CreativeSolutions

EV Battery Pack Thermal Simulation, Design Changes and Performance Analysis with FloEFD

Creative Solutions – Guilherme Tondello

Nov.2017

CreativeSolutions MOBILIS

About Creative Solutions

- Brazilian company
- Strategic Mentor Graphics partner in Latin America
- 10+ years of experience in CAE for Mechanical and Electronics engineering
- Engineers from the best universities in the country,
- International experience

- Customers from all areas, including Automotive, Aerospace, Power Generation, Oil and Gas, Construction, Electronics, Communications, Mining, etc

About Mobilis

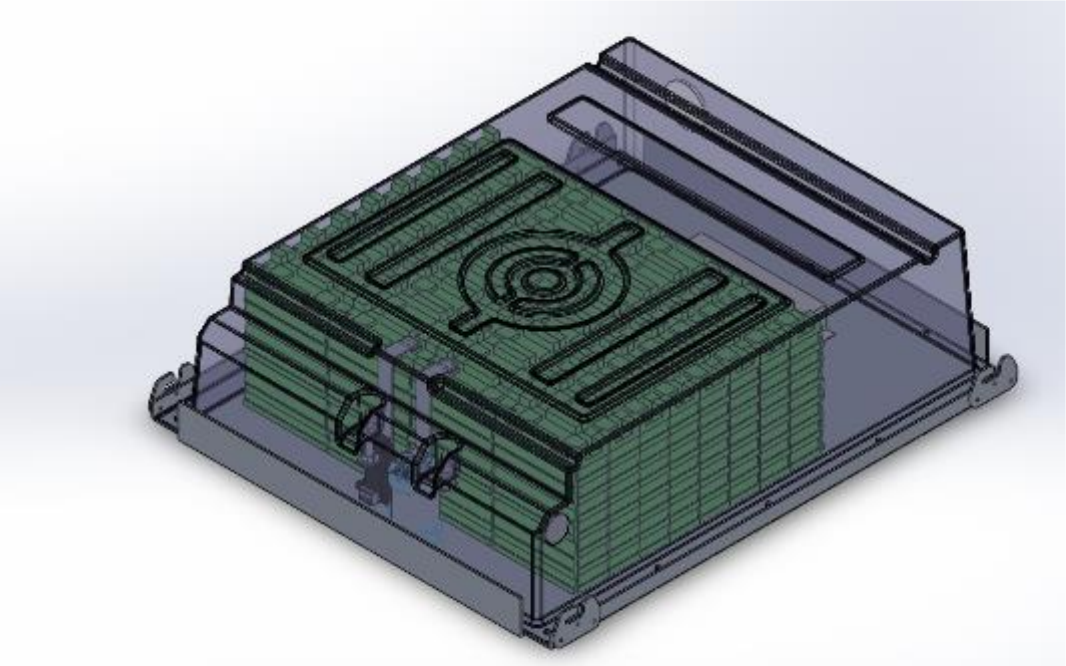
➢ Founded in 2013

➢ Mission: translate people's mobility needs, and design viable electric vehicles for use in Brazil with global vision and standards.

➢ **Li: a modular platform electric vehicle to be used in resorts, condominiums, industries and public services**.

➢ Three versions available: Offroad, Work, Comfort. More coming.

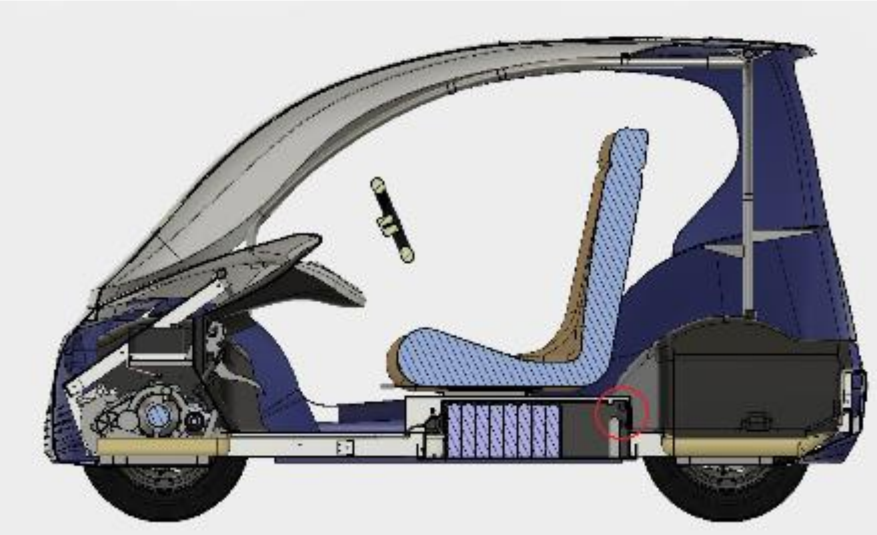
Introduction



Objective

- Evaluate Thermal performance of Mobilis' battery pack.
- Propose modifications based on results
- Assure proper cooling under diferent usage scenarios
- Optimize battery life

Introduction



Tool used

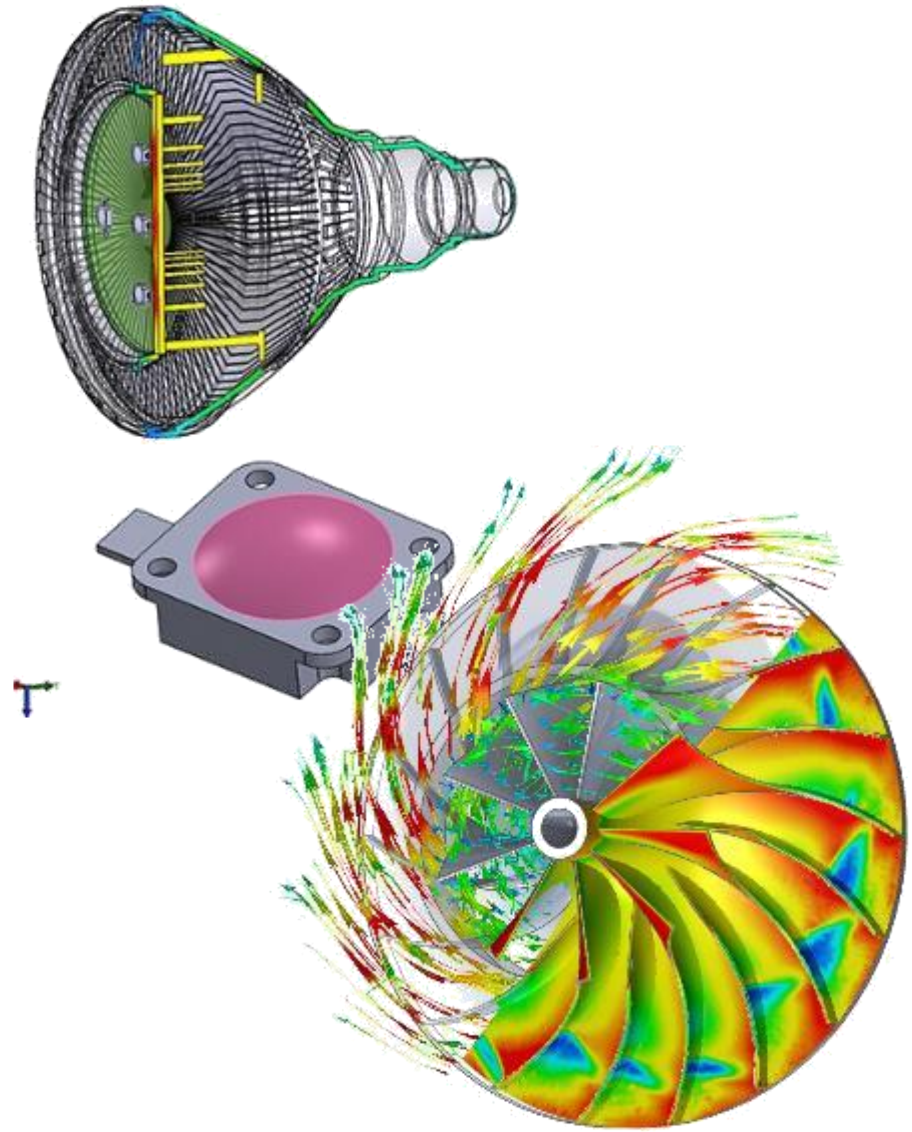
FloEFD™

Mentor Graphics®

SIEMENS

All analysis were made on FloEFD, 3D CFD tool from Mentor Graphics.

FloEFD works seamlessly with each CAD system, operating inside the CAD, making the product development work much easier, since the geometry is modified, and the simulations are done in the same environment, without the need to change > export > import files.



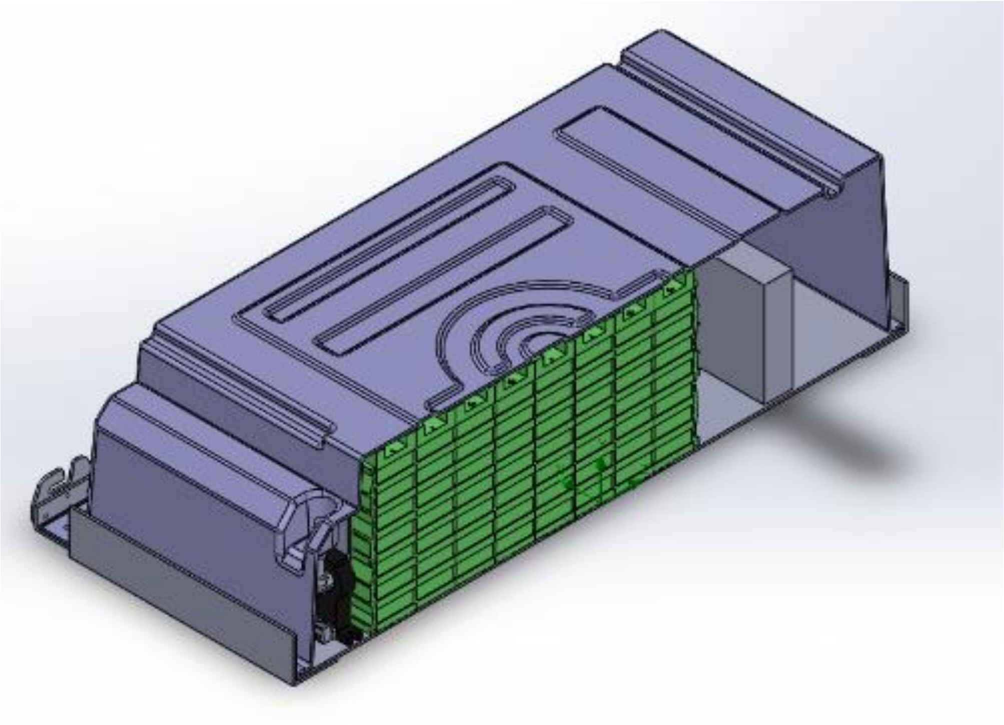
Materials - Solids

Plastic Box: Polypropylene

Thermal Conductivity: 0,12 W/m.K;

Specific Heat: 1,7 J/kg.K;

Density: 904 kg/m³;



Battery Encapsulation: Polypropylene

Thermal Conductivity: 0,12 W/m.K;

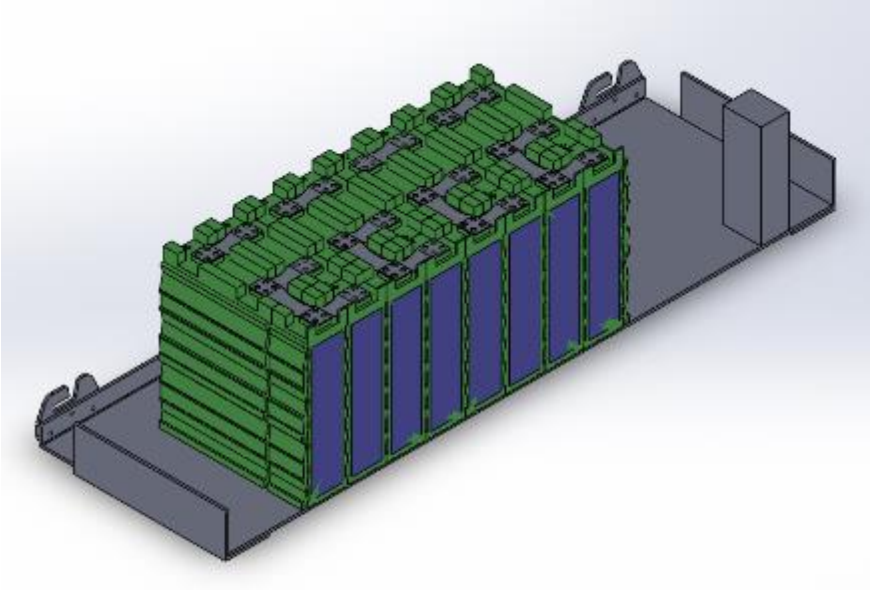
Specific Heat: 1,7 J/kg.K;

Density: 904 kg/m³;

Materials - Solids

Battery Core: Sheets of copper lithium and aluminum with plastic film between them.

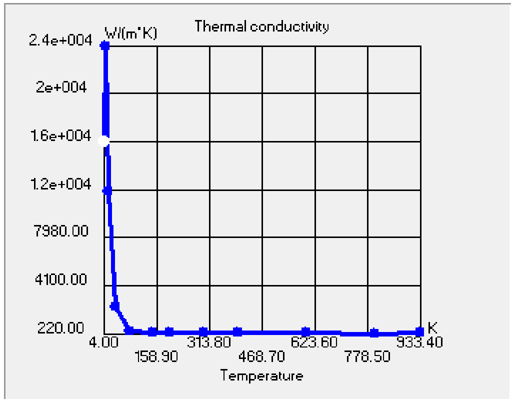
Thermal Conductivity : Biaxial / Orthotropic
Axial (transversal): 138.7 W/m.K;
Radial (in-plane): 277,4 W/m.K;
Specific Heat : 553.218 J/kg.K;
Density : 5110.4 kg/m³;



Materials - Solids

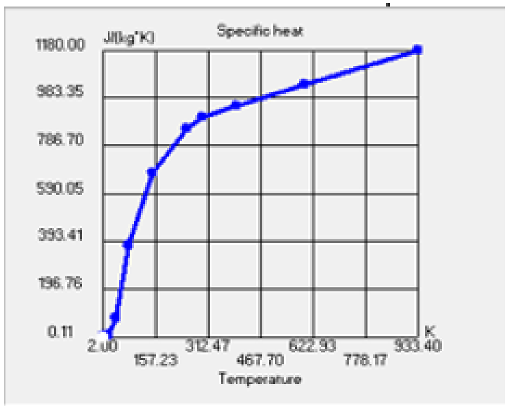
Base plate and connectors: Aluminum

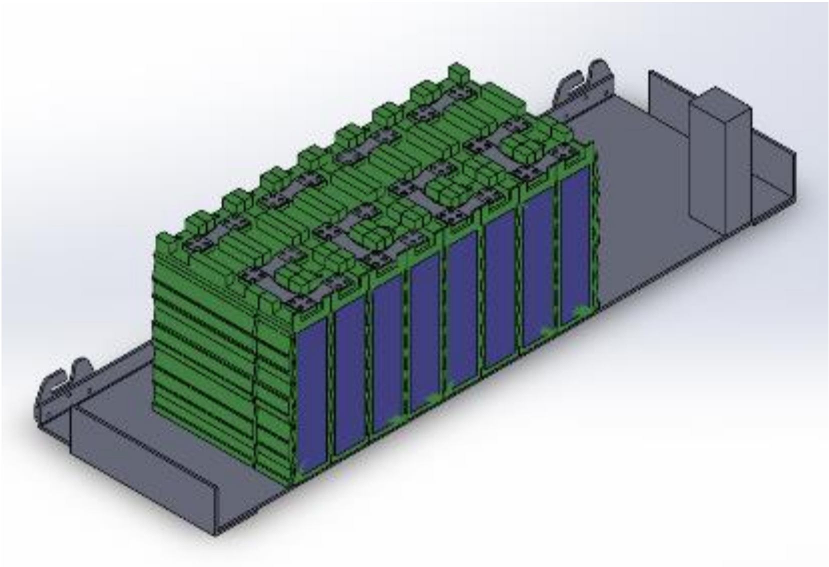
Thermal Conductivity : Obtained from FloEFD database.



Density : 2688.9 kg/m³

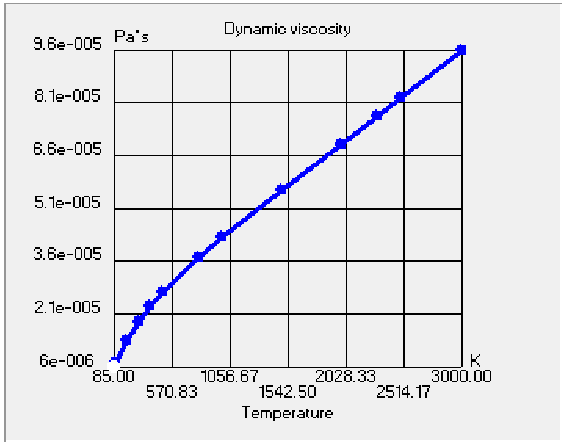
Specific Heat : Removed from the software database.

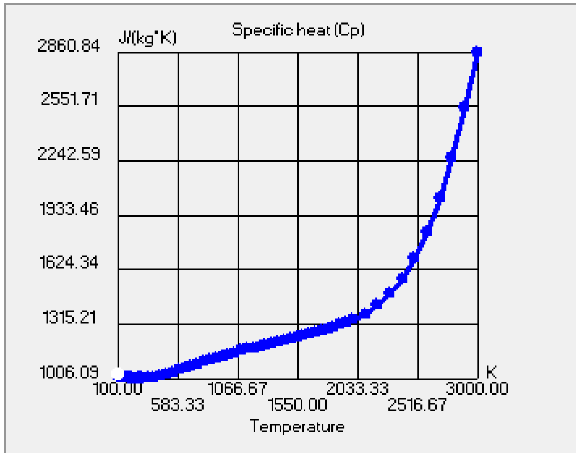


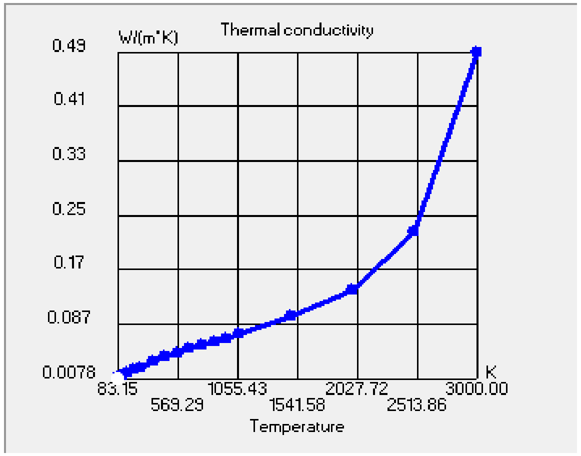


Materials - Fluids

Air







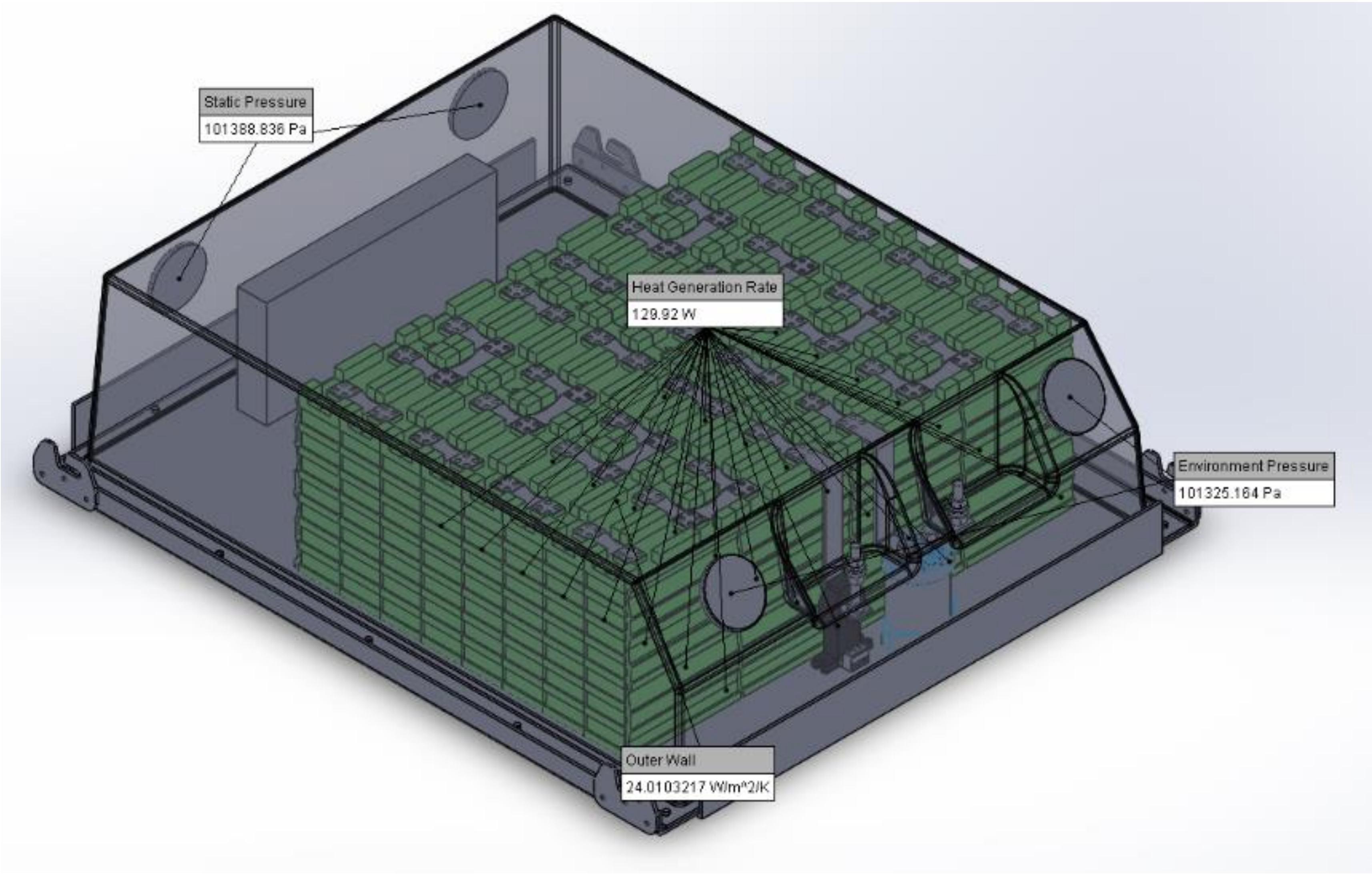
Air properties were taken from FloEFD fluid database, including temperature dependent curves for most properties.

Boundary Conditions
Regular Use Condition

- Air Inlets: Positive static pressure [Pa] **64**;
- Air Outlets: Ambient Pressure [Pa]: **101 325**;
- Ambient temperature [ºC]: **30;**
- Vehicle Velocity [m/s]: **6,94;** (25 km/h);
- Power Dissipated per Cell [W]: **4,06;**
- Kinematic viscosity [10E-6 m^2/s]: **16,04;**
- Plate Length [m]: **0,71134**;
- Reynolds [Re]: **307971**;
- Average Nusselt [Nu]: **649,41**;
- Aluminum Plate Convective Heat Transfer Coefficient
- Resulting HTC [$W/(m^2)K$]: **23,7364;**

Boundary Conditions
Regular Use Condition

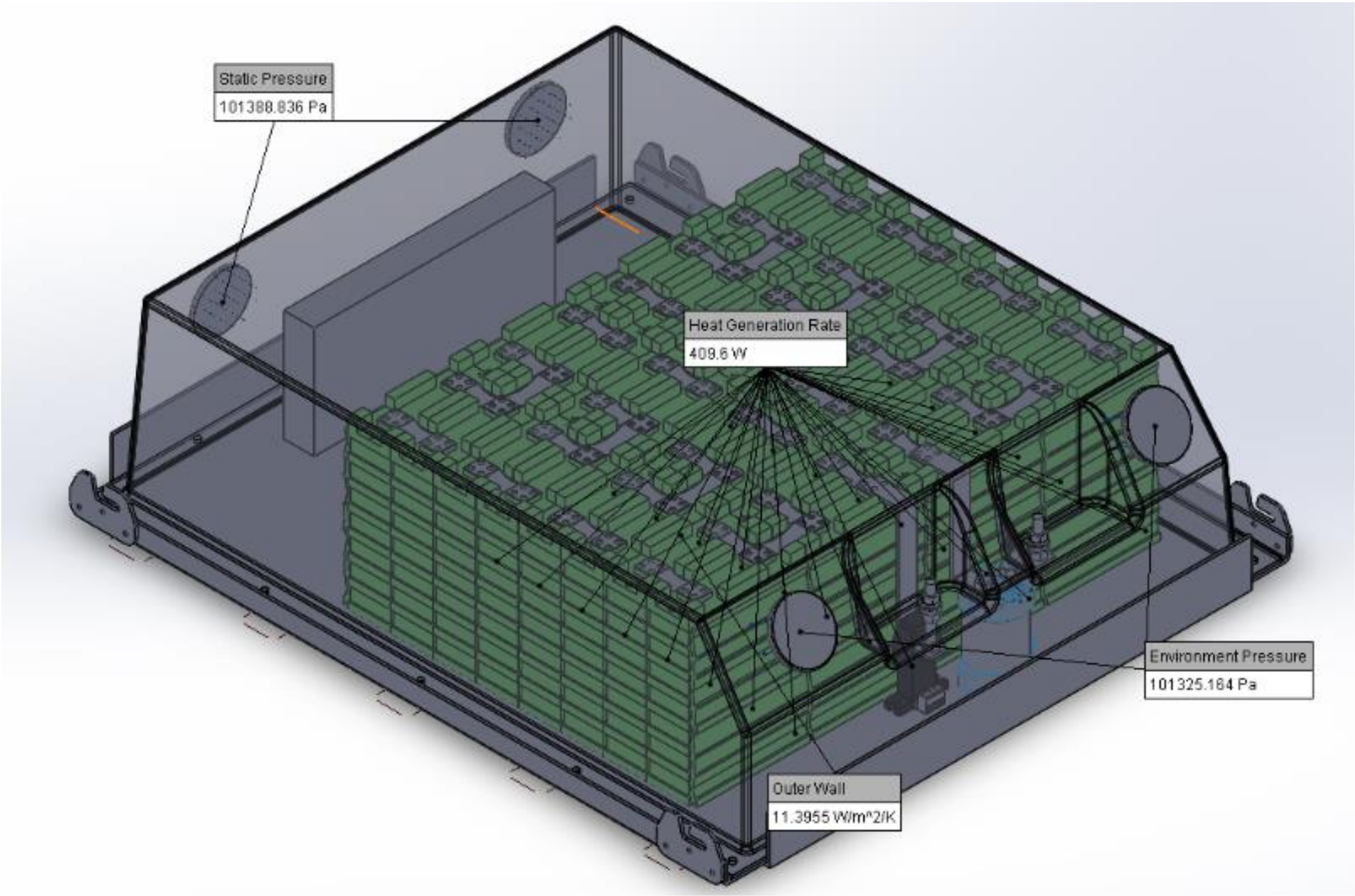
CreativeSolutions



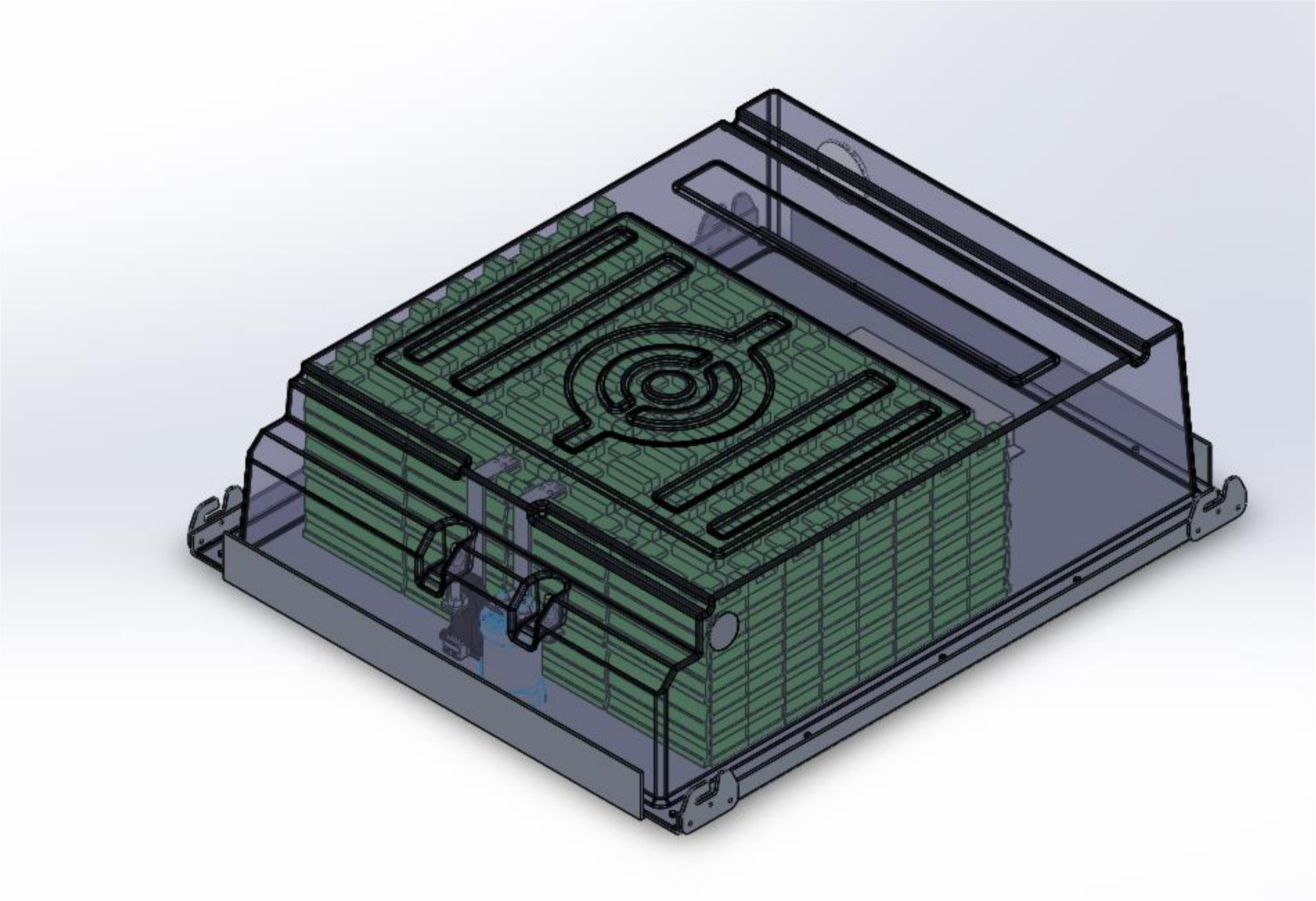
Boundary Conditions
Critical Use Condition

- Air Inlets: Positive static pressure [Pa] **64**;
- Air Outlets: Ambient Pressure [Pa]: **101 325**;
- Ambient temperature [ºC]: **38;**
- Vehicle Velocity [m/s]: **2,78;** (10 km/h);
- Power Dissipated per Cell [W]: **12,8;**
- Kinematic viscosity [10E-6 m²/s]: **16,505;**
- Plate Length [m]: **0,71134**;
- Reynolds [Re]: **119718**;
- Average Nusselt [Nu]: **304,957**;
- Aluminum Plate Convective Heat Transfer Coefficient
- Resulting HTC [W/(m²)K]: **11,4465**;

Boundary Conditions
Critical Use Condition



Original Geometry



Original Geometry

CreativeSolutions

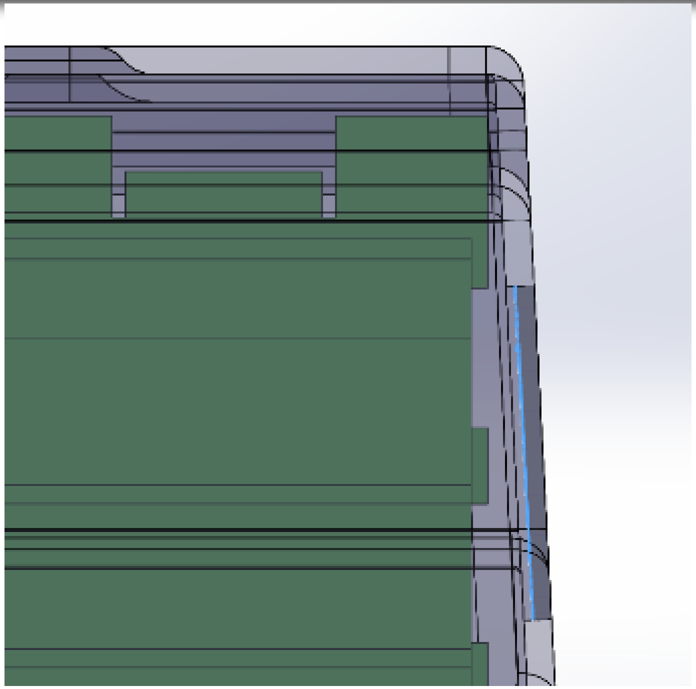


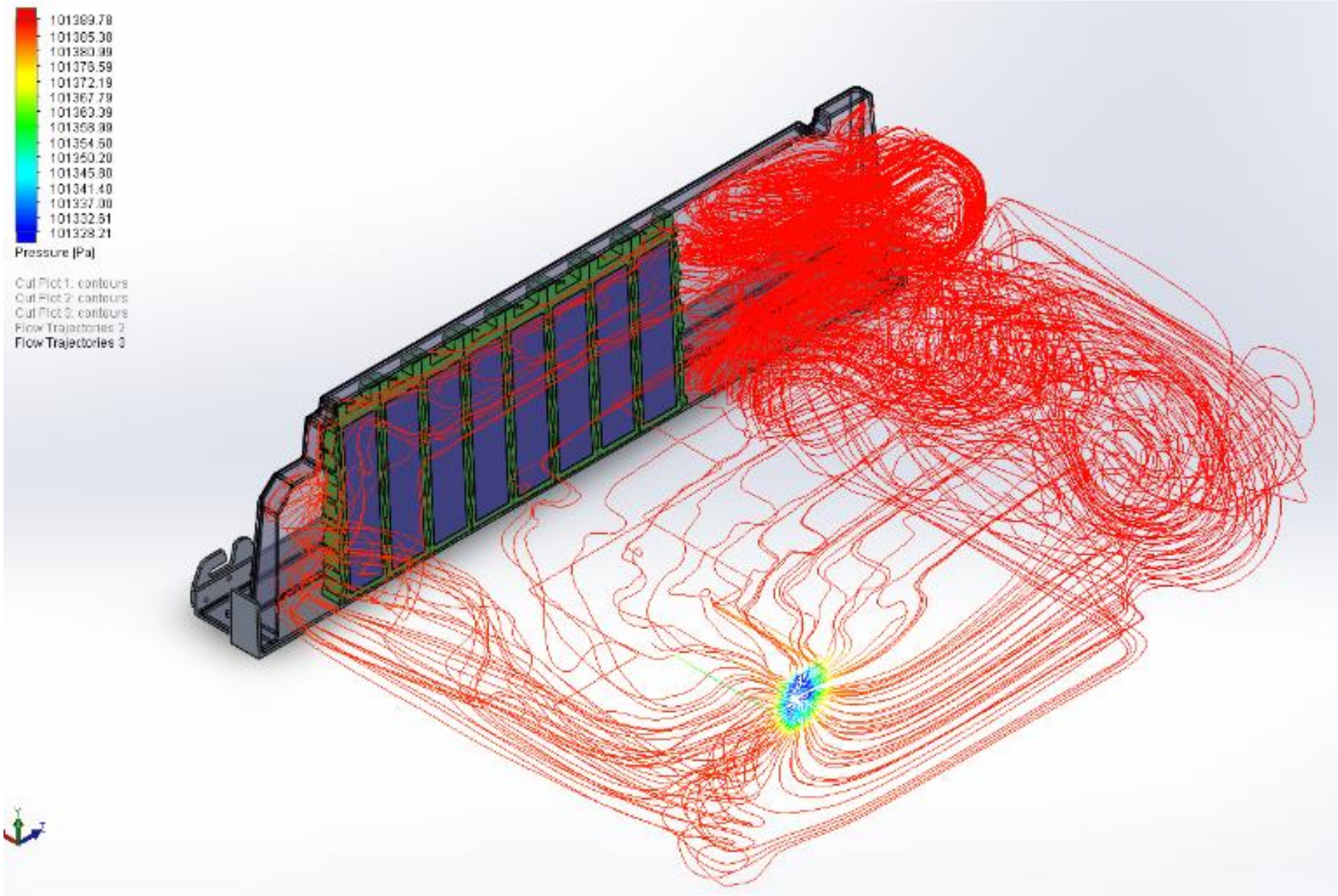
Illustration of the spacing between battery and case.

Local Parameter	Minimum	Maximum	Average	Bulk Average	Surface Area [m^2]
Pressure [Pa]	101388.17	101389.00	101389.00	101389.00	0.0031
Velocity [m/s]	0	1.337	1.202	1.211	0.0031
Velocity (Z) [m/s]	-1.335	0.002	-1.201	-1.210	0.0031
Temperature (Fluid) [°C]	27.90	35.15	35.00	35.00	0.0031

Integral Parameter	Value	X	Y	Z	Surface Area [m^2]
Mass Flow Rate [kg/s]	0.0042				0.0031
Volume Flow Rate [CFM]	7.7888				0.0031

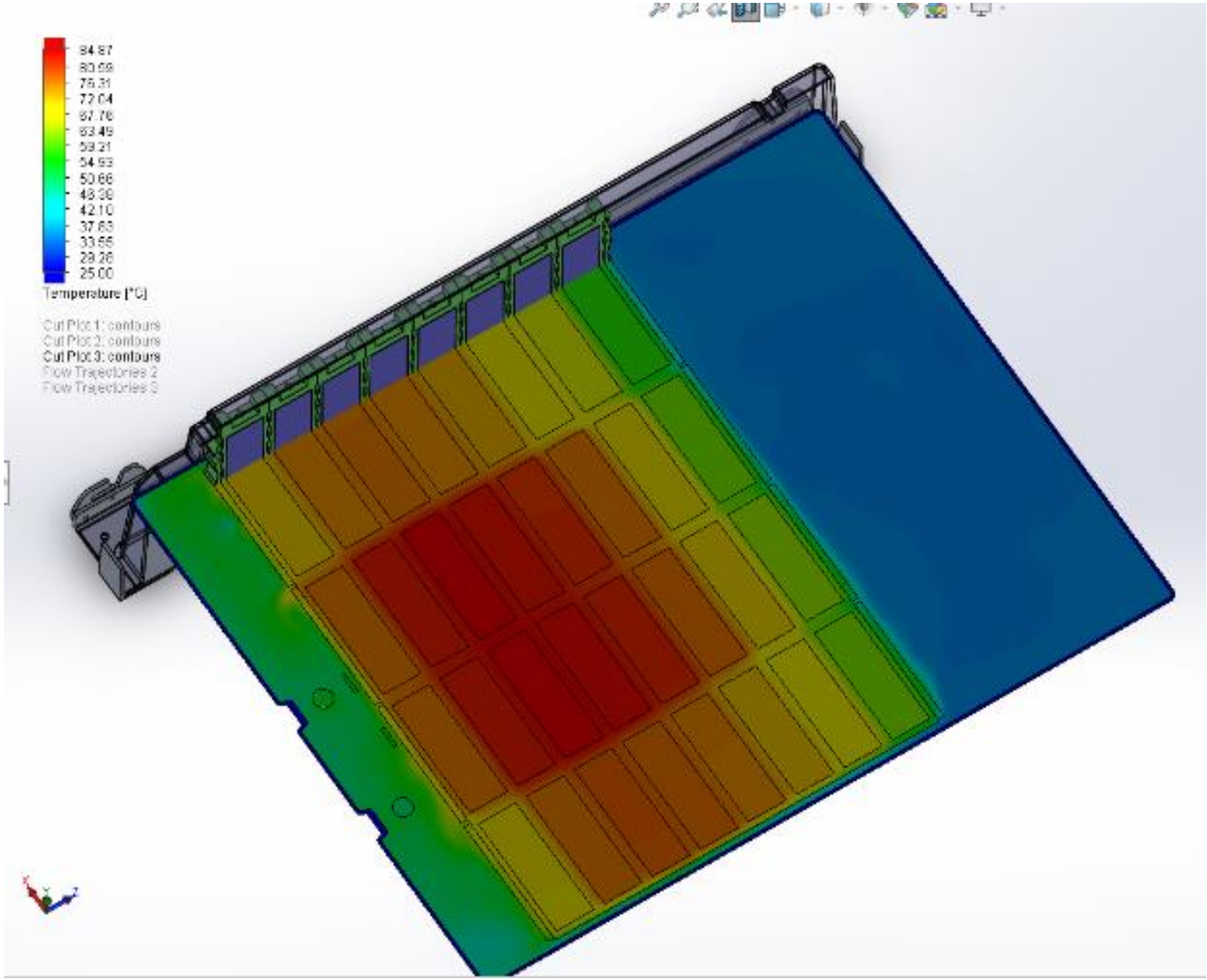
Volumetric flow at the equipment outlet

Original Geometry
Pressure Distribution



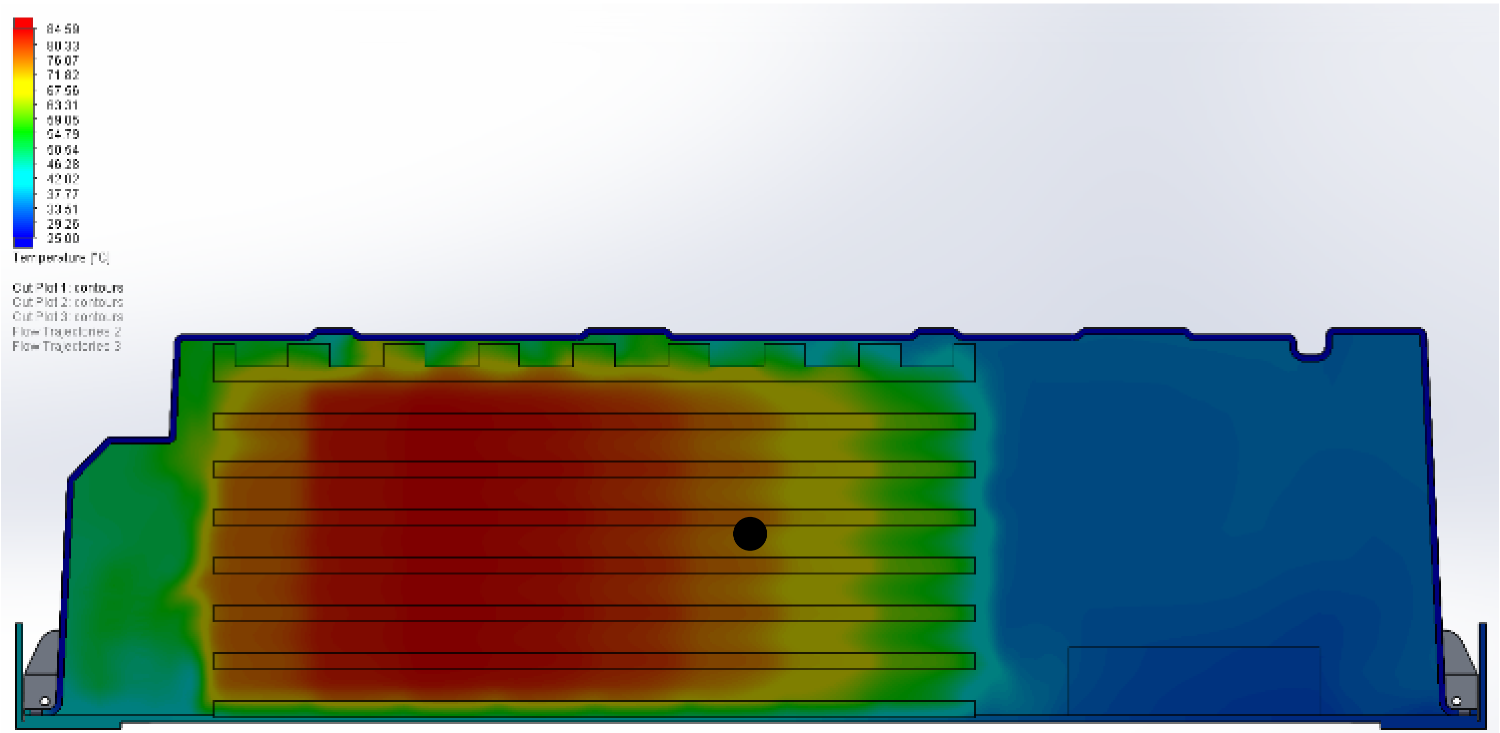
Pressure distribution resulting from restricted opening.

Original Geometry
Temperature Distribution



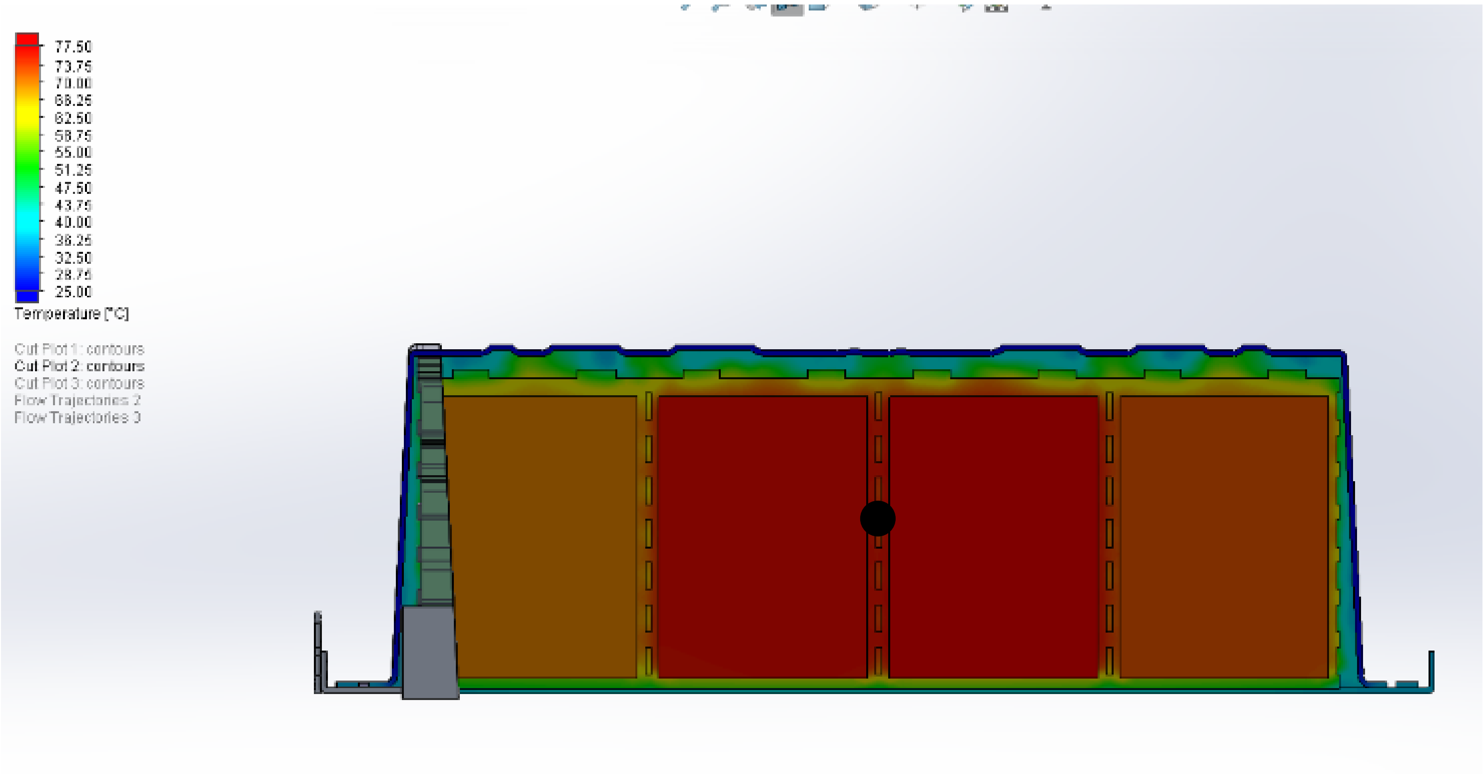
Temperature distribution resulting from reduced flow, core temperatures Max. 84ºC. Upper view.

Original Geometry
Temperature Distribution



Temperature distribution resulting from reduced flow, core temperatures Max. 84ºC. Side view.

Original Geometry
Temperature Distribution



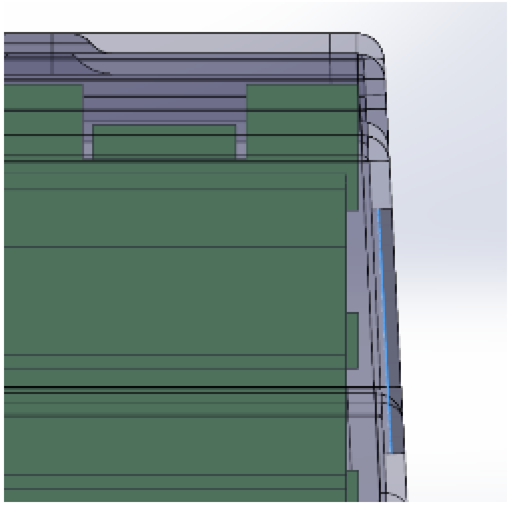
Temperature distribution resulting from reduced flow. Front view.

Original Geometry

- Flow rates much lower than cooler datasheet specification (7.8 vs 25 CFM)
- Outlet has smaller diameter than inlet
- Small clearance between outlet and battery pack restricts flow

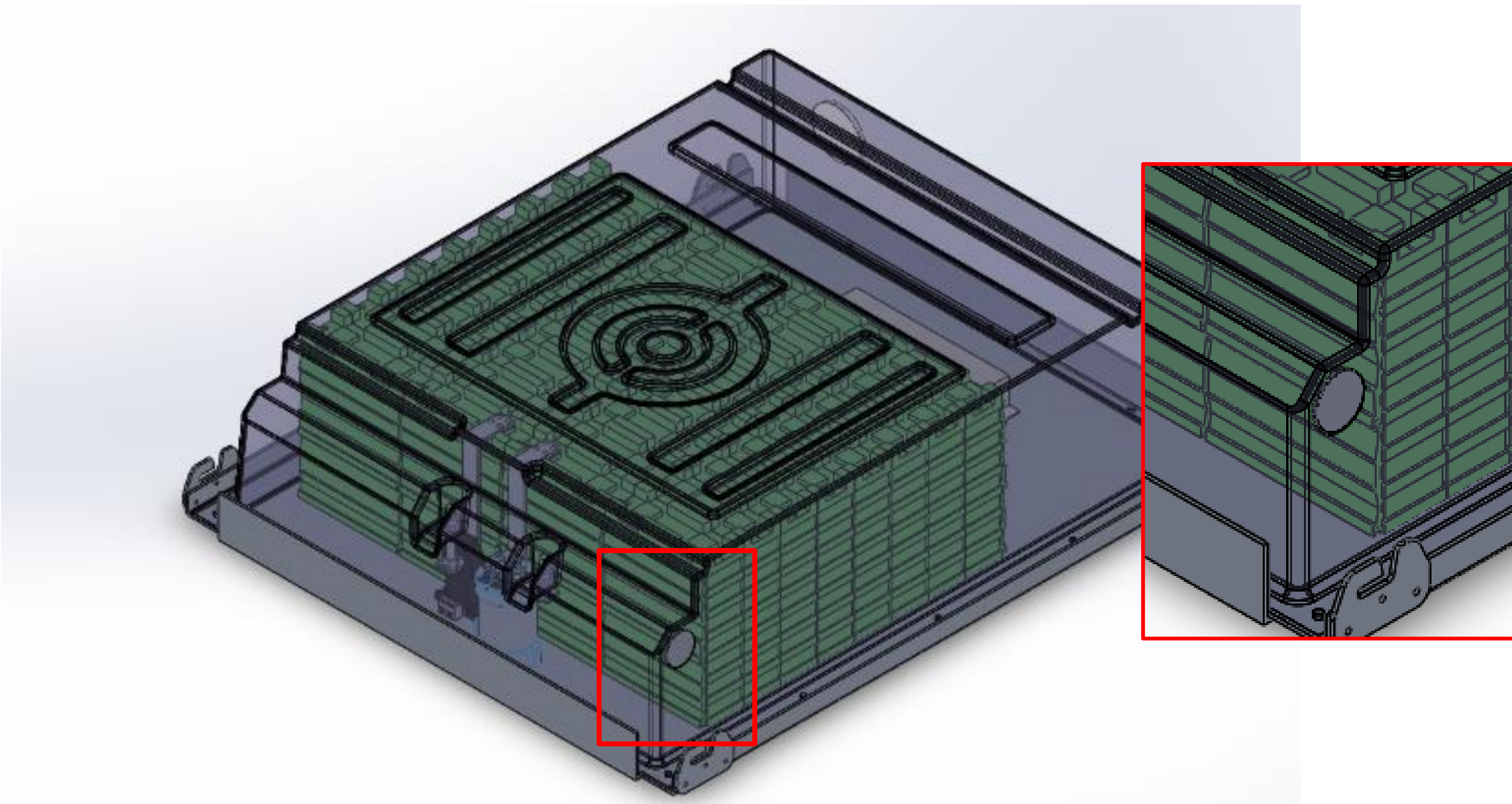
Strategy:

- Evaluate moving outlet to clear away from battery pack and improve flow.

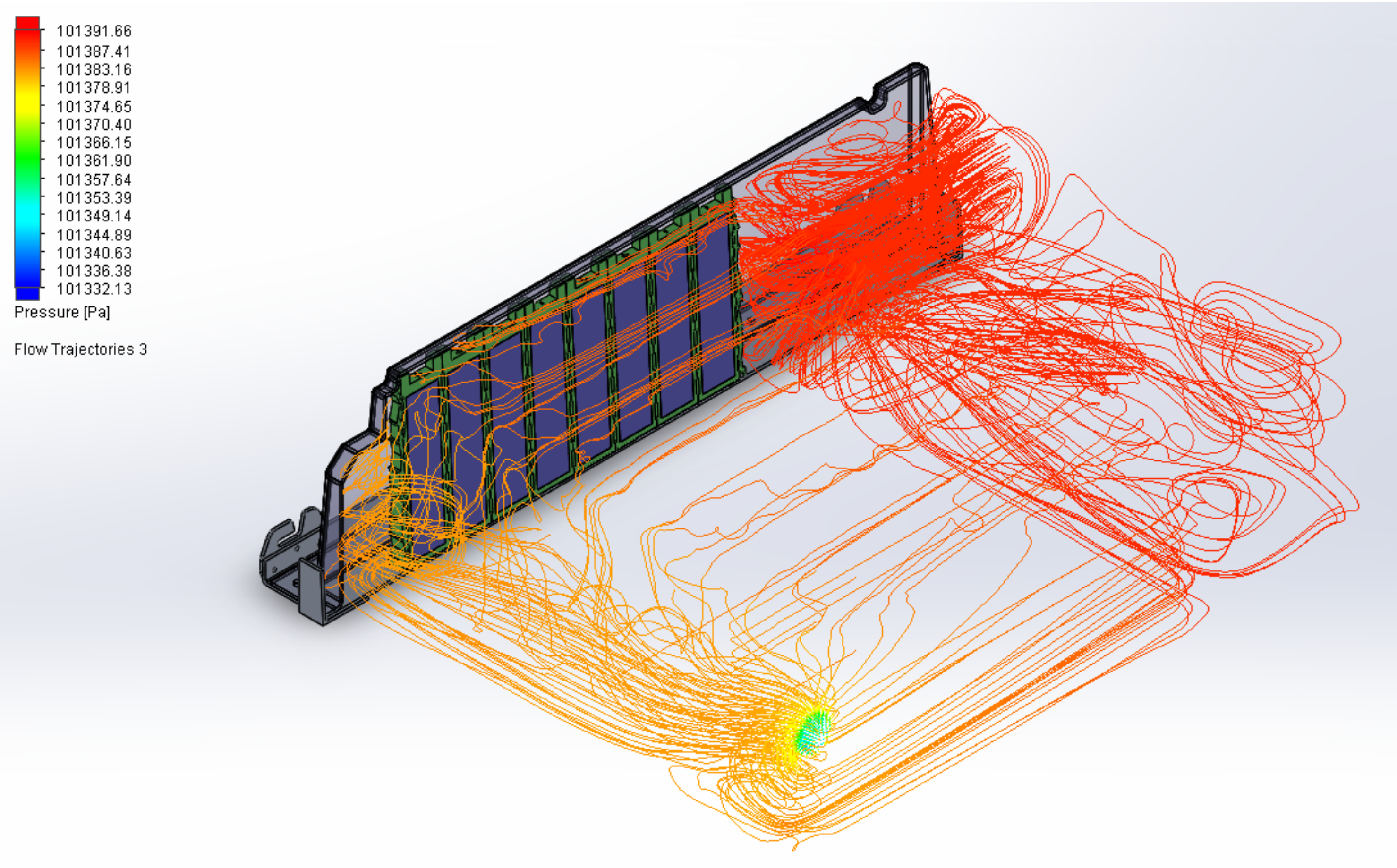


Secondary Geometry

- Air outlet displaced away from the battery pack.

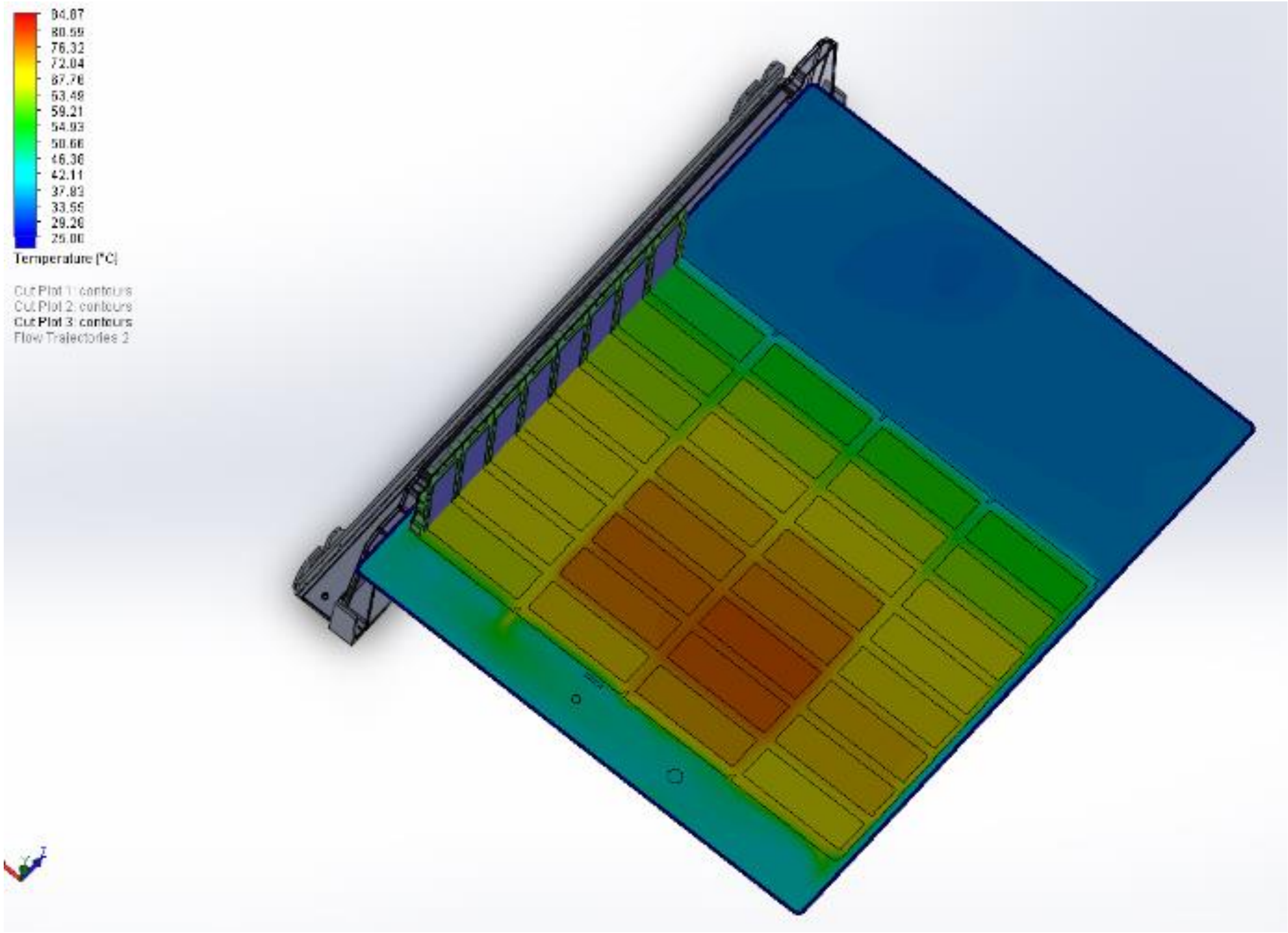


Secondary Geometry
Pressure Distribution



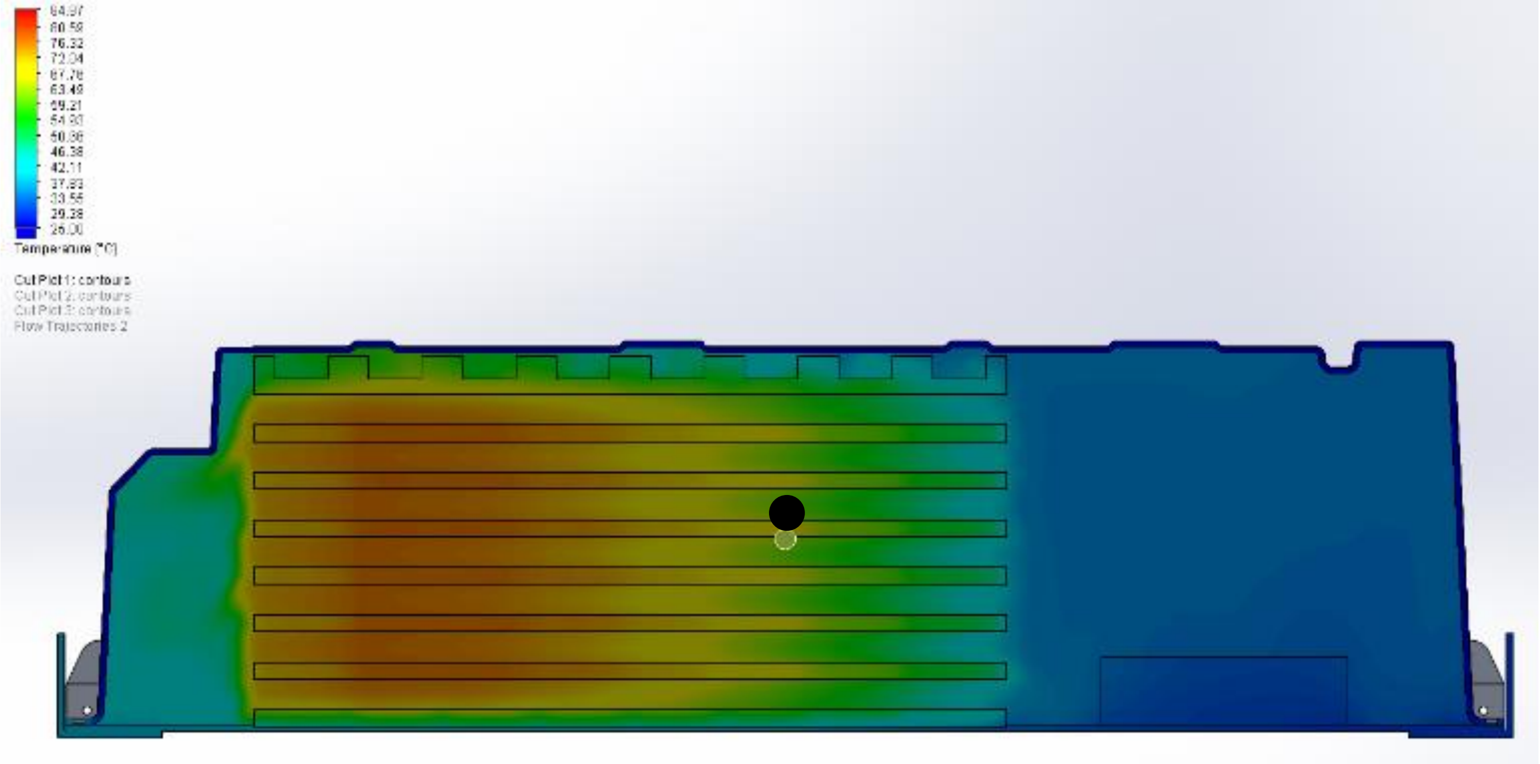
Pressure distribution, smoother transition than observed in original geometry.

Secondary Geometry
Temperature Distribution



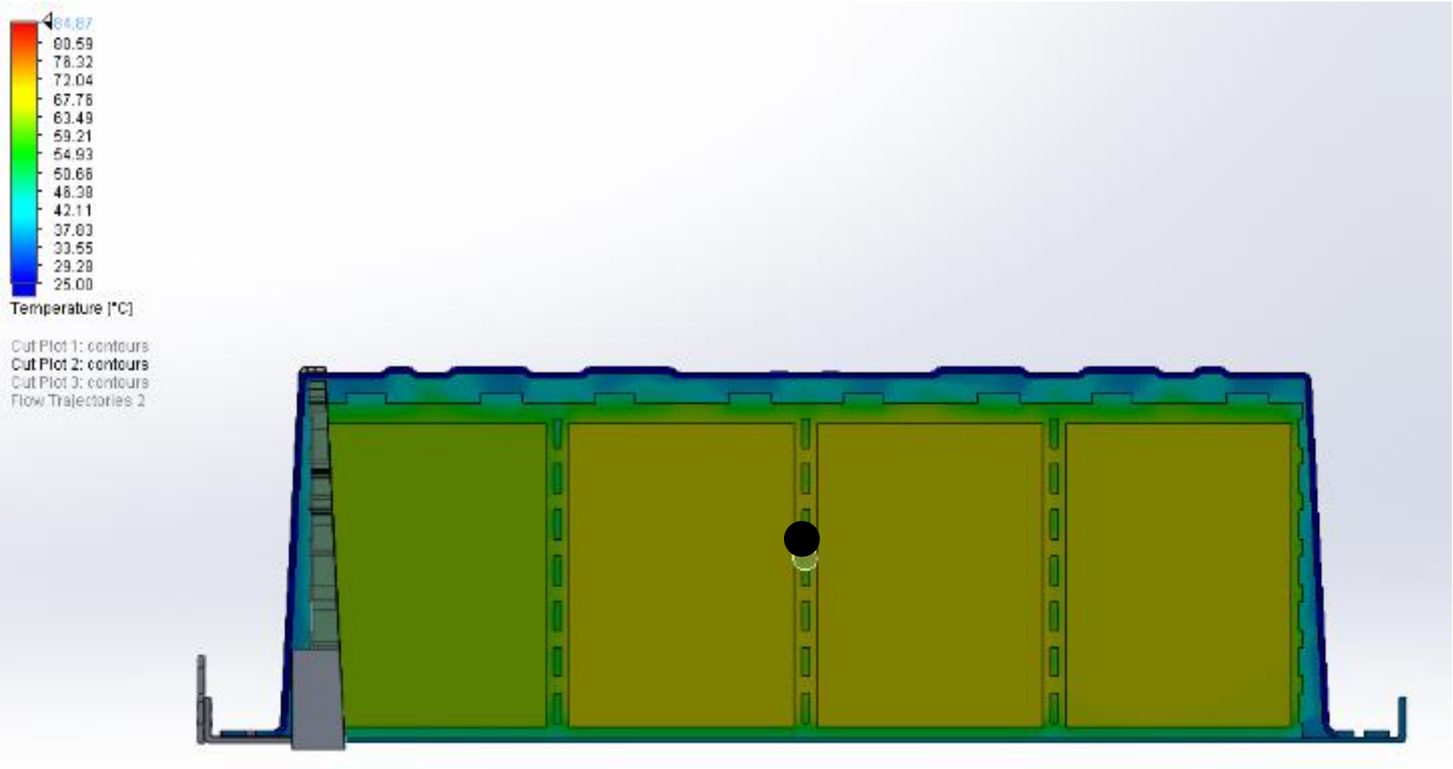
Temperature distribution resulting from the new position of the air outlet, core temperatures Max. 78ºC. Upper view.

Secondary Geometry
Temperature Distribution



Temperature distribution, core temperatures Max. 78ºC. Side view.

Secondary Geometry
Temperature Distribution



Temperature distribution resulting from the new position of the air outlet. Front view

Secondary Geometry
Volumetric flow

CreativeSolutions

- Improvement in flow rate and thermal performance
- Subtler pressure gradients indicate less flow restriction in outlet
- **Flow rate increase from 7.8 CFM to 15.1 CFM** (25 CFM ideal)
- **Max temperature decreased by 6 ºC**

Initial volumetric air flow

Local Parameter	Minimum	Maximum	Average	Bulk Average	Surface Area [m^2]
Pressure [Pa]	101388.17	101389.00	101389.00	101389.00	0.0031
Velocity [m/s]	0	1.337	1.202	1.211	0.0031
Velocity (Z) [m/s]	-1.335	0.002	-1.201	-1.210	0.0031
Temperature (Fluid) [°C]	27.90	35.15	35.00	35.00	0.0031

Integral Parameter	Value	X	Y	Z	Surface Area [m^2]
Mass Flow Rate [kg/s]	0.0042				0.0031
Volume Flow Rate [CFM]	7.7888				0.0031

Secundary volumetric air flow

Local Parameter	Minimum	Maximum	Average	Bulk Average	Surface Area [m^2]
Pressure [Pa]	101385.83	101389.00	101389.00	101389.00	0.0031
Velocity [m/s]	0	2.623	2.344	2.361	0.0031
Velocity (Z) [m/s]	-2.620	0	-2.341	-2.358	0.0031
Temperature (Fluid) [°C]	28.73	35.00	35.00	35.00	0.0031

Integral Parameter	Value	X	Y	Z	Surface Area [m^2]
Mass Flow Rate [kg/s]	0.0082				0.0031
Volume Flow Rate [CFM]	15.1818				0.0031

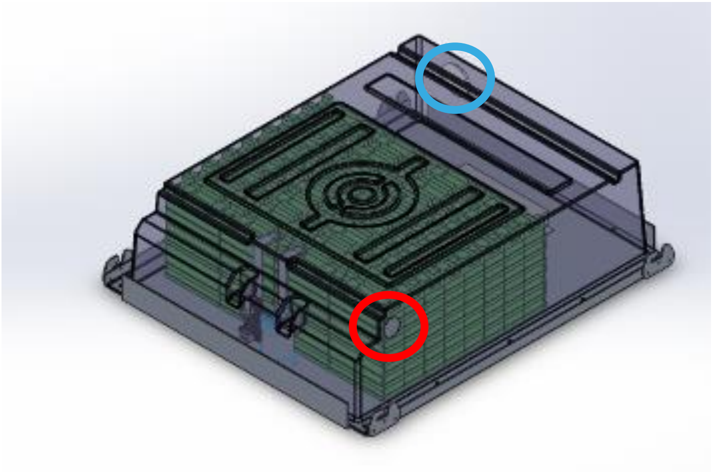
Secondary Geometry
Conclusions

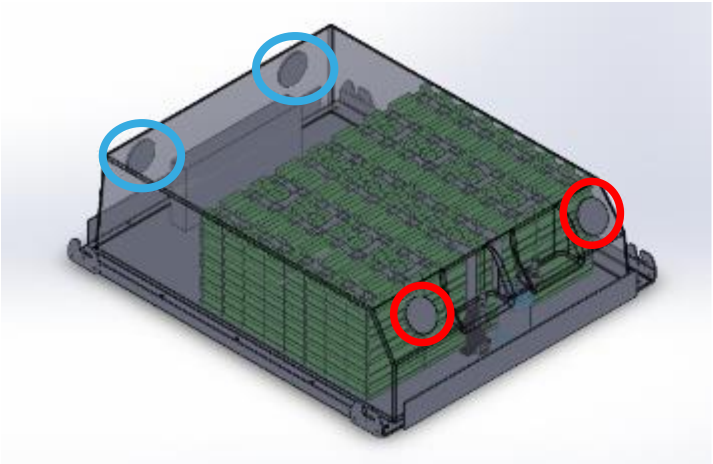
Conclusions

- System thermal behavior highly dependent on air cooling design
- Max temperature still exceeding critical temperature (60 ºC)
- Cooler still not running efficiently

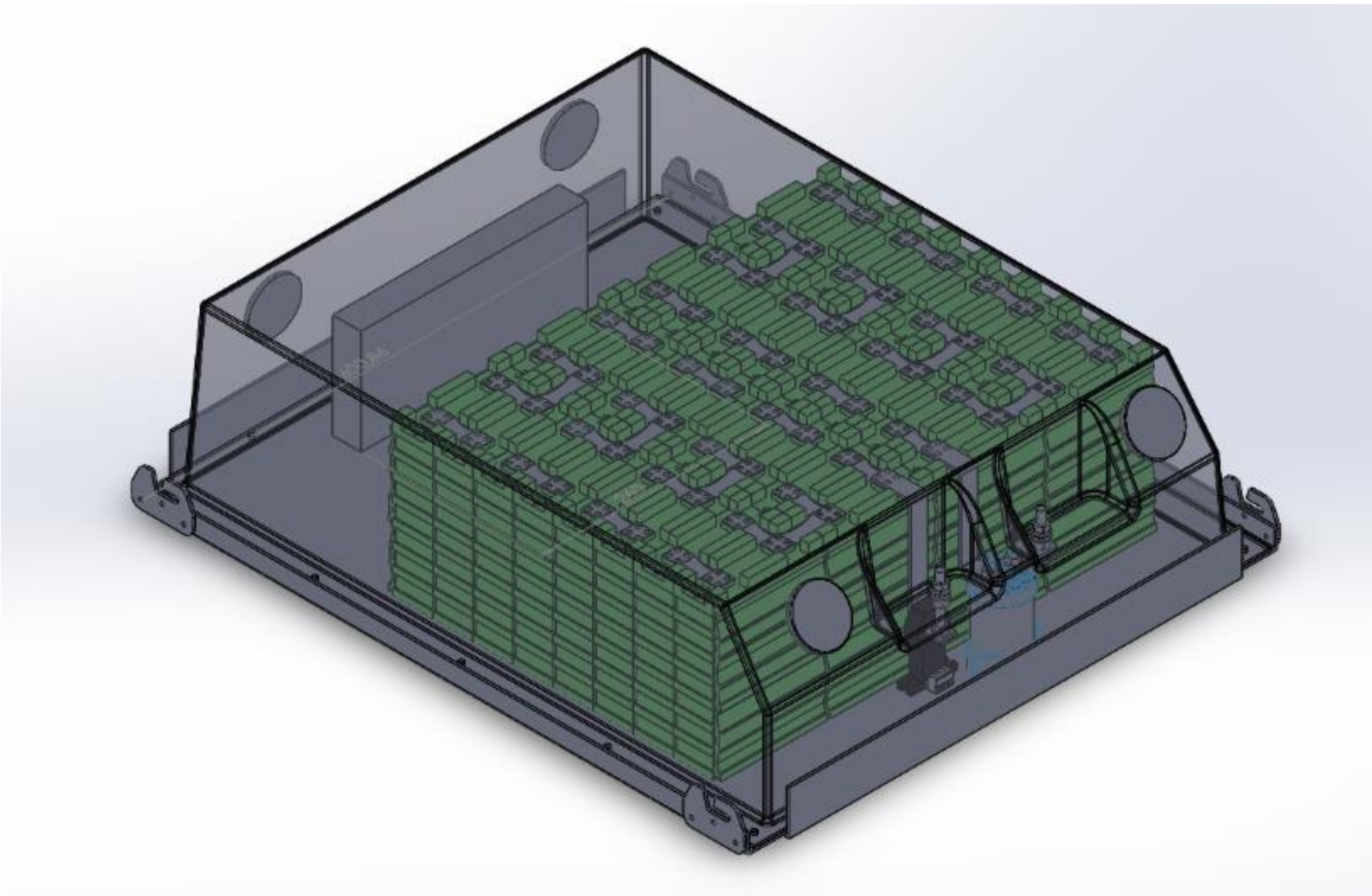
Strategy:

- Increase air outlet diameter
- Slightly displace air outlets and slightly change case geometry to have outlets angled at 45º
- Double air inlet, cooler and outlet.





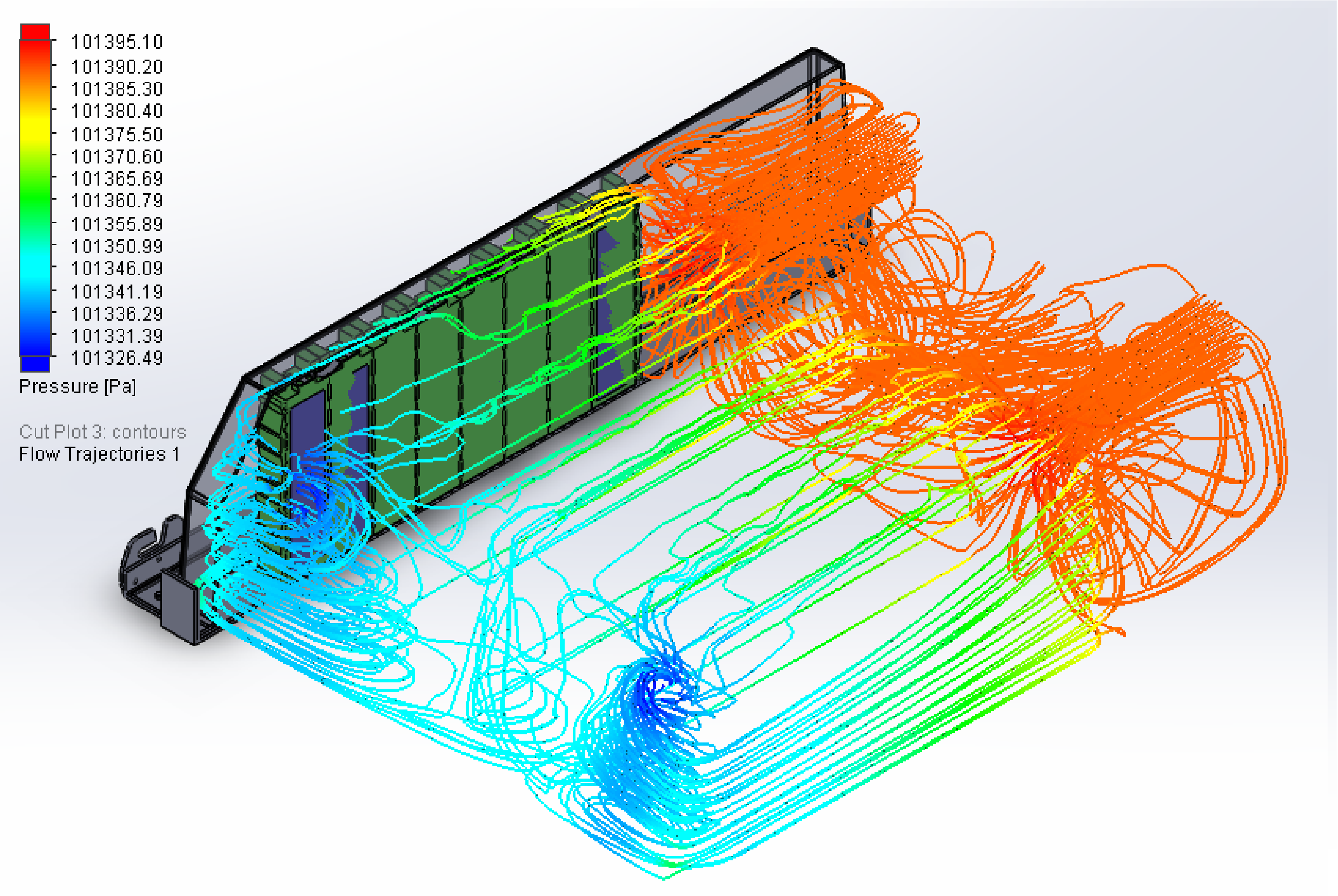
New Geometry Analysis
Steady State Regime – Regular Use Condition



New Geometry Analysis

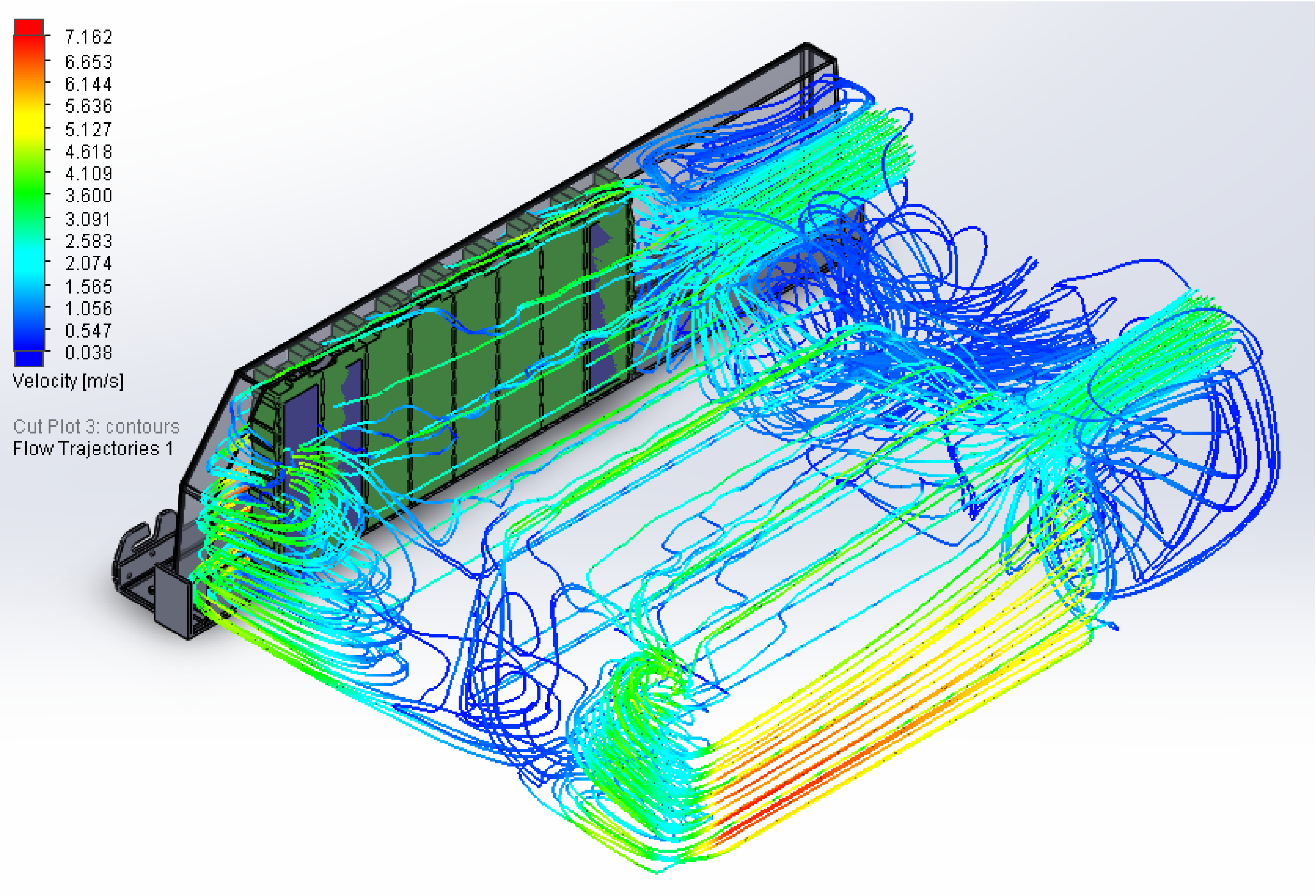
Steady State Simulation – Regular Use Condition

Pressure Distribution



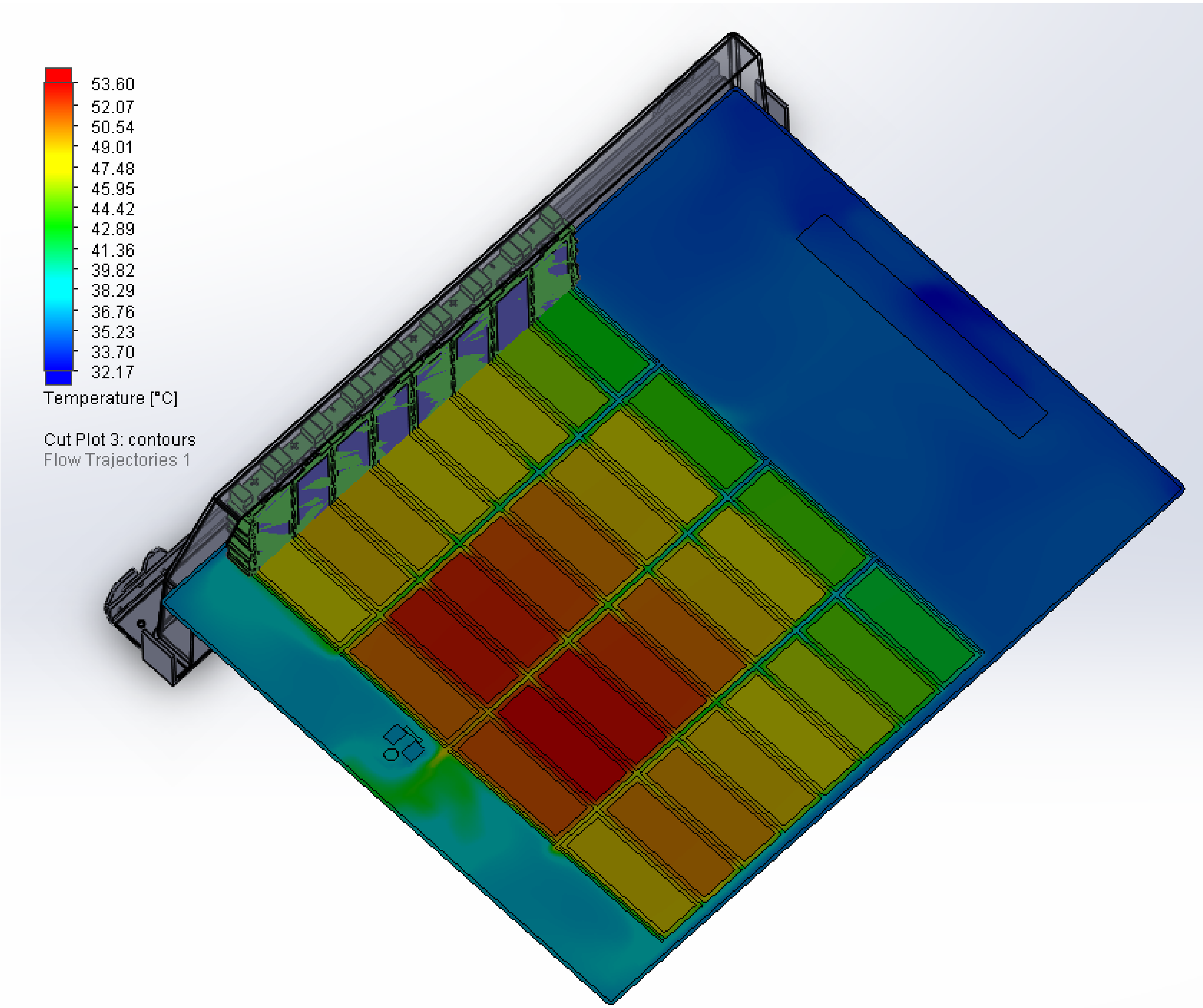
Pressure distribution from new geometry, smooth gradients.

New Geometry Analysis
Steady State Simulation – Regular Use Condition
Flow Speed Distribution



Flow Speed distribution from new geometry, few regions of stagnation.

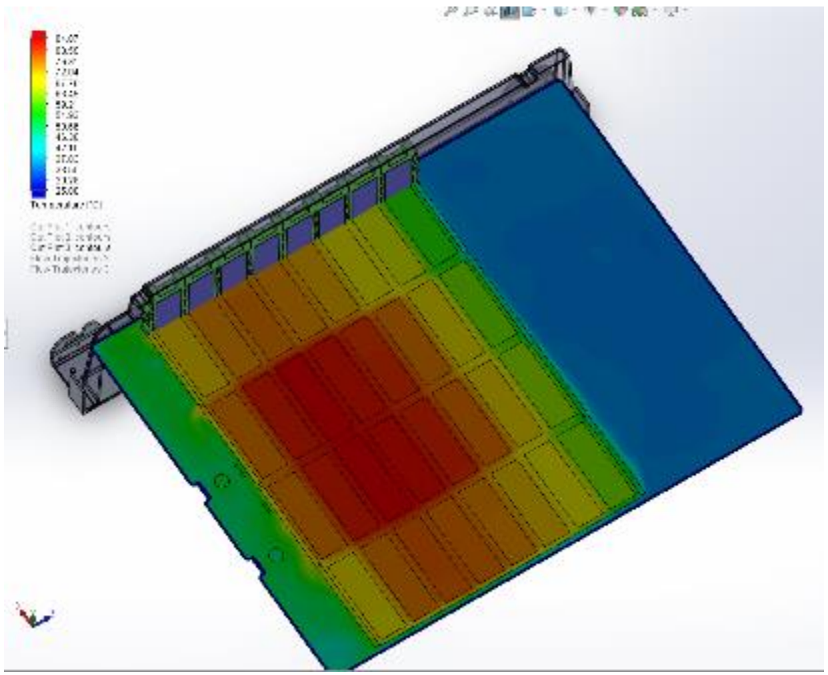
New Geometry Analysis
Steady State Simulation – Regular Use Condition
Temperature Distribution

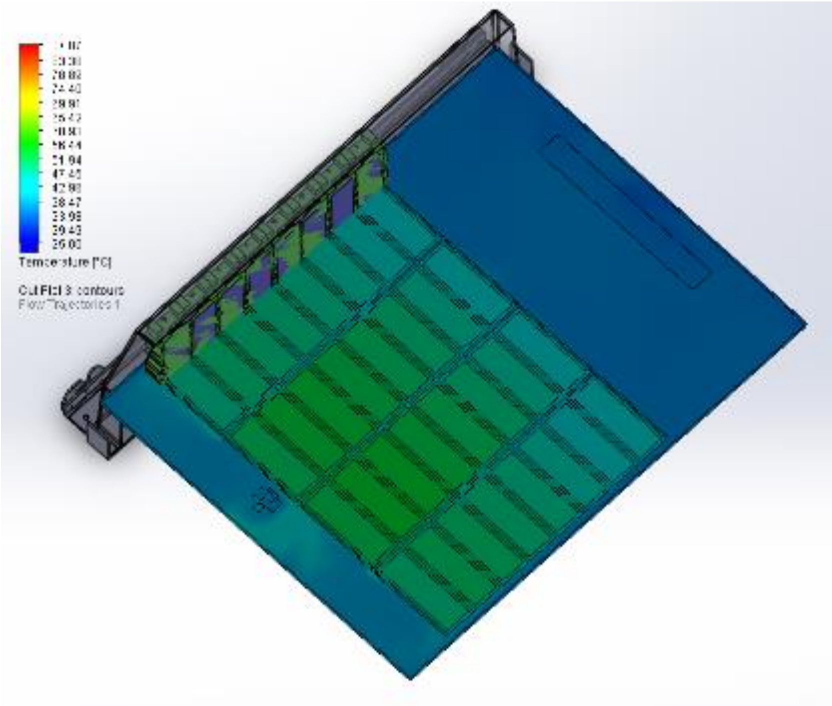


Temperature distribution from new geometry, core temperatures Maximum 53.6ºC. Upper view.

New Geometry Analysis
Steady State Simulation – Regular Use Condition
Temperature Distribution

Temperature comparison between Original and New Geometry.

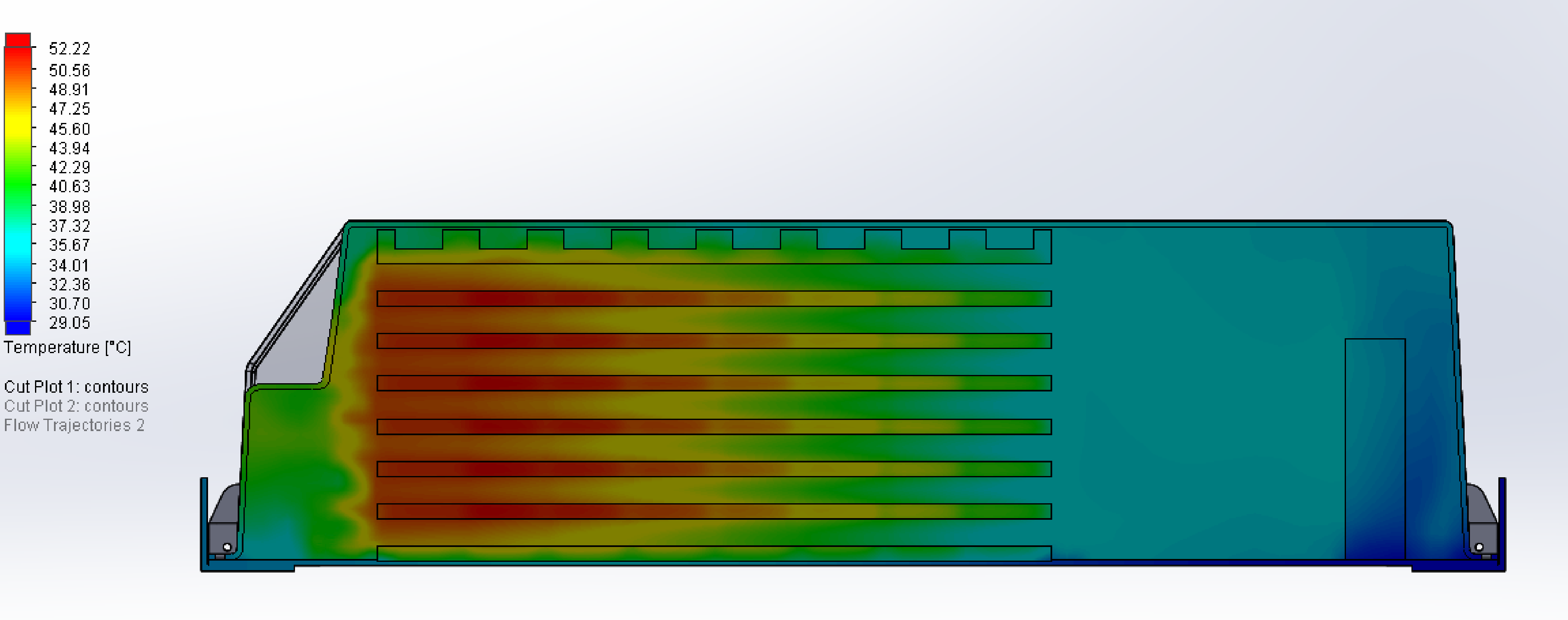




New Geometry Analysis

Steady State Simulation – Regular Use Condition

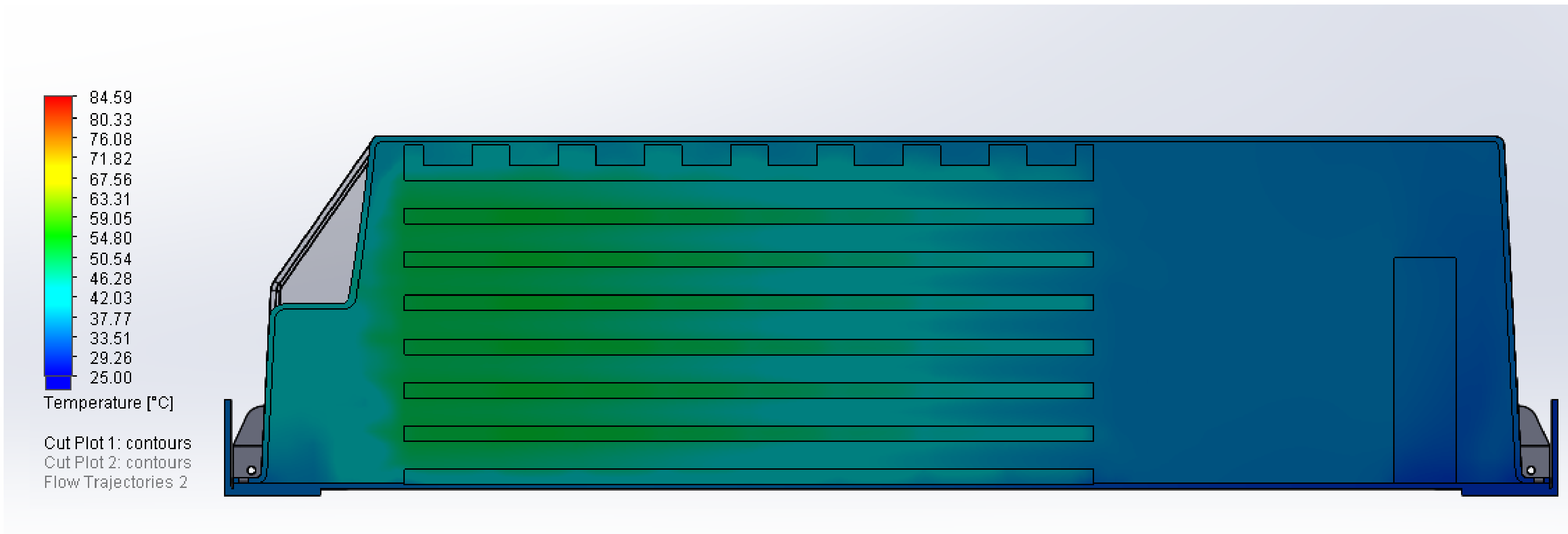
Temperature Distribution

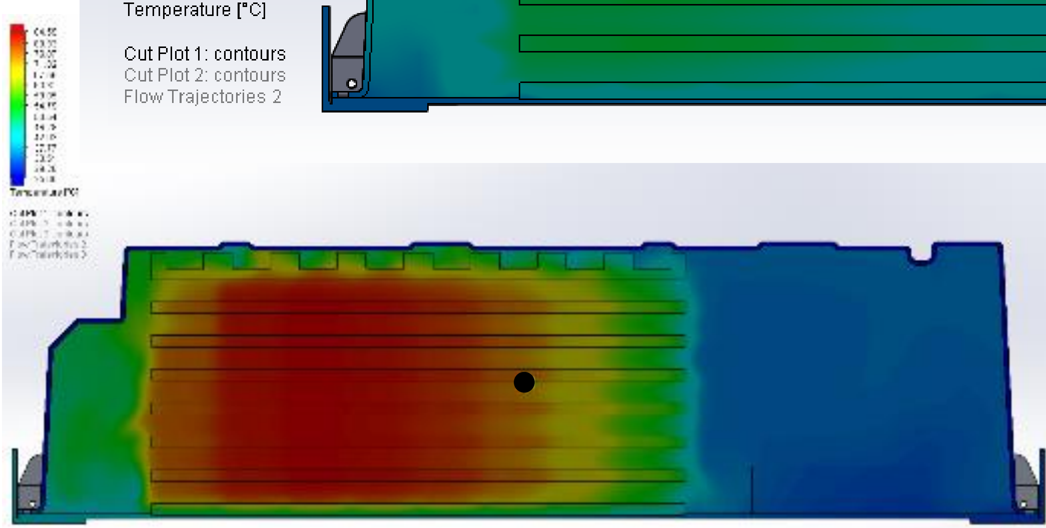


Temperature distribution resulting from the new geometry, core maximum temperatures 53.6ºC. Side view.

New Geometry Analysis
Steady State Simulation – Regular Use Condition
Temperature Distribution

Temperature comparison between Original and New Geometry.

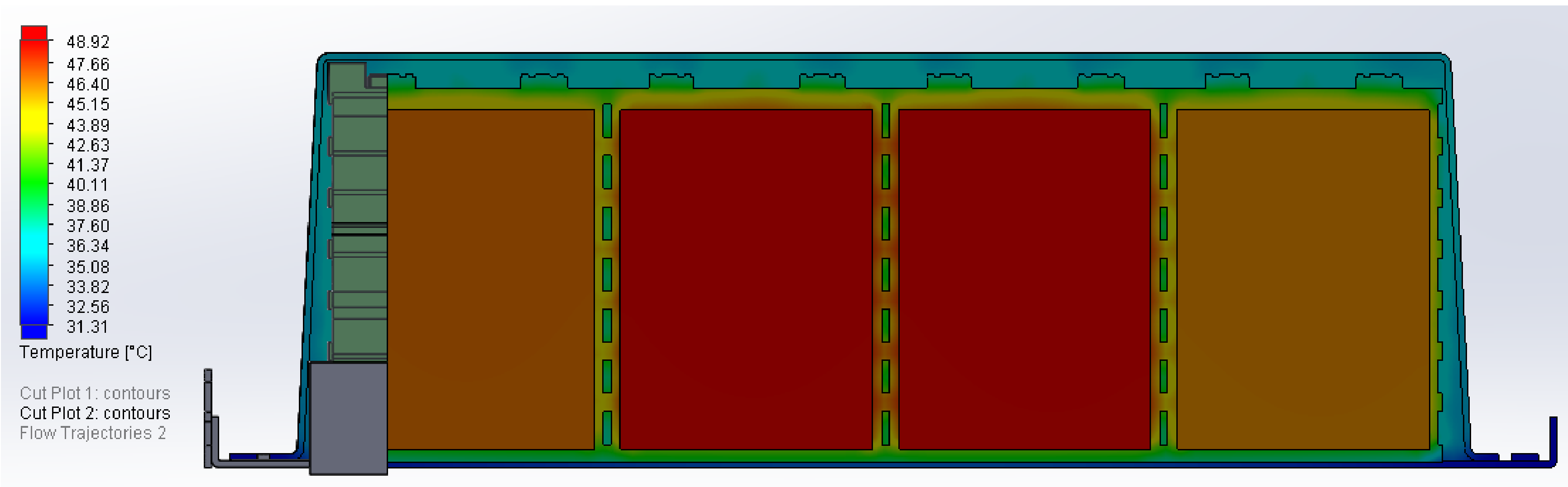




New Geometry Analysis

Steady State Simulation – Regular Use Condition

Temperature Distribution



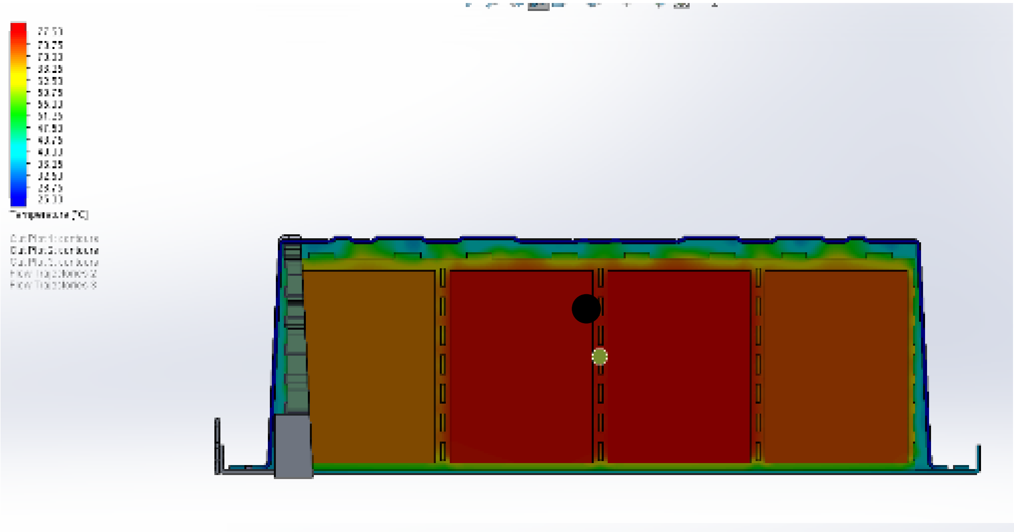
Temperature distribution. Front view.

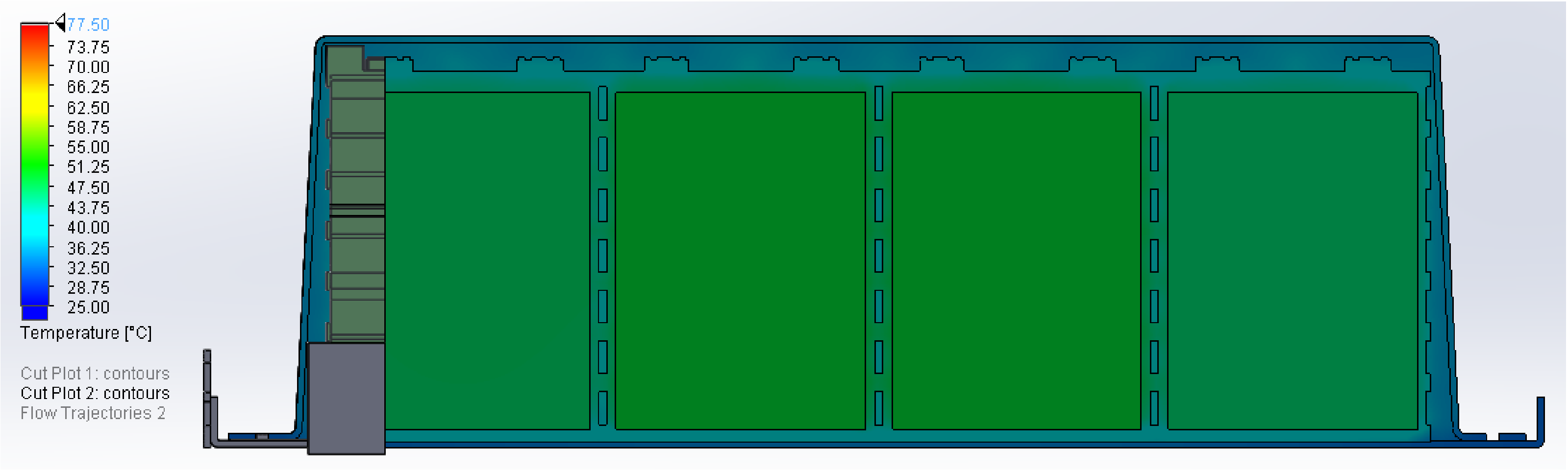
New Geometry Analysis

Steady State Simulation – Regular Use Condition

Temperature Distribution

Temperature comparison between Original and New Geometry.





New Geometry Analysis

Steady State Simulation – Regular Use Condition

Volumetric Flow Original vs New Geometry

CreativeSolutions

Original Geometry

- Volumetric flow in the outlets showing strong losses: 7.8 CFM vs 25 CFM

Local Parameter	Minimum	Maximum	Average	Bulk Average	Surface Area [m^2]
Pressure [Pa]	101388.17	101389.00	101389.00	101389.00	0.0031
Velocity [m/s]	0	1.337	1.202	1.211	0.0031
Velocity (Z) [m/s]	-1.335	0.002	-1.201	-1.210	0.0031
Temperature (Fluid) [°C]	27.90	35.15	35.00	35.00	0.0031

Integral Parameter	Value	X	Y	Z	Surface Area [m^2]
Mass Flow Rate [kg/s]	0.0042				0.0031
Volume Flow Rate [CFM]	7.7888				0.0031

New Geometry

- Volumetric flow in the outlets very close to those specified in cooler datasheet: 22 CFM vs 25 CFM = 0.88 factor

Local Parameter	Minimum	Maximum	Average	Bulk Average	Surface Area [m^2]
Velocity [m/s]	1.698e-004	5.682	4.563	4.696	0.0030
Velocity (X) [m/s]	-4.154	4.265	0.120	0.120	0.0030
Temperature (Fluid) [°C]	35.00	39.58	37.91	37.99	0.0030

Integral Parameter	Value	X	Y	Z	Surface Area [m^2]
Mass Flow Rate [kg/s]	-0.0118				0.0030
Volume Flow Rate [CFM]	-22.0616				0.0030

Local Parameter	Minimum	Maximum	Average	Bulk Average	Surface Area [m^2]
Velocity [m/s]	0.002	5.914	4.641	4.749	0.0030
Velocity (X) [m/s]	-4.215	4.236	0.126	0.165	0.0030
Temperature (Fluid) [°C]	35.00	39.64	37.90	37.95	0.0030

Integral Parameter	Value	X	Y	Z	Surface Area [m^2]
Mass Flow Rate [kg/s]	-0.0113				0.0030
Volume Flow Rate [CFM]	-21.0774				0.0030

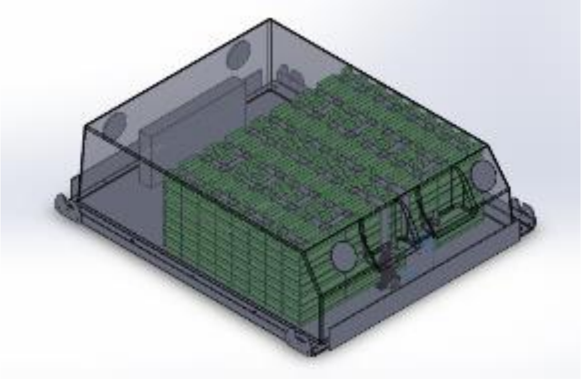
New Geometry Analysis
Transient Simulation – Critical Use Condition

Transient Simulation

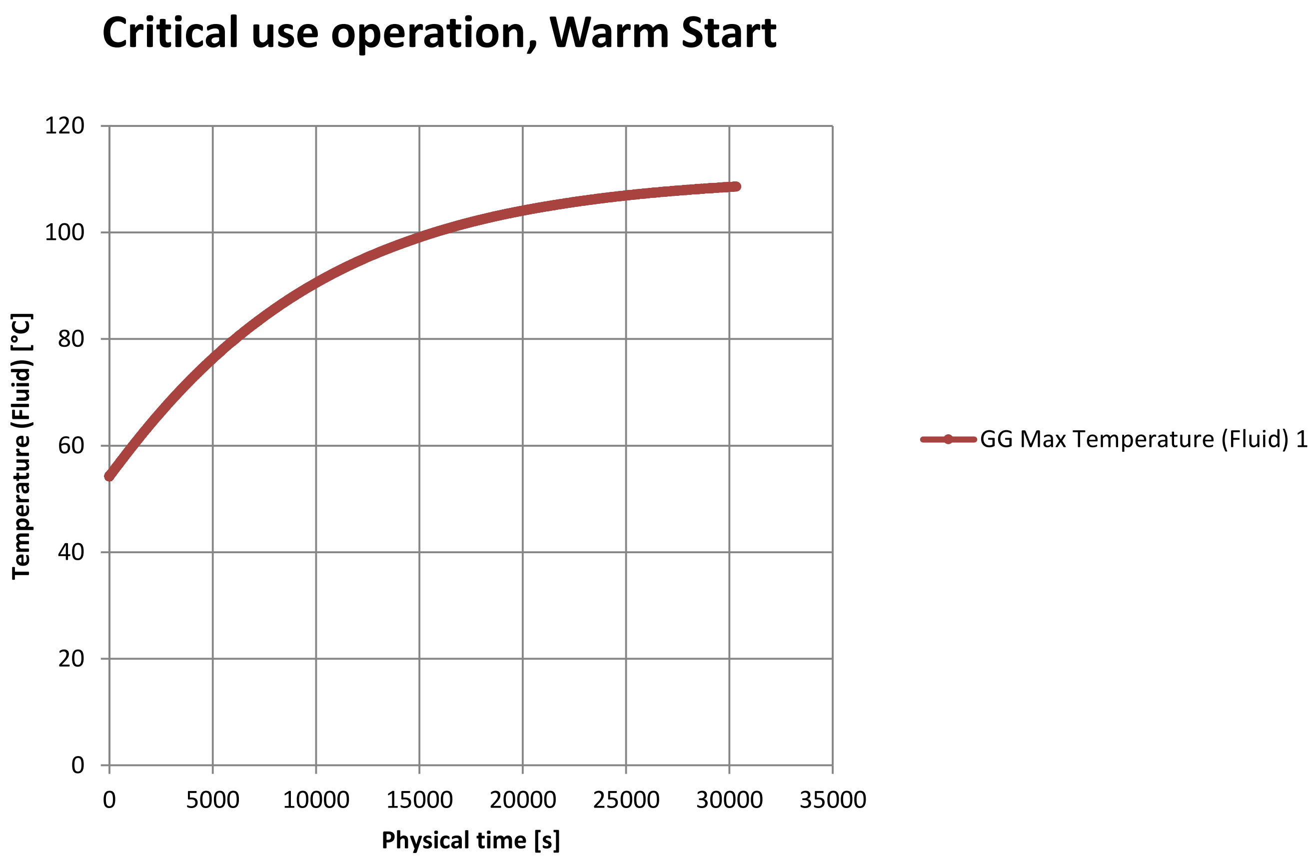
- "Warm Start": Initial temperature distribution from Regular Use condition
- Critical Use boundary conditions (low vehicle speed, high ambient temperature, and high power dissipation in batteries)

Objective:

- Evaluate how long the system can work in harsh condition till it reaches critical temperature.



New Geometry Analysis
Transient Simulation – Critical Use Condition
Max Temperature over Time



- ~9 hours to reach Steady State Max Temperature of 104 ºC
- **19 minutes to reach max allowed temperature of 60 ºC**

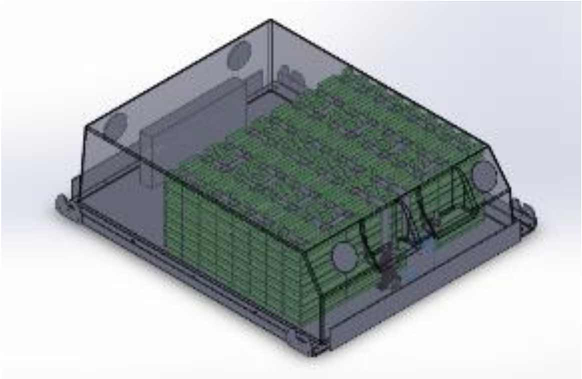
New Geometry Analysis
Transient Simulation – Critical Use Condition

Transient Simulation

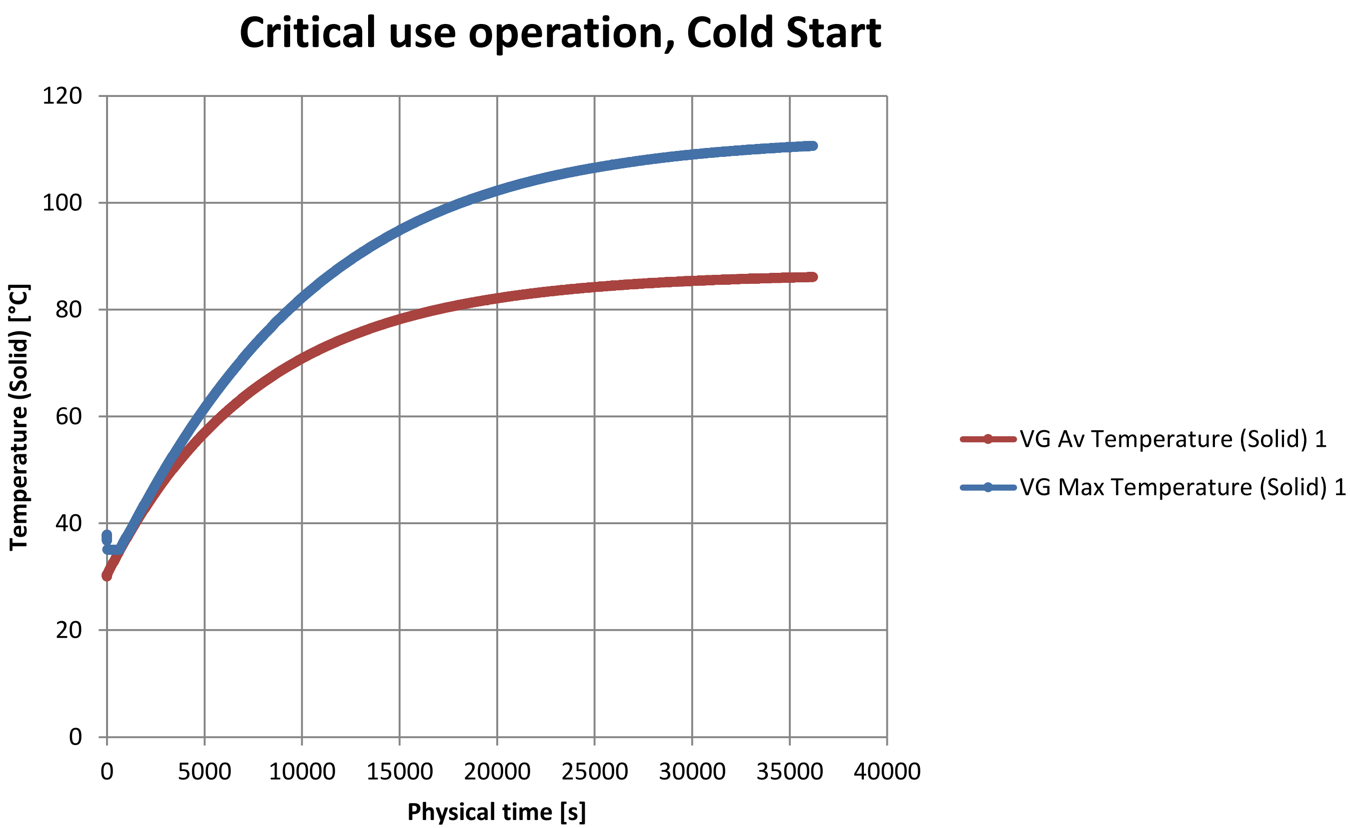
- “Cold Start”: Starting at ambient temperature
- Critical Use boundary conditions (low vehicle speed, high ambient temperature, and high power dissipation in batteries)

Objective:

- Evaluate how long the system can work from rest, in harsh conditions till it reaches critical temperature.

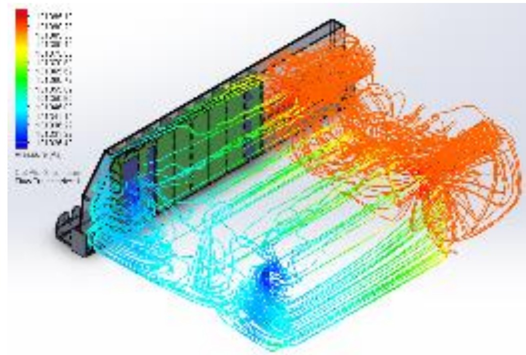


New Geometry Analysis
Transient Simulation – Critical Use Condition



- ~10 hours to reach Steady State Max Temperature of 104 ºC
- **78 minutes to reach max allowed temperature of 60 ºC**

Conclusions



Original Design:

- ➢ Had serious geometry issues, causing 1/3 of the expected flowrate.
- ➢ A single inlet/outlet is not enough to secure proper cooling.

Final Design:

- ➢ At regular use conditions, battery pack will stay comfortably under critical temperatures
- ➢ Coming from regular use, the vehicle can operate ~20 minutes under very critical conditions

Strategic Advantage:

- ➢ Quickly simulate dozens of scenarios for different operating conditions, varying battery cells aging, dissipated power, initial and ambient temperature, vehicle load and speed, etc.
- ➢ Battery cells can be rotated accordingly to distribute aging homogeneously.
- ➢ Important liability protection.


CreativeSolutions