News

Lightweighting & its System-Level Impact on EV Architectures

From a systems engineering perspective, how does lightweighting affect EV battery pack design, structural integrity, and thermal management?

Reaching back to Newtonian physics, the simplicity of the Second Law of Motion gives us some clues. To refresh, *F* is force, *m* is mass, and *a* is acceleration (F = ma).

Successful lightweighting strikes right at the heart of this, and the impact is clear. If mass (*m)* can be reduced, there are options.

For example:

- A reduced mass allows a vehicle to accelerate faster, even with the same electric motor. For high-performance vehicles, lightweighting is ideal, as it also helps with cornering, enhancing the driver experience.
- Range can be extended by using a less powerful motor while maintaining the same acceleration capabilities.
- Vehicle costs can be reduced by decreasing battery size while preserving the existing driving range.

Thermal management effects will differ depending on what strategy the designer or engineer chooses. Structural integrity is unlikely to suffer, as experience with lightweight metals and composites is extensive, making the decision a question of cost.

As vehicles become lighter, structural components often have less thermal mass. Does this create new challenges for managing localized heat, thermal gradients, or long-term material fatigue?

Thermal management typically involves moving heat from unwanted areas to more optimal locations, usually outside the vehicle. However, some systems use “waste” heat for cabin heating. [Waste heat is the excess thermal energy a vehicle generates during operation that isn’t useful for propulsion and must be removed or redirected to prevent overheating.]

The most effective way to relocate heat is with a liquid, and water is an ideal heat-transfer fluid. Internal combustion engine (ICE) vehicles generate far more waste heat, but cooling only becomes a limitation under extreme conditions. In EVs, if lightweighting is implemented to reduce motor power and extend range, it can also make cooling demands on the battery and inverter chips easier to manage.

Many EVs now integrate battery cooling channels directly into the pack structure. How does this integration affect durability, manufacturability, and weight distribution?

Cooling channels are hollow in cross section, meaning they can act as both load-bearing elements and as conduits for heat exchange fluids. Incorporating them into the structure of the battery pack optimizes the space, but this can also add complexity to the manufacturability and serviceability of the pack.

However, EV battery packs (like battery packs in most electronics), are not typically regarded as serviceable items. They should last the life of the vehicle, and often their lifetime defines the lifetime of the device. For example, there are several Tesla battery packs that are filled with a structural foam. Essentially, it turns the entire battery pack into a monolith, making service physically impossible.

The integration of multiple functions in the battery pack is going to make it lighter and more cost-effective, improving manufacturability.

What is the most significant thermal challenge in EVs, and where are engineers making the most progress?

Inverters are currently at the top of this list because they serve as the critical choke point for the dc-ac conversion required to make EVs move. The rapid switching they perform is highly efficient, but even fractions of a percent in losses generate substantial heat when kilowatts of power are pushed through chips roughly the size of a Girl Scout cookie.

Battery thermal management has also evolved significantly as designs have shifted from cylindrical cells to pouch cells in modules, and now to fully integrated pouch cells at the pack level. Pouch formats offer far more surface area for efficient heat exchange.

At the same time, power electronics are transitioning from 400 to 800-volt architectures and higher. These higher-voltage systems reduce conductor size and cut thermal losses during power transmission.

Together, these advancements improve overall system efficiency, but they all ultimately funnel through the inverter, which remains the system’s fundamental thermal bottleneck.

How are new materials, such as thermally conductive composites or hybrid metal polymer systems, helping engineers balance lightweight design with effective heat dissipation?

Advanced materials like these are good options for designers, as they provide incredible freedom in optimizing shape to function, while providing a high strength and light weight design. For high-volume production, they can also be manufactured quite cost-effectively. Such materials could prove to be interesting choices for things like electric motor housings, an area where complex shapes and high structural integrity requirements beckon innovative materials.

One area where these materials may require greater research and development is in electromagnetic shielding. This shielding is designed to limit interference with the complex electronics already present in EVs, including the exotic computing and sensor arrays required to enable fully autonomous vehicles. However, options such as electroplated or co-molded metal linings can offer support.

How does simulation help validate thermal management strategies and predict stress or expansion mismatches between dissimilar materials?

I would assume that most vehicle manufacturers already use simulation technology in their operations. These tools are widely accessible, and their advantages are now embedded in modern manufacturing best practices. Leveraging **simulation** for system design has become the obvious approach, whether engineers are evaluating thermal management, managing dissimilar materials, or addressing other challenges in vehicle development.

As EV architectures continue to evolve, do you expect lightweight structures to play a larger role as active thermal pathways or integrated heat exchangers?

Increasing integration will continue to be beneficial for the same reasons it has always been: lighter weight, lower cost, and easier assembly. Adding functions will naturally follow whenever possible. However, unlike the solid-state electronics we've come to expect and rely on, systems like heat-exchange loops will likely retain some modularity simply because the origin of the heat (battery or inverter) and its destination (typically the surrounding air) are located in different sections of the vehicle.

Additionally, the heat-exchange fluid in an EV is one of the few serviceable fluids that occasionally needs to be changed, so there may be a practical limit to how much integration makes sense.

On the other hand, in relatively low-power systems (such as electric scooters), battery packs often use an integrated heat-exchange mechanism in which the cells are immersed in, or encased by, a phase-change material that's solid at room temperature and absorbs heat as it melts.

Wax is an example of such a material that's solid at room temperature but melts (and absorbs heat while doing so) at relatively modest temperatures. There's no need for an external heat exchanger because the duty cycle and power output are relatively modest and the heat load can be managed this way.

Such an approach seems far less feasible in a higher-power environment like an EV, although options like liquid-to-gas systems with an integrated condenser could potentially be employed.

How does lightweighting at the vehicle level affect efficiency, range, and battery performance?

Going back to Newton's Second Law of Motion, lighter weight is almost always better for performance, efficiency, and range. The only codicil to that statement is that the use of lightweight materials requires knowledge of how to exploit them safely.

There’s a lot of history, from fighter planes to bicycles, that can be used as proof sources for proper material use, and industry leaders can lean on those insights to implement lightweight materials in a way that doesn’t compromise overall performance.

What lessons from aerospace or high performance computing thermal design could be applied to next-generation EV systems?

Aerospace has long been a powerful driver of materials science innovation, in part because it operates with fewer cost constraints. While adoption can take time, materials like titanium and carbon fiber composites owe much of their early development to military aerospace programs.

High-performance computing is emerging as a similarly demanding field, and only recently has it begun to surpass the heat flux requirements found in EV inverters. The heat flux in an Nvidia H200 chip, for example, is estimated to fall within the same range, roughly 70 to 200 watts per square-centimeter.

Before the rise of **AI**, data centers relied on relatively simple thermal management approaches, with air cooling as the standard. But as AI chips have grown more power-intensive, they generate far more heat, making the liquid-cooling strategies long used in EVs increasingly common in data centers.

With the rapid acceleration of AI chip development, thermal management innovations may eventually flow in the opposite direction, from AI hardware back into EV inverter technology. However, given how tightly AI board design and operating practices are guarded, any meaningful crossover may take years to emerge.

Looking ahead, which innovations in materials science, manufacturing, or cooling methods do you think will most change how engineers approach EV lightweighting and thermal design?

EVs are already dominating several major automotive markets with the technology available today. The scale of current production has resolved many cost-related challenges, and there’s still substantial opportunity for steady improvement.

While few areas demand dramatic breakthroughs for this momentum to continue, advances in battery capacity, charging speed, and charging infrastructure will drive exciting developments in materials science and the smart adaptation of existing technologies. It’s going to be fascinating to watch. And drive.

Read the full article, available on evengineeringonline.com