CAD-Embedded **Battery Pack Design Optimization** for Mobilis Electric Vehicle

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> "We were very insecure about the operating conditions of our battery pack. We couldn't know for sure if the cooling solutions adopted would suffice in the most diverse climatic conditions we can find in the country. Thankfully, with FloEFD™ and the expertise of Creative Solutions, it was possible to develop a good model of our battery pack. Numerous situations were simulated and with this, we were able to optimize the design in order to guarantee the perfect operation of the batteries in different conditions **Thiago Hoeltgebaum, R&D Director, Mobilis**

Creative Solutions is a customer-centric group which offer computational design and simulation services to its clients in diverse areas such as automotive, aerospace, energy generation, oil and gas, and telecommunications among others and have customers spread throughout Latin America. Recently, we engaged Mobilis, a Brazilian company, to develop small electric vehicles (EV) for recreational use. The purpose of this work was to optimize the battery pack geometry in Mobilis to avoid problems caused by insufficient refrigeration, while maximizing the internal air flow and keeping the system under ideal operation conditions, extending the life of the equipment. CAD-embedded simulation capabilities of FloEFD were central to our work for battery design optimization.

Figure 1 shows the battery pack design and its location on the floor, underneath the driver seat of the vehicle. The battery pack has 4.1kWh of total energy and peak power of 12.3kW with 32 cells in a 16S2P configuration (two cells in parallel and 16 of such units connected in series). The battery pack weighs 60kg, has a volume of approximately 30 liters and is air-cooled. Cells were supplied by GB Systems in China and have Lithium Iron Phosphate (LFP) based chemistry.

The work was done in two parts:

- In the first stage, temperature distributions in the battery pack were simulated with the original pack design to examine the severity of thermal issues in the pack, and
- In the stage two, CAD-embedded battery pack design optimization was pursued to reduce maximum temperature and to deliver more uniform temperature distribution among cells during operation.

A more uniform temperature distribution and lower maximum, as is well-known by now, results in longer battery life. Simulation studies were conducted in two distinct operating conditions, see Table 1. The FloEFD-driven redesign of battery pack, as showcased in this article, resulted in significant improvements in the thermal behavior that guarantees thermal comfort of the batteries under very critical conditions.

Battery Pack Design Exploration

The original battery pack design, as shown in Figure 1(b), consisted of one inlet and outlet for air with an outlet port on the side with smaller diameter than the inlet port. Although the calculated Reynolds number didn't exceed transition value for turbulence, in this work turbulent flow is assumed for aluminum base plate (enclosure of the battery pack) due to the likely interactions between air and uneven ground underneath the vehicle. Since the battery pack is air-cooled, air flow distribution within pack has a strong impact on battery thermal behavior. This section discusses results based on steady-state simulations to assess thermal behavior of battery pack. Figure 2 shows air pressure distribution in the pack. Figure 3 shows temperature distribution in the pack with the peak temperature of 84ºC, significantly higher than maximum recommended temperature (60ºC) from the cell manufacturer. Further analysis showed that the air outlet location rendered low volumetric flow and its reduced diameter in relation to the entrance was a limiting factor. However, the barrier formed because of the air outlet port being very close to the battery cells was the most impacting factor in the thermal performance of the system, motivating change in geometry. Essentially, the constrained space between the cells and the air outlet port rendered insufficient air flow.

Through a couple of design iterations, modifications were made to:

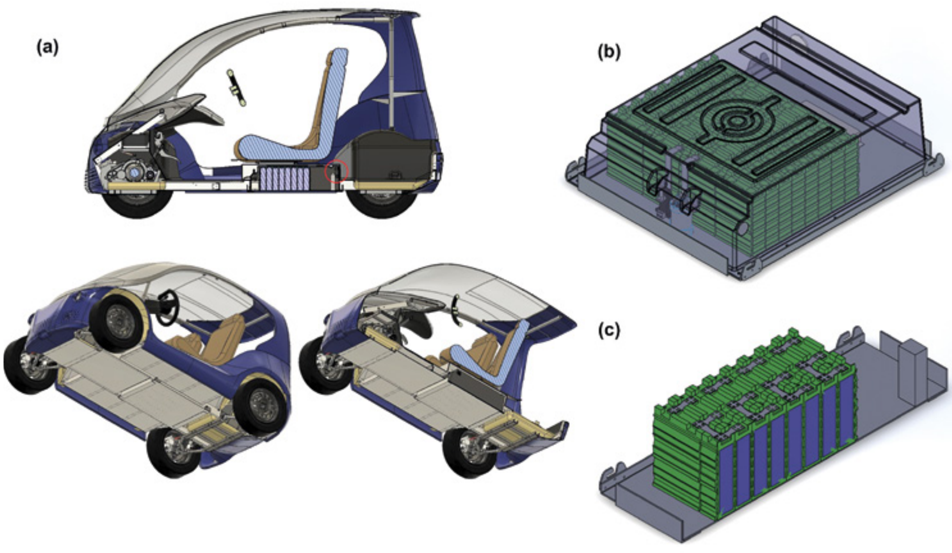

Figure 1. (a) Battery pack housed at the floor of Mobilis vehicle (b) Battery pack design (c) Cells configurations in the battery pack

1. Increase the number of inlets and outlets to two,
2. Shift air outlet ports to the front face of the pack from the side, and
3. Increase outlet ports diameter to match with inlet ports.

The resultant CAD design is shown in Figure 4. Figure 5 shows air flow (pressure distribution) in the re-designed pack. Flow constriction near the outlet (see Figure 2) from the original pack design was eliminated with very few areas of flow stagnation compared to the original design. Also, the new design improved air flow rate in the narrow area of battery cells and battery pack enclosure to aid in convective heat transfer. Figure 6 shows the resulting temperature distribution in the new pack. As can be seen, maximum temperature is 54ºC (compared to 84ºC for the original design) and is well within the maximum recommended temperature by the cell manufacturer.

Operational Viability of Redesigned Battery Pack under Critical Conditions

Once the redesigned, battery pack operated within the battery manufacturer-recommended temperature limits, we simulated the thermal response of the redesigned battery pack under the critical conditions. Critical conditions (Table 1) are defined as the conditions vehicle may get exposed to for short periods of time but is not designed to operate continuously. Our analysis showed the redesigned pack will reach very unsafe temperatures

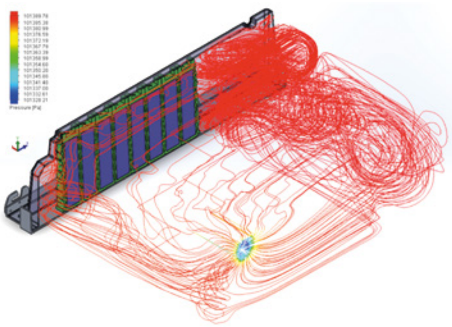

Figure 2. Air pressure distribution inside original battery pack

Status	Nominal Operation	Critical Operation
Ambient temperature (°C)	30°	38°
Average heat generation (W/cell)*	4.06	12.8
Average vehicle speed (mis)	6.94	2.78
Reynolds Number	307,971	119,718
Average convective heat transfer coefficient for A1 base plate (W/m2-K)	23.7364	11.4465
Air inlet	Positive static pressure of 64 Pa	
Air outlet pressure (kPa)	101.325	

Table 1. Summary of operating conditions

of up to 110ºC, if operated under such critical conditions continuously, as shown in Figure 7. The focus, however, was to estimate temperature ramp up in the battery pack once it's subjected to such extreme conditions and if it would be enough for the system to react.

Figure 8 shows the temperature rise in the battery pack when subjected to these critical operating conditions. Under such conditions, the battery pack can operate for ~78 minutes from rest conditions before the battery pack temperature rises beyond the maximum recommended temperature of operation (60ºC). Thanks to battery's large thermal mass, this slow temperature rise rate offers reasonable time to take necessary actions to avoid safety or battery life-limiting damages to the battery pack.

Impact on Mobilis EV Development

For any industry, disruptive technology such as with electric vehicles, it is very important for a company to take all steps to assure there are no design flaws, unpredicted use conditions, and limit liability risks. With the help of FloEFD's unique CAD-embedded simulation capabilities, we were able to quickly simulate dozens of scenarios and explore the battery thermal behavior with change in battery CAD design. This opened many battery design optimization possibilities for Mobilis EV. Through FloEFD-driven design exploration simulations, we could obtain an optimized battery pack design and assured the cooling system was adequate for the harshest cases, such as driving on a long steep uphill with the vehicle loaded, when the asphalt is hot, or starting the vehicle when it has been parked outside on a sunny summer day. The simulations were instrumental for Mobilis to understand if there are use conditions that can negatively impact battery life and should be avoided by customers as well as for devising strategies to mitigate liability issues that can be caused by misuse or random unpredictable system failures.

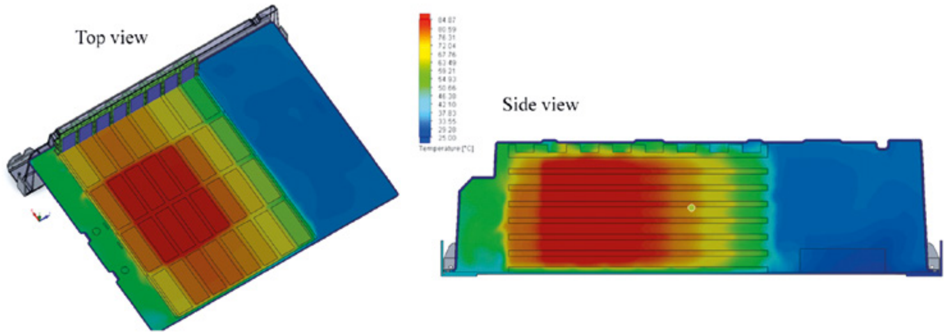

Figure 3. Temperature distribution in battery pack with original pack design. Simulation results are for the nominal operation.

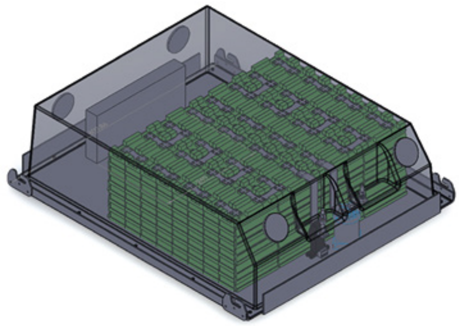

Figure 4. Redesigned battery pack with changes to air inlet and outlet ports location, dimension and numbers

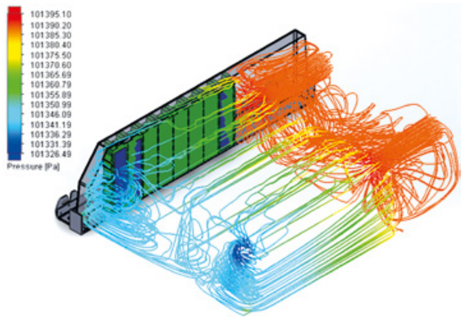

Figure 5. Air pressure distribution inside the redesigned battery pack

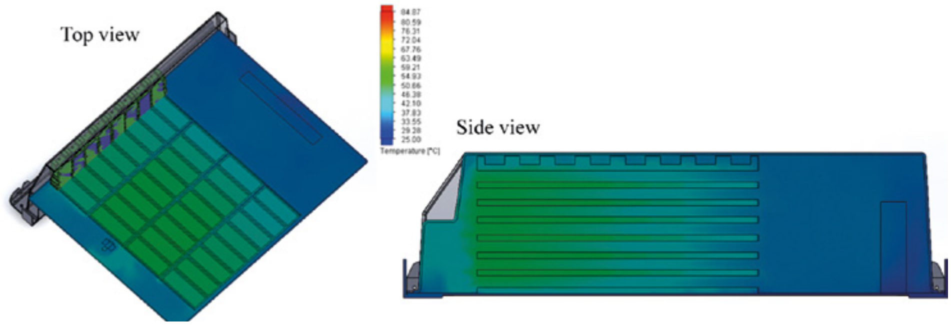

Figure 6. Temperature distribution in the redesigned battery pack for the nominal operating conditions. Maximum temperature in the pack is 54ºC. Color legend is kept the same as in Figure 3 for ease of contrast between the original and the redesigned pack

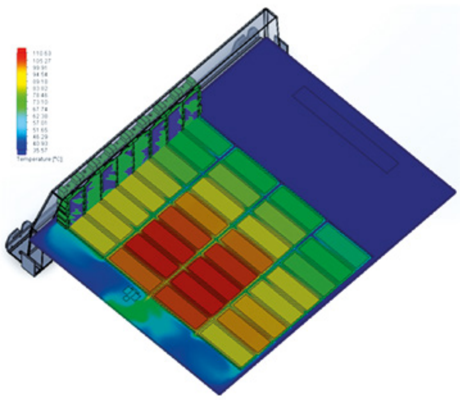

Figure 7. Redesigned battery pack temperature profile if operated under critical conditions continuously. Max temperature reaches unsafe levels of 110ºC

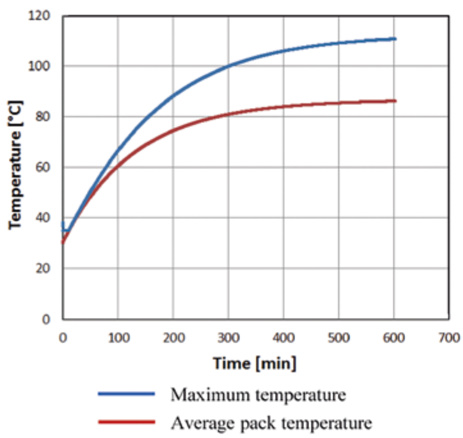

Figure 8. Battery pack temperature rise with time when subjected to critical operating conditions