CPG - Application Beyond Airbag Modeling

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1 Abstract

CPG (Continuum-based Particle Gas) Solver is a new fluid solver in LS-DYNA. This solver was developed primarily to solve airbag applications more accurately, and as a result make airbag modeling predictive. It was soon realized that this solution method could be used beyond airbag modeling. This paper will focus mainly on EV battery modeling to demonstrate how CPG solver can push the envelope and assist with EV battery modeling and design.

2 Brief Introduction to CPG solver

Auto OEMs now use CAE as an active tool to design vehicles for crash safety. Airbags are part of passive safety system that are sophisticated and complex and are quite critical for occupant protection. So far airbag modeling has heavily relied on experimental data for airbags to be properly represented in a CAE model. This approach lacks predictive capabilities that has been the standard for structural design. This limits use of simulation to design and predict airbag interaction and deployment behavior.

Historically, the absence of computational physics based airbag simulation has limited predictive capabilities, making the development of a robust and accurate airbag simulation a critical necessity. This led to the development of an accurate, predictive fluid solver for airbags - CPG (Continuum-based Particle Gas) Solver. CPG adopts continuum theory and resolves the compressible Navier-Stokes equation coupled with an ideal gas equation of state. Like CPM (Corpuscular Particle Method), which is the current method for Airbag modeling, CPG is a particle-based approach that also does not require a volumetric mesh to represent the gas. CPG uses Eulerian grid to sample the gas particles in the volume, which gets resampled as the shape of the volume changes.

CPG potentially will enhance predictive capabilities of airbag modeling to the same standard as the other aspects of automotive crash safety. This new capability expands into other avenues of simulation which traditionally were non-existent. For instance, EV battery simulations which require FSI, thermal and other aspects related to catastrophic situations in battery design and safety.

3 EV Batteries

The revolution of storage of energy in batteries has led to transition from ICE engines to electric vehicles[Fig 1]. This has placed EV batteries at the forefront of automotive innovation. These energy storage systems must meet stringent requirements for energy density, safety, durability, and cost-effectiveness. Engineers are tasked with designing battery systems that not only deliver high performance but also integrate seamlessly into vehicle architectures.

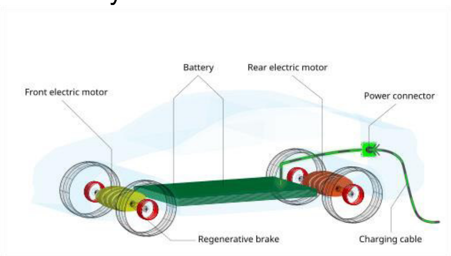

Fig 1. EV Propulsion System

EV batteries are typically composed of lithium-ion cells, which are grouped into modules and assembled into packs [Fig 2]. Each cell operates through reversible electrochemical reactions involving lithium ions migrating between the anode and cathode during charge and discharge cycles. The configuration and chemistry of these cells determine the overall energy capacity, voltage, and thermal behavior of the battery pack.

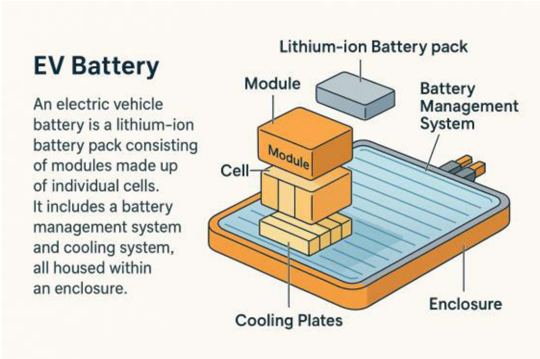

Fig 2. EV Battery Schematic

Engineering design of EV batteries involves multidisciplinary considerations across thermal, electrical, and mechanical domains. Thermal management is essential to prevent overheating and degradation, often implemented through liquid cooling channels or phase-change materials. Electrical design focuses on minimizing resistance and ensuring fault tolerance, while mechanical design ensures structural integrity under vibration, impact, and thermal expansion.

Finite element analysis (FEA) and system-level modeling are commonly used to validate design choices and optimize performance. The selection of cell format—cylindrical, prismatic, or pouch—affects packaging efficiency, energy density, and cooling strategy, making it a critical design decision

4 Risks from EV Batteries

EV batteries, while essential for electric mobility, pose distinct safety risks that must be carefully managed—namely mechanical, electrical, and thermal abuse—each of which can lead to system failure if not properly addressed can cause serious loss of property and life.

4.1 Mechanical Abuse

Mechanical abuse refers to physical damage sustained by the battery due to external forces such as impact, puncture, vibration, or compression. One of the most critical sources of mechanical abuse is **vehicle crashes**, which can deform or rupture the battery enclosure, compromise cell integrity, and lead to internal short circuits. In high-impact collisions, the mechanical stress may cause electrode misalignment, separator failure, or direct contact between the anode and cathode, triggering localized heating and potential thermal runaway. Engineers mitigate these risks by designing crash-resistant battery housings, integrating structural reinforcements, and conducting crash simulations to validate mechanical resilience under various impact scenarios.

4.2 Electrical Abuse

Electrical abuse occurs when the battery is operated outside its safe electrical limits, such as through overcharging, over-discharging, or exposure to excessive current. Overcharging can result in lithium plating on the anode, increasing the likelihood of internal shorts and thermal instability. Over-discharging may degrade the electrolyte and active materials, reducing capacity and cycle life. High current loads can cause rapid heating and accelerated degradation. These risks are managed through the Battery Management System (BMS), which continuously monitors voltage, current, and state-of-charge to enforce operational boundaries and prevent electrical faults.

4.3 Thermal Abuse

Thermal abuse involves exposure of the battery to temperatures beyond its safe operating range, either due to environmental conditions or internal heat generation. Elevated temperatures can accelerate side reactions, degrade cell components, and initiate thermal runaway—a self-propagating exothermic reaction that can lead to fire or explosion. Conversely, low temperatures can impair ion mobility and cause lithium plating during charging. Effective thermal management systems, including active cooling, insulation, and heat spreaders, are essential to maintain temperature uniformity and prevent localized hotspots. Engineers also model heat propagation within the pack to ensure thermal stability across all operating conditions.

5 Regulatory Landscape

As electric vehicle adoption accelerates globally, regulatory bodies have introduced standards to ensure the safety, performance, and sustainability of EV battery systems. While some regulations are already in effect, many are scheduled to enter compliance starting in 2026 and beyond. These standards address critical aspects such as crash safety, thermal stability, electrical isolation, and environmental impact. The table below summarizes key regulations across major regions:

Region	Regulation / Standard	Key Requirements	Compliance Date
USA	FMVSS No. 305a	Crash safety, electrical isolation, emergency response documentation	2027
USA	EPA 40 CFR Â§86.1815-27	Battery energy reporting, range accuracy, SoC display standards	2027 (light-duty), 2031 (heavy-duty)
USA	SAE J2929	Abuse testing protocols, thermal runaway prevention	Voluntary
USA	Inflation Reduction Act (IRA)	Tax credits tied to domestic battery sourcing and production	Active
EU	Regulation (EU) 2023/1542	Carbon footprint, battery passport, recycled content, due diligence	2024 to 2031
EU	Battery Passport Requirement	Digital traceability of battery materials and lifecycle data	2027
China	GB38031-2025	No fire/explosion for 2 hrs, bottom impact, fast-charge cycle safety, non-toxic smoke	Jul-26
Global	UN GTR No. 20	Electrical safety, abuse resistance, fire/toxic gas mitigation	Adopted globally
USA	ANSI EVSP Roadmap	Identifies gaps in EV battery safety, performance, and recycling standards	2023

Table 1. Regulatory Landscape

6 EV Battery Testing

EV battery testing is a **resource-intensive and time-consuming process** due to the complexity of the systems and the stringent safety standards they must meet. Each battery must undergo a wide range of evaluations—mechanical, electrical, thermal, and environmental—which often require specialized equipment, controlled conditions, and extended testing durations. Long-term cycle life tests alone can span several months, while abuse tests such as crash simulations or overcharging require repeated builds and high-cost materials. The need for precision and repeatability further adds to the cost, especially when testing across multiple configurations and chemistries.

Physical testing becomes particularly challenging when batteries are subjected to destructive abuse scenarios, such as thermal runaway or explosion. In these cases, the battery may rupture, ignite, or release toxic gases, making it difficult to collect meaningful post-event data[Fig 3]. Instrumentation can be damaged, and high-speed cameras or sensors may fail to capture critical moments due to the violent nature of the event. This limits the ability to analyze failure mechanisms in detail and often necessitates multiple test iterations, further increasing cost and complexity.

As a result, simulation tools will become essential for complementing physical testing by enabling detailed analysis of complex scenarios, predicting failure mechanisms, and optimizing system performance across a wide range of conditions. These tools significantly reduce the need for repeated destructive trials, lower development costs, and enhance safety validation by allowing virtual replication of mechanical, electrical, and thermal abuse cases that would be difficult or hazardous to reproduce physically.

Fig 3. EV Battery Thermal Runaway testing

7 Using CAE to simulate EV battery tests

7.1 Limitations of EV Battery Simulations

Simulating electric vehicle (EV) batteries presents several challenges due to the complexity and scale of the models involved. Detailed modeling of an entire battery pack can result in extremely large numerical models, which may become prohibitively expensive to solve. Futhermore, the accurate representation of complex material properties requires extensive experimental testing to accurately characterize the material. Parameter identification and calibration are also non-trivial tasks, often involving tedious processes to isolate and tune critical variables.

Another major limitation lies in the multi-physics nature of battery systems. Multi-physics solvers, which can handle coupled thermal, electrical, mechanical, and fluid-structure interaction, are essential for improving model accuracy but add to the computational burden. Battery aging and degradation further complicate simulations, as these effects evolve over time and require long-term modeling strategies. Ultimately, there is a trade-off between model complexity and computational cost—more detailed models offer higher accuracy but demand significantly greater resources, making real-time or large-scale simulations challenging.

7.2 Description of the Model used for this study

The model selected for this study is a generic electric vehicle (EV) battery pack developed by Ansys for internal research and testing purposes. This model features a full battery pack configuration composed of prismatic cells, offering a realistic and comprehensive representation of a typical EV battery system. It is designed to support a wide range of simulation needs, including electromagnetic (EM) analyses, and is fully compatible with multi-physics solvers, enabling coupled simulations across thermal, electrical, and structural domains.

This model [Fig 4] was intentionally developed to be as generic and broadly applicable as possible. This allows it to serve multiple roles: as a reference benchmark for EV battery simulations, a distribution-ready template for users, and a learning tool to help engineers and researchers better understand the behavior and architecture of EV batteries. Its completeness and versatility make it an ideal candidate for evaluating solver capabilities, testing modeling strategies, and guiding best practices in battery simulation workflows.

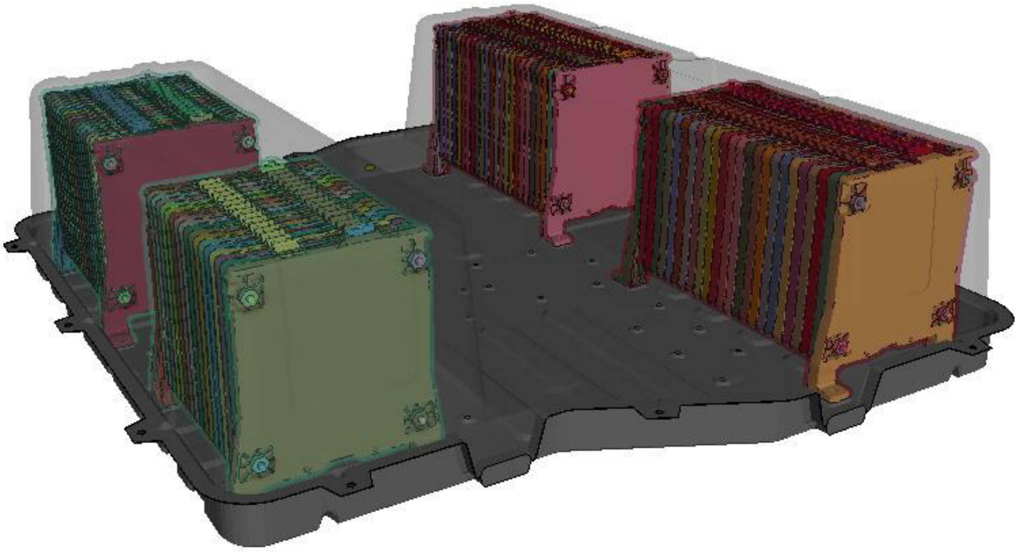

Fig 4. Generic Battery Pack used for this Study

7.3 Model Preparation

To adapt the original model for use with the Continuum-based Particle Gas (CPG) solver, several modifications were necessary to ensure the geometry was suitable to capture FSI correctly. All holes and openings, including vents, were sealed to create a watertight volume, as required by the solver. Most of these openings, primarily intended for mounting, would be sealed in real-world applications via bolts or other fasteners, justifying their closure in the simulation. Since the study did not require detailed resolution of every individual prismatic cell, the modules were grouped and wrapped within an envelope to represent the cell clusters that was more computationally efficient. Finally, to accurately capture interactions during dynamic events, appropriate contact definitions—specifically TIED and SLIDING contacts—were implemented between relevant components.

8 CPG solver in LS-DYNA for EV battery development

It is evident that multi-physics capabilities are essential if leveraging CAE in the development of electric vehicle (EV) batteries. LS-DYNA's explicit solver, when coupled with the CPG solver, provides a robust platform for simulating complex battery scenarios. To demonstrate this capability, three representative case studies were selected:

- Thermal runaway event
- Road debris impact on the underside of the battery pack
- Drop test

Disclaimer: The simulations presented in this study are intended solely to demonstrate the modeling and solver capabilities. No physical test data were available for correlation, and the results should not be interpreted as validated predictions.

8.1 Thermal Runaway

The objective of the thermal runaway simulation is to evaluate the effectiveness of gas venting pathways and assess the structural integrity of the battery pack during a thermal event. Specifically, the simulation aimed to verify that gases released during cell combustion are properly vented away from the vehicle cabin, thereby enhancing occupant safety. Additionally, the model was used to examine the containment of gases and the structural response of the battery enclosure under such conditions.

In the test setup, a subset of prismatic cells within the battery pack was assumed to undergo thermal runaway, releasing high-temperature gases. The gas properties and mass flow rate were derived from a tank test, this was used as input for *AIRBAG_CPG.

Key evaluation metrics included:

- **Structural deformation**, to identify potential cracks or failures in the enclosure
- **Venting performance**, to ensure gases followed controlled paths and to assess the effectiveness of vent placement and design [Fig5,6]
- **Thermal propagation**, by monitoring temperature rise in neighboring cells to evaluate the risk of cascading failure [Fig5,6]

Fig 5. Flow of Gas, Temperature and Deformation Plot

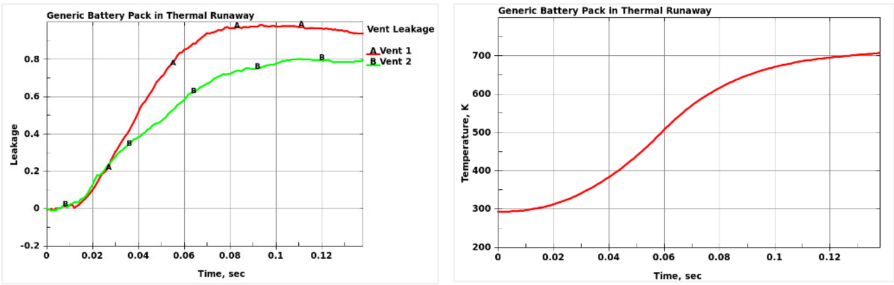

Fig 6. Vent Leakage and Temperature in the Batt Pack

8.2 Road Debris Impact

In alignment with China's upcoming EV battery safety regulation GB 38031-2025, a *bottom impact test* has been introduced to assess battery pack integrity under road debris impact conditions. Effective July 1, 2026, this regulation mandates that battery packs withstand an impact from a 30 mm-diameter steel ball with an energy of 150 joules, without exhibiting leakage, cracks, explosion, or loss of insulation. To explore the robustness of the battery design under even more severe conditions, a simulation was conducted using a 100 mm-diameter steel ball with an impact energy of 1095 joules—significantly exceeding the regulatory requirement.

The simulation setup initialized the battery pack with air and open vents to replicate realistic test conditions. Key outputs evaluated included:

- **Pressure and volume changes** within the battery enclosure due to gas compression and venting dynamics [Fig7,8]
- **Structural deformation and potential failure** of the battery housing under impact
- **Movement of individual cells**, which could pose a risk of internal short circuits.

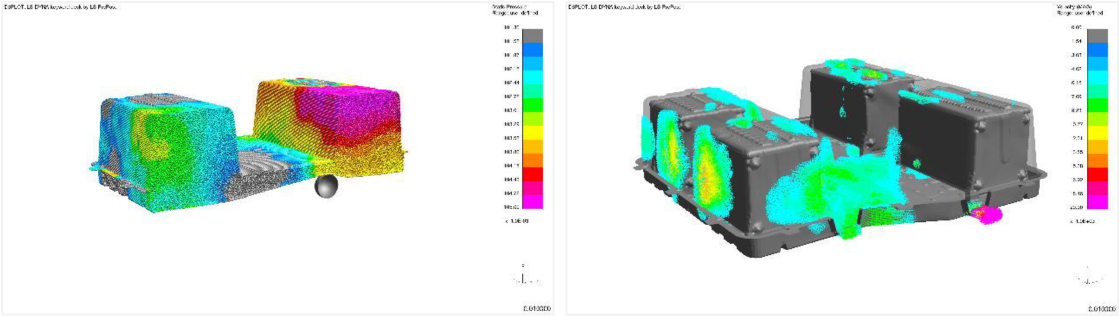

Fig 7. Pressure contours and Vector plots of air particles

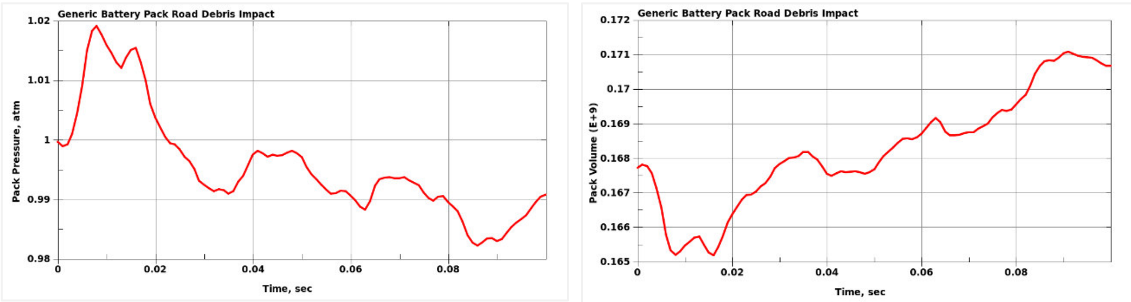

Fig 8. Pressure and Volume in the battery pack

8.3 Vertical Drop Test

The drop test simulation was conducted to evaluate the mechanical robustness of the battery pack under accidental drop conditions, such as during handling or installation. In this setup, the battery pack with internal volume initialized with air was dropped vertically onto a rigid surface—representing the ground—with an initial velocity of 1000 mm/s.

The simulation focused on three key evaluation metrics:

- **pressure and volume changes** within the battery enclosure due to compression and potential venting, in this case it was observed the pressure increased even with volume increase as the air from outside was entering into the battery pack through the vents [Fig 9]

- **structural deformation and failure**, particularly in the enclosure and mounting interfaces [Fig 9]

- **movement of individual cells**, which could lead to internal short circuits or compromise electrical isolation.

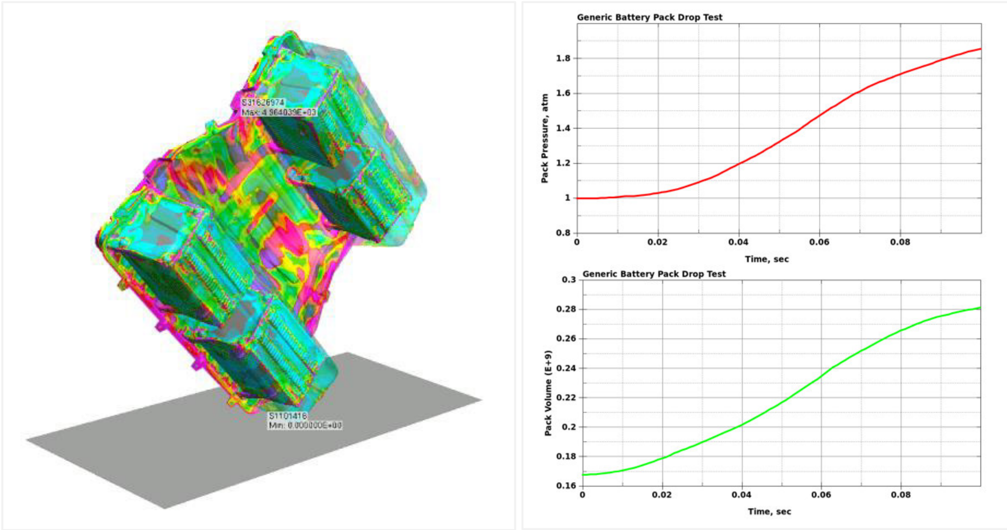

Fig 9. Deformation with Pressure and Volume plots

9 Conclusions and future work

This study demonstrates the capability of the simulation framework to handle extreme scenarios and provides valuable insights for optimizing battery pack design for future regulatory compliance and enhanced safety. This approach produced results that closely align with real-world behavior across various scenarios. Some of them include thermal runaway, road debris impact, and drop tests, this has been validated through collaborative efforts with OEM partners. Notably, the integration of the CPG solution into existing battery pack models was simple, while incorporating complexities related to battery safety. This ease of adoption suggests that CPG can be rapidly integrated into standard EV battery development workflows.

Looking ahead, two primary areas have been identified for further enhancement.

- Coupling the CPG solver with a thermal solver is a promising next step, initial studies indicate strong potential for improved fidelity in thermal-mechanical simulations.
- While the CPG solver offers high accuracy, its current computational performance is significantly slower. Ongoing efforts are focused on optimizing runtimes to make CPG more viable for large-scale or time-sensitive simulations.

10 Literature and References

1. Patil, N. (2024). *Rapid Design Studies of an Electric Vehicle Battery Module*, Altair
2. Sasena, M., & Chu, D. (2023). *Battery Sizing and Design for Electric Vehicles*, MathWorks
3. Ghosh, N., Garg, A., Li, W., Gao, L., & Nguyen-Thoi, T. (2022). *Engineering Design of Battery Module for Electric Vehicles: Comprehensive Framework Development*. *Journal of Electrochemical Energy Conversion and Storage*, 19(3), 030902, ASME
4. Crashworthiness Models For Automotive Batteries, *A Report on the Department of Energy Project 2088-A031-15 for the National Highway Traffic Safety Administration*
5. An Investigation on the Ground Impact of Electric Vehicle, Zhiwei Zhao *et al* 2022 *J. Phys.: Conf. Ser.* 2396 012030
6. Preliminary Validation of New Continuum-based Particle Gas (CPG) method for Airbag Deployment Simulations, Hiromichi Ohira, Richard Taylor, Shinichi Arimoto, Kosho Kawahara, Hiroyuki Umetani, Edouard Yreux, Inaki Caldichoury, Shinya Hayashi, Masato Nishi, 2024 LS-DYNA User's Conference
7. Experimental study of thermal runaway process of 256Ah prismatic nickel-rich battery, Ningning Wei, Minghai Li, Front. Energy Res., 06 August 2023
8. Crashworthiness Models For Automotive Batteries, *A Report on the Department of Energy Project 2088-A031-15 for the National Highway Traffic Safety Administration*
9. An Investigation on the Ground Impact of Electric Vehicle, Zhiwei Zhao *et al* 2022 *J. Phys.: Conf. Ser.* 2396 012030
10. Preliminary Validation of New Continuum-based Particle Gas (CPG) method for Airbag Deployment Simulations, Hiromichi Ohira, Richard Taylor, Shinichi Arimoto, Kosho Kawahara, Hiroyuki Umetani, Edouard Yreux, Inaki Caldichoury, Shinya Hayashi, Masato Nishi, 2024 LS-DYNA User's Conference