Lighten Up:
The Future
Of Lightweighting
Has Finally Arrived

By Gregory E. Peterson, Michigan Manufacturing Technology Center Principal Materials Engineer to the LIFT Institute

Lightweighting Could Be Financially Viable for Replica Vehicles

The term “lightweighting” has been used for many years in the automotive industry to describe efforts to make vehicles lighter for improved fuel efficiency. Recently, as new technological innovations have become increasingly popular, so, too, has the use of lightweight materials. Although materials like carbon fiber and magnesium possess incredible potential for engineers and manufacturers, a number of roadblocks have prevented lightweighting from reaching mainstream acceptance. These struggles have been especially prevalent for those in the specialty vehicle market, as issues such as strict vehicle regulations, high material costs and joining problems have held back many companies from using lightweight innovations.

However, recent changes in the industry have opened the door to new lightweighting opportunities, completely changing the market landscape.
The Long Road to Lightweighting

Previously, all completed replica vehicles had to meet the same Federal Motor Vehicle Safety Standards (FMVSS) regulations as automobile manufacturers, including crash requirements and emissions regulations. This made the production of replica vehicles and frames nearly impossible due to the high cost, effectively banning the sale of replica vehicles.

Change came to the lightweighting industry in 2017 when the Specialty Equipment Manufacturers Association (SEMA), representing more than 70,000 companies, successfully lobbied for new legislation. This resulted in a law being passed allowing replica vehicle manufacturers to sell completed, turnkey vehicles. SEMA estimates that this regulation could generate more than 1,000 turnkey vehicles each year, with new revenues approaching $80 million to $100 million annually. Although this legislation is still pending approval from the National Highway Traffic Safety Administration (NHTSA) and the Environmental Protection Agency (EPA), it has opened the door to more possibilities for lightweighting technologies, such as lightweight aftermarket frames.

So Much Demand, So Little Supply

This new legislation did not solve all the issues for the lightweight-automotive industry, however, as many remain concerned about the production time for making lightweight frames for replica vehicles. Waiting six to nine months for a single custom frame is not unusual. Although there are issues with the supply side, there is no shortage of demand for such frames. SEMA members have reported that there is widespread need for a well-engineered, lightweight, safe and affordable frame to support not only this emerging market, but also a wide variety of aftermarket bodies for trucks and cars.

An additional market driver is the call for a strong and lightweight frame for military use. A number of companies working with the Department of Defense have identified the need for a lightweight frame to be used in military vehicles to effectively increase the payload capacity. Commander Innovations, a Michigan-based military supplier, is pursuing this frame concept, working in a collaborative agreement with the Michigan Manufacturing Technology Center (commonly referred to as The Center) to develop it. This high demand and interest in a lightweight-frame option turned into an innovative, collaborative, entrepreneurial opportunity for several organizations throughout the United States.

A Solution to the Problem

The Center, supported by the National Institute for Standards and Technology (NIST), recently completed a design for a new aftermarket frame that could provide SEMA replica-vehicle manufacturers with the product they desire. With such a complex product needing to be designed and engineered, The Center pulled from local and national expert resources to find companies with the engineering capabilities necessary to create a lightweight aftermarket frame. These organizations supported and assisted with the entire process of making the frame a reality, with their unique partnership ultimately leading to success.

After considering dozens of body frames, the 1963–67 Corvette (C2-second generation Corvette design) was selected because of its worldwide popularity and having the most desirable body style among aficionados. Further specifications for this lightweight, strong and safe replacement frame for the C2 Corvette were developed with Dynamic Corvettes, a Corvette specialist based in Saginaw, Mich. Detroit Engineered Products (DEP), an OEM Tier 1 design firm with unique software capabilities, developed all CAD models and performed the finite element analysis.

The design and production of this aftermarket frame required much consideration, planning and expertise from organizations around the nation. Going into the development process, some of the engineering targets were:

1. 30-percent lighter weight
2. Four times stiffer in bending
3. Safety
4. Low tooling-investment costs
5. No painting or priming following build completion
6. No assembly welding
7. Quick and simple build process
8. Minimal technician training to become an assembly expert

Design and production of the aftermarket frame required much consideration, planning and expertise.
9. Automotive build quality
10. Robust construction
11. Incorporate C5-C7 Corvette suspension hardpoints
12. Allow for 275-mm front and 315-mm rear tire widths
13. Competitive price

Due to the wide demand for lightweight frames like this, the goal was to make one that could easily “morph” into virtually any wheelbase, vehicle length and width without requiring additional tooling. For this particular project, two frames were developed that shared key structural parts: a short wheelbase, narrow body frame for the C2 lightweight frame and a larger frame for heavy-duty military trucks. This “dual use” approach provided economies of scale for all end users that help reduce the frame cost.

**STARTING FROM SCRATCH**

Before beginning the frame production, DEP created a CAD model, working from a C2 Corvette frame supplied by Dynamic Corvettes, that was meshed and used as the basis for evaluating the frame stiffness. In this process, the meshed CAD model was analyzed for torsion and bending displacements (Figure 1). The results from this testing created the baseline targets for the lightweight frame.

With these targets in place, the design of the lightweight frame began. This process started with the determination of the manufacturing processes. After careful consideration, materials were selected based on the engineering team’s experience in designing lightweight structures. With this knowledge, it was decided that aluminum, magnesium, car-
bon fiber and advanced high strength steel (AHSS) would provide the best combination of lightweight, high strength and low cost for each component of the frame.

In terms of tooling, the engineering team made sure to carefully select affordable and proven options, including:
1. One extrusion die (aluminum front and rear modules and bumpers)
2. One pultrusion die (carbon-fiber rockers and crossmembers)
3. Sand castings (four magnesium corner nodes-ablation cast)
4. Software for laser cutting and welding 1600Mpa Flash Bainite steel (front and rear cradles)

Another challenge in the design process came from the joining requirements, which included no parent material degradation, sealing the mating surfaces from road contamination, non-robotic (manual) processes and cost effectiveness. The team decided the best solution would be a combination of structural adhesives and mechanical fasteners with inert washers.

FROM CONCEPT TO REALITY: DOES THE LIGHTWEIGHT FRAME PASS THE TEST?

All this thought and consideration paid off once the frame was actually designed, as it demonstrated improvements over the baseline in stiffness, safety, assembly time and cost.

Stiffness
Several design factors played into the overall stiffness of the aftermarket frame. Working from the original C2 body-mounting surfaces, the lightweight frame was designed so that a C2 body could be easily fitted. Additionally, the lightweight frame was designed to allow substantial bonding areas between the frame and the C2 body. This created a much stronger overall structure (Figure 2).

Pennex Aluminum, an experienced automotive supplier, selected the material, built the tooling and supplied extrusions for the front and rear energy-absorbing modules on the lightweight frame. Bending and torsional stiffness analysis indicated the lightweight frame is 4.5 times stiffer than the baseline C2 steel frame. (See Figure 3 for analysis results.)

The improved torsional stiffness of the lightweight frame is most evident when it is combined with a body. The torsional stiffness of a C2 carbon-fiber body bonded to the lightweight frame is >27 KNm/degree, per DEP analysis results. This value is competitive with current production sports cars and greater than many recent high-performance vehicles. To compare this to other vehicles on the market, the 2010 Lamborghini Murcielago, Lamborghini’s highest-performing car at that time capable of more than 200 mph in SV form, has a torsional stiffness of ≈20 KNm/degree.

Safety
Safety was another key engineering parameter guiding this frame design. Although there were no FMVSS crash requirements to meet, the frame was engineered to absorb energy in a controlled manner using current technologies proven on production sports cars. With aluminum extrusions in both the front and rear crush zones, the crash model indicated a peak acceleration of approximately 30 g’s and an average g-level from initial frontal impact to rest of approximately 20 g’s. The engine mounts also were tuned to break away, allowing the front module to continue crushing for added safety in a crash.

Assembly Costs
In terms of assembly, key objectives for the lightweight frame focused on maximizing quality and minimizing costs. The target assembly time was less than two hours for two technicians. For comparison, the average assembly time for steel aftermarket frames can exceed 40 hours for highly skilled welders using dedicated fixtures. Additionally, these steel frames must then be primed and painted or powder-coated. This adds cost and complexity to the assembly process.

The engineering team was able to meet these objectives by:
1. Minimizing the parts count
2. Designing modular sub-assemblies
3. Integrating key process control points (KPCP) into the castings to create self-fixturing nodal points and consistent net-build capability
4. Incorporating simple and robust joining processes
5. Eliminating post-build priming and painting
6. Utilizing inexpensive measurement equipment
7. Eliminating ancillary build fixtures
8. Minimizing the training time necessary to achieve an expert skill level using an existing workforce

The combined cost and time savings in these areas helped the team achieve their goal of a two-hour assembly time.

**Morphing Process**

The engineering team was able to design a lightweight frame that was easily reconfigurable without requiring new tooling. To accomplish this, the wheelbase, width...
and length of every frame is adjusted by trimming the carbon fiber reinforced polymer (CFRP) pultrusions and the aluminum extrusions to desired lengths and adjusting the trimming software for the ultra high-strength steel (UHSS) cradles.

The CAD process morphed a 1963-67 Corvette frame to a large, heavy-duty military truck frame. The military frame has an additional crossmember that is identical to the existing crossmember geometry. The castings are common (magnesium for the Corvette, aluminum for the military application), and the geometry of the extrusions and pultrusions is the same. Essentially, there are no tooling changes required to make virtually any size frame, from a 1960 Bugeye Sprite to a 9-ton truck engineered for extreme off-road capability.

**Competitive Pricing**

Historically, many customers have been driven away from lightweighting technologies due to the associated high cost. However, the cost of this particular lightweight frame is comparable to custom steel frames. While the lightweight frame does incorporate materials that can be two to 20 times more expensive per pound than low-carbon steel, the engineering team focused on offsetting the higher material costs by creating savings in other areas.

This was accomplished through a number of cost-cutting techniques, including using significantly less material, assembly that only takes 10 percent of the time needed for a typical aftermarket frame, less-expensive trained assembly labor and less-expensive joining processes. These factors, along with many others, helped the team develop an affordable, lightweight, multi-material frame.

**THE FUTURE OF LIGHTWEIGHTING IS NOW**

The demand for a lightweight, affordable, competitive frame is apparent and increasing, and the combined efforts of these expert organizations helped to make it a reality. Although this frame is still in the development phase, it symbolizes the future of lightweighting and demonstrates the potential uses of lightweighting technologies in years to come, including supporting niche electric-vehicle and military-vehicle manufacturers.

**LIGHTWEIGHT FRAME CREDITS**

The lightweight-frame project was supported by NIST, Federal Institutes LIFT and IACMI, with contributions by America Makes (3-D printing experts) and Manufacturing Extension Partnerships, including the Michigan Manufacturing Technology Center and the University of Tennessee Center for Industrial Services Institute for Public Service. Contributing automotive suppliers included Detroit Engineered Products, the Aluminum Extrusion Council, Pennex and Henkel. Commander Innovations provided the military requirements. Dynamic Corvettes provided support for the baseline Corvette frame.

**REFERENCES**

1. Car and Driver, June, 2009

**ABOUT THE AUTHOR**

**Gregory E. Peterson** is Principal Materials Engineer for the Michigan Manufacturing Technology Center’s Accelerating Technology Team, and also the Center’s Principal Materials Engineer assigned to the Lightweight Innovations for Tomorrow (LIFT) Institute. Mr. Peterson’s background includes OEM (Pontiac product engineering, CPC Advanced Vehicle Engineering, DaimlerChrysler SRT, Lotus), Tier 1 and startup experience. He has engineered lightweight products for numerous industries including sustainable energy, military, aerospace, agriculture, truck/bus, as well as automotive. Mr. Peterson holds numerous patents in a wide variety of fields. He serves as a member of the Lightweighting World Editorial Advisory Board.