RAPID DESIGN STUDIES OF AN ELECTRIC VEHICLE BATTERY MODULE

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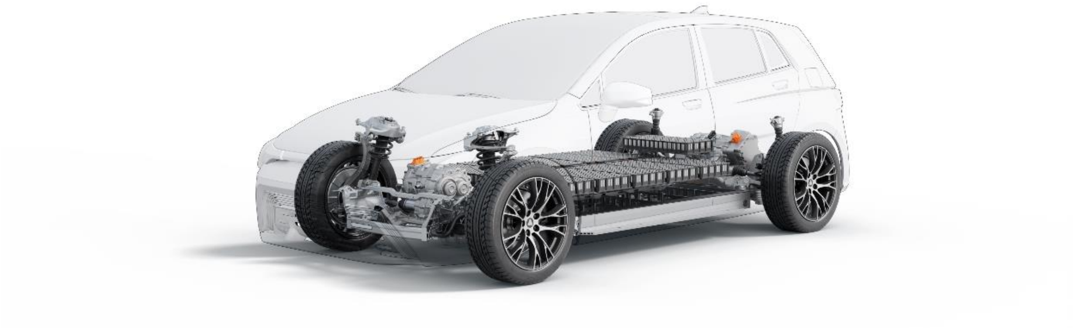


Introduction

The rapidly growing electric vehicle (EV) market is at the forefront of transportation innovation, driven by the need for cleaner, more sustainable mobility solutions. At the heart of every EV lies a remarkable technological innovation – the battery module. These compact, powerful energy storage units are revolutionizing the automotive industry and have become the backbone of sustainable transportation. Central to the development of high-performance EVs is the design and engineering of the battery module. Finite element analysis (FEA) plays a pivotal role in optimizing battery module performance, safety, and reliability. This whitepaper explores the effect of cylindrical cells versus prismatic cells on the structural integrity of a battery module through a design study, made easy and efficient using Altair's revolutionary Altair SimSolid® technology.

Envisioning the Challenges

Battery modules are the driving force of EVs, serving as the primary energy storage units that power the electric motor. A battery module is a complex assembly of individual battery cells, housing, thermal management systems, and safety mechanisms. Selecting the type of cells to be used in an EV battery module is a crucial decision that impacts the vehicle's performance, range, safety, and cost. The choice between cylindrical cells, prismatic cells, and pouch cells depends on a range of factors, including design, packaging, and performance considerations. Since pouch cells are especially susceptible to heat generation and physical damage, they were eliminated as a choice in this design study. The following table lists the primary differences between cylindrical and prismatic cells.

Parameter	Cylindrical Cells	Prismatic Cells
Energy Density	Lowest	Highest
Power Output	More	Less
Packaging	Least Space-Efficient	More Space-Efficient
Weight	More	Less
Cost	Less Expensive	More Expensive

Figure 1. Comparing differences between cylindrical and prismatic cells

For this study, the battery modules were designed using Altair® Inspire™. The module with cylindrical cells had curvilinear cooling lines, and the module with prismatic cells had C-shaped cooling lines. Using Inspire, one can quickly create, modify, and defeature solid geometry (CAD) models, use PolyNURBS to create free-form smooth geometry, and study multiple assembly configurations.

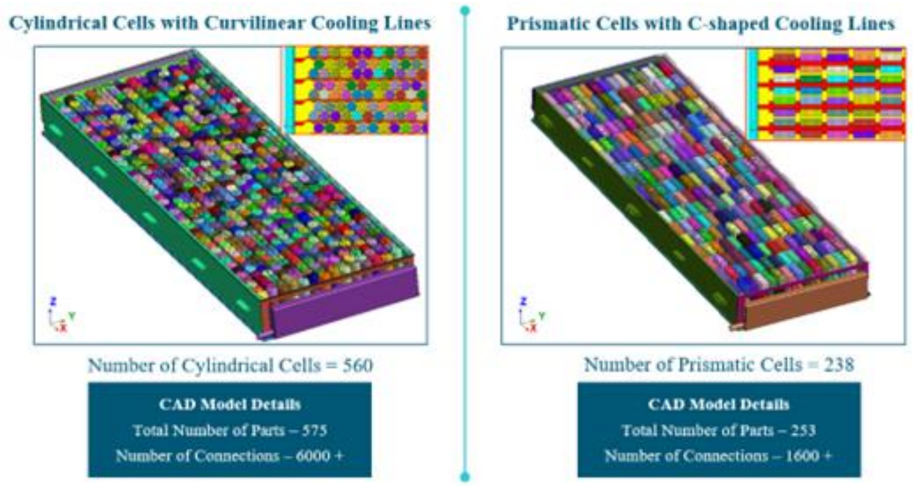


Figure 2. (Left) Battery module with cylindrical cells and curvilinear cooling lines, (Right) Battery module with prismatic cells and C-shaped cooling lines

FEA of an EV battery module is a critical process with significant implications for performance, safety, and design optimization. However, it also comes with three major challenges:

1. **Complex Geometries**: EV battery modules often have complex geometries with irregular shapes, which can make meshing and modelling for FEA simulations intricate, time consuming, and computationally intensive.
2. **Scalability**: Battery modules come in various sizes and configurations. FEA models need to be scalable to accommodate these different parameters, which can be a challenge for modeling and simulation software.
3. **Computational Resources**: Performing FEA simulations with the necessary level of detail and accuracy often requires substantial computational resources. Managing the computational workload can be difficult.

This makes the EV battery module a prime candidate for simulation using Altair SimSolid. Why? Altair SimSolid introduces a new and unique technology for analysis that does not require a mesh and operates directly on original, unsimplified CAD geometry. The CAD model is the simulation model. It eliminates geometry preparation and meshing: the two most time-consuming, expertise-intensive, and error-prone tasks performed in a conventional structural simulation. Also, Altair SimSolid supports all typical connections (bolt/nut, bonded, welds, rivets, sliding) and analysis of linear static, modal, and thermal properties, along with more complex coupled, nonlinear, transient dynamic effects. With such a versatile, user-friendly, and computationally inexpensive CAE solution available in the market, designers and CAE engineers now have more power than ever to quickly analyze the most complex structures, compared to CAD-based or traditional FEA tools.

Exploring the Altair SimSolid Workflow

During the process of modeling an EV battery module for analysis using Altair SimSolid, there are some key considerations to keep in mind:

Geometry Settings: Options include Standard, Increased, and High. This setting represents the initial density of the equations used on a part-by-part basis. For most parts, Standard is the best choice. It only needs to be increased for parts with extreme aspect ratios such as long, narrow parts or thin, complex curved shells.

Solution Settings: Custom solution settings include the “Adapt to Thin Shells” option which has additional checks for curvature and thickness. Using this setting for thin solids like sheet metal and stamped parts is the best way to achieve more accurate results.

Material Properties: Accurate material properties must be used to ensure accurate results. These properties include elastic modulus, Poisson's ratio, and yield strength.

Connections: Establishing proper connections between different parts and surfaces through bonded contact, welds, or rivets is essential towards getting the correct values of stress concentrations at the connection junctions. This is also essential in accurately determining assembly level behavior.

Boundary Conditions: The boundary conditions must be realistic and appropriate to the intended service condition. In the present case, the battery module is constrained at the side supports to perform modal analysis. Further, a uniform frequency function (0 to 10000 Hz) with an amplitude factor of 1, combined with an excitation of 5G (along the vertical z-axis), are used as boundary conditions for the frequency response analysis. The volumetric heat generated by cells and the temperature at inlet, and outlet of cooling lines is used to carry out a steady-state thermal analysis. These thermal loads are further used as inputs for a linear static structural analysis.

One important point to reiterate here is that Altair SimSolid eliminates the complex, time-consuming steps of CAD clean-up and meshing while analyzing the battery module. Also, most embedded CAD-based FEA systems are limited to simple part analyses and don’t allow easy comparison of different design configurations. Evaluating changes to a large assembly is particularly problematic. Altair SimSolid offers a better, more efficient way to set up and manage design studies.

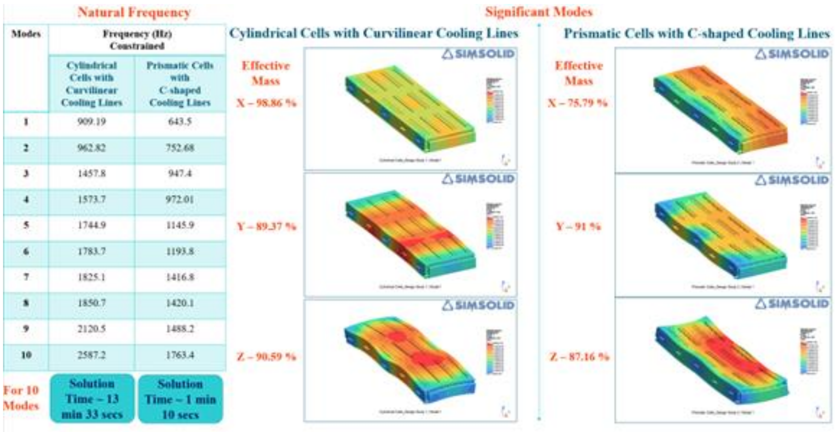
The baseline study has been performed using the battery module with cylindrical cells and curvilinear cooling lines. Once the results of the analysis are ready, the CAD model of battery module with prismatic cells and C-shaped cooling lines is imported to Altair SimSolid. It is placed into a new design study and Altair SimSolid then automatically reapplies or maps the existing baseline material properties, connections, and boundary conditions to the new model. Alternatively, one can simply copy the design study and then manually adjust geometry and connection data. This second method is useful in situations where one wants to evaluate non-geometric changes such as suppressing parts, variations in material properties, or adjustments to connection tolerances.

Measuring the Outcomes: Dynamic Analysis

In this whitepaper, we will evaluate the two battery module designs considering dynamic, thermal, and linear static analyses.

A basic dynamic or modal analysis is primarily used to determine the natural frequencies of a structure. It is also used to check if all the parts of an assembly are properly connected.

Figures 3 and 4 present the results of the modal and frequency response analysis for both variants of the battery module, along with contours for significant mode shapes. Since the magnitude of natural frequencies is greater than 0 Hz, the presence of any rigid body modes indicating loose connections can be ruled out. Also, we can observe that the battery module with cylindrical cells and curvilinear cooling lines has higher frequencies compared to the battery module with prismatic cells and C-shaped cooling lines, indicating that the former has higher stiffness.


Natural Frequency

Modes	Frequency (Hz) Constrained	
	Cylindrical Cells with Curvilinear Cooling Lines	Prismatic Cells with C-shaped Cooling Lines
1	909.19	643.5
2	962.82	752.68
3	1457.8	947.4
4	1573.7	972.01
5	1744.9	1145.9
6	1783.7	1193.8
7	1825.1	1416.8
8	1850.7	1420.1
9	2120.5	1488.2
10	2587.2	1763.4
For 10 Modes	Solution Time – 13 min 33 secs	Solution Time – 1 min 10 secs

Figure 3. Results of modal analysis

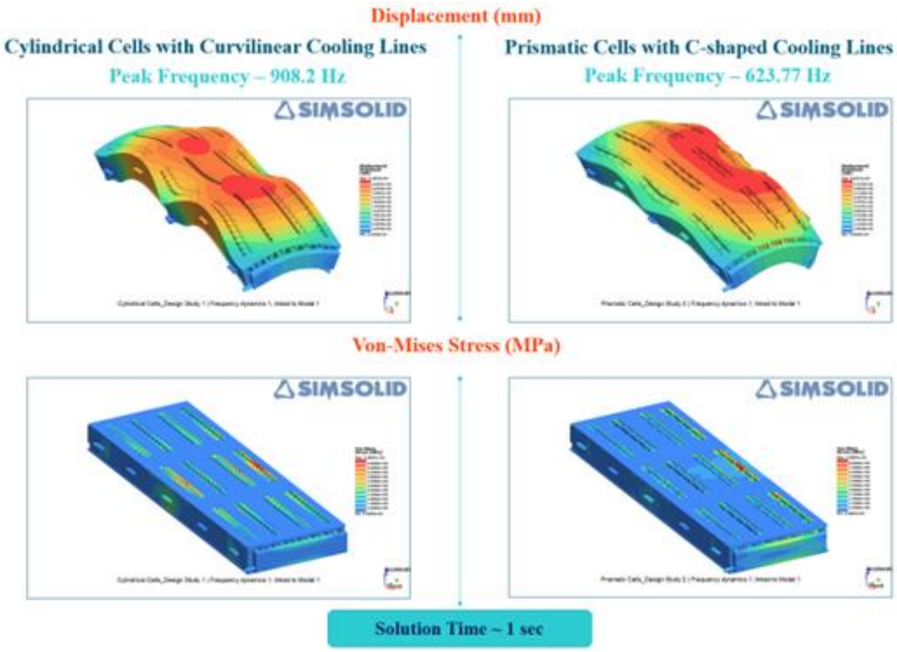


Figure 4. Results of frequency response analysis

Steady-State Thermal Analysis

Efficient thermal management is crucial to prevent overheating and thermal runaway in battery cells. For this study, we simulated the thermal behavior and investigated the temperature distribution of the battery module with both cell types.

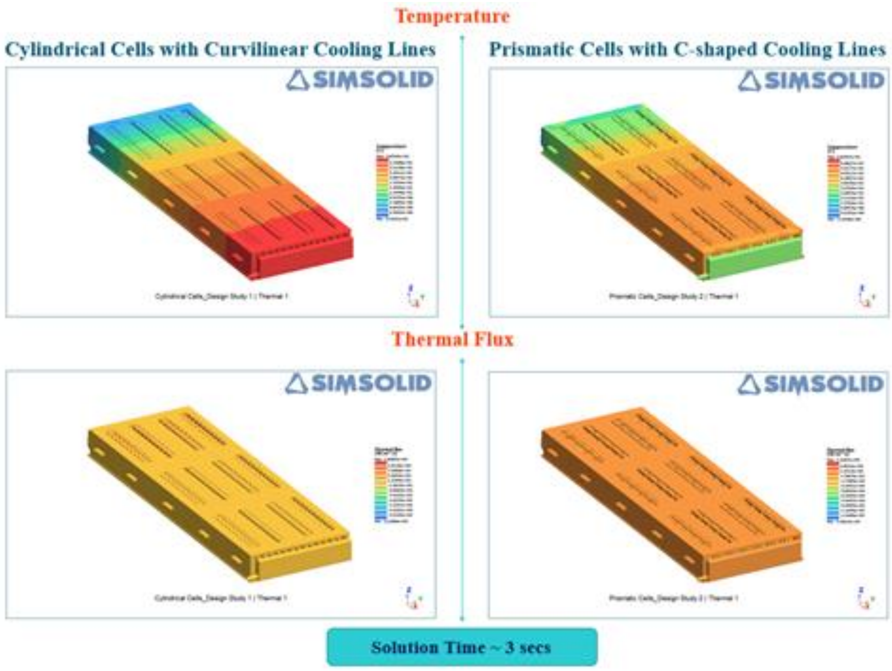


Figure 5. Results of steady state thermal analysis

From the contours, we can observe that the battery module with cylindrical cells and curvilinear cooling lines reaches a maximum temperature of 30°C. In contrast, the one with prismatic cells and C-shaped cooling lines reaches a maximum temperature of around 66°C. Hence, we can conclude that the battery module with cylindrical cells is more thermally efficient than its prismatic cell counterpart. Proper thermal management is essential to ensure consistent performance, maintain the temperature of the battery within safe operating limits, and prolong the battery's life.

Linear Static Analysis

Battery modules must withstand various mechanical stresses, including those from collisions, vibrations, and rough road conditions. Ensuring the mechanical strength of the battery module is essential for structural stability and safety in various conditions, such as crashes and extreme weather. A linear static analysis assesses the mechanical strength and structural integrity of the module, contributing to safety and reliability. Figure 5 presents the contours for displacement and Von Mises stress.

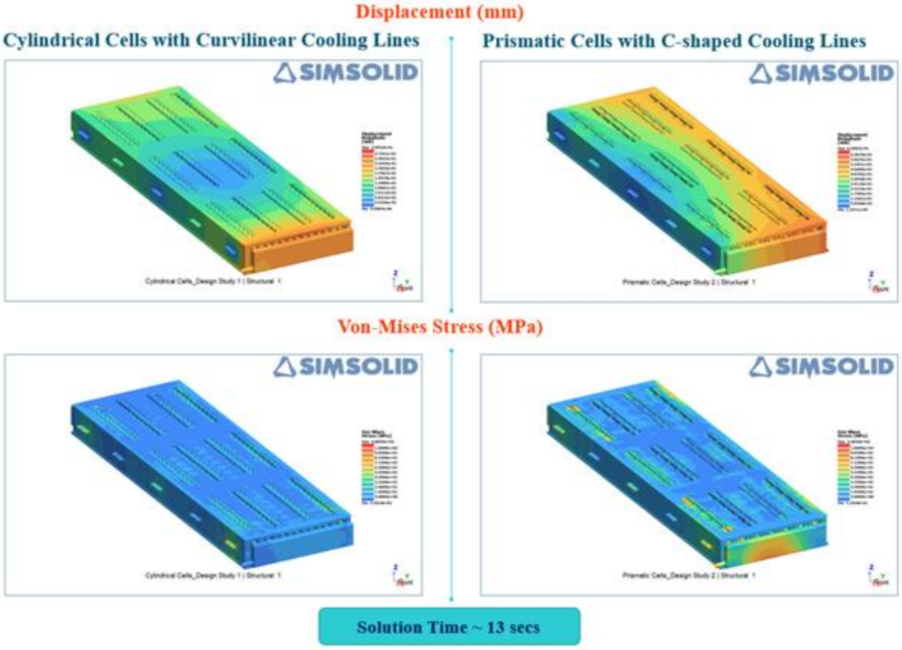


Figure 6. Results of linear static analysis

From the contours, we can observe that the battery module with cylindrical cells and curvilinear cooling lines has lower displacement but experiences a slightly higher stress than the battery module with prismatic cells and C-shaped cooling lines. By assessing structural integrity via simulation, designers can optimize the battery module's strength and safety. This ensures that the battery module is robust and safe in real-world situations. Early identification of design flaws and weaknesses – and being able to rapidly evaluate design alternatives with Altair SimSolid – can lead to cost savings by minimizing the need for costly redesign and prototype iterations.

Choosing the Path Forward

The global automotive industry is undergoing a significant transformation, and the driving force behind this change is the shift towards EVs. This shift is not merely a trend, but a necessity driven by environmental concerns, government regulations, and technological advancements.

Applying simulation using Altair SimSolid is essential for creating safe, efficient EVs within ever-shrinking design timelines. As EV technologies advance and battery modules evolve, simulation will remain an indispensable tool for engineers and designers. It contributes to the electrification of the automotive industry by addressing design complexities and ensuring that battery modules meet safety and regulatory standards. However, it also involves various challenges related to accuracy, scalability, and computational resources, which can be easily addressed using design studies in Altair SimSolid. By applying realistic boundary conditions, and material properties, making connections, and interpreting the results appropriately, design and CAE engineers can ensure that their designs meet the necessary safety and performance standards. Moreover, Altair SimSolid is fast, with typical solution times measured in seconds to minutes on a standard PC, enabling comparison between multiple design scenarios quickly and accurately.

Furthermore, the choice between cylindrical, prismatic, and pouch cells involves a trade-off between factors such as energy density, packaging efficiency, cost, weight, mechanical strength, and thermal management. It is essential to consider the specific requirements of the EV and the intended battery pack design when selecting the appropriate cell type. Additionally, advancements in battery technology are ongoing, and the choice of cell type may evolve as innovations in cell design and chemistry become available.

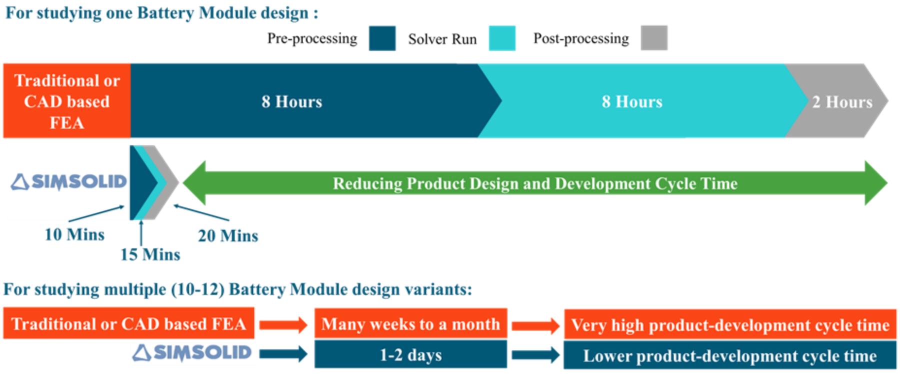


Figure 7. Faster product development cycles using Altair SimSolid®

Thus, we can conclude that designing a safe, efficient, and reliable battery module is paramount to the success of EVs. By optimizing thermal management, ensuring structural integrity, reducing costs, and accelerating development, Altair SimSolid contributes significantly to the electrification of the automotive industry, pushing for a cleaner and more sustainable future. One can also explore Altair® SimLab® to evaluate more complex multiphysics phenomena, including structural, drop-impact, computational fluid dynamics, thermo-electric, and thermal runaway to analyze battery module performance.