HEAVY-DUTY EQUIPMENT

Traditionally, off-road vehicles such as construction and agricultural equipment have been built from steel without serious concern for their weight. Many of these vehicles, such as wheel loaders, need to maintain their current weight to fulfill their function so they are not appropriate candidates for lightweighting. On the other hand, a wide range of heavy-duty vehicles such as dump trucks, garbage trucks, tractors, cultivators, broadcast seeders, etc., can be made more fuel efficient, less polluting and have their payload increased through targeted reductions in weight. Tata Technologies’ lightweighting efforts in the heavy duty equipment market to date have focused on increasing the use of AHSS along with targeted use of aluminum in areas like the cab.
ADDITIONAL CONSIDERATIONS

Materials selection is just one important step towards achieving a market leading design. Moving away from the exclusive use of conventional mild steel creates challenges in design, manufacturing and supply chain management, among other areas.

For example, traditional high volume welding technology, such as resistance spot welding (RSW), is limited in its ability to weld uncoated steel to aluminum by the solubility of the materials in solid state. This results in the formation of brittle intermetallic compounds. One of the most promising alternatives involves the use of hybrid jointing methods, such as self-piercing rivets (SPR), in combination with adhesive bonding. SPR generally provide joint strength in the range of 2 to 2.5 kilonewtons per joint, substantially higher than RSW, making it possible to reduce the number of joints from ~5,000 to ~6,000 RSW currently to ~3,000 to ~4,000 SPR per vehicle.

On the other hand, rivet guns are larger than spot welding guns which can create difficulties in accessing assembly framing stations. The challenge can be addressed by careful layering of the build sequence in order to provide sufficient access at all stages of the process. The increased cycle time of SPR, which typically range from two to six seconds (compared to one to two seconds for RSW), can be addressed by automation and multi-feed technology. This approach carries a higher cost, but can often be offset by the 30 percent reduction in energy and the elimination of the need for water and compressed air supply for SPR assembly.

LIGHTWEIGHTING FOR THE AEROSPACE AND DEFENSE INDUSTRY

The aircraft industry was the first to introduce lightweight materials, such as aluminum alloys, on a widespread scale beginning in the 1920s and continues to lead in the adoption of CFRP materials. In fact, CFRP is the same material used to produce the fuselage and wings of the Boeing 787 Dreamliner. It’s no secret the automotive industry is following the lead of the aerospace industry when it comes to lightweighting. Composites provide significant weight reduction, are resistant to corrosion and fatigue, and are damage tolerant. But they also present significant challenges including high cost and difficulty in preventing manufacturing defects. Tata Technologies’ aerospace and defense lightweighting expertise is focused on the design and engineering of composite structures.
CONCLUSION

Automotive OEMs and suppliers face the challenge of re-engineering the next generation of lightweight vehicles to meet aggressive fuel economy and emissions standards scheduled to come into force in the coming years. The most promising method to meet these standards is the substitution of lightweight materials, which will require not only careful consideration of alternatives but also many related changes in vehicle product design and manufacturing methods. Tata Technologies delivers cutting edge solutions for lightweight vehicle product design and development through the use of our 5R Rightweighting methodology.

To achieve our customer’s lightweight targets, we implement our 5R Rightweighting methodology to evaluate the use of all steel grades, aluminum, magnesium, composites, and other materials to achieve the required weight reduction, cost and vehicle attribute targets. We produce concept studies that consider material selection, frame configuration, fastening and joining, manufacturing processes, cost considerations, supply chain management, recycling and recovery, among other factors, to develop platform architectures that enable our customers to deliver leading edge vehicles that meet the needs of the market and turn a profit.
ABOUT TATA TECHNOLOGIES

Tata Technologies founded, in 1989, enables ambitious manufacturing companies to design and build better products through engineering services outsourcing and the application of information technology to product development and manufacturing enterprise processes.

With over 8,500 professionals, representing 28 nationalities, Tata Technologies focuses on the manufacturing industry - covering every aspect of the value chain from conceptualisation, manufacturing, aftermarket and maintenance repair overhaul support. Tata Technologies supports clients through engineering services outsourcing, product development, IT services and product management solutions.

Tata Technologies serves clients in 27 countries, with a delivery model specifically designed for engineering and IT engagements that offers a unique blend of deep, local expertise integrated with fifteen global delivery centres across Europe, North America and Asia Pacific.

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