Design. Make. Test. of an optimised Formula E Student Battery Module

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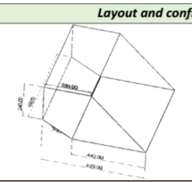
DESIGN

Product Design Specification

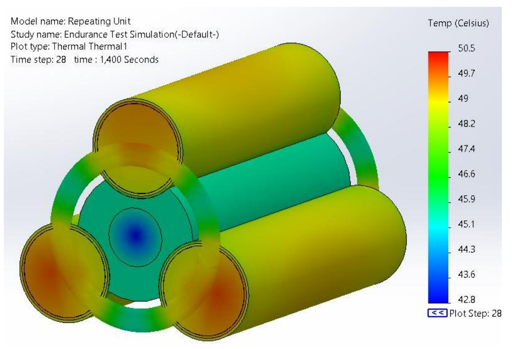
After analysis on performance requirements and Formula Student regulations, a detailed product specification was made. This included calculating the capacity from first principles and selecting the design max power, optimizing lap time sensitivities.

Aspect	Objective	Source	Verification
Pack Performance			
Peak Power	Max pack power < 80kW	FSUK Rule EV 2.1.1	Pulse Test
Operating Voltage Range	Pack must operate between 12V and 700V to integrate with motor controller	Bamocar-D3 datasheet	Design for Optimum Voltage
Pack Energy	Minimum 5.49 kWh	Section 2.2	1C Discharge
Layout and configuration			
Pack Volume		EV21 Chassis Constraint	From CAD volume evaluation
Pack Components			
Cells	All type of cells are allowed, except Molten Salt Cells, Thermal Batteries, and Fuel Cells	FSUK Rule EV 5.2.1	Cell Selection
Module	Each module within the pack must have a maximum static voltage below 120 V DC and maximum energy of 6 MJ	FSUK Rule EV 5.3.2	Design to value with safety factor and test
Cell weight	To improve upon the previous design, we aim to select a cell and an optimum configuration of mass maximum 27kg	Target	Iterate cell selection and concepts to optimum
Module Structural Weight	To improve upon previous module we aim to design a module lighter than the current one (i.e. < 1.75kg)	Target	
Mechanical			
Module attachment	The inter-module mechanism must withstand vibrations caused by car.	FSUK Rule	Vibration Rig Test
Fasteners	All fasteners must be metric grade 8.8 or higher and include positive locking mechanisms. T 10.2.2 states all the approved mechanisms	FSUK Rule EV 5.5.11	Design Review
Electrical			
Electrical integration	Ensure new design is compatible with electric circuitry being designed including the battery management system	Target	Design Review
Electrical Configuration	Module Terminal must be electrically separable without the use of tools	FSUK Rule T 13.1.6	Inspection
	The maximum permitted voltage between any two electrical connections is 600 V DC	FSUK Rule EV 4.1.1	Testing
Insulation and Wiring	All insulation and wiring must be rated to the max tractive system (TS) voltage and a temperature of 85°C	FSUK Rule EV 4.5.2, EV 4.5.3, EV 5.4.7	Design Review
	Modules must be electrically insulated from one another	FSUK Rule EV 5.4.6	Inspection
Safety			
Separation	Each module must be separated from others with vertical insulating walls of equivalent strength to 0.9mm thick steel or 2.3mm thick aluminium	FSUK Rule EV 5.5.4	Design Review
Fire Safety	All container materials must be fire retardant to UL94-V0	FSUK Rule EV 5.5.3	Design Review
Thermal			
Operating temperature & measurement	Cell temperature must be < 60°C BMS must monitor temperature of at least 30% of thermally critical cells	FSUK Rule EV 5.8.2, EV 5.8.4	Cycling Pack Testing with Thermistors
Production			
Cost	The cost of this project is not to exceed GBP 1000 for the first iteration unless more funding is applied for	Target	BoM and Cost of Manufacturing & Procurement
Quality Standard			
Design Standard	Drawings must meet BS 8888 and IRG design requirements	Internal Requirement	Assessed

Cell Selection for Power and Mass Optimization

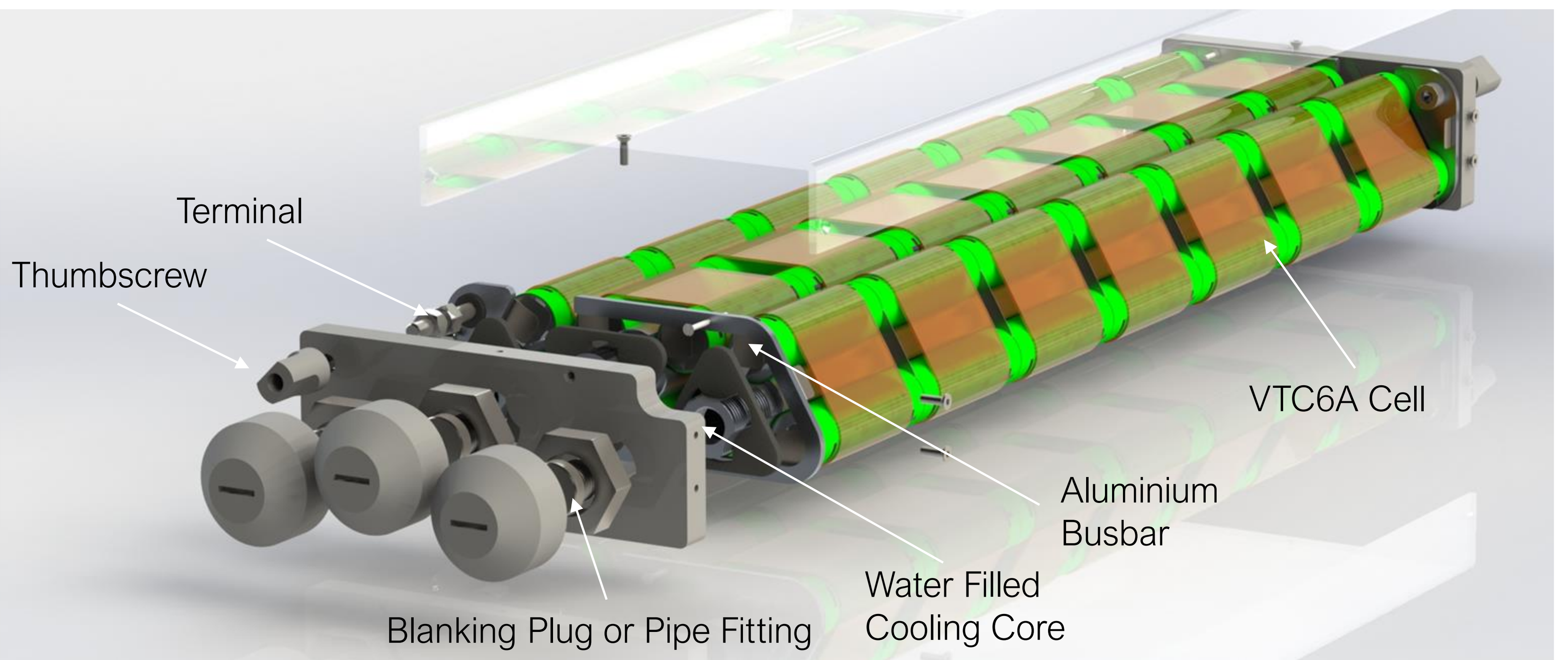
Our first mission was to select the best cell for our application, as the smallest length scale we could have an impact on. This involved populating an extensive cell spreadsheet whereby data sheet characteristics were processed considering pack level characteristics such as mass, capacity and power to best satisfy our PDS. From here, we used a search algorithm to mass optimize the configurations of the most promising cells and selected the Murata VTC6A.

Thermal Management & Modelling



From cell testing, we were able to model the internal resistance as a function of Temperature and State of Charge so that its corresponding heat generation would accurately represent the observed surface temperature of our selected cell. This model was implemented into thermal FEA serving as a powerful design tool to iterate for the most suitable thermal management system. Our final design uses grooved Aluminium tubes filled with water as an effective passive cooling method.

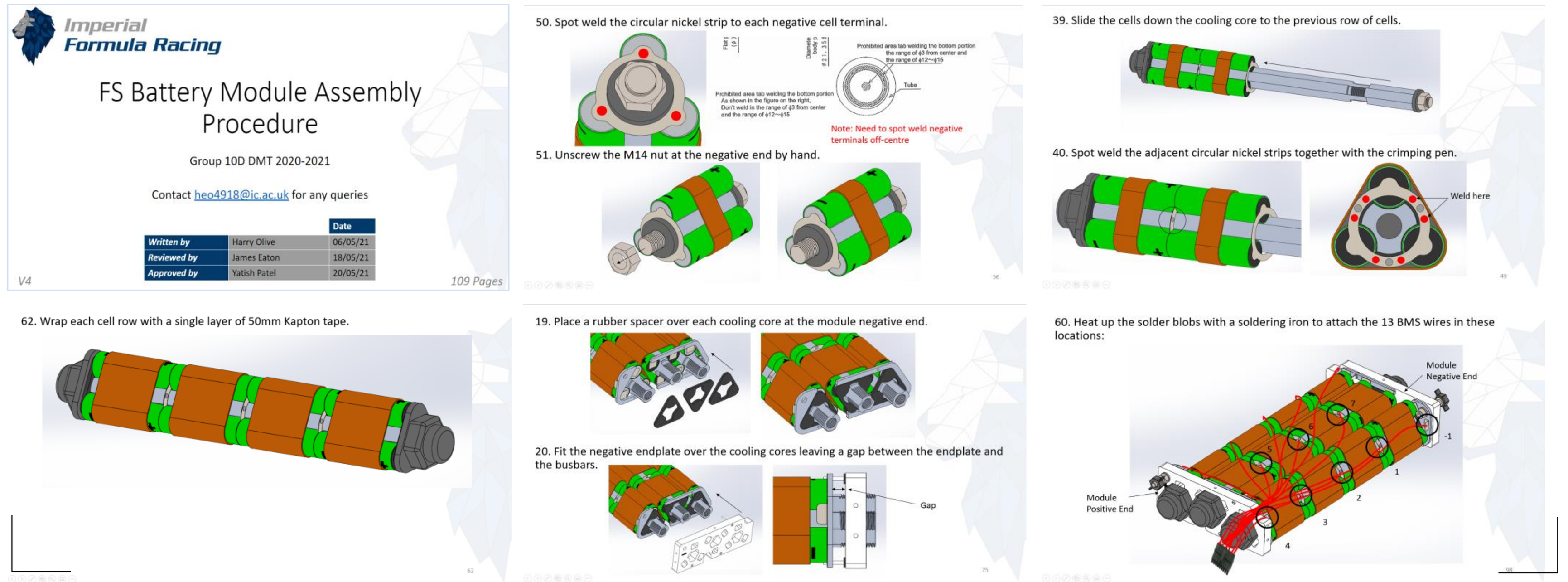
Final Design



MAKE

Assembly Procedure

A detailed assembly plan was produced with step-by-step assembly instructions.

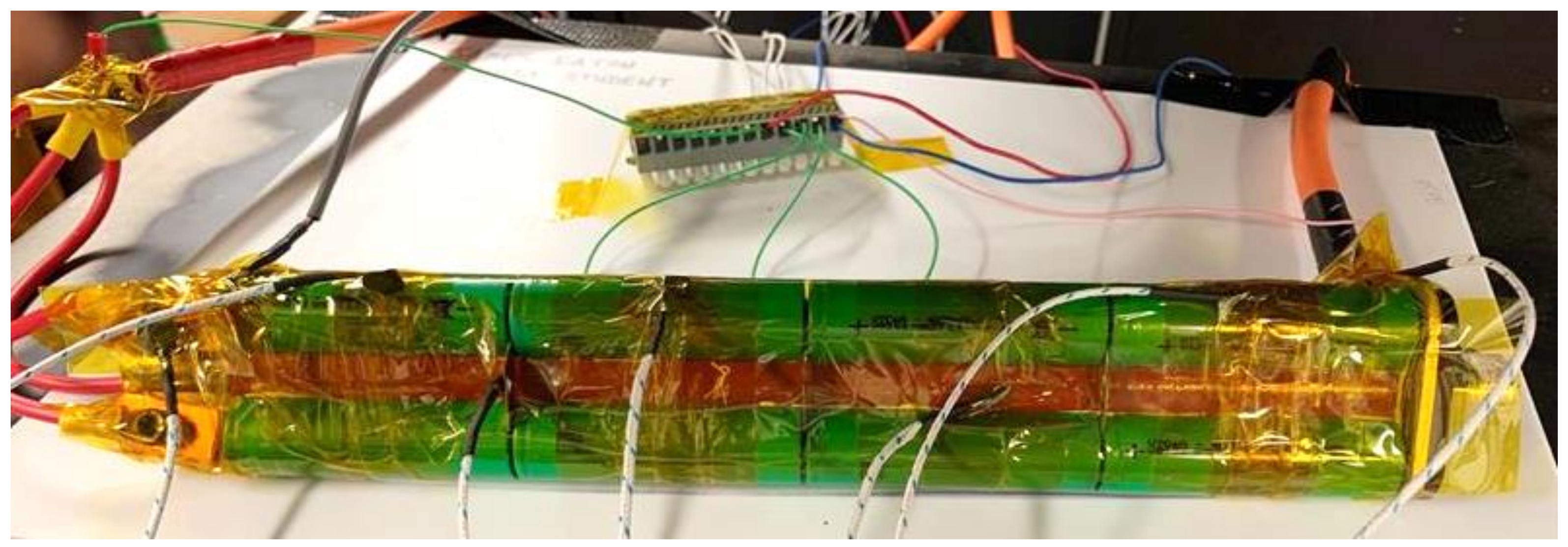


Parts Review

With all the parts procured, a complete dry assembly was attempted prior to official assembly with electrical connections. All parts fit together with ease.

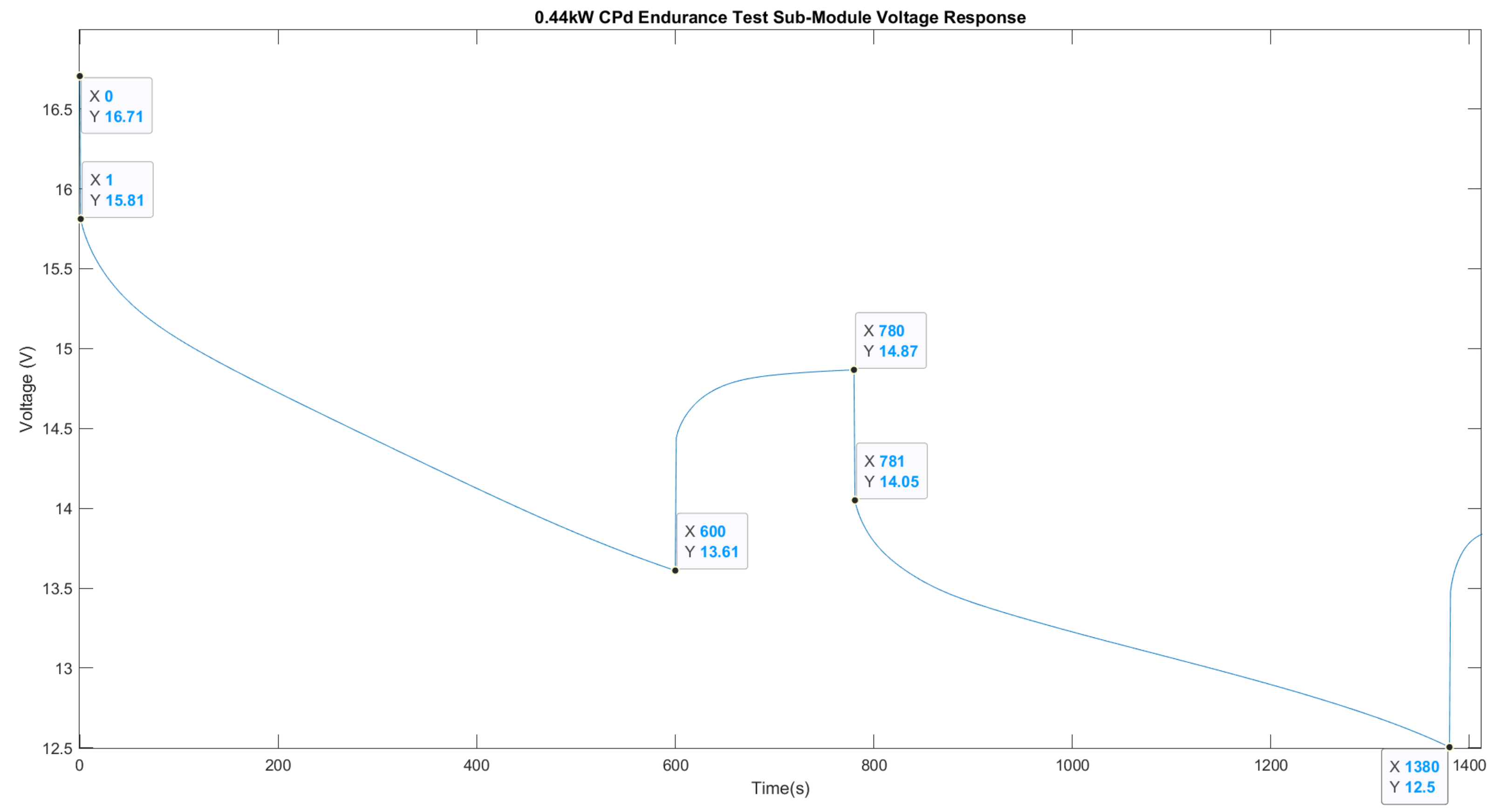
Sub-Assembly & Test Set-up

All three sub-modules were assembled but due to spotwelding issues with Aluminium busbars the full module assembly was not completed. Instead, a sub-module was tested but this preserved most of the test data required to evaluate. The most important test prepared included a complete realistic endurance discharge cycle on a vibrations rig at a pack equivalent discharge power of 14kW which was demonstrated to be the max expected average power needed for endurance, the single most straining event on the battery. Due to software failure, however, only a 14kW CP test was performed.



TEST

Endurance Voltage Response



The module design proves successful as its thermal and electrical response comply to the PDS. This can be observed by noticing that the sub-module completes the scaled 14kW CP 1400s. This satisfying as we did not know how our design capacity would be affected by the ohmic overpotential. This is because it was difficult to accurately predict the internal resistance in the assembly. We observe an initial voltage drop of approximately 0.9V with initial current of 27.8A corresponding to an internal resistance characterization of 32mΩ.

Thermal Response & Model Predictions