1D & 3D thermal simulations of Li-ion batteries for automotive applications

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Principal engineer – Thermal Simulation

Fortescue WAE

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Fortescue WAE

Company profile

What we do

- World leading technology and engineering service operation
- We pride ourselves in solving the most difficult applied engineering challenges
- Our capabilities cover a wide range of disciplines, from light weighting to fluid dynamics to design with novel materials
- Our algorithms and software enable electric vehicles to travel further and faster whilst increasing efficiency

Background

- Established in 2010, originally the in-house engineering business of the Williams Formula 1 motorsport team.
- Based in Oxfordshire, UK we successfully deliver products and services to a global customer base
- > 900 employees
- Award-winning business including RAC Simms Medal in 2015 and Queens Award for Enterprise, in 2018
- Acquired by Fortescue Metals Group on the 1st of March 2022 to support the drive to zero emissions to combat climate change

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Electrification excellence

Innovative powertrains for Motorsport

FORMULA E

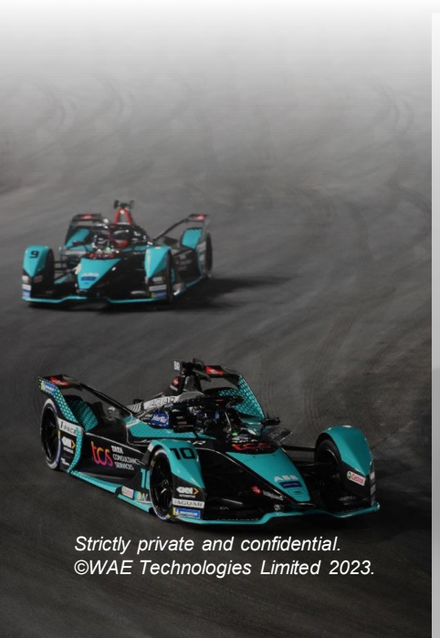
- WAE were awarded Gen3 battery contract of the ABB FIA Formula E World Championship by the FIA World Motor Sport Council in July 2020
- The Gen3 battery specification showcases advanced battery technology through improved energy density, lifecycle, durability, fast charging and power capability

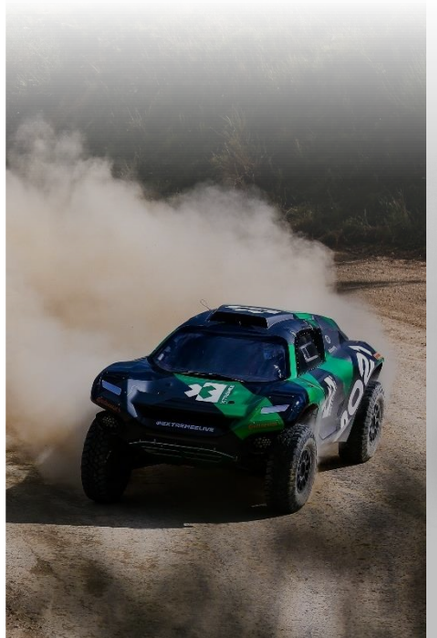
EXTREME E

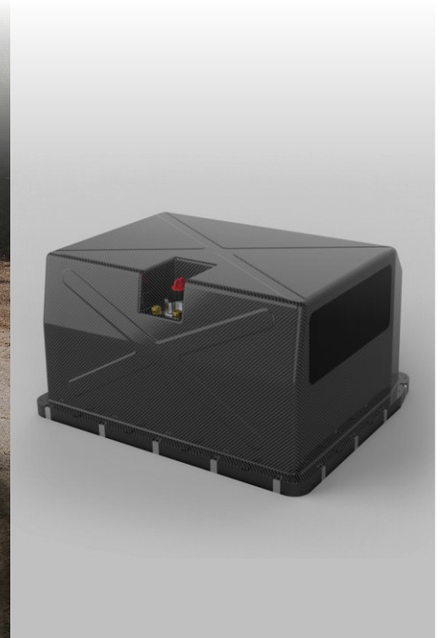
- In May 2019, Extreme E announced the launch of an electric SUV off-road racing series and a partnership with WAE to supply identical 54 kWh battery packs for the Extreme E teams
- The batteries have been specially-designed and developed to withstand extreme environments, conditions and terrains, producing a maximum power output of 470 kW (equivalent to approx. 630 bhp)

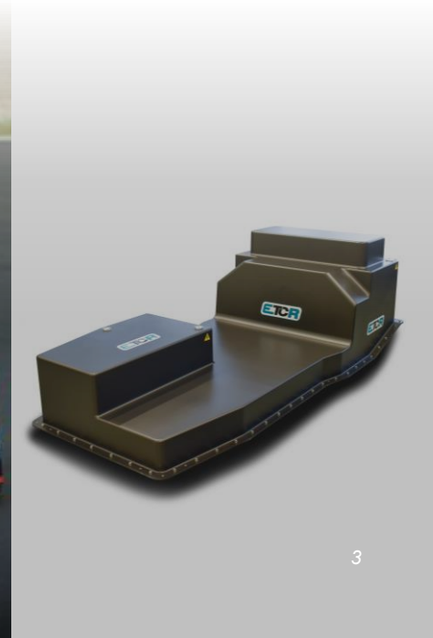
ETCR

- WSC Group chose Williams Advanced Engineering to design, develop, manufacture and supply the batteries and vehicle control modules for the first electric multi-brand Touring Car racing series ETCR
- The series started in 2021 with shake down testing being carried out by WAE in 2020 at key race circuits round the world









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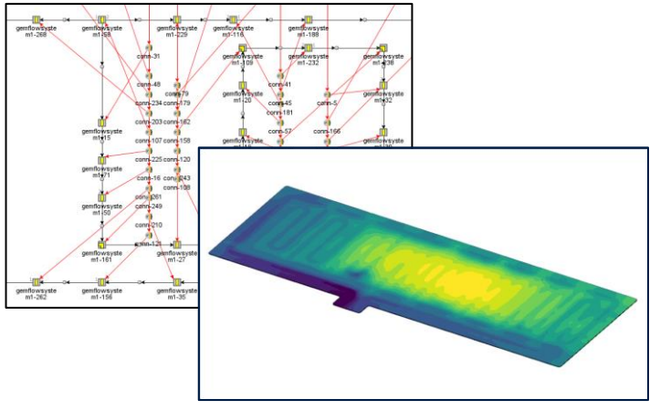
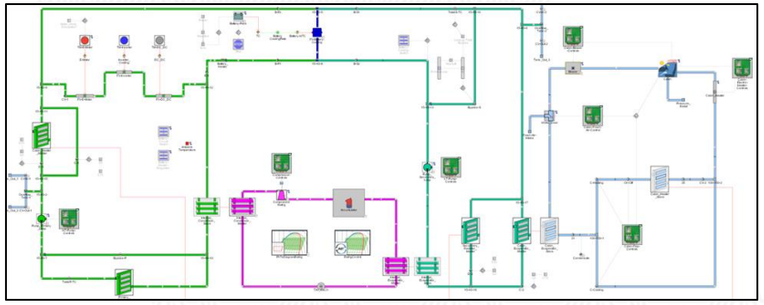
1. Applications of GT-SUITE for the thermal study of Li-ion batteries





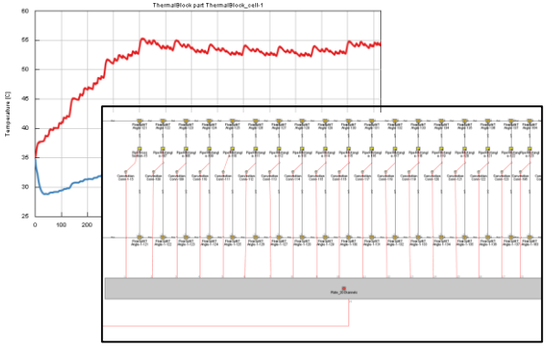
Preliminary 1D thermal analysis

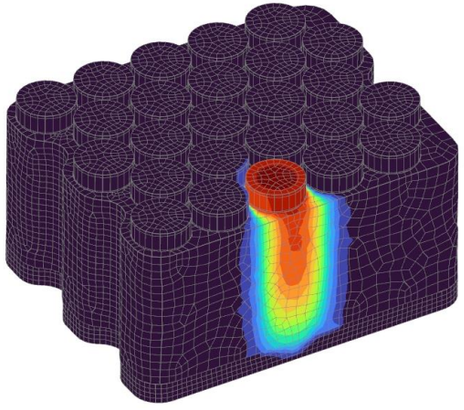
Detailed 1D/3D thermal analysis

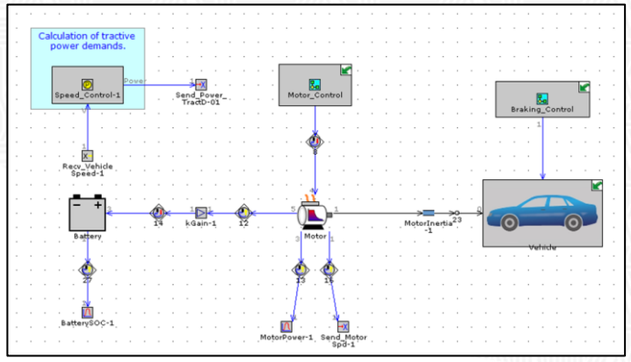
Propagation of the thermal runaway

Integration into cooling system or HVAC

Integration into vehicle model







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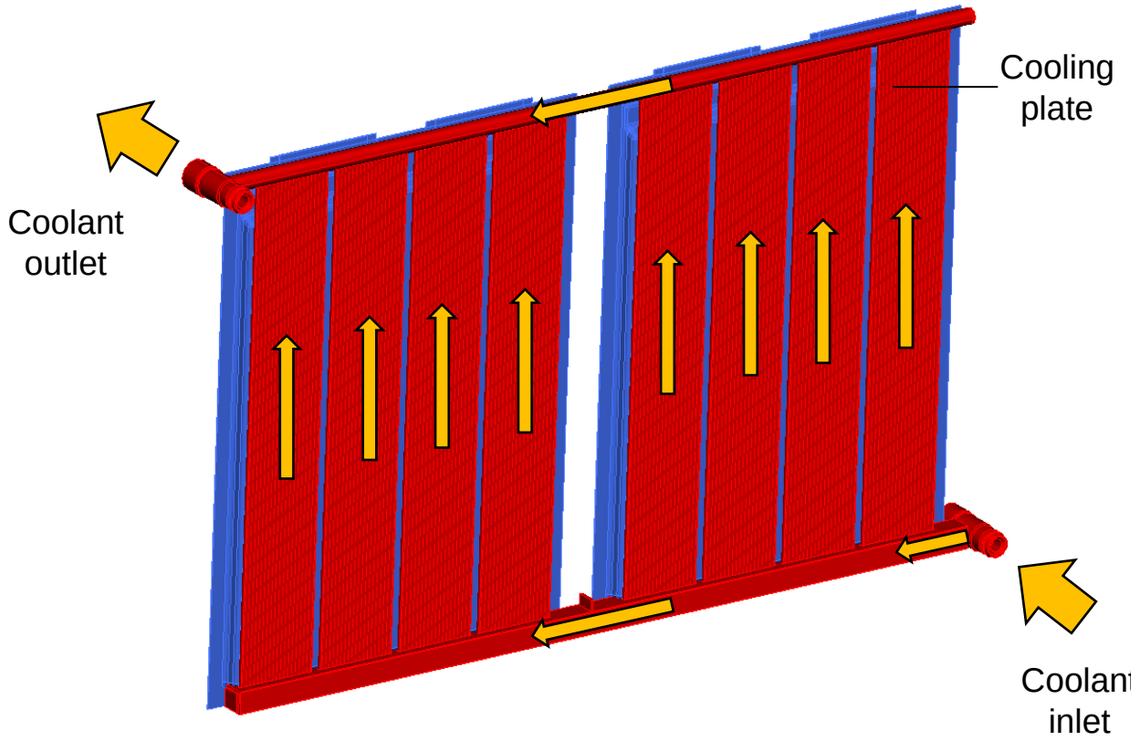
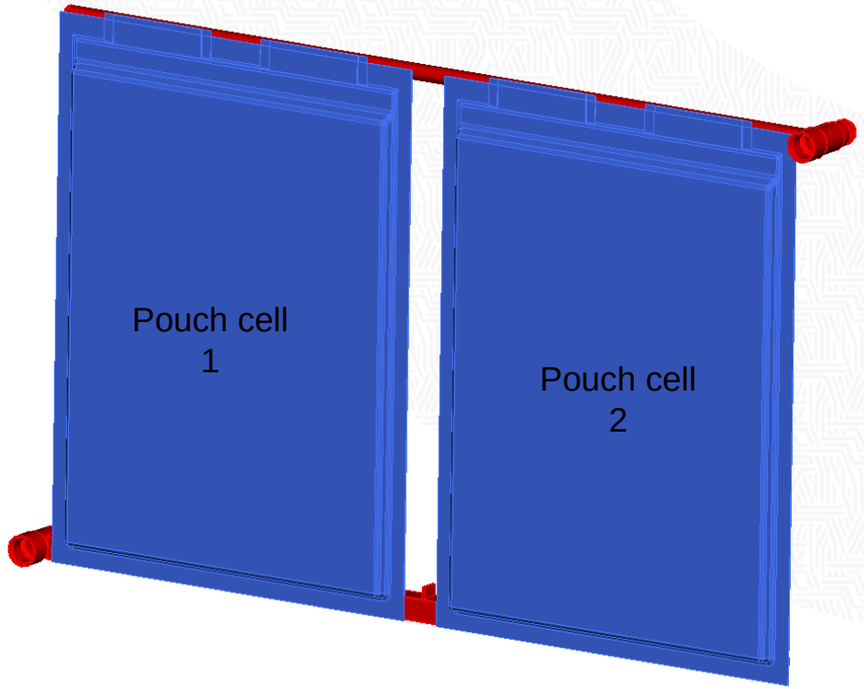
2. Preliminary 1D thermal analysis

- The case used for showing the potential of GT-SUITE to predict the thermal performance of Li-ion batteries in the concept phase consists of two pouch cells cooled by one cooling plate. The dielectric fluid running along the microchannels of the plate cools down the front face of the cells.
- A 1D model was built to evaluate the feasibility of the proposed design and to perform an initial sensitivity study on the influence of the plate (channels dimensions, number of channels, etc.) and the operating conditions (coolant selection, volume flow, inlet temperature) on the cell temperature.





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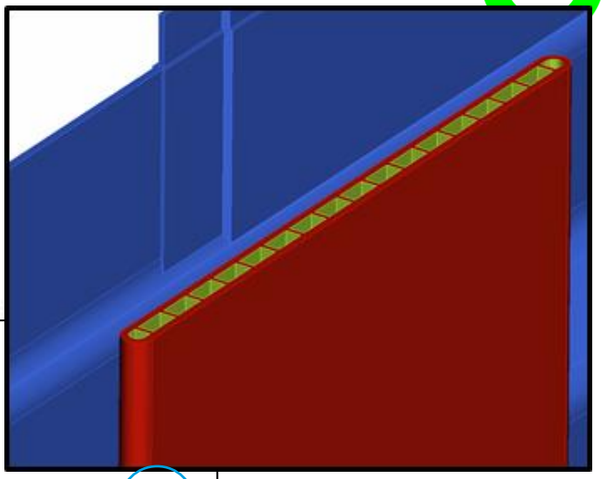
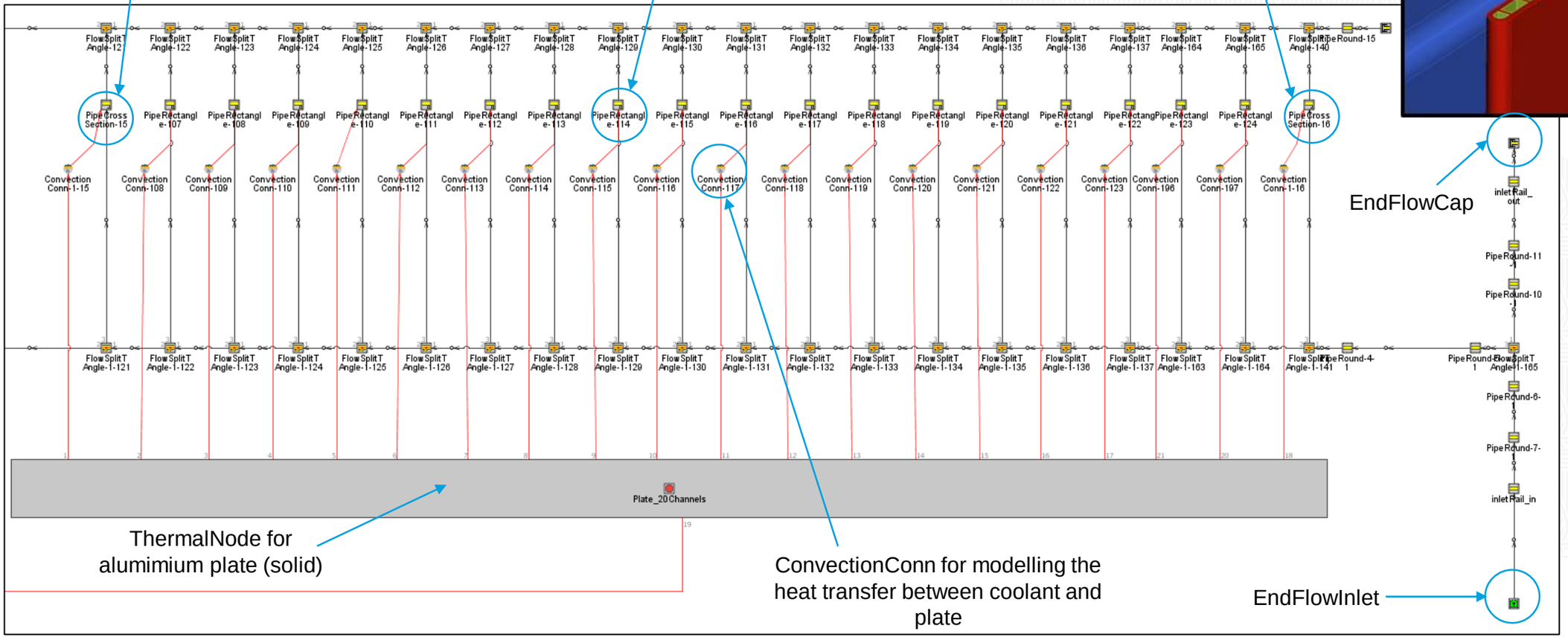
2. Preliminary 1D thermal analysis

PipeCrossSection (pipe with arbitrary cross section) for lateral microchannels

PipeRectangle (pipe with a rectangular cross section) for central microchannels

PipeCrossSection (pipe with arbitrary cross section) for lateral microchannels





EndFlowCap

ThermalNode for alumimium plate (solid)

ConvectionConn for modelling the heat transfer between coolant and plate

EndFlowInlet

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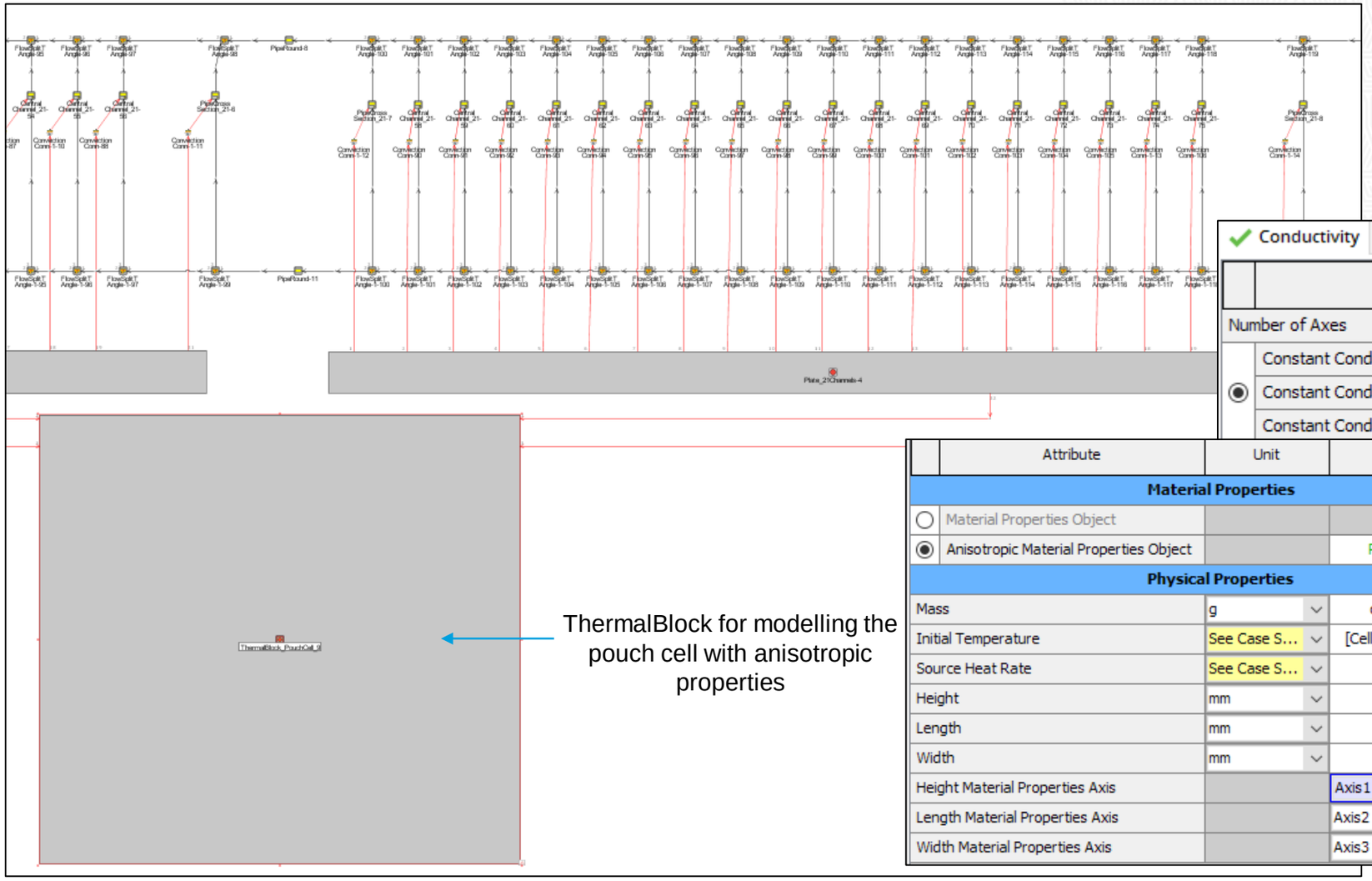
2. Preliminary 1D thermal analysis



ThermalBlock for modelling the pouch cell with anisotropic properties

✓ Conductivity ✓ Density ✓ Specific Heat ✓ Options

	Attribute	Unit	Object Value
	Number of Axes		ThreeAxis
	Constant Conductivity (Axis 1)	W/(m-K)	25
◉	Constant Conductivity (Axis 2)	W/(m-K)	25
	Constant Conductivity (Axis 3)	W/(m-K)	2
	bles (Axis 1)	W/(m-K)	

	Attribute	Unit	Object Value
	Material Properties		
○	Material Properties Object		
◉	Anisotropic Material Properties Object		PouchCell_properties ...
	Physical Properties		
	Mass	g	def (=H×L×W×Rho) ...
	Initial Temperature	See Case S...	[Cell_InitialTemperature] ...
	Source Heat Rate	See Case S...	[Heat_cell] ...
	Height	mm	141 ...
	Length	mm	111.7 ...
	Width	mm	12.3 ...
	Height Material Properties Axis		Axis1
	Length Material Properties Axis		Axis2
	Width Material Properties Axis		Axis3

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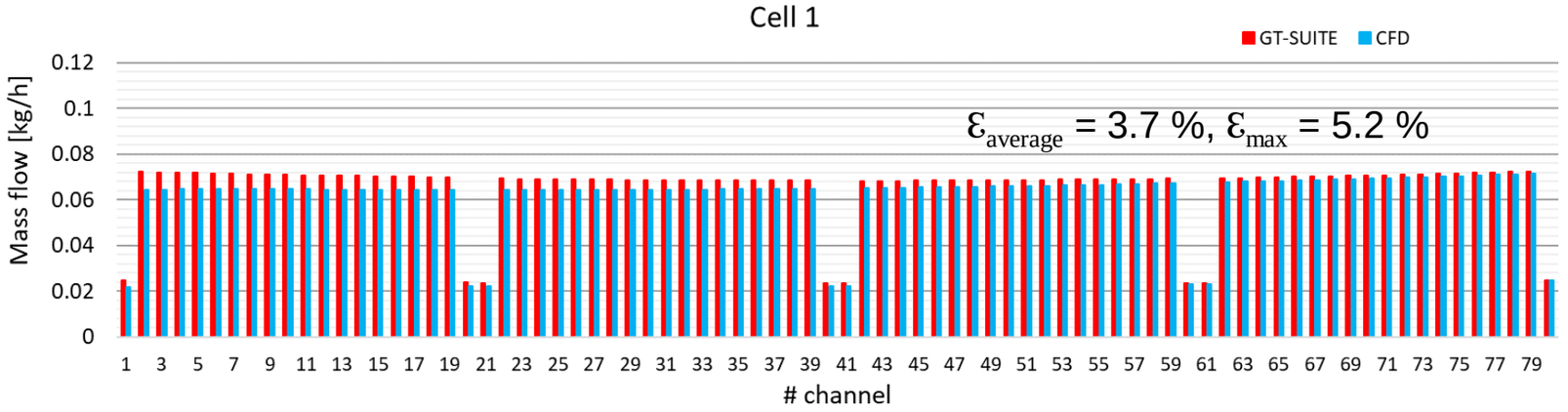
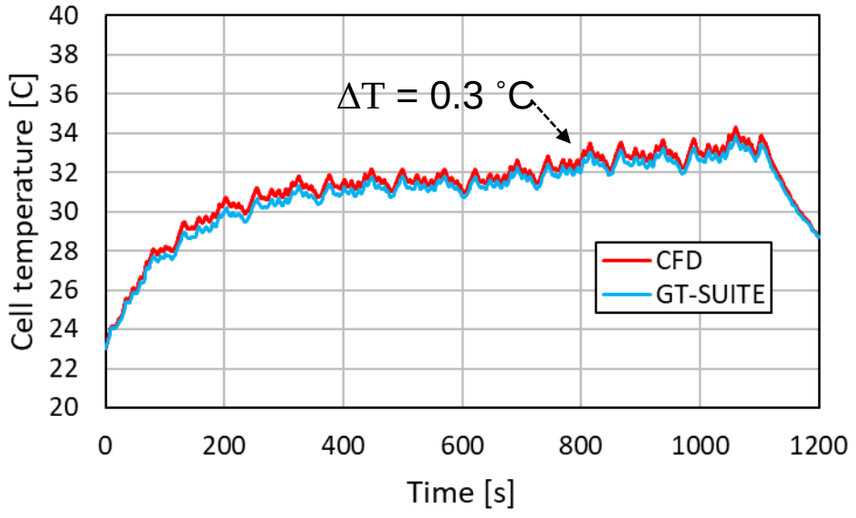
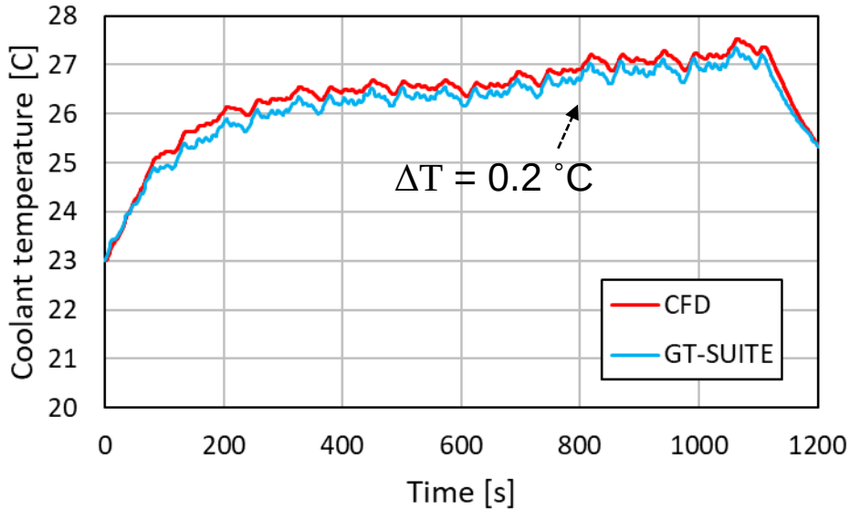
2. Preliminary 1D thermal analysis

GT-SUITE is able to predict with high level of confidence the temperature of the cell, the temperature of the coolant and the flow distribution between the 160 microchannels of the plate.







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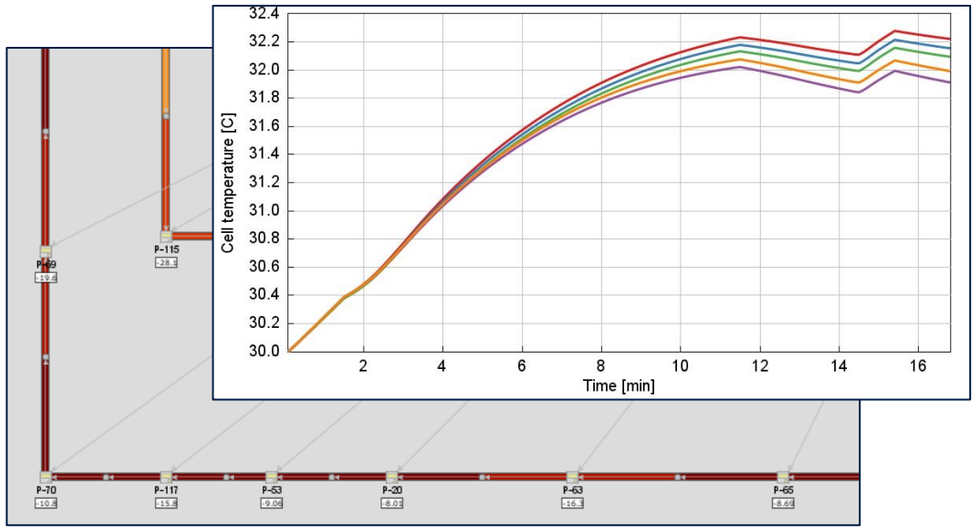
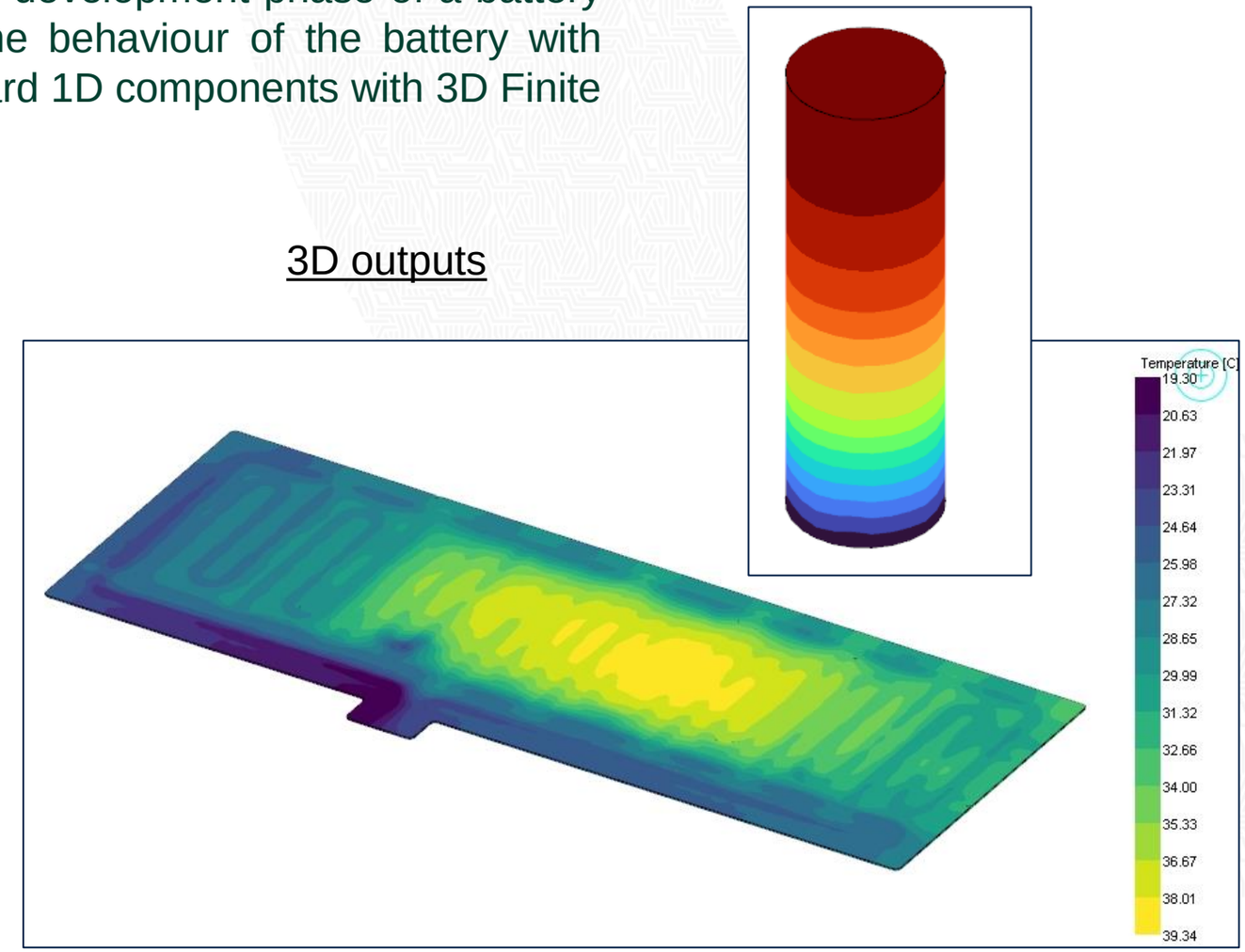
3. Detailed 1D/3D thermal analysis

The use of GT-SUITE & GEM3D in the design and development phase of a battery programme offers a more accurate analysis of the behaviour of the battery with steady and transient drive cycles, combining standard 1D components with 3D Finite Element components.

Standard 1D outputs



3D outputs



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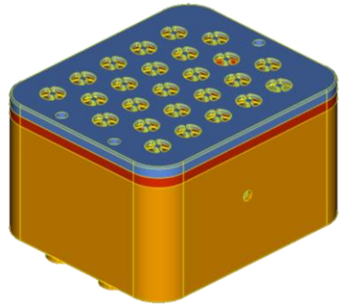
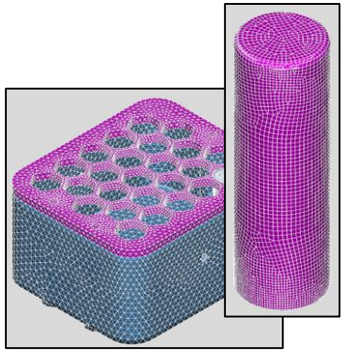
4. Propagation of the thermal runaway

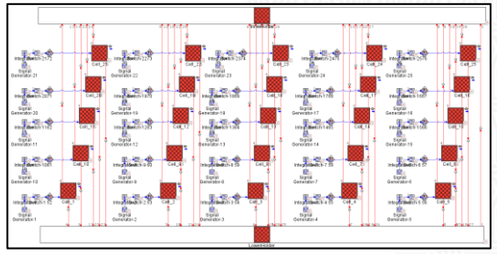
The test module consists of 25 cylindrical cells separated by foam to reduce the probability of thermal runaway propagation. The GT-SUITE model includes the lid, cells, intercell spacing material, cells holder, glue and case.



CAD

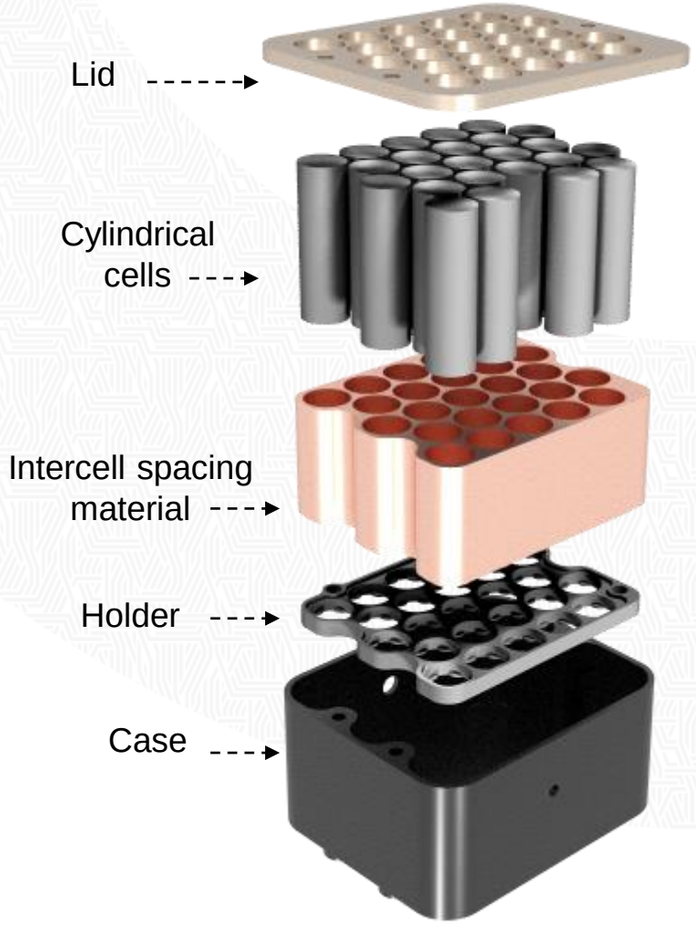


GEM3D



GT-ISE

CELL TEST



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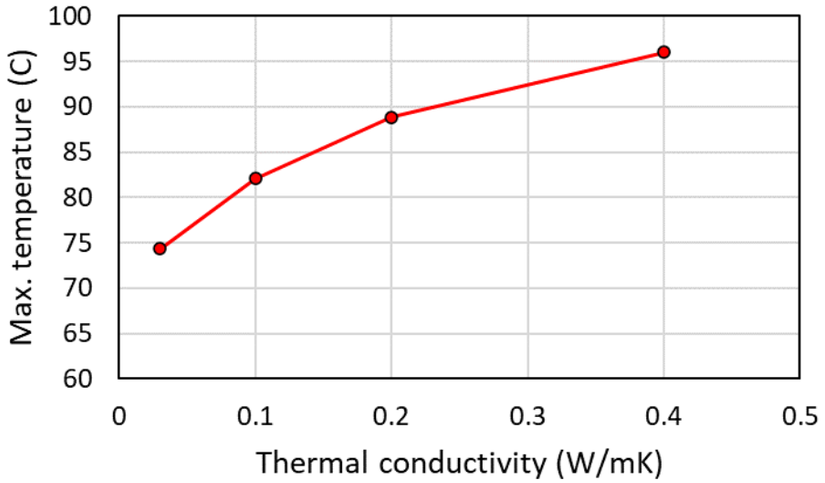
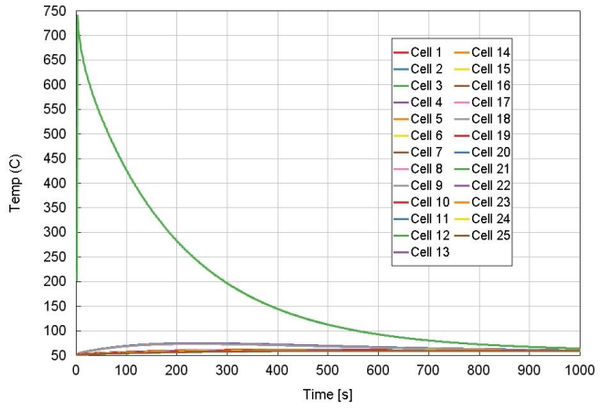
4. Propagation of the thermal runaway

- The higher the thermal conductivity of the foam, the higher the temperature of the neighbouring cells.

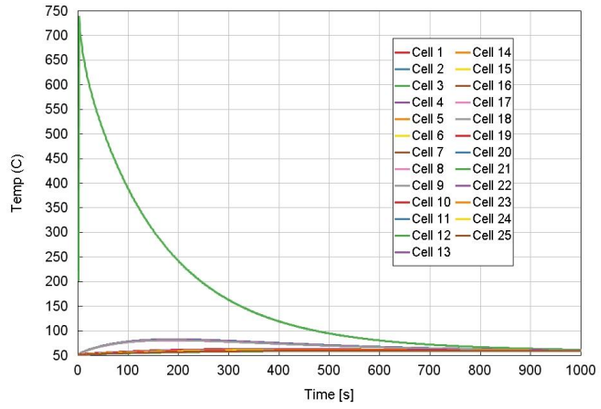
- The propagation of the thermal runaway could be suppressed with the four foams, but a further increase of the thermal conductivity would trigger a chain reaction (T_{onset} ≈ 100 C).



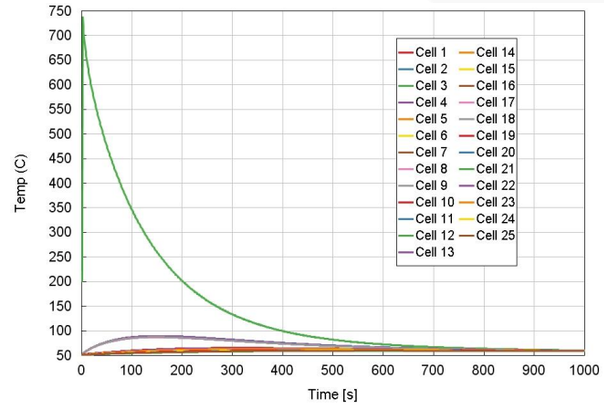
0.03 W/mK



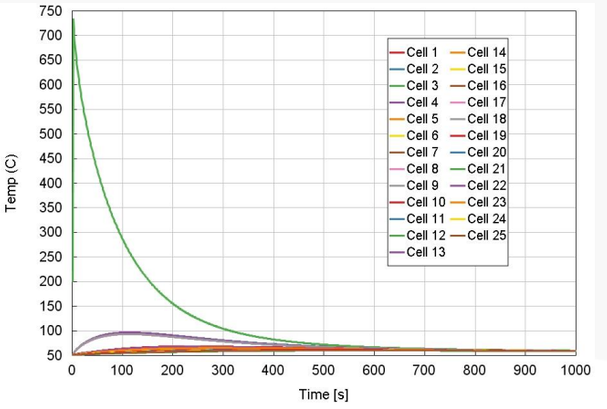
0.1 W/mK



0.2 W/mK



0.4 W/mK



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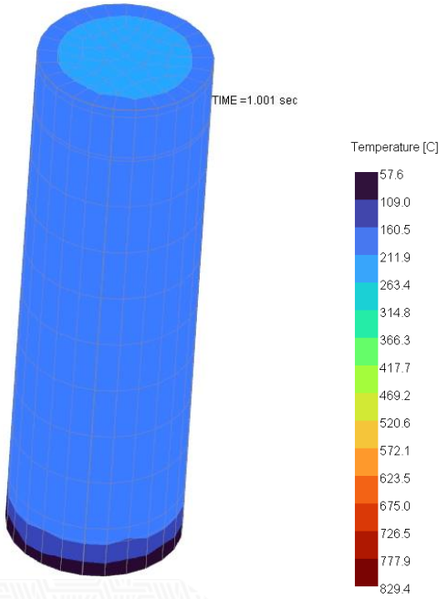
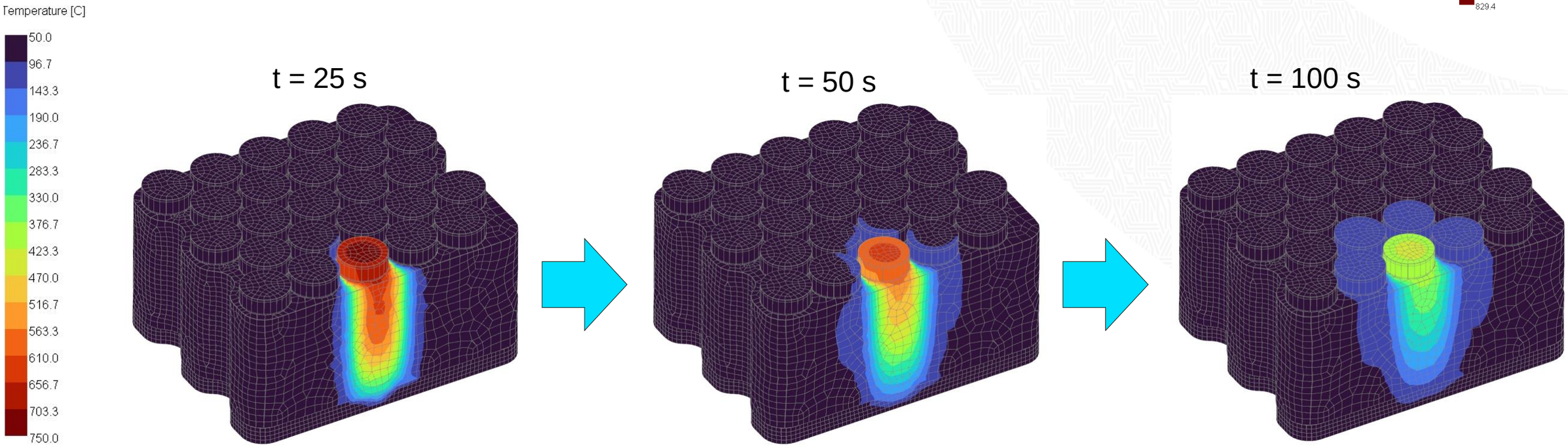
4. Propagation of the thermal runaway

- The use of a 3D Finite Element model of the battery in GT-SUITE allows the analysis of the temperature distribution of all the components during the thermal runaway event in just minutes.
- These model can be used for optimizing the design of the battery at critical scenarios and for performing sensitivity studies that could help us to understand the thermal behaviour of the module.





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5. Conclusions

- WAE is actively working in developing new simulation methodologies to support the development of electric powertrains for high performance cars and electric motorsport series.

- GT-SUITE offers a comprehensive set of fluid, thermal and electrical libraries to study the performance of Li-ion batteries from fast concept stage to detailed design.

- The fidelity of these thermal simulations can be adjusted from 0D to 3D calculations within a single model environment thanks to the use of GT-SUITE and GEM3D.

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