This is Harsh Meel, DE of the accumulator subsystem.
The team had been using 22Ah 96S1P EPS cells from EvoK and we had to procure a new set of cells for E13. This mail would briefly summarise the cell selection, and the parallel configuration initiative.

Cell Selection

We looked into various configurations and possibilities of cells for our accumulator. We focused on Melasta as they provide very high energy to weight ratios and are very popular in the FS community for the quality of their cells and the variety of options.
On the parameters of Energy and at least 10 C discharge rate. The following cells were shortlisted.

MELASTA High Drain Type LiPo & LiFePO4 Battery Model List (Version 2019)

Cell Model No.	Weight	Energy/WT	Total Energy	PARA LLEL	Total wt. of pack	Voltage (V)	Capacity	Comments	Max Continuous Charge Rate	Max Continuous Discharge Rate	Max Current through cell	Max Discharge Current of Tabs	Impedanc
	(grams	(Wh/kg)	(Wh)		(kg)	Max	(Ah)		(C)	(C)		(A)	(mΩ)
SLPBA385205	390.0	208.72	7814.4	1	37.44	403.2	22	Best for 1P, length can be accomadated	10A	10	200	200	0.7±0.2
SLPBA495183	393.0	207.12	7814.4	1	37.728	403.2	22	Better C rating	10A	15	200	200	0.6±0.2
SLPB9143158	132.5	201.06	7672.32	3	38.16	403.2	7.2	Energy < 7.7kWh	10A	15	108	120	1.2±0.2
SLPB8650140	132.5	199.66	7619.04	3	38.16	403.2	7.15	Energy < 7.7kWh	10A	10	71.5	96	1.5±0.3
SLPB9956117	141.5	193.50	7885.44	3	40.752	403.2	7.4	thick and low height	10A	15	111	120	1.1±0.2
SLPBA070145	215.0	192.74	7956.48	2	41.28	403.2	11.2	Best 2P, but thick. accumulator length increase by 5 cm!!	10A	15	168	200	0.9±0.2
SLPB7172200	215.0	189.30	7814.4	2	41.28	403.2	11	Thin cell	10A	10	110	160	1±0.3
SLPB8363124	148.0	187.50	7992	3	42.624	403.2	7.5		10A	15	112.5	160	1.1±0.2
SLPB8870175	228.0	183.38	8027.52	2	43.776	403.2	11.3		10A	20	160	160	0.8±0.2
SLPB8245180	144.0	181.15	7512.48	3	41.472	403.2	7.05		10A	20	120	120	1.1±0.2
SLPB7364159	154.0	180.19	7992	3	44.352	403.2	7.5		10A	20	150	160	0.9±0.3
SLPB92A6213	458.0	177.73	7814.4	1	43.968	403.2	22		10A	25	320	320	0.5±0.2

After much shortlisting and discussion, we decided to go ahead with :

Model	Weight	Energy	Total Energy	Config	Total wt. of	Capaci	Price	Max Continuou s	L	W	T

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1. 3P cells were rejected for the sheer number of cells to handle at the first time and the greater dimension of the battery.

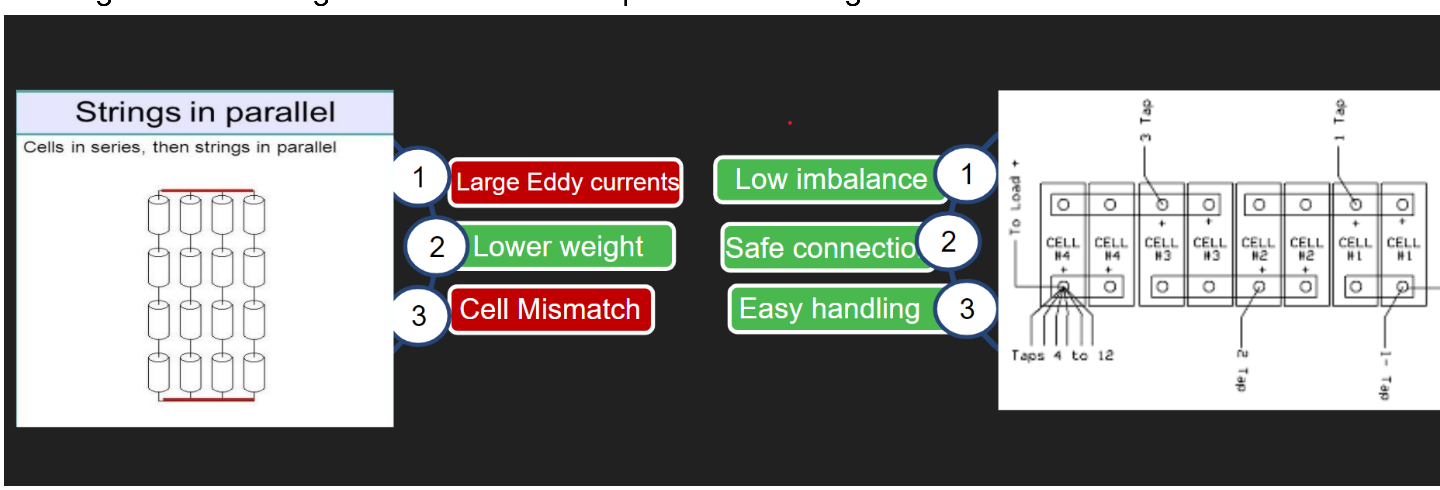
2. Among the 2p cells, SLPB7172200 , though had a high energy to weight ratio but had a height of 200 mm, thus making its integration difficult.
3. SLPBA070145 had superior energy to weight ratio and shorter height. Thus was selected.

The decision to move to a parallel configuration over series was done due to the following reason:

- Lesser cell degradation and inefficiency: Discussion with the cell manufacturer made it clear that high capacity cells would age fast on frequent high traction use.
- Lesser cell tab heating: The major feedback from Formula bharat 2021 was that our cell tab heating was very heavy both in terms of energy consumption and weight.
  Lets, take Power of heat generated in 96S1P = P
  For an “n” 96S**n**P configuration
  Power heat on single cell in parallel = P/n^2
  Power heat on total battery = P/n
  Reducing heating makes charging and discharging more efficient and is the first major step in the direction of complete removal of cell tab cooling fans.
- Reduced C rates across cells when discharging prevent high discharge losses.
- Weight : The lower capacity cells usually have +10 to +15 higher energy densities than larger cells. Saving approx 6-10 kg as of E13.
- Flexibility with configuration allowed to design a compact battery with **4 cm lesser height,** allowing the placement of Motor controller on top of accumulator and a much thinner rear chassis.

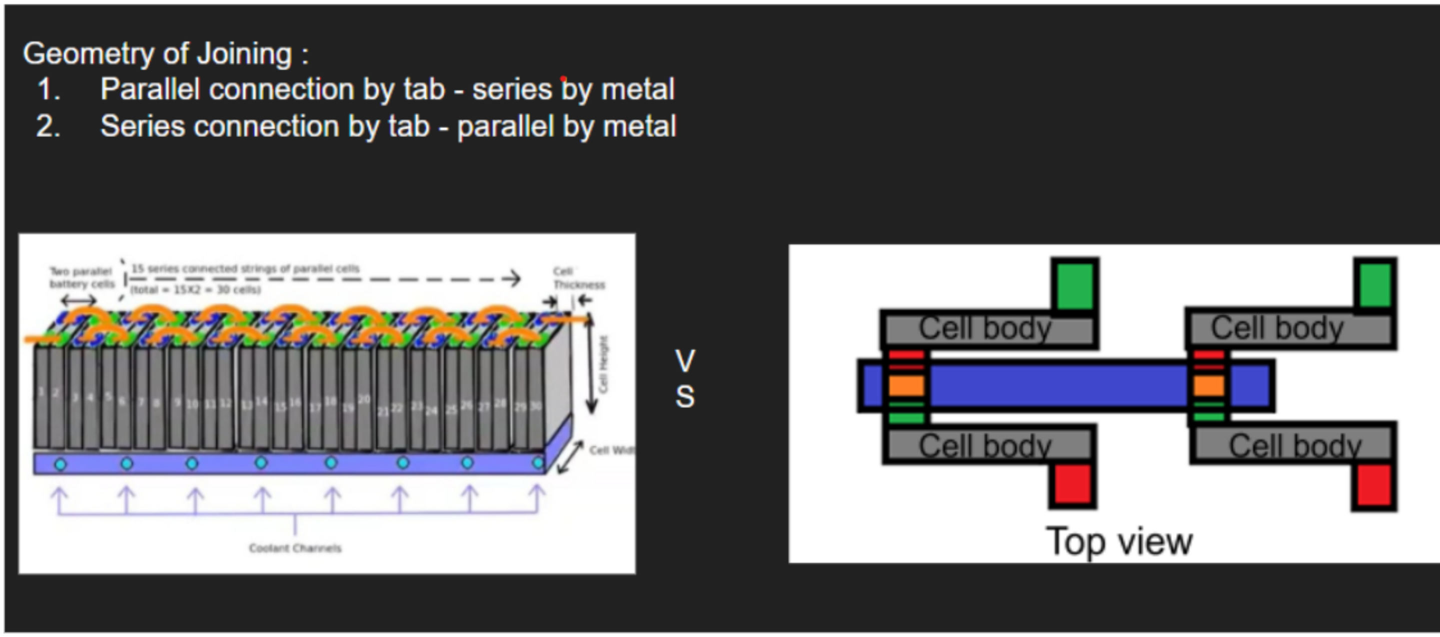
Parallel Configuration:

This was the first time parallel configuration was done since Evo4(scrutineering didn’t clear). So we did go through all possible geometry and selection types:
A.String Parallel Configuration Vs Standard paralleled Configuration



Comments:

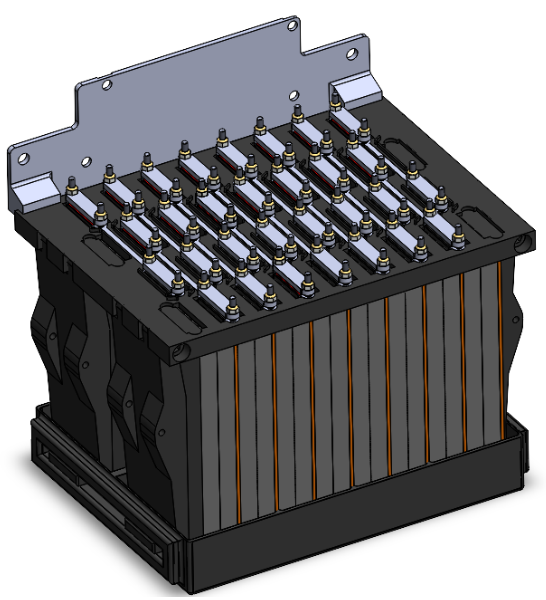
1. The safety issues for string configuration are more critical than the paralleled cell configuration.
2. the paralleled cell configuration is preferred over string configuration.



Here, Series connection by tab to tab and parallel by metallic connection (alumnium busbar) was decided because:

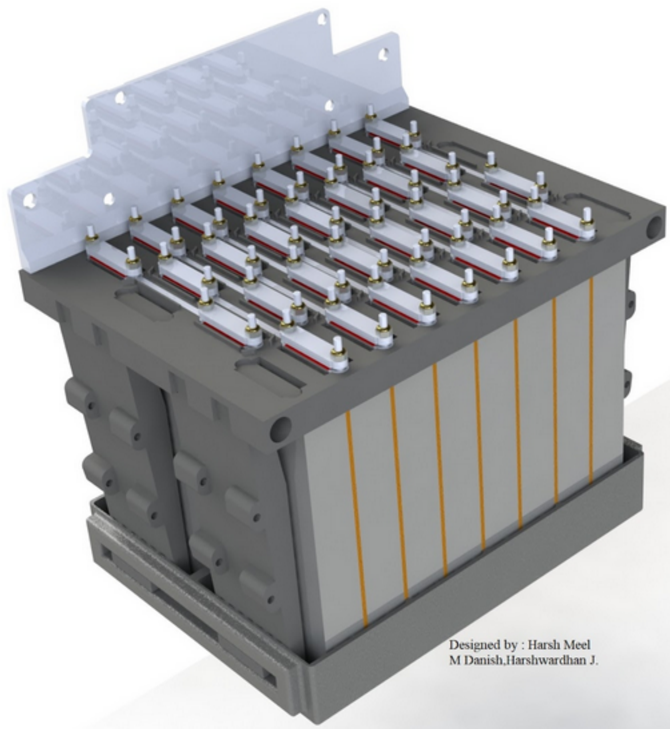
a. Lowest resistance in high current path (tab to tab)
b. Easier integration in existing stack design format
c. Lighter weight (no need for heavy metallic busbars)

Finally the Parallel configuration looks like this in the cell stack (16s2p):



Mechanical Design of the Accumulator

Stack Design

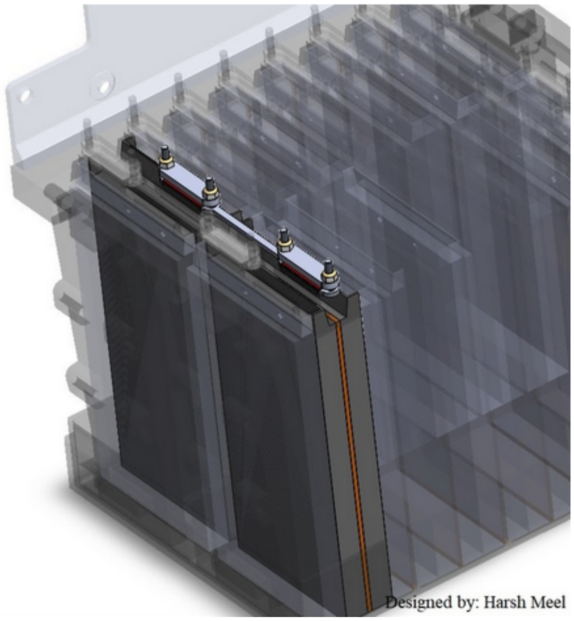


Looking at this as an excellent opportunity to upgrade the accumulator, we expired on the various possibilities of cells and what can be done at the moment. We are switching to Parallel Configuration. The goals of the stack design corresponding to that was:

1. Reliability: The number of cells doubled, and thus chances of shorting and failure are critical.
2. Compact Design: The new cell's dimensions allowed more compact and lighter packing.

The stack design was made on the foundation of E12 as it was robust and reliable with a lot of hands-on experience.

Cell Joining

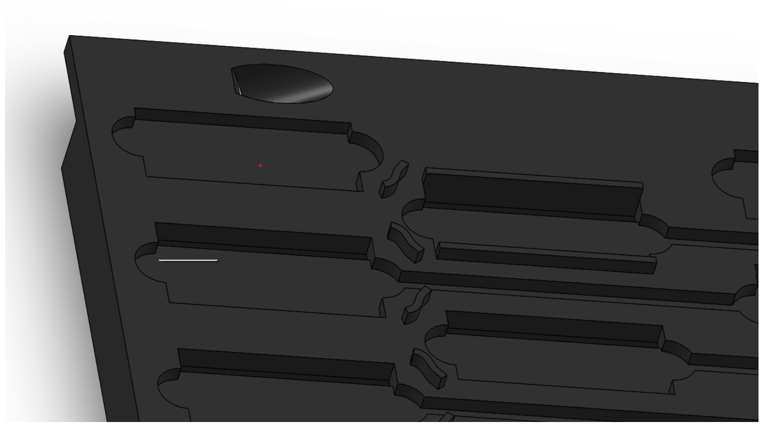


Aluminium busbars with M3 clinch bolts are used. The parallel connections are made by an aluminium strip of 3mm*2 mm cross-sectional area.

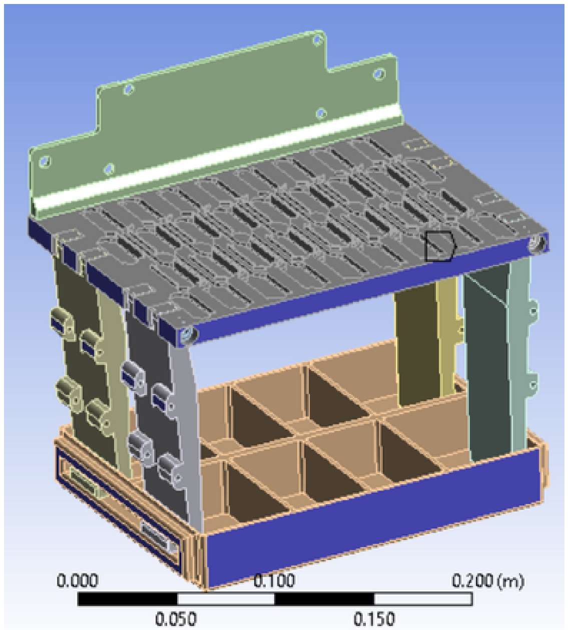
Potential Shortening Problem:
Objects like a washer could have shorted the cells as it can slide beneath the top separator snake too (+ 6 mm dia)

So, to ensure this doesn't occur,

A. Cell separators of 2 mm height were introduced in the busbar base.
B. The busbar bolt thickness was reduced to M3 from M4 to increase inter busbar space to prevent shortening.

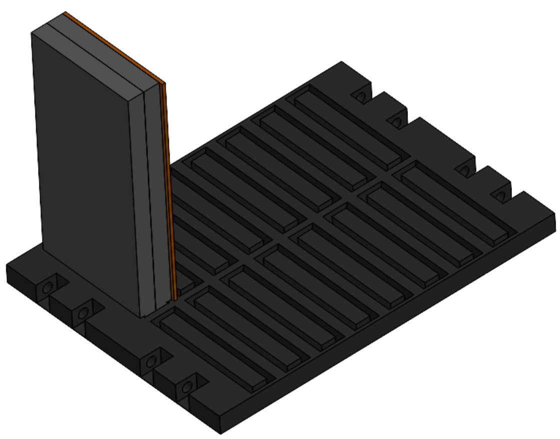


Stack Structural parts



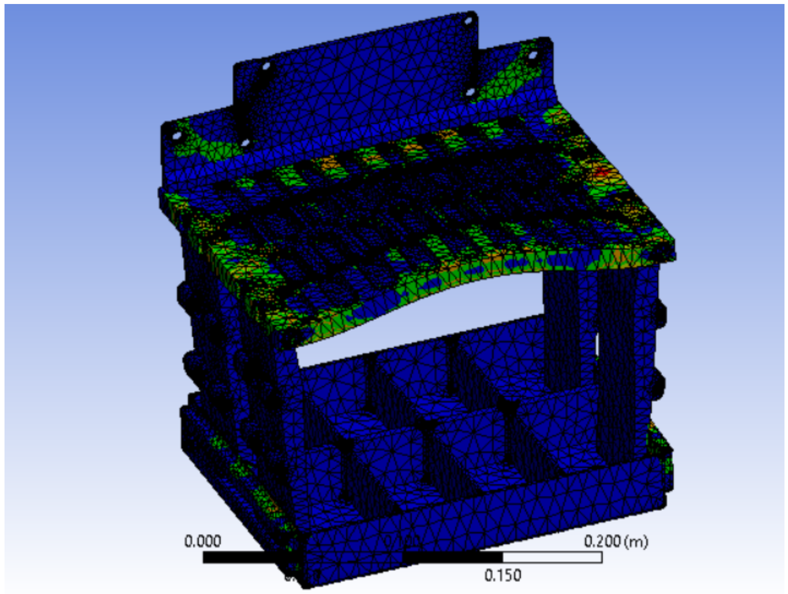
Changes:

1. The busbar base thickness was reduced by 3 mm, as the weight of the cells is distributed over a large area and the weight of each cell itself is less.
2. The AMS mount's supports were extended along the longitudinal direction by shifting busbar PCB connectors to the centre of the busbar. Thus, giving support to the shorter side against buckling.
3. A filling in the middle of the stack was provided to give flexural rigidity and strength.



Bottom-up View

Results of simulation



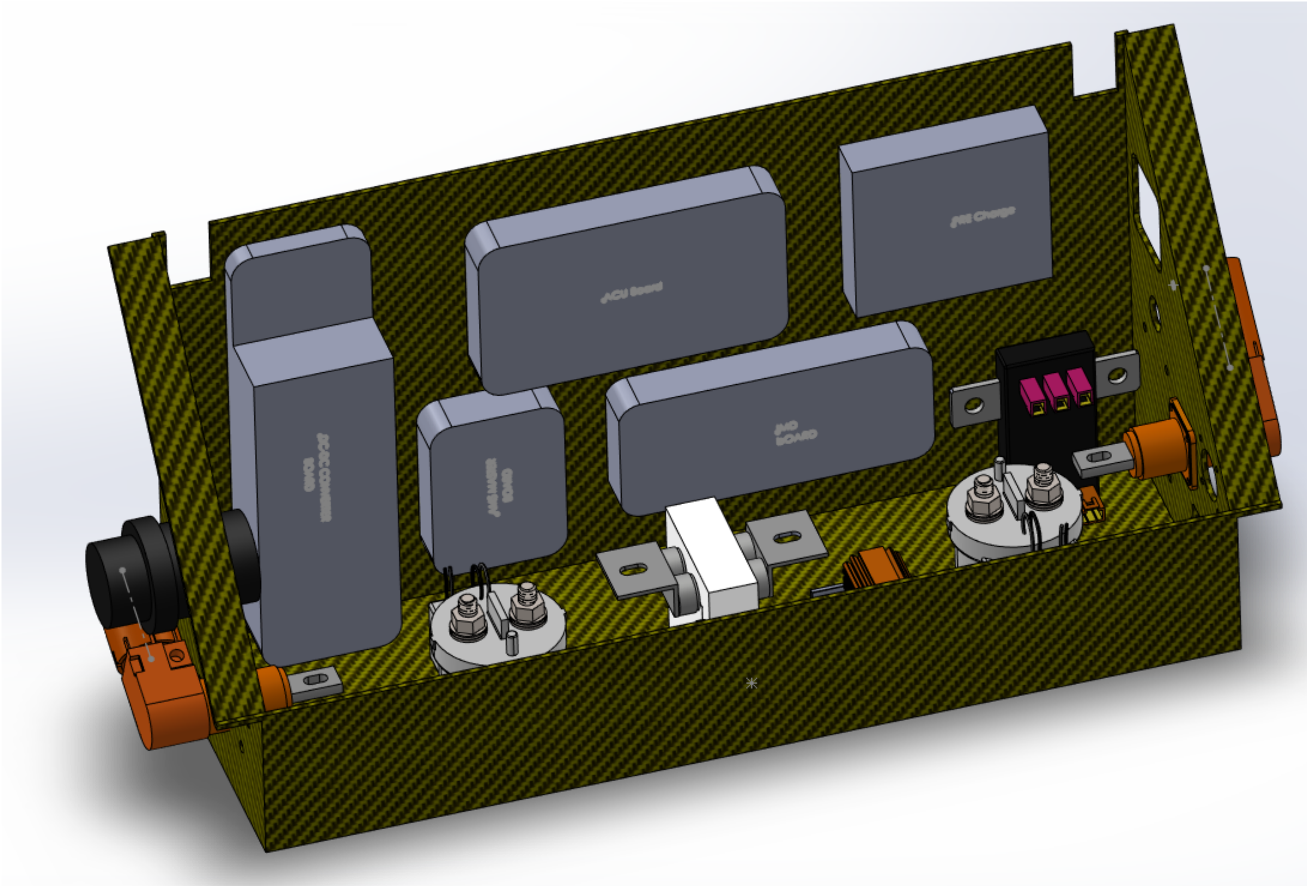
1. The Minimum Safety factor against Von Mises stress was 2.03 or 22.16 MPa Equivalent Stress.
2. Maximum Deformation was 3 mm at the further edge of the busbar from the AMS mount, bearable by the PCB.

Front Layer design

As the dimensions of the container have changed, the container's width is increased, and there is a decrease in height; we needed to ensure that the front enclosure can accommodate all the components and ensure that all rule book requirements are met. We also had a goal to make it as clean as possible with easy serviceability during testing. The other goal was to decrease the longitudinal space between the walls to decrease the accumulator's dimensions for better clearance with the chassis.
The significant changes from E12 are

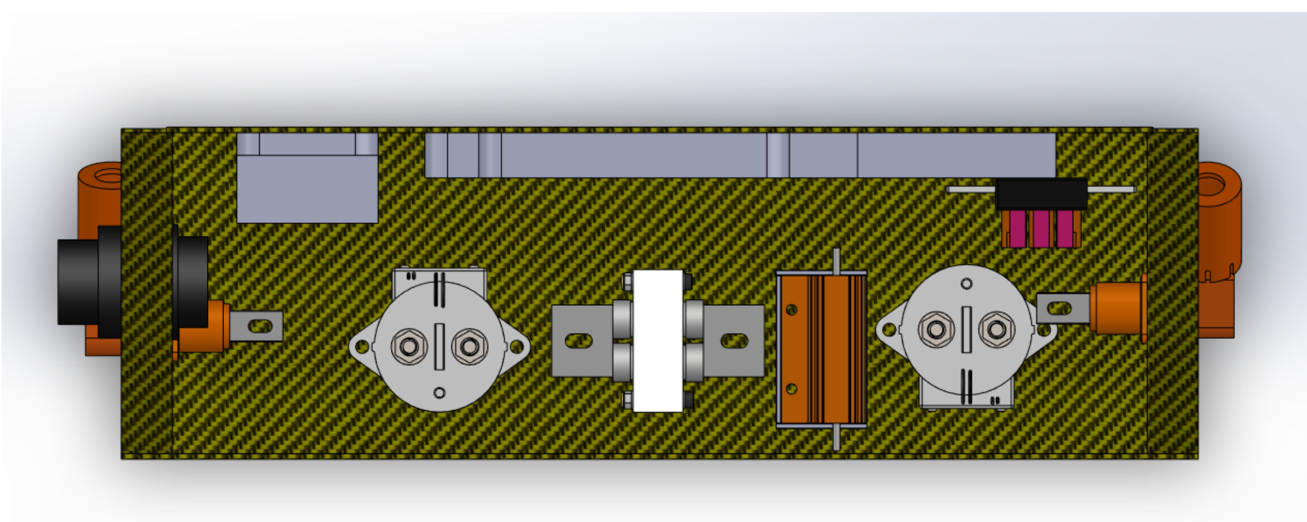
1. DC-DC board gets longer
2. ACU gets bigger
3. A PCB might replace the IVT

After looking into multiple iterations for the front layer placement, we have finally come up with the following placement.

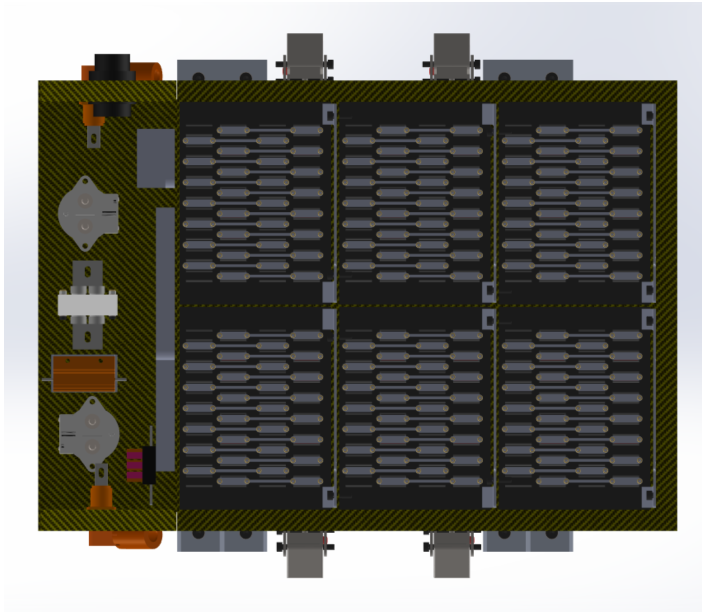


The DC-DC converter has been rotated, and the space in front of it is free of components, with only wires coming in. The AMS board has been shifted down as it is usually removed for debugging, thus not causing a problem. The IVT has been pushed further back, which ensures that the lower connection of IVT is accessible.

These changes allowed us to reduce the length of the front layer from 160mm to 140mm, but we needed to increase the height by 8 mm as we have placed the DC-DC board vertical.



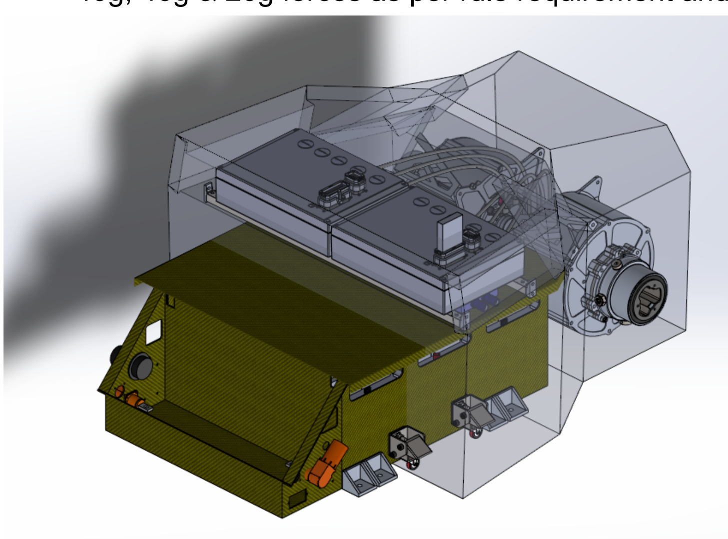
Container

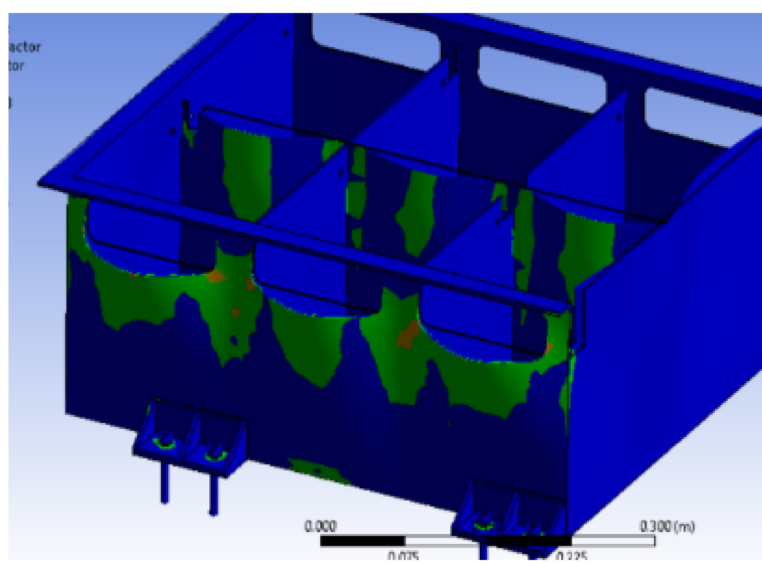


This container's design is taken from Evolv; the basic structure has been modified to accommodate the new cells we chose. After checking all the various configurations of how the cells can be held in the accumulator and estimating the space required, it was decided that there would be six stacks placed as shown above.

Due to this arrangement & the size of cells, the accumulator's length (x-direction of the car) has been increased by 50mm, and it is wider by 60mm. The selection of cells was also influenced by the placement of motor controllers and chassis structure which also had constraints from the suspension system. We decided that the Motor Controllers were to be kept above the accumulator, a win-win for all.

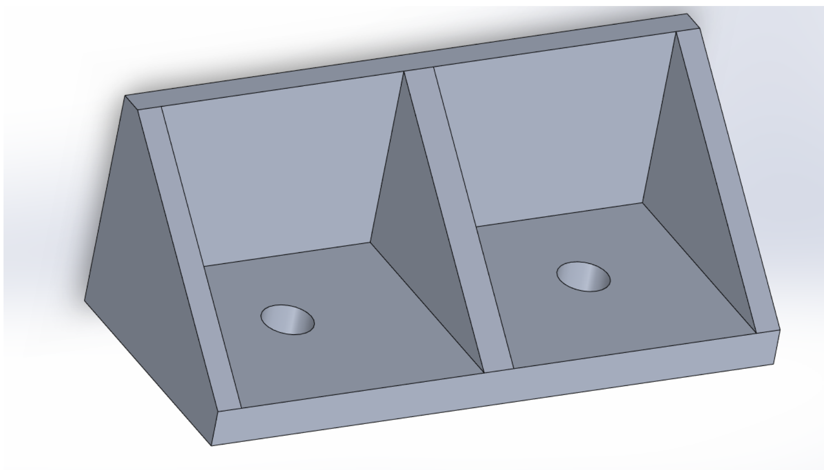
The thickness and spacing of the container walls were carried over from last year's design, which was validated from the structural tests. As we will be implementing this on a monocoque chassis, the entire base of the accumulator would be sitting on the floor of the chassis. This meant lesser force would be going on to the mounts in reality. The simulations were done for 40g, 40g & 20g forces as per rule requirement and it had a good safety factor (>2).



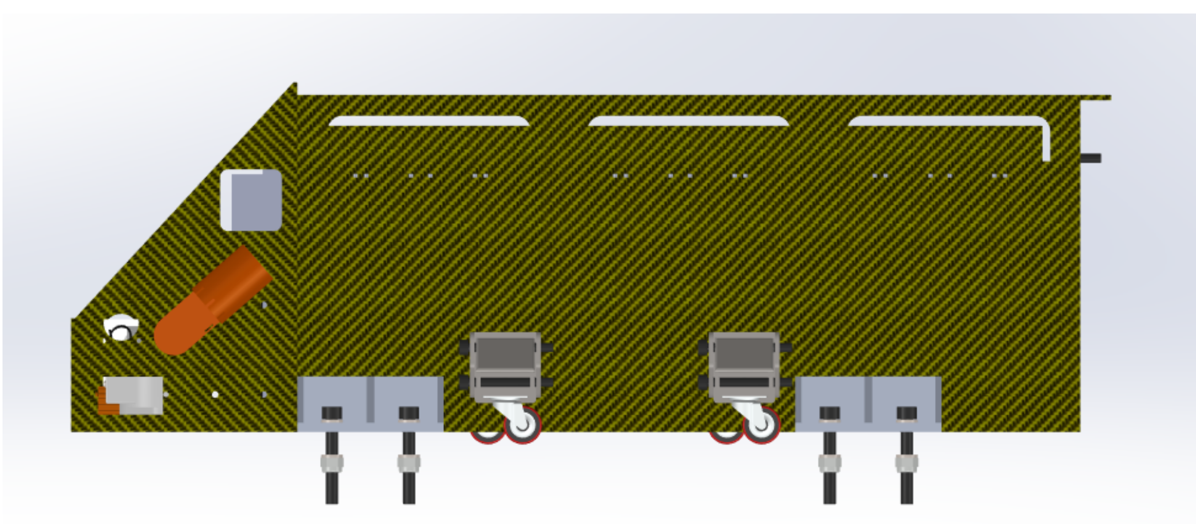


Mounts

The mounts & inserts need to take in loads of 20kN in any direction. This simulation failed on the previous design, and the inserts would be very bulky if each of them had to take 20kN of force. Instead of designing a thicker and stronger mount which would increase the material and hence the wt. We combined the mount as this 20kN would be transferred from 2 fasteners instead of 1, and it would be considered as a single mounting point. The wt. would approximately be the same overall.



An added advantage of this is that it solves the problem of aligning it perfectly while applying adhesive (the mounts tend to move/slip). This was simulated for 20kN forces and did not fail in any direction.
The mounting points have moved to the sides of the container as there wasn't enough space in the front and back. We have 4 identical mounts, which makes the container fastened with 8 M8 bolts. The rear mount had to be shifted forward as the chassis is curving and becoming tapered at the back. This wouldn't be a problem as the accumulator sits on the chassis floor.



Manufacturing

Following is an elaborate procedure for busbar clinching. These busbars were clinched for the E13 (first parallel configuration battery).

The lower busbars were made 2mm thick, and the M3 clinch studs were pressed hydraulically.
The lower busbars are 1mm thinner than the upper busbars because the lower busbars are supported by the busbar base below them. The load would be equally distributed thence. While the upper busbar does not have support, there might be a chance of bending. To tackle this problem, we increased the cross-section area by choosing the thickness to be 3mm.

While designing the new battery, we had to accommodate double the cells and the space had to be used optimally, such that shorting does not happen. Thus, we went on with M3 clinch studs rather than M4.