BEVs in a Flash:

Accelerating Battery Electric Vehicle Development Using Simulation

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GAMMA TECHNOLOGIES

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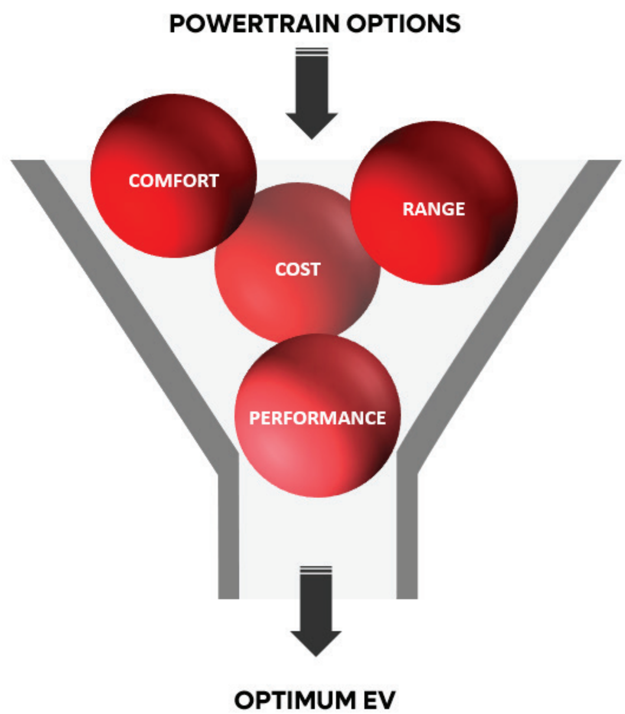
INTRODUCTION

The push for reduced greenhouse gas emissions continues to grow, driving a more diverse and electrified future for the transportation industry. Electrification is entering every aspect of the global transportation industry, from scooters to farm tractors, on and off-highway commercial and heavy-duty vehicles, aircraft, and of course, traditional passenger cars.

As the sense of urgency is increasing and a public demand for electrified solutions becomes more tangible, the demand for faster time to market is of the utmost urgency for vehicle OEMs and suppliers. This is a driving motivation to rely heavily on Computer-Aided-Engineering (CAE) and simulation to assist in reducing development time and cost, while maintaining, or improving, the driving experience for vehicle buyers.

Over the past decades, the automotive industry has adopted CAE and simulation for component-level design, and now the frontier has become systems integration. Vehicle and powertrain engineers need to quickly build complex systems models to optimize key vehicle attributes, such as: range, performance, thermal security and cabin comfort, and drive quality at the most competitive price possible. To empower vehicle and powertrain engineers to answer their difficult questions, a fully integrated, predictive, and scalable set of CAE solutions must be utilized. This toolset must be available at different phases of the development cycle, from the early architecture concept phase to the final hardware verification step, and be harmonized across departments, physics domains, and support a scalable and interoperable deployment to enable productivity beyond the traditional simulation experts.



This eBook will cover several of the key solutions available within the Gamma Technologies' GT-SUITE platform, which addresses the transportation industry's most pressing challenges. At Gamma Technologies (GT), we feel an immense sense of pride in the degree of trust our customers have placed in our solutions, which help guide their transformations.

EFFICIENCY & PERFORMANCE

While vehicles powered by internal combustion engines (ICE) remain a mainstay in today's market, electric vehicles continue to gain traction with both average and commercial consumers. Through a combination of more stringent federal emission requirements, the eco-conscious consumer, and technical advancements, electric vehicles have been able to significantly penetrate the automotive market, accounting for 14% of all new cars sold globally in 2022 [1]. Innovative technical solutions have contributed to achieving reduced charging times, increased range, and performance comparable to their gas counterparts.

Vehicle range still remains the biggest challenge faced by battery electric vehicles (BEVs), with the average range of roughly 250 miles [2], leaving much to gain when compared to the 403 miles range [3] of the average gasoline fueled vehicle. Figure 1 shows the current BEV range distribution according to the US Environmental Protection Agency (EPA). Some vehicles are pushing beyond 400 mile range, with a few even breaking the 500 mile range.

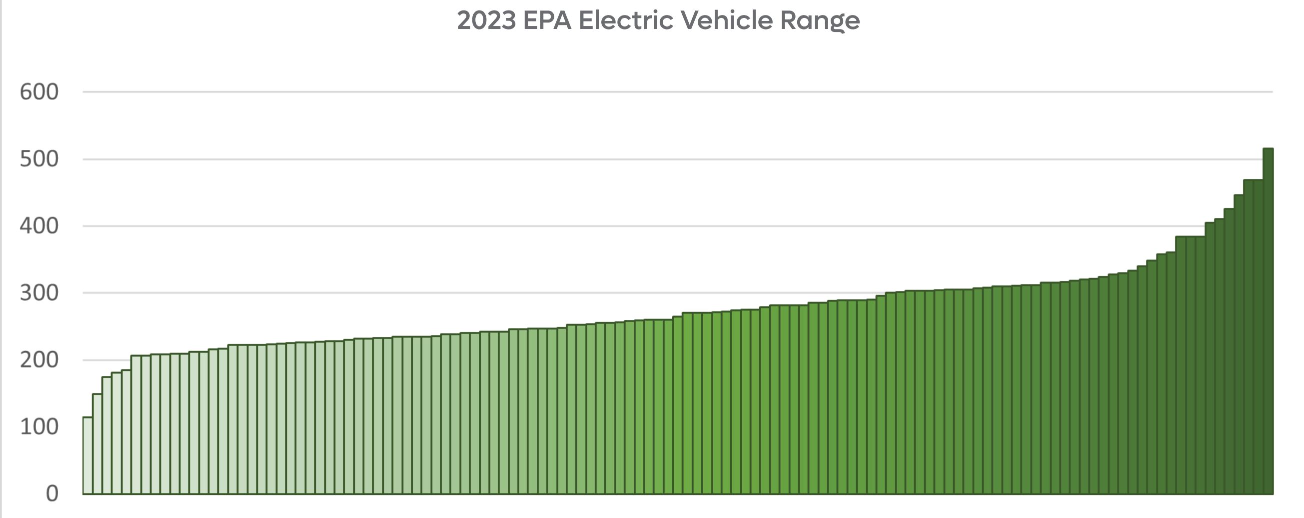


Figure 1: BEV Vehicle Range (EPA 2023 Dataset)

Driving range is dependent on a variety of factors, most importantly: usable battery energy, aerodynamics, effective mass, and the efficiency of every major subcomponent within the system. Major components consist of battery systems, electric drive units, power converters and auxiliary/parasitic electric loads. As in any system, there are component interactions that need to be considered and ultimately the exercise becomes a multi-objective optimization. For example, a larger battery size will theoretically extend the range, but also increases the mass and the required force to accelerate the vehicle. At this point, an increase in torque is required by the motor and a greater power converter is required to drive the load. It is vital that in the early stages of the development process, appropriate sizing for all components is determined to set realistic vehicle metrics.

This necessitates a system-level design that can effectively predict all vehicle metrics while accounting for system noise factors that will impact the performance of the vehicle. As with any other typical engineering system, the largest impact on the overall system and sub-component performance is dependent on thermal efficiency. Systems problems and how they are impacted by thermal factors and environments, will be further detailed in the corresponding section: Thermal Management for Efficiency, Comfort, and Safety.

Another variable to consider is vehicle lifespan, with the life expectancy of a typical modern vehicle around 12 years [4] or about 200,000 miles [5]. This is an important criterion when consumers consider the total cost of ownership of a vehicle. Typically for a BEV, vehicle life is determined by battery state of health (aging), which is critical for manufacturers to predict in order to set appropriate warranty terms. As current electric vehicles age, this topic will only continue grow in importance, especially as vehicles hit the used market or reach end of life.

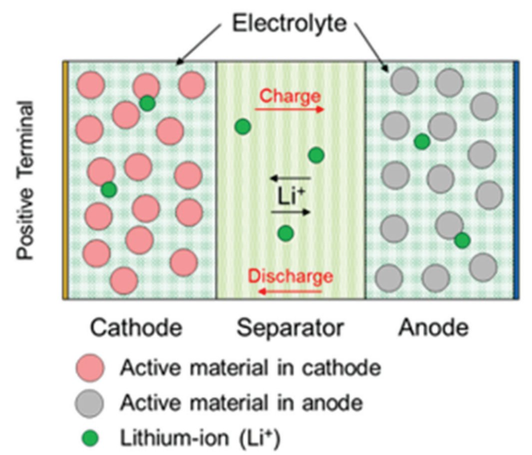


Figure 2: Li-Ion Battery Schematic

As leaders in system-level CAE simulation, Gamma Technologies continues to invest in research and development around electric vehicle (EV) and subsequent components. At the heart of any electric vehicle lies a battery. Batteries can be modeled with different levels of fidelity, ranging from data-driven to predictive. One typical data-driven approach is a resistive battery model, with optional Resistance-Capacitive branches capable of capturing the electrical dynamics.

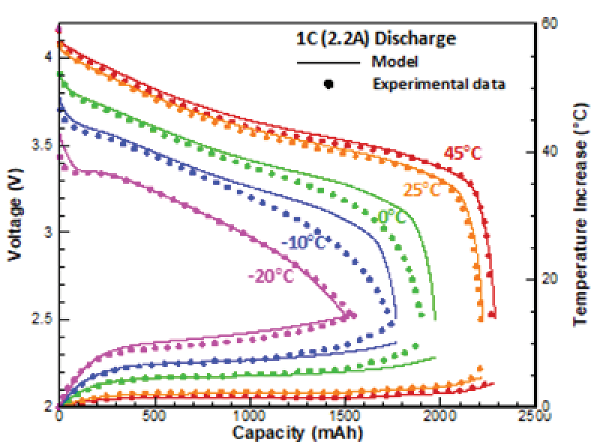


Figure 3: GT-AutoLion Simulation vs Experimental Data

On the predictive side of battery modeling, we have GT-AutoLion, which is based on a "Pseudo 2D" (P2D) electrochemical model for Lithium-Ion (Li-Ion) batteries. The model captures the electrochemical reactions occurring inside a Li-Ion cell and predicts the terminal voltage, current, power, heat rejection, and amount of Lithium throughout the cell. Several different battery cell geometries can be modeled, cylindrical, stacked prismatic (pouch), rolled prismatic, and coin. GT-AutoLion includes various aging mechanisms for predicting calendar as well as cycle aging effects under real-life operating conditions.

Similar to the battery, GT-SUITE includes various levels of fidelity for electric motors. The least complex is a map-based electro-mechanical motor model, which uses efficiency or loss maps to calculate electro-mechanical response. This level of model is useful for efficiency, sizing, and system-level thermal management studies.

For increased model fidelity, GT-FEMAG can be used to implement a motor multi-physics solution across electromagnetic, thermal, and mechanical domains. FEMAG is a 2D multi-physics finite element analysis tool optimized for motor design and analysis, incorporating electromagnetic design, thermal security, and prediction of noise and vibration. FEMAG is fully integrated with in GT-SUITE, allowing engineers the ability to design high-efficiency and high-performance electric machines within the overall vehicle system model, ensuring that the motor design and control are optimized for the application.

Gamma Technologies also offers GT-PowerForge, an integrated design software to assist in the design of complex power converters and specifically, the ability to model electrical subcomponents and generate realistic electrical systems based on the desired controls.

GT-PowerForge can predict losses, mass, volume, and cost to design a power converter to meet the vehicle requirements. With an extensive library of power converter components that includes data from different manufacturers, users can quickly develop a component model for analysis or be included in the overall system model. The library includes models of semiconductors, film capacitors and magnetic materials.

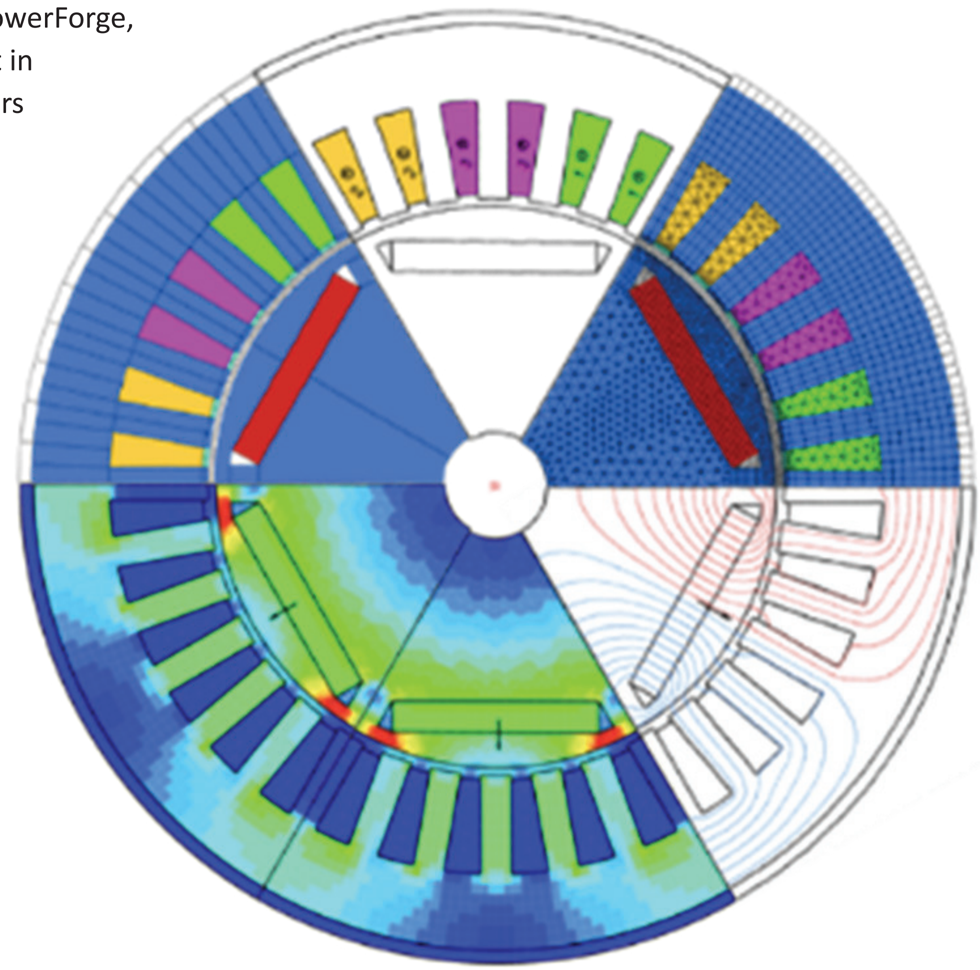


Figure 4: GT-FEMAG Electric Motor

THERMAL MANAGEMENT FOR EFFICIENCY, COMFORT, AND SAFETY

While the value gap between gas and electric vehicles may be closing, it is important for EV manufacturers to continue establishing trust with their consumer base. Electric vehicle manufacturers are continuing to make strides around intuitive vehicle handling, high-tech interfaces, and improved infrastructure making the BEVs more viable than ever. Consumers have the expectation that electric vehicles will function the same, if not better than conventional combustion-powered vehicles. In addition, with more manufactures developing electric vehicles, maintaining the safety and longevity of an electric vehicle may ultimately outweigh the range and efficiency issues electric vehicles commonly face.

Consumers have the expectation for their vehicles to operate, be comfortable, and reliable, regardless of weather conditions. From a technical perspective, this translates to the vehicle functioning effectively in a wide array of ambient environments. In conventional combustion-powered vehicles, a significant amount of waste energy is created which can in turn be used to heat the cabin. Alternatively, BEV vehicles draw directly from their battery, to heat the vehicle cabin and provide auxiliary energy for heating and cooling. Therefore, a significant tradeoff between vehicle range and cabin comfort exists. Additionally, performance and efficiency of the battery, motor, and power electronics are all strongly dependent on operating temperature, which must be maintained in a narrow range for optimum energy efficiency and thermal security.

The capability of GT to effectively model cabin comfort has been demonstrated and widely accepted by the industry. With extensive capability to model 1 dimensional flow, even for two-phase refrigeration circuits. Figure 5 shows an integrated GT-SUITE full vehicle model, which includes mechanical, electrical, thermal-fluids, and controls systems. Typical thermal management circuits include the following:

- A/C Systems, battery cooling, under hood cooling
- High-temperature cooling circuit
- Low-temperature cooling circuit
- Indirect refrigerant circuit
- Cabin air circuit
- Under hood air circuit

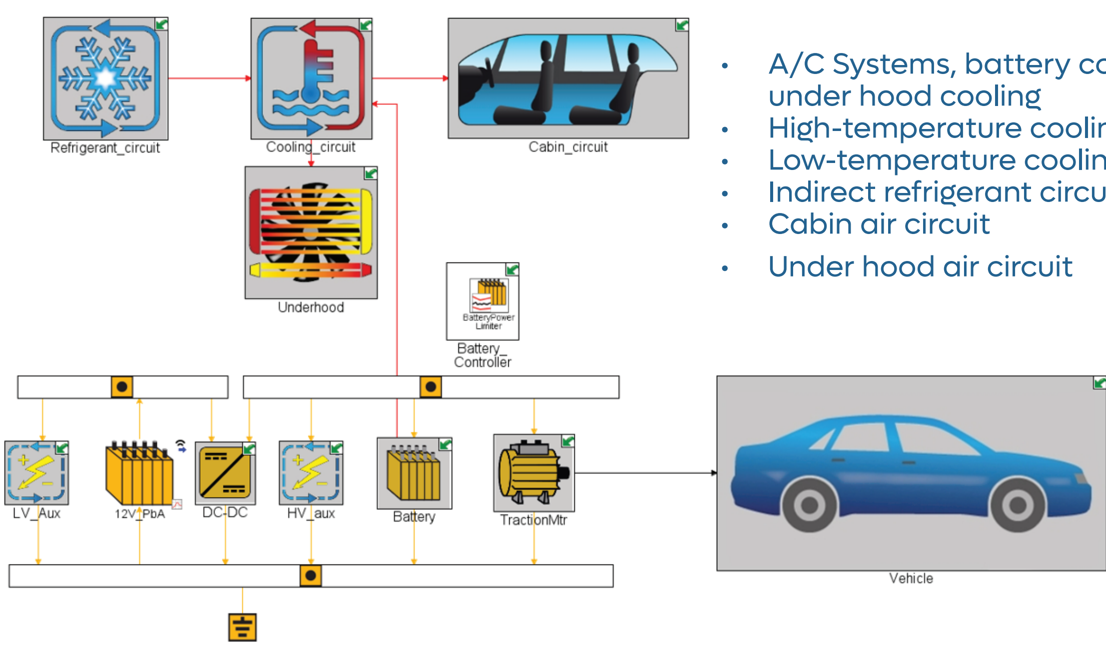


Figure 5: GT-SUITE Electric Vehicle Example

These are highly integrated circuits which have strong interactions and interdependencies. With the ability to simulate a fully integrated system, the robustness to noise factors such as ambient conditions and drive cycle can be used to evaluate the system interactions and dependencies. Figure 6 shows example results from a vehicle simulation predicting the impact on vehicle range with different cabin thermal management settings.

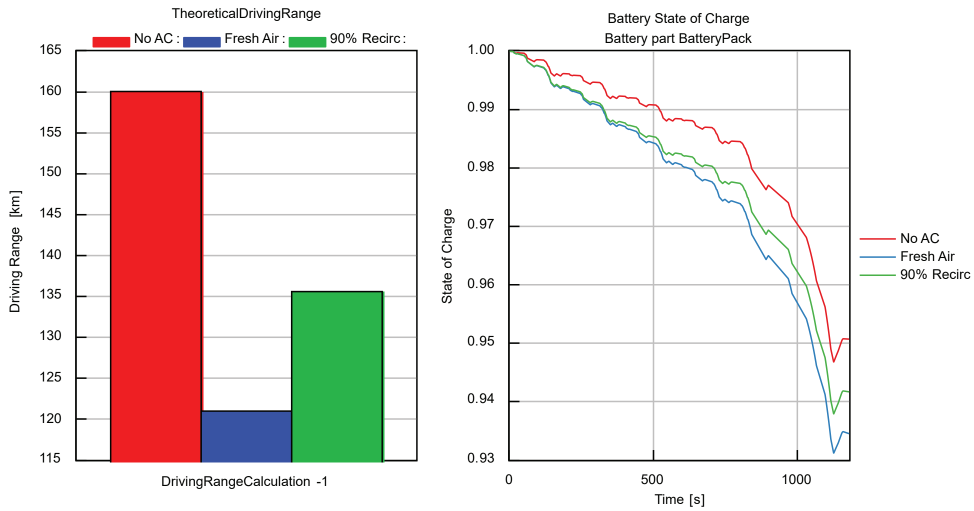


Figure 6: Cabin Comfort vs. Range

To quantifiably assess and predict human comfort in the cabin, GT-TAITherm can be used. Using GT-TAITherm, built-in human comfort models allow engineers to extensively assess human comfort within the vehicle cabin. Figure 7 displays simulation results predicting the average conditions in the vehicle cabin while also demonstrating the distribution within the cabin.

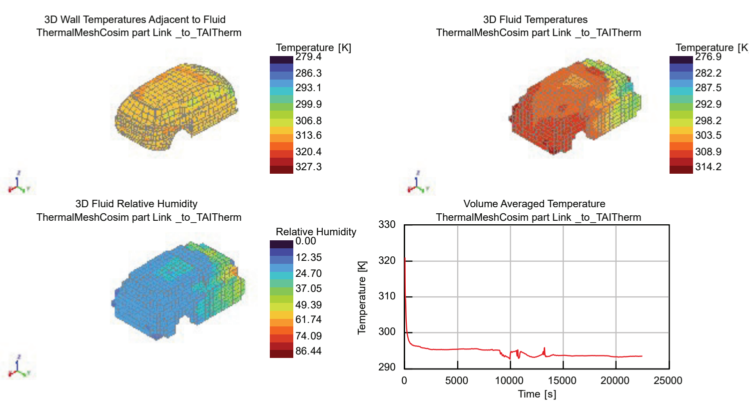


Figure 7: Vehicle Cabin Thermal Modeling in GT-TAITherm

Beyond cabin comfort, thermal security of components is a critical safety concern. Due to high expense and safety considerations, the feasibility of prototype testing thermal runaway is undesirable, thus driving industry to adopt simulations as the primary development tool. Simulation becomes even more attractive when considering the number of iterations required. Thanks to simulation, the battery can be assessed down from single cell to system-level thermal runaway propagation using GT-AutoLion integrated with a detailed thermal management model. Figure 8 illustrates results from thermal runaway model using GT-AutoLion, demonstrating how quickly the thermal runaway of individual battery cells can propagate to the remaining cells in the systems.

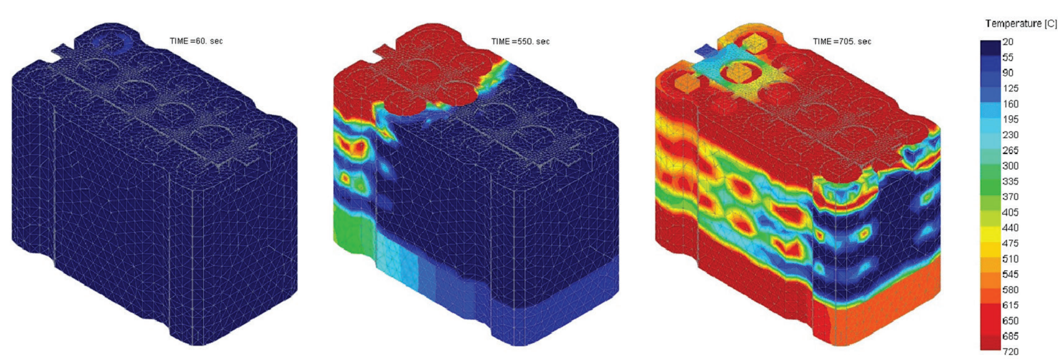


Figure 8: GT-SUITE Battery Thermal Runaway Results

DRIVE QUALITY

Creating a consistent driving experience that is enjoyable is critical for manufacturers, especially when trying to differentiate from the competition. This requires an understanding of the influences that impact drive quality, with the largest being undesirable noise and vibration perceived by the driver.

In a conventional vehicle with a combustion engine, the powertrain conceals many of the noise and vibration (NVH) variables. Removing the engine exposures can highlight or even exacerbate NVH that may have previously not been an issue. This, in turn, exposes the driver to other noise sources e.g., pumps, compressors, e-motor, power electronics, gear boxes and environmental noise. Implementation of innovative technologies can also introduce new NVH factors to contend with. For example, when E-axles, comprised of an electric motor integrated within a drive axle, were first implemented in BEV's, it quickly became evident that gear whine would be a significant issue to resolve. This new noise source occurs at 5-10kHz frequency, which in conventional combustion-powered vehicles is likely not audible. It is imperative to understand how these components interact with one another to understand their effect on the system. After obtaining a good understanding of the sources the of NVH, components can be designed to reduce the transmission of the NVH or a control strategies developed to avoid operate in the regions where NVH could be an issue.

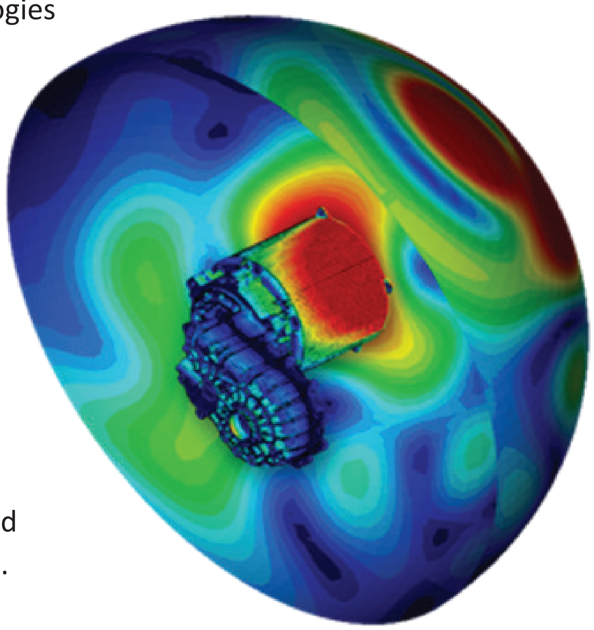


Figure 9: Meshless Acoustic Solution Example in GT-SUITE

GT has extensive capability to model most of the NVH sources in an electric vehicle. These NVH sources can be split into two different subgroups: electrical sources and mechanical sources. The majority of BEV systems consist of DC batteries driving AC electric motors, thus requiring the use of DC to AC converters (PWM transistors) in order to get 3 phase current. Depending on the power converter control strategy, i.e. the pulse width frequency used to convert the electrical signal from DC to AC can induce noise harmonics. These noisy electrical systems translate to motor forces and cause vibration to stator then to chassis/cabin. These forces can be further sub categorized to mechanical loads, magnetostriction, maxwell forces, local deformation, all of which can be modeled in GT. Mechanical sources include but are not limited to gears, shafts, clutches that can be excited by the harmonic electrical noise.

Power electronics can be modeled using GT-PowerForge as mentioned in Efficiency and Performance section. Depending on the state of a vehicle development, power electronics can be coupled to a map-based electric machine or for more detailed analysis, with Gamma Technologies' GT-FEMAG. The use of the more detailed electric motor models predicts torque response of the electric motor allowing further analysis of the drivetrain.

Comprehensive NVH analysis requires the use of 3D models for several components: shafts, gears, bearings, and the system housing, which are included in the GT library to model complex mechanical systems. These 3D models can be utilized to conduct a variety of NVH analyses such as rigid or flexible block vibrations, stress analysis and vibroacoustic analysis of any structure.
All the tools/models can be combined and used in the analysis across acoustic solutions domain, by using the loads generated from the mechanical model and assessing the structure deflections. Further acoustic analysis can be accomplished using techniques in the GT-SUITE acoustic library, with two levels of fidelity: rapid sound assessment, and spectrally resolved finite element analysis.

OPTIMIZATION AND MASSIVE COMPUTING

As our world adapts to millions of data points accessible at our fingertips, we can grow, predict, and infer multiple scenario outcomes in the same way it would have previously required years of research, development, prototyping, and validation. The ability to quickly converge to an optimal design is at the core of developing and designing electric vehicles. In large complex systems, optimization typically turns into a tradeoff between all vehicle requirements.

GT-SUITE contains two primary optimization methodologies: direct optimization and design of experiments (DOE), both of which may be used alongside the aforementioned simulations. These methods can be set up to meet the customer requirements as well as the type of analysis being conducted. Several forms of search algorithms allow for fast and effective convergence to a solution. Multiple objectives can be assessed simultaneously and can be either set to maximum, minimize, or target a set value.

For full system models, design space exploration gives the user the ability to gain a real understanding of the systems response and ensure robust design. The optimizer can also be used at any level fidelity model to be incorporated into the workflow at different stages of development. The data can further be exported and utilized for meta model tables if desired. Figure 10 shows some sample results from a response surface fit of a DOE.

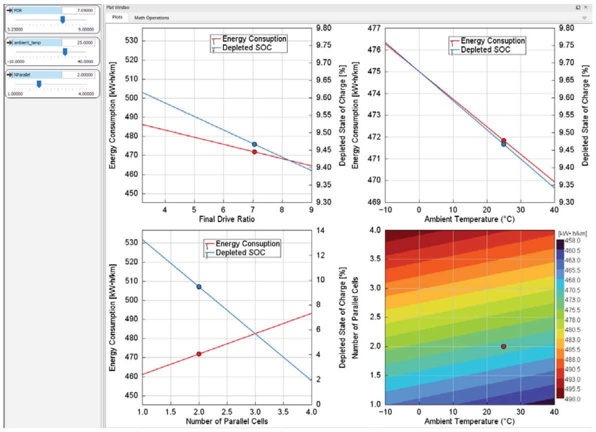


Figure 10: Interactive DOE Response Surface Post-Processing

DELIVERING A REFINED EV

Consumers expect a precise and exact product with no compromise to performance, efficiency, and safety. As competition increases the baseline for entry into the EV market will become higher. Customer minimum expectations will increase as we continue seeing consumers transition from conventional to battery electric vehicles.

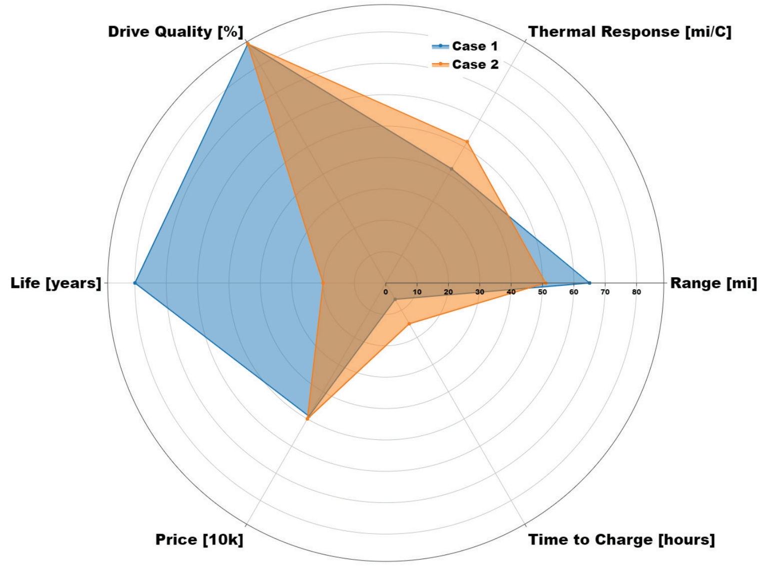


Figure 11: Example Electric Vehicle Spider Plot

A refined electric vehicle offers consumers an exceptional experience from cabin comfort, and performance, to range that is, consistent regardless of weather conditions and age of the vehicle, for a competitive price. To build a strong brand identity while being quick to market, BEV manufacturers must have their pulse on industry trends, new technology and novel approaches, while also being able to execute development inside pre-existing workflows. GT-SUITE allows OEMs the opportunity to be nimble in their growth as they filter through varying approaches in the market as well as implementing a technically rigorous process. Simulation allows manufacturers to deliver BEVs that are cost effective, quick to market, dependable, and safe with extensive analysis tools.

GT offers versatile vehicle simulation solutions, based in physics, that empowers engineers to work in tandem to deliver refined BEVs.

REFERENCES

1. International Energy Agency, “Global EV Outlook 2023; Catching up with climate ambitions,” Paris, 2023.
2. U.S. Environmental Protection Agency & U.S. Department of Energy, “Fuel Economy Guide,” 2023.
3. U.S. Department of Energy and U.S. Environmental Protection Agency, “https://fueleconomy.gov,” 2022. [Online].
4. Todd Campau, “Average Age of Vehicles in the US Increases to 12.2 years, according to S&P Global Mobility,” 23 05 2022. [Online]. Available: https://www.spglobal.com/mobility/en/research-analysis/average-age-of-vehicles-in-the-us-increases-to-122-years.html. [Accessed 23 06 2023].
5. K. Budd, “How Today’s Cars Are Built to Last,” 1 November 2018. [Online]. Available: https://www.aarp.org/auto/trends-technology/how-long-do-cars-last/. [Accessed 23 June 2023].

INTERESTED TO LEARN MORE?

Gamma Technologies develops GT-SUITE, the industry-leading Model-Based Systems Engineering (MBSE) CAE system simulation software.

GT-SUITE provides a comprehensive set of validated 0D/1D/3D multi-physics component libraries, which simulate the physics of fluid flow, thermal, mechanical, multi-body, structural, electrical, magnetic, chemistry, and controls.

GT-AutoLion is the industry-leading lithium-ion battery simulation software used by cell designers and OEMs to predict performance, degradation, and safety for any Lithium-ion cell. It predictively models the electrochemical processes within Lithium-ion cells using a fast and reliable, electrochemical, physics-based approach.

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BATTERY THERMAL MANAGEMENT SIMULATION

In GT-SUITE batteries are optimized on the cell, module, and pack level. The temperature and current distribution within the cells and pack are simulated to predict the battery performance under a variety of dynamic conditions.

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TRAININGS & SEMINARS

GT is committed to providing the best possible training and customer support to all users of GT-SUITE. This includes making sure that GT users have the information they need to solve their simulation challenges. To help users get the most out of GT-SUITE, we offer a series of videos to help users with common challenges.

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