Cranfield Formula Electric Series

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Aim

The aim of the project is to design thermal management system for the new Cranfield Formula Electric Series. "*The thermal system is critical to ensure maximum performance and safe operation*".

Objectives

- Definition of system requirements
- Design of power train
- Control Systems, Hazards & Safety
- Battery cooling
- Design of thermal system
- Battery crash structure design
- Performance calculations

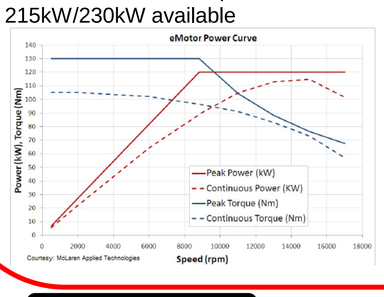
Powertrain

Requirements

- 20 minutes non-stop race
- Maximum speed possible

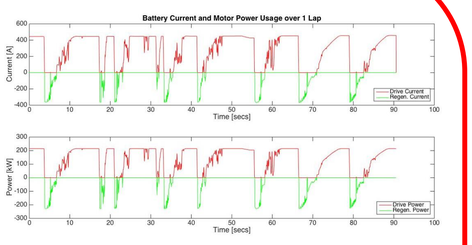
Motor Specification

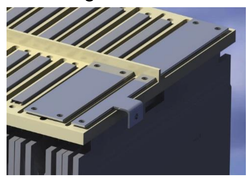
- Motor selected: **McLaren e-motor**
- Permanent magnet synchronous motor/generator
- Rear wheel drive - dual motor
- Each motor capable of delivering maximum of **120 kW**, **130 Nm**
- Total Motor Power Required: 215kW/230kW available



Battery Specification

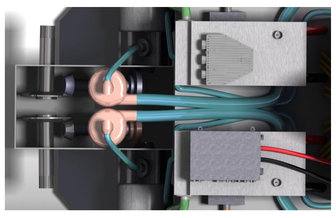
- 2 Cells in Parallel (80Ah)
- 160 Cells in Series (592V nom.)
- Total Mass of Battery: 325kg
- Peak Drive Current: 459A (5.7C)
- Peak Regen Current: 369A (4.6C)
- Capacity Used: 77Ah (96% DoD)
- Custom design **bus bar:**





Transmission

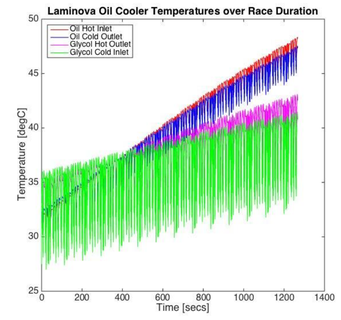
- Single speed
- Designed to withstand the torque and power from the motors and the regeneration
- Total gear ratio: 1:6



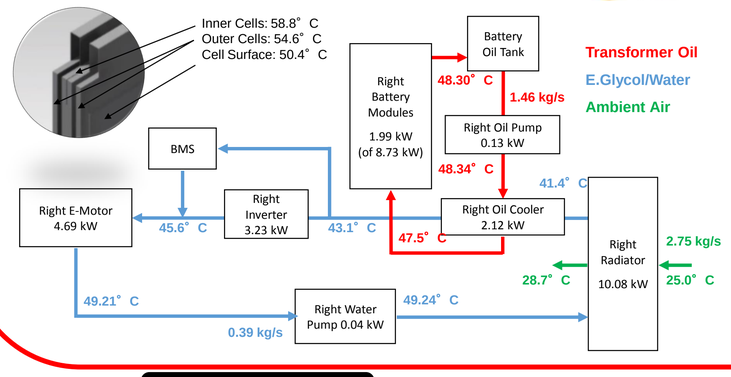
Thermal System

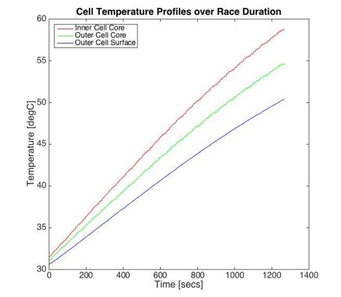
Thermal Circuit

- Dual coolant circulation strategy
- Independent left and right coolant circuits
- Laminova heat exchanger between fluids
- Battery Coolant: **NYTRO 10XN Oil**
- Motor Coolant: **E.Glycol/Water**
- Oil Pump Flow Rate: **100 L/min**
- Water Pump Flow Rate: **20L/min**



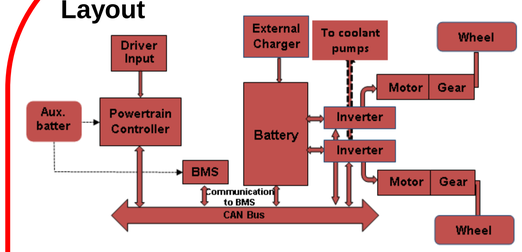
MATLAB Code Thermal Estimation





Control System

Layout

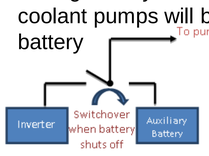


Electronics

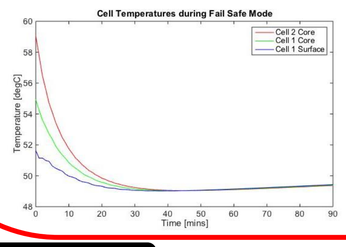
- Inverter & Motor Controller: McLaren **MCU-510**
- Battery Management System: **RiMAC** (Master BMS, slave circuits in the battery pack)
- Powertrain Master Controller: **CIU100**
- Auxiliary battery power for all ECUs and power coolant pumps during fail safe mode

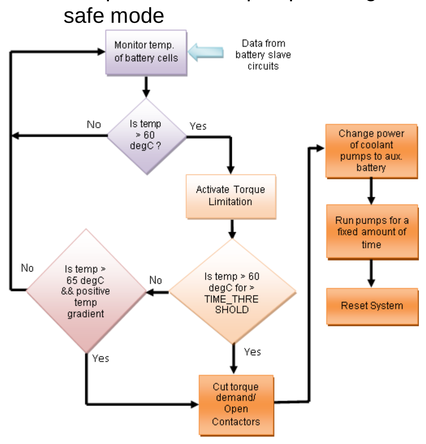
Hazards & Safety

- Safety goal (ISO26262) – to maintain battery temperature within 60˚ C
- BMS ECU constantly monitoring temperatures of battery cells & charging/recharging rates
- During battery shut off due to hazard, coolant pumps will be powered by aux. battery

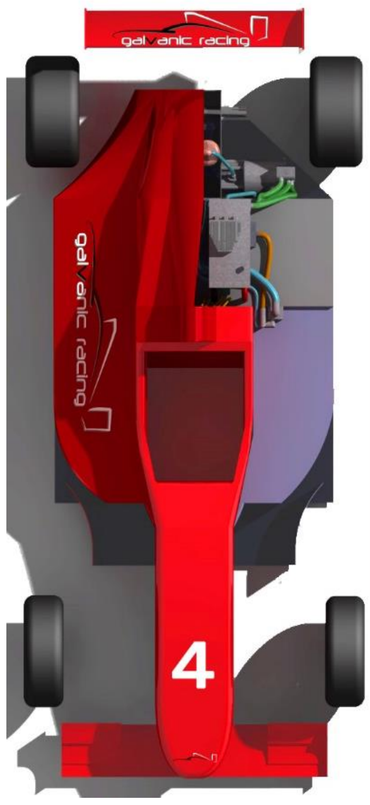


Fail-Safe Strategy on hazard detection





The temperature are within limits, even if the vehicle stops and the radiator is not functional.

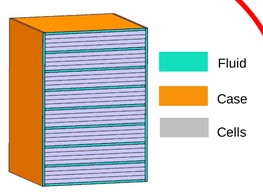


Battery Cooling

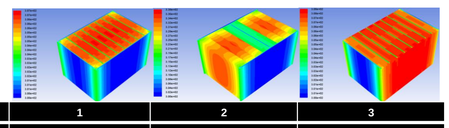
Fluid cooled battery with the following objectives:
- Improve temperature distribution **homogeneity**
- **Decrease core cell maximum temperature**, keeping it below 60˚ C

Simulations performed for one module of 32 cells with fluid tunnel between cells:

- **Module Design: 2mm thick fluid between each 4 cells**

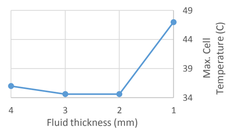


- Variation in number of fluid domains:



Configuration	1	2	3
# on the sides	4	2	2
# between cells	7	1	7
Min temp	31.2	42.4	33
Max temp	34	63.2	35
Gap temp	2.8	20.8	2

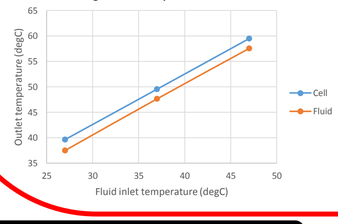
- Variation in fluid thickness between each 4 cells:



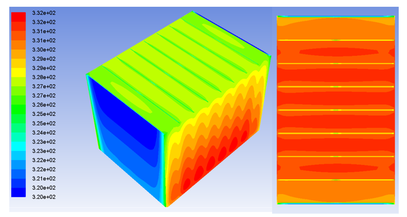
Final Layout			
Geometry		# of cells	32
		# of fluid domains	9
		Fluid thickness (mm)	2
		Dimensions (mm)	225x227x302
		Weight (kg)	28.64
Simulation		Temperature inlet	47
		Mass Flow (kg/s)	0.03237
Results	Average heat generation	Max cells temp	53.13
		Min cells temp	50.19
		Max outlet fluid temp	51.82
		Min outlet fluid temp	46.93
	Maximum heat generation	Max cells temp	59.47
		Min cells temp	53.69
		Max outlet fluid temp	57.54
		Min outlet fluid temp	47.29

- **Inlet temperature: 47 ˚ C**

Linear change in temperature:



Two situations considered:
When the cells are generating the maximum heat: the maximum core cell temperature needs to be below 60 degC.
When the cells are generating the average heat: the maximum and the minimum cell temperature needs to be between 50 and 55 degC.



¾ Inlet View Outlet View
Temperature Distribution in K

In the tables, all the temperatures are expressed in ˚ C

Conclusions

- Galvanic racing vehicle delivers a power to weight ratio of **0.24 kW/kg**
- **System kept in optimal temperature ranges for ALL conditions.**
- **Custom designed** battery pack modules and bus bar.
- Excellent overall system integration.
- Battery Crash Structure passes safety pass criteria mandated by the CFES technical team, with 100 % cell survival after 50 km/hr wall impact.

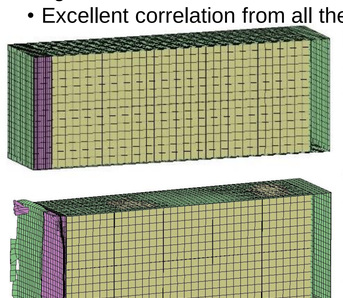
Performance

Weight with driver	**883kg**
Power	**215kW**
Power to Weight	**0.24kW/kg**
0-100km/h Time	**4.65s**
Predicted Lap Time Donington Circuit	**1'30.56s**
Top Speed at Donington	**231 km/h**

Battery Crash Structure

Validation tests

- Tensile FEA test for carbon fibre prepreg against manufacturer published data, following the BS EN 2597 method to match manufacturer's test.
- Compressive FEA test for a selection of aluminium honeycombs rated 25, 130, and 400 according to their crush strengths (psi) against Eskandarian et al tests following their methodology.
- Excellent correlation from all the tests.



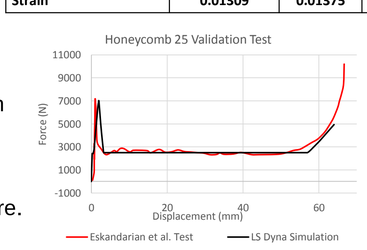
M21/40%/285T2/AS4C-6K Prepreg Validation Test			
	Published Data	Simulation	Error
Tension Strength (Mpa)	885	877.9	0.80%
Tension Modulus (Mpa)	67.6e+3	63.8e+3	5.62%
Strain	0.01309	0.01375	5.04%

Material selection

- Hexcel M21/40%/285T2/AS4C-6K Prepreg,
- Hexcel 3/8 – 5052 – .0007 aluminium honeycomb (Honeycomb 25), due to its excellent performance on our crash structure and low density.

Crash structure

- "Sandwich" structure (carbon fibre-honeycomb-carbon fibre) on the lateral faces of the box to absorb energy upon impact.
- Two additional stiffener carbon fibre strips on the top and the bottom of the box to add rigidity to the structure.
- 100% cell survival after 50 km/hr impact against rigid wall.



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