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# ELECTRIC VEHICLE BATTERY PACK UNDERBODY SHIELD DESIGN AND OPTIMIZATION: A STUDY ON DACIA SPRING

***Abstract:*** *The increasing popularity of low-cost electric vehicles (EV) is driven by their affordability compared to conventional gasoline-powered cars, making them an attractive option for many citizens. Growing awareness and concern about environmental issues, such as air pollution and climate change, have played a major role in the rising demand for low-cost electric vehicles as an eco-friendly transportation solution. In addition, government incentives and tax credits are making electric vehicles accessible to a large number of consumers. With EV`s popularity, their power sources, in case of mechanical impact, can explode or catch fire, posing a potential safety risk. However, advances in battery technology and safety measures have greatly minimised these risks. Manufacturers have implemented various safety precautions, such as reinforced enclosures and thermal management systems, to prevent such incidents. In addition, strict regulations and standards have been introduced to ensure the safe production and use of electric vehicle batteries. In this article, we will discuss an underbody protection shield for batteries that has been developed and optimised to provide additional protection for a Dacia SPRING battery pack. The underbody shield has been developed to provide additional protection to the battery, reducing the risk of damage from debris or impact.*

***Key words:*** *Electric vehicle, lithium-ion battery, topography optimization, underbody shield*

## 1. INTRODUCTION

One of the key components in electric vehicles is the battery underbody shield. This shield plays a crucial role in protecting the battery pack from potential damage and ensuring the overall safety and performance of the vehicle. The shield deflects rocks, debris, and other objects that could puncture or damage the battery, potentially causing a fire or other safety hazards. Underbody shields can also contribute to a vehicle's aerodynamic efficiency. By smoothing out the airflow under the car, they can reduce drag and improve range. This is especially important for EVs, where maximizing range is a key concern [1-2].

The significant weight of battery packs in new battery electric vehicles (BEVs) necessitates the positioning of the housing beneath the passenger compartment floor. This strategy minimizes the shift in the vehicle's centre of gravity (CG), thereby maintaining optimal handling characteristics. This positioning strategy presents a compelling advantage from the perspective of battery pack survivability during frontal, lateral, and rear-end collisions [3] .

Belingardi et al. [4] conducted an analysis of the battery pack's impact protection in their research, with a particular focus on side impacts resulting from collisions with another vehicle or a stationary object like a pole. These scenarios were identified as the most critical conditions for battery safety. The study evaluated three distinct approaches for strengthening the lateral rocker, a crucial component in protecting the battery pack during side impacts. One approach utilized a conventional internal partition, while the other two employed extruded profiles integrated into the rocker. Finite element analysis, conducted using a simplified model, was employed to assess the efficacy of these reinforcement options. The results clearly demonstrated the effectiveness of various reinforcement strategies within the rocker and emphasized the importance of selecting an appropriate wall thickness. This selection ensures optimal interaction between the different components of the vehicle side structure and battery case, ultimately enhancing overall battery safety.

A recent incident involving a Dacia SPRING fire in autumn 2023 was reported by the vehicle's owner [5].

**Figure 1** Perforated battery case [5].

**Figure 2** Underbody deformed high voltage cable shield [5].

Fortunately, the event resulted in no casualties, but significant property loss was incurred. As evidenced by Figures 1 and 2, the assessors' report clearly documented the presence of distortions in the affected vehicle. A comprehensive visual examination of the specific location revealed the following: two nearly round holes, approximately 5-6 mm in diameter, were identified in the lower metal casing of the traction battery towards the rear of the car. Visual inspection confirmed that these perforations penetrated the interior of the traction battery modules.

Researchers [6] developed a protective barrier, known as an underbody shield (UBS), for the battery of an electric vehicle in their work. This shield was fabricated from carbon fibre reinforced thermoplastic composites and comprised a primary shield plate and a collision prevention bar (CPB). Finite element analysis was employed to assess the mechanical response to impact, considering the placement of the CPB and the configuration of the underbody shield plate. To achieve optimal performance, the researchers utilized hybrid composites. The target thickness of the underbody shield was 2.4 mm. A car "crash" simulation test was conducted using a concrete barrier. The results demonstrated that the UBS effectively shielded the battery from impact damage. The battery experienced minimal deformation (only 5 mm) and no loss of battery fluids. Notably, the UBS constructed from hybrid composites achieved a total mass of 3.88 kg, representing a significant 52% weight reduction compared to a steel UBS with equivalent deformation. This study contributes to the enhancement of driving efficiency in electric vehicles by offering a lightweight and effective alternative for battery protection.

Shui et al. [7] employed a four-step finite element (FE) analysis to optimize the design of electric vehicle battery enclosures. This optimization aimed to minimize enclosure mass and deformation while maximizing minimum natural frequency, considering the impact of vibrations and shocks on battery pack mechanics and overall vehicle safety. The FE analysis utilized various design of experiments (DoE) methods (CCD-RSM, CCD-ANN, LHS-RSM, LHS-ANN) to create models for deformation, natural frequency, and mass. The optimal DoE method (CCD-ANN) was then used to develop and optimize empirical models for these three design aspects using NSGA-II. The initial deformation analysis revealed significant loads on the central surface (0.0015-0.0016 m). Modal analysis identified six modes per approach with minimum natural frequencies between 91.62 and 99.67 Hz. Optimizing these frequencies is crucial to ensure they fall outside the typical vibration range (7-200 Hz) experienced by EVs during operation.

## 2. SHAPE TOPOGRAPHY OPTIMIZATION

Topological optimization of an electric vehicle battery protection shield can significantly enhance system efficiency and durability by tailoring its geometry to maximize impact energy dissipation and mitigate battery damage risk [8]. The computer-aided design (CAD) was performed in Solidworks, followed by finite element analysis (FEM) using HyperMesh simulation tool and the OptiStruct solver. Visualization of the results in HyperView facilitated their understanding and interpretation, allowing informed decisions to be made for the optimization of the battery protection shield design.

### 2.1 Underbody shield geometry design

This paper presents the design and topological optimization of a protective shield for the underbody of an electric vehicle, primarily aiming to enhance efficiency and durability in the context of the lack of adequate protection against road debris. The main objective was to devise a shield robust enough to safeguard the vehicle against obstacles encountered on the road while maintaining a low weight and aerodynamic profile to minimize the negative impact on vehicle performance [9]. The adopted approach involved a detailed analysis of the loads acting on the shield, followed by the exploration of innovative and structurally efficient solutions.

Figure 3 illustrates the region of interest of the protective shield, highlighting its additional role in providing safety for the high-voltage cables located in the underbody of the electric vehicle.

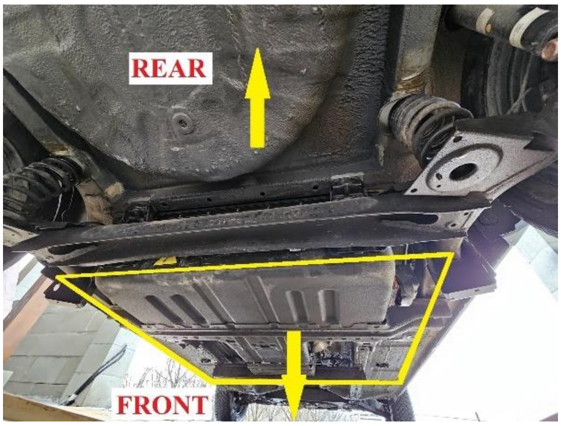



**Figure 3** Dacia Spring underbody-battery pack integration, underside view.

The definition of optimized ("design") and non-optimized ("non-design") zones in the final CAD model represents a crucial step in the critical evaluation of the current protective shield design (Figure 4). This comparative analysis allows for the identification of the strengths and weaknesses of the current solution, providing a solid foundation for the formulation of improvement strategies that can lead to the achievement of the initially established objectives.

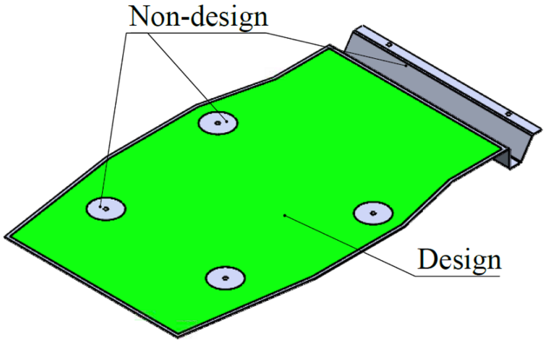



**Figure 4** Proposed underbody-battery pack shield model for optimization.

### 2.2 Topography optimization

To obtain an optimized model, a rigorous methodology was implemented, comprising the following:

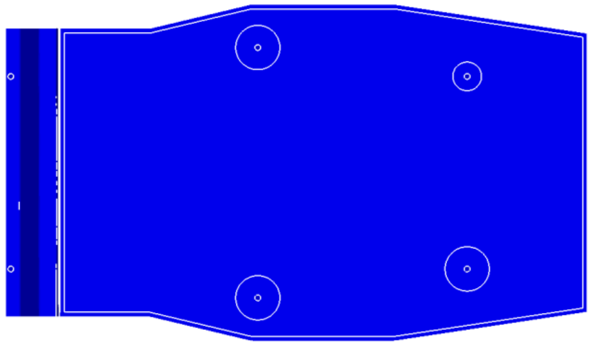
- model import in HyperMesh;
- optimization responses;
- design variables for optimization;
- optimization responses;
- create optimization objective;
- post processing in HyperView.

The first stage of the optimization process involved importing the CAD model of the protective shield into HyperMesh simulation tool to initiate the study. Rigid zones, the optimization zone, and the free zone were defined, and the material from which the shield is made, namely 6063-T1 aluminium, was subsequently allocated, with the following properties: initial density 2.7 x $10^{-6}$ kg/mm3, Young's modulus 70 GPa, yield stress 0.09026 GPa, ultimate tensile stress 0.175 GPa, failure plastic strain 0.75 and Poisson`s ratio 0.33. This preliminary stage established the baseline configuration for detailed design analysis.

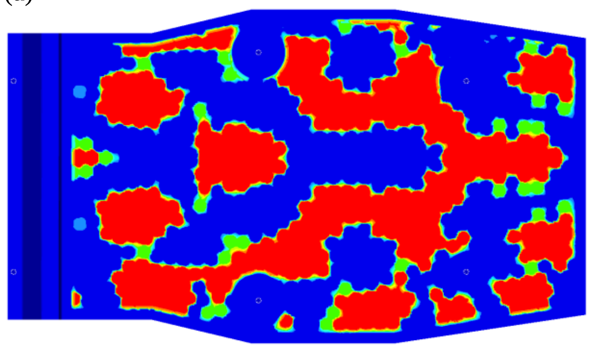
Topological optimization is used to modify the geometrical shape of planar or deformed surfaces of a model, generating a reinforcement network that leads to an optimal distribution of material. This approach is particularly useful for models discretized into shell finite elements, allowing for the obtention of structures with increased structural efficiency and superior constructive-functional parameters.

The model was discretized into 96,080 combined elements (square and triangular) with a length of 2 mm, the optimization zone for the presented study being represented by the central surface of the protective shield. This discretization allowed for a detailed analysis of the structural behaviour of the model in the area of interest. After the model discretization, the choice and assignment of the material is particularly important, and in this study the material assigned to this component is aluminium, with the mechanical characteristics from MAT 1, a density of 2.7 g/$cm^3$, a Poisson's ratio of 0.33 and a Young's modulus of 70 GPa.

Defining the frequency range of overloads that occur during the operation of the electric vehicle is a crucial step in topological optimization, ensuring an accurate and relevant approach to the problem. The optimized shape proposed by the author is the result of topological optimization at a frequency of 22-30 Hz, a range considered to be dominant in the transmission of vibrations to the vehicle chassis due to the wheel-road interaction according to figure 5 [10].



(a)



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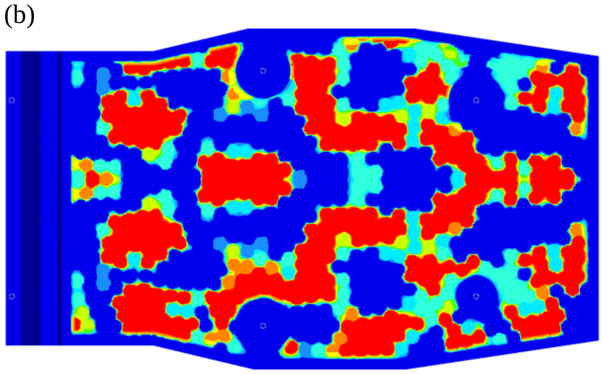
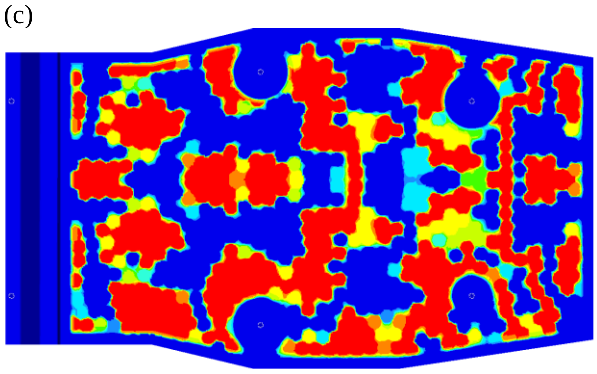


(c)



(d)

**Figure 5** Iteration process of topography optimization: (a)- iteration 0; (b)- iteration 4 (c)- iteration 7 (d)- iteration 11.

## 3. OPTMISED MODEL RESULT

Running the topological optimization algorithm using the Optistruct solver on the baseline model of the under shield resulted in an optimized shape after a specific number of iterations determined by the optimization program. The optimized shape was then refined using SolidWorks software by simplifying the areas identified by the algorithm, approximating them with simple and easy-to-manufacture geometric shapes, while maintaining the structural performance achieved as presented in figure 6.

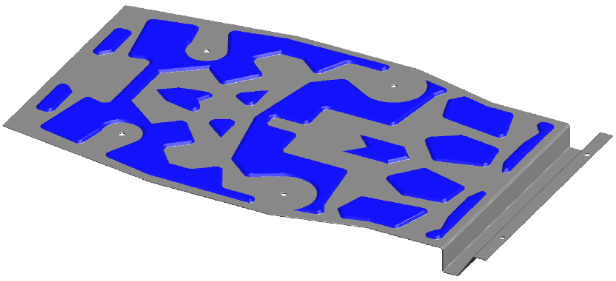


**Figure 6** Final model with optimised pattern on the design surface.

## 4. CONCLUSIONS

In this paper, an under shield for protecting the battery of an electric vehicle was designed and optimized. The shield was modelled from a lightweight material, ensuring efficient protection against stones or other objects that could damage the battery of the electric vehicle. Its aerodynamic design also helps to reduce wind resistance and improve the energy efficiency of the vehicle, contributing to increasing its range.

The implementation of optimized designs for aluminium structures has the potential to achieve significant reductions in weight while simultaneously increasing stiffness. Future efforts should focus on validating the current findings by developing a comprehensive vehicle model and conducting comparative impact simulations to assess the safety shield's performance under realistic crash scenarios. As EV technology advances, we can expect further developments in underbody shield design, potentially including utilization of even lighter and more durable materials and integration of active aerodynamic features for further efficiency improvements.

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