FSAE Zips Formula Electric Accumulator Design

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Executive Summary

Our group is designing the accumulator for the Zips Formula Electric Team. The Accumulator is the housing that stores the batteries and the necessary electrical components to power the car. The design must meet all rules set forth by the SAE association for formula electric cars. Some design considerations included proper separation of high voltage and low voltage components along with ensuring structural rigidity in case of a collision. After numerous design iterations the accumulator design was manufactured and assembled.

Acknowledgments

A special thanks to:

Our senior design advisor and advisor for the zips electric team: Dr. Daniel Deckler

Electrical Engineering Lead: Adam Long

Team Captains: Adam Kuhar and David Streen

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Introduction

The accumulator is an essential subsystem of the Zips Electric Racing vehicle that will compete this summer for the first time in the University of Akron's history. The team has been in existence since 2013 but always fell short of completing a rules compliant car. This year our team has been diligent in designing and manufacturing a rules compliant car. So far we have reached milestones that past years teams have missed, such as being accepted to attend FCA's (Fiat Chrysler Automotive) Test and Tune event. We will continue to improve on the car so that we can perform to the best of our ability this summer at competitions.

The accumulator is the mechanical enclosure housing the electrical components needed to supply power to the car. The design needed to be compact and lightweight to help reduce the overall size and weight of the car. The project so far has included analyzing, and designing an accumulator to accommodate the electrical components. The housing needed to be water resistant, lightweight, and safe. The accumulator was designed around the 300 V battery packs that will be used for the 2019 car. Included in the accumulator design are fuses, relays, and insulation to construct a safe, and rules compliant car for competition.

Conceptual Design

The design for the accumulator for the Zips Formula Electric Team needed to follow a list of rules and be incorporated with other subsystems for the car. The accumulator is the housing that contains and protects the batteries packs as well as the necessary electrical components. To ensure proper protection of the components and the people operating on the car the design must meet all rules set forth by the SAE association for formula electric cars. To ensure safety when performing maintenance on the accumulator, the battery packs must be separated into compartments that contain less than 120 volts. All high voltage and low voltage components must be separated by a physical barrier and all components must be attached with positive locking fasteners to ensure nothing can break loose when the car is operating. The case itself was designed to ensuring structural rigidity in case of a collision. Multiple designs were considered before a final one was chosen, these conceptual designs can be found in the appendix..

Embodiment Design

The general layout of the accumulator can be seen in Figure 1, with simplified callouts of interfacing components. Figure 2 shows the layout of the case as well as the overall dimensions.

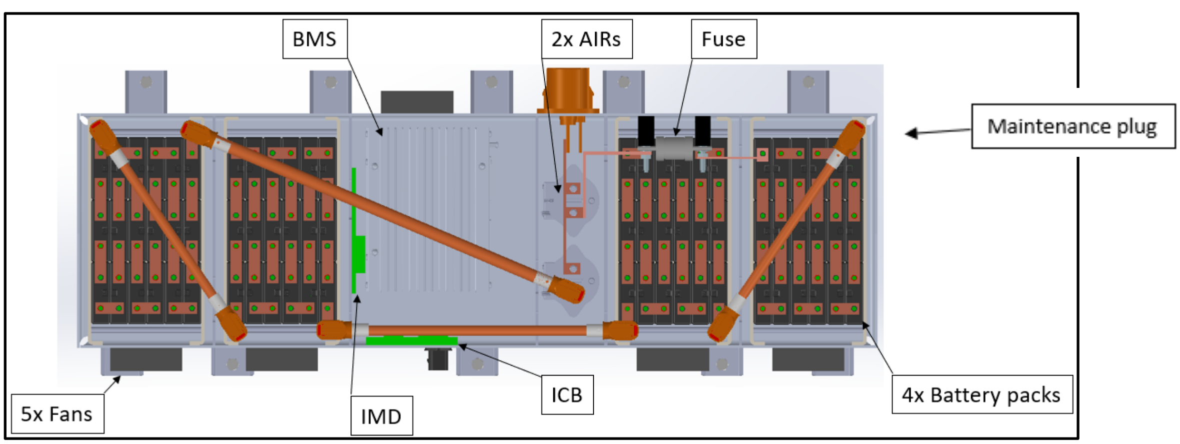


Figure 1 - *Schematic of Interfacing Components*

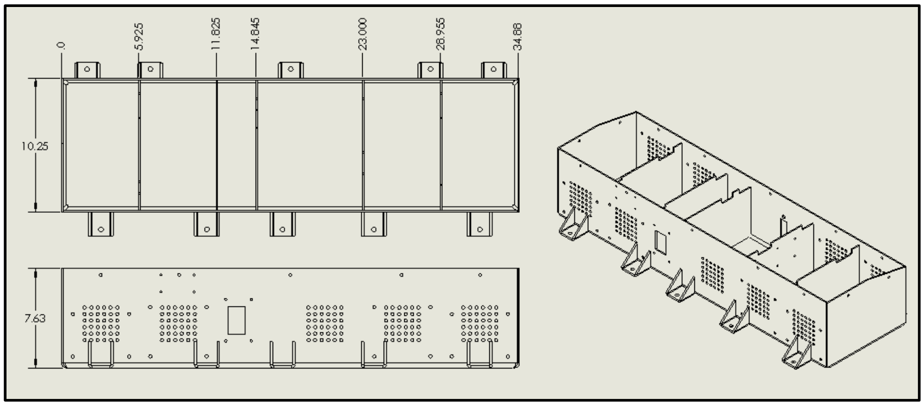


Figure 2 - *General Layout and Dimensions of Accumulator Container*

Material for the accumulator was initially chosen based on rules provided by SAE. This includes general guidelines for thicknesses of materials to ensure safety of the driver and bystanders. We chose to go with aluminum for our design because of its durability but most importantly its reduced weight when compared to steel. To ensure proper rigidity when using aluminum vs steel we used an increased thickness of material and verified its strength using FEA analysis. The accumulator contains complex bends, cutouts and welds that it would be more efficient if a third party manufacturer fabricated the container. Figure 3 shows more of the fabricated components including the aluminum brackets that hold the battery packs in place and copper busbars that link the batteries in series with each other.

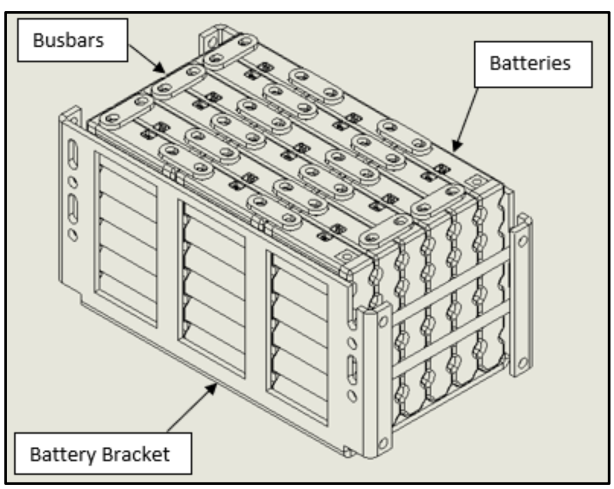


Figure 3 - *Fully Assembled Battery Pack*

Detailed Design

During normal operation of the vehicle the accumulator is subjected to around 1.5 G-forces that act on the 10 mounting brackets. Our design needs to conform to FSAE rules which state that the mounting points of the accumulator must be able to withstand 40 G's in the all directions. Each mounting tab must also withstand 15 kn of force each to ensure safety in the event of a collision and still remain rules compliant.

Part Drawings

Individual part drawings can be found below.

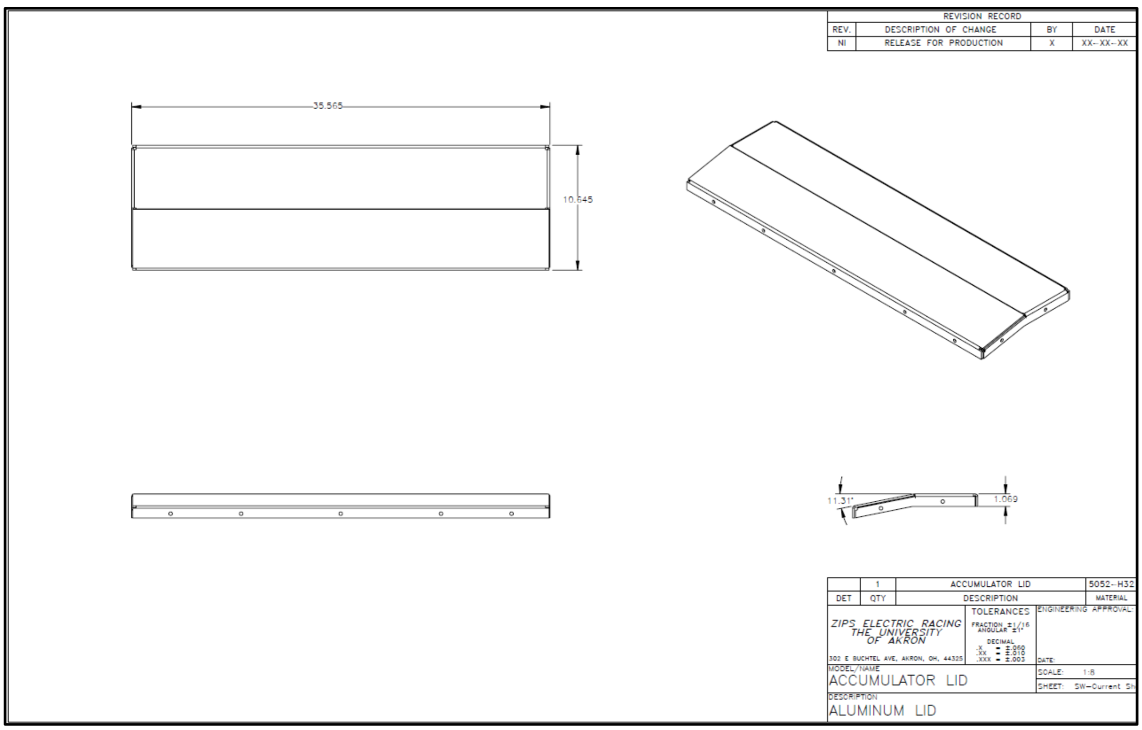
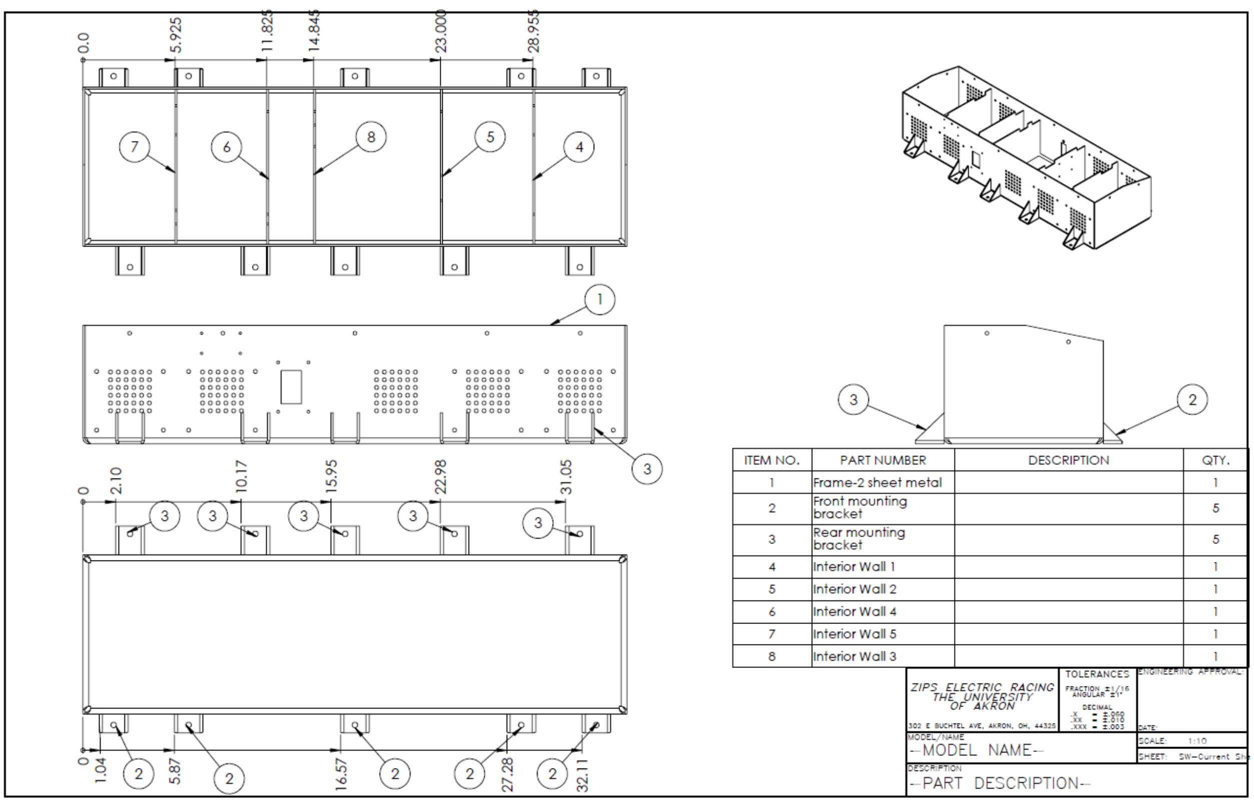


Figure 4 - *Accumulator Lid*



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Frame-2 sheet metal		1
2	Front mounting bracket		5
3	Rear mounting bracket		5
4	Interior Wall 1		1
5	Interior Wall 2		1
6	Interior Wall 4		1
7	Interior Wall 5		1
8	Interior Wall 3		1

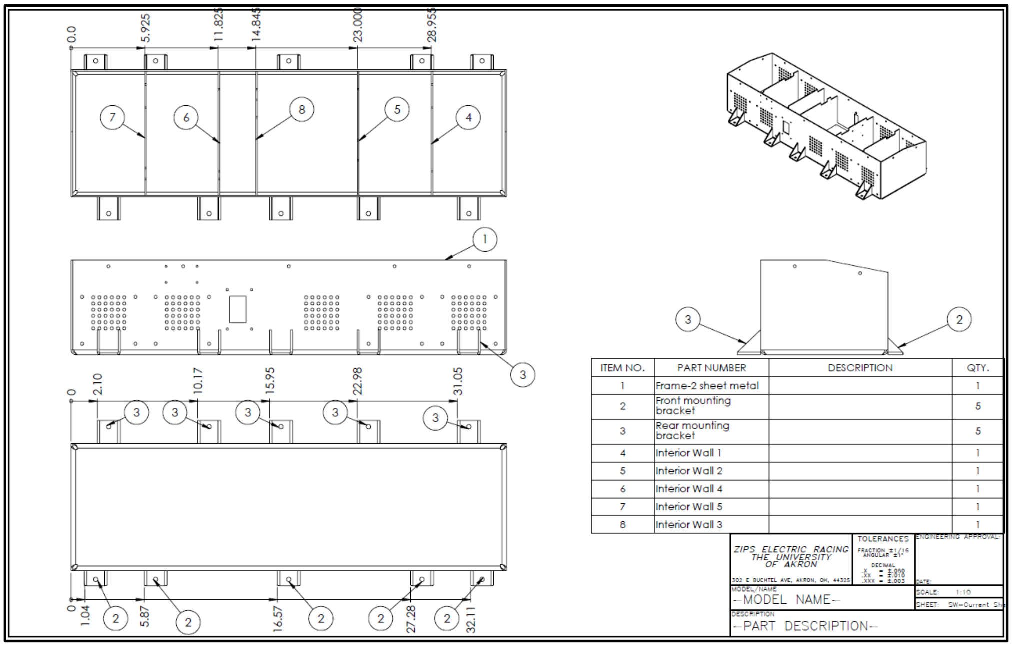


Figure 5 - *Accumulator Container*

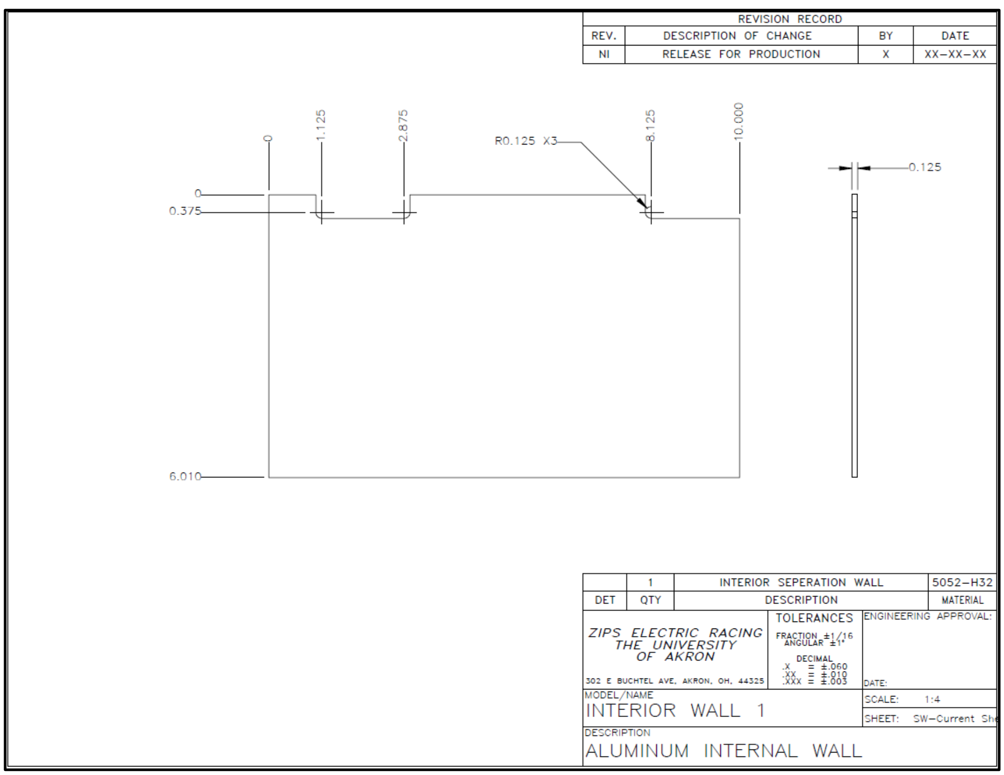


Figure 6 - *One of Five Interior Walls*

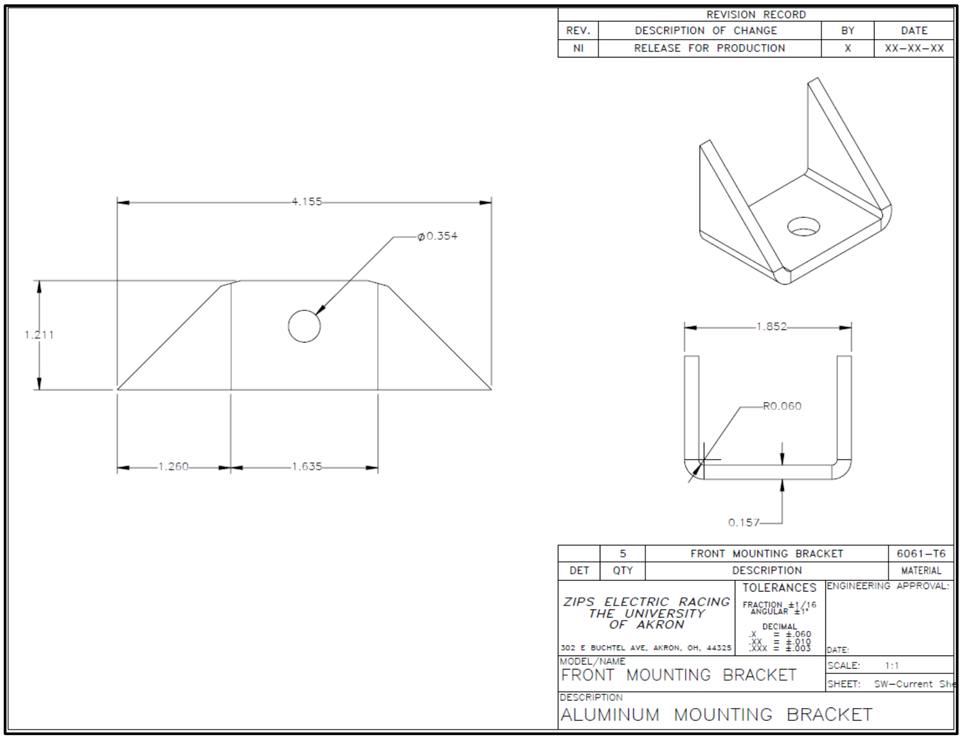


Figure 7 - *Front Mounting Bracket*

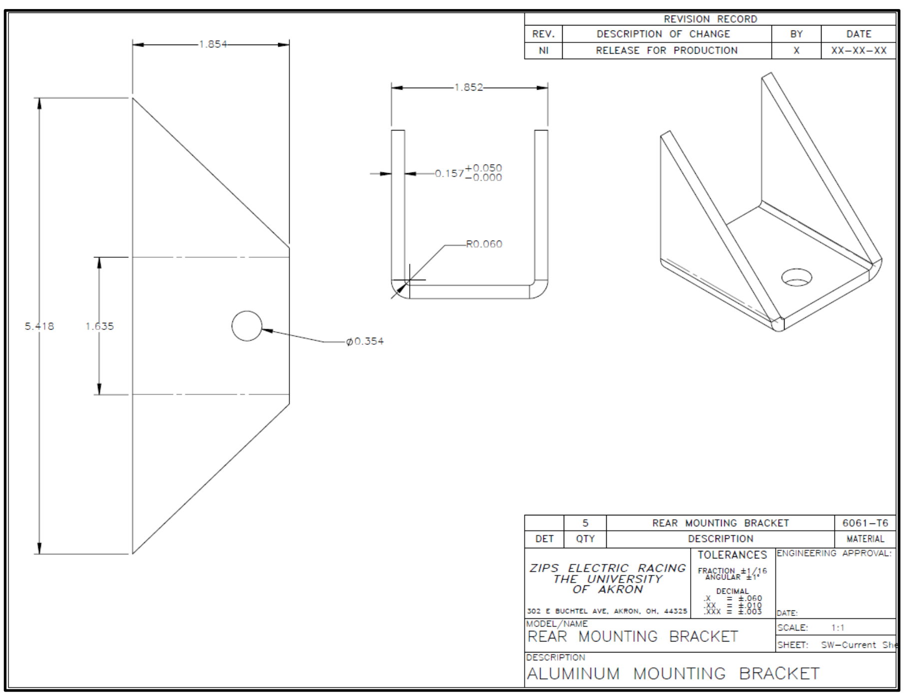


Figure 8 - *Rear Mounting Bracket*

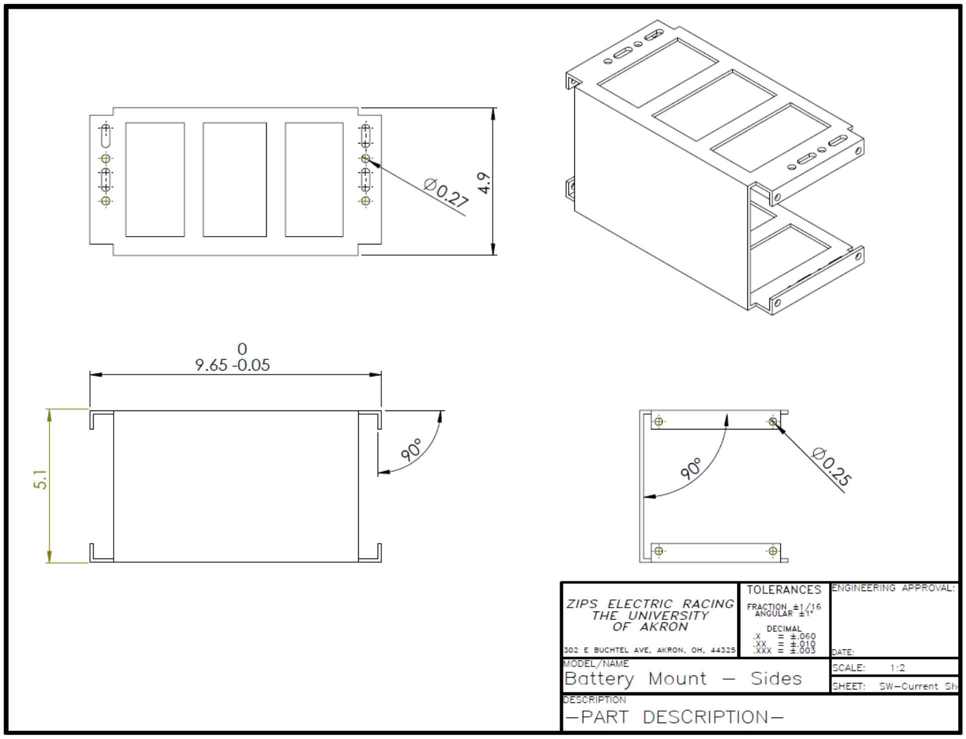


Figure 9 - *Battery Brackets*

Material used for the accumulator container was 5052 H32 Aluminum with a yield strength of 228 MPa. The reason we chose this type of metal because it is much lighter than steel and is great for welding. 6061 T6, with a yield strength of 276 MPa, was used for the mounting brackets because it has a higher yield strength, and we found it was necessary after performing FEA. All components that were either manufactured or necessary for assembling the accumulator were put into a cost report below.

Description	Supplier	Part Number	Cost/Unit	Unit	Quantity	Planned Date	Planned Expenditure
Mechanical							
Aluminum Sheet	Alro	48 x 92 Sheet x 0.100in	$ 300.00	sheet	0	12/1/18	$ -
Fabrication/ Manufacture	Harris Welding		$ 840.48	labor	1	12/1/18	$ 840.48
WaterProofing	Mo-Flow	18"x18" sheet	$ 26.99	sheet	3	12/1/18	$ 80.97
Lid Latches	McMaster Carr	51335A71	$ 51.43	piece	2	12/1/18	$ 102.86
Battery Pack Frames			$ 75.00	pieces	0	12/1/18	$ -
Transportation Cart		23135T44	$ 600.00	pieces	1	12/1/18	$ 600.00
Nuts + Bolts	Fastenal						
Nuts + Bolts	Fastenal		$ 200.00		1	12/2/18	$ 200.00
High Voltage Tools/PPE							
H.V. On/Off Light			$ 20.00	ea	1	12/1/18	$ 20.00
Sand	Home Depot		$ 6.00	ea	1	12/1/18	$ 6.00
H.V. Screwdrivers	McMaster Carr	53285A61	$ 55.00		1	12/1/18	$ 55.00
H.V. Face mask	McMaster Carr	3942T48	$ 86.50	ea	2	12/1/18	$ 173.00
H.V. Blanket	McMaster Carr	5571T14	$ 235.87	ea	2	12/1/18	$ 471.74
H.V. Gloves	McMaster Carr	5333T81	$ 83.81	pair	2	12/1/18	$ 167.62
H.V. Pliars	McMaster Carr	57115A18	$ 54.04	ea	1	12/1/18	$ 54.04
fire extinguisher			$ 100.00		1		$ 100.00
H.V. Tool Set	Klein Tools	33525	$ 796.00	ea	1	12/1/18	$ 796.00
Electrical Glove Testing	Salisbury						
							$ 3,667.71

Figure 10 - Cost Report

One of the design criteria was for the accumulator to withstand 15 kN in all directions. After performing FEA on the mounting brackets a material with a higher yield strength was needed.

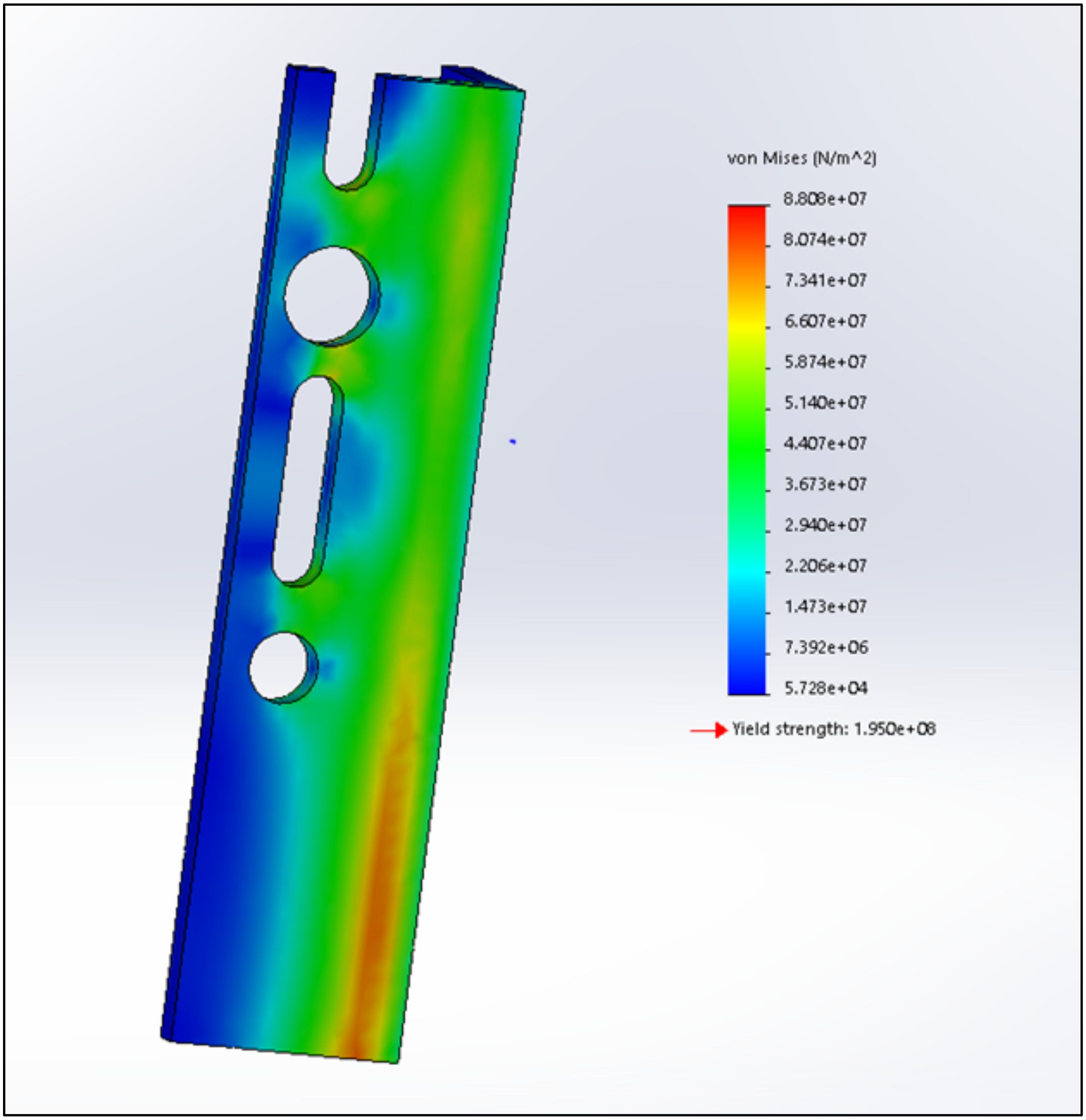


Figure 11 *- FEA for Battery Pack Brackets*

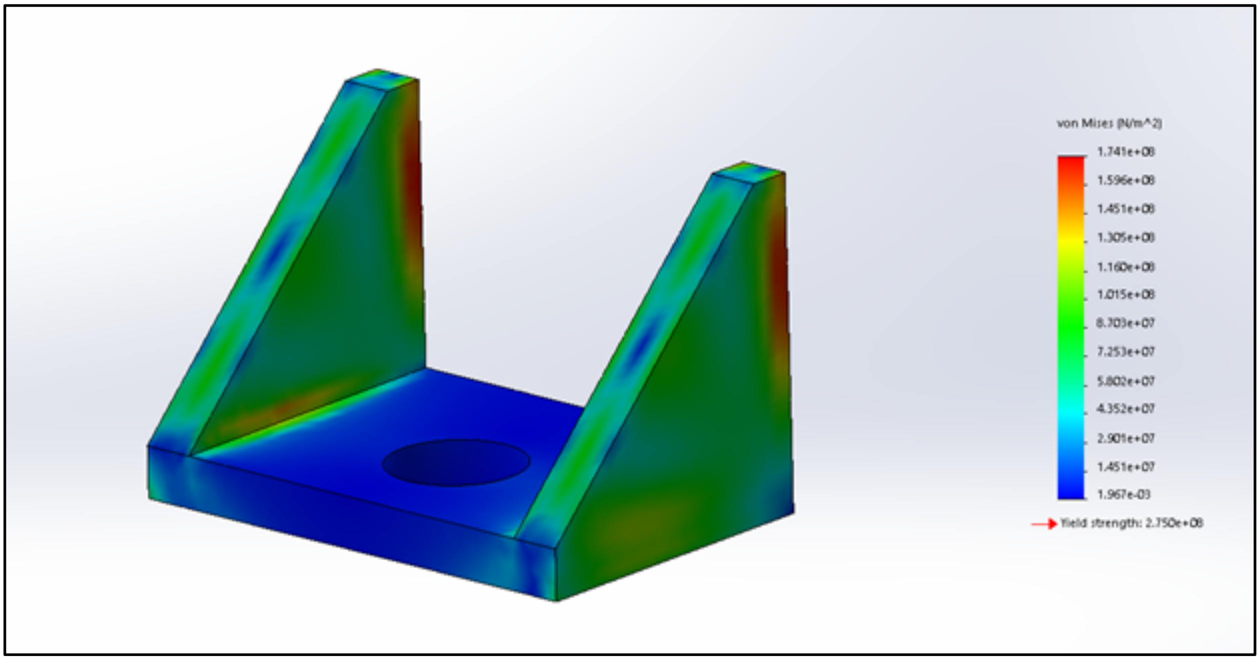


Figure 12 *- FEA for Front Mounting Brackets*

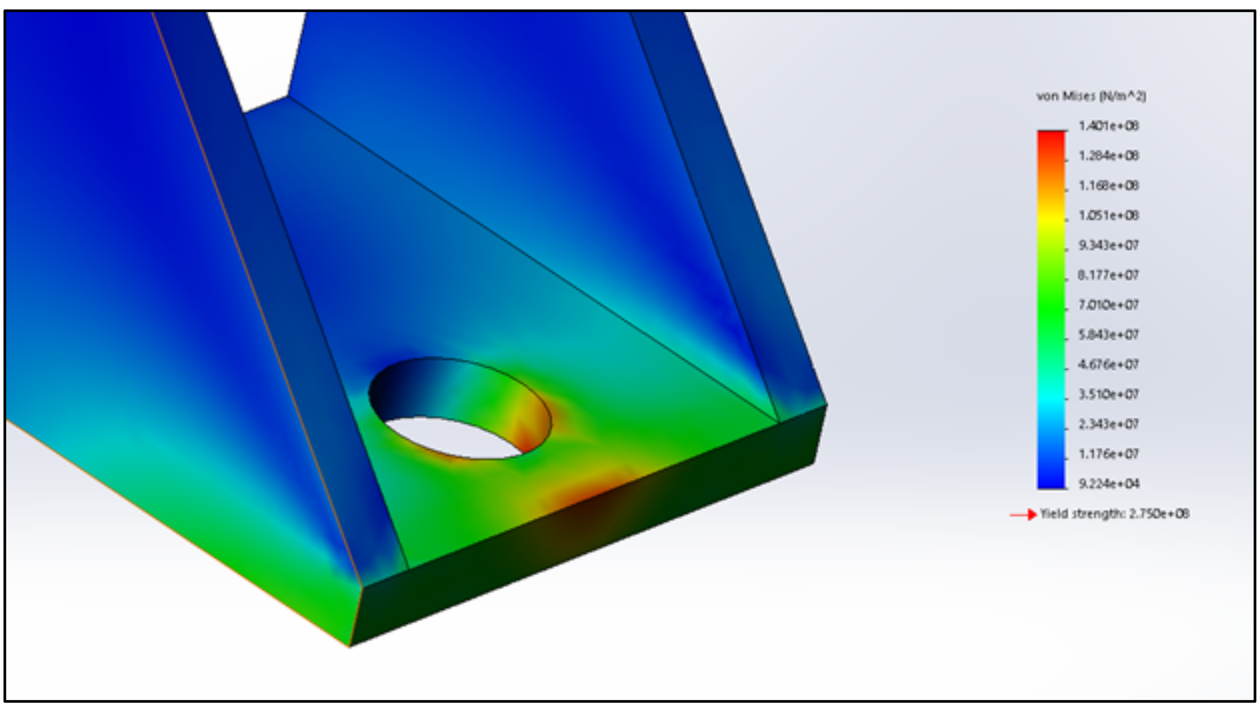


Figure 13 *- FEA for Rear Mounting Brackets*

Discussion

The entire design of the accumulator revolved around rules created by FSAE. They are what drove our design decisions during the beginning stages of our project. Our team was not familiar with electrical systems when the project began, so working closely with the electrical leads was a main priority. The first step in our design process was to familiarize ourselves with what the accumulator subsystem really was, this was done again by speaking with electric leads and also consulting the FSAE 2019 rules. Once we felt comfortable with the necessary components needed and over all footprint dimensions we began integrating our design to match the rules. All rules that were considered can be found below along with how the rule was incorporated into the design and any associated issues that we ran into regarding that rule.

Rules

***EV.3.1.1* All cells or super capacitors which store the Tractive System energy will be built into accumulator segments and must be enclosed in (an) accumulator container(s).**

The accumulator for the 2019 car is using battery cells rather than super capacitors for our tractive system energy storage device. The rules allow for multiple accumulator containers while our design opted for a single container. This was chosen for simplicity of design and integration into the vehicle with sacrifice to overall size and weight while handling. A design that we thought of was to have two containers that would be mounted in the side impact pods of the car, this idea was not something we wanted to pursue because of space constraints with the established frame design.

***EV.3.1.2* Each accumulator segment must contain:**

- ***Maximum static voltage of less than 120 V DC***
- ***Maximum energy of 6 MJ***

The maximum voltage that was chosen for our accumulator was 300V, this meaning we would need to separate the battery packs into at least three separate segments to remain rules compliant. The batteries used were lithium ion batteries, where each pack contains 4.2 volts. A total of 72 packs are used to power the tractive system. For simplicity our general layout included four segments each containing 18 packs, that are mirrored from the center plane of the car, see Figure 1. In our design stage we spent a considerable amount of time coming up with multiple configurations of the battery packs to best utilize the space within the frame. This was crucial to our success because we learned the most once we started coming up with ideas and working with other subsystems to check integration. Each of the four segments used battery brackets, see Figure 9, to hold the 18 packs in place. The batteries in each segment were placed in series using zinc plated copper busbars that were bolted into the terminals of each pack. This also created some structural rigidity to hold the packs in place with help of the battery bracket. The battery segments are connected in series with each other through the use of maintenance plugs, this will be discussed further in rule **EV.3.3.1**

***EV.3.1.3* Each accumulator container must be removable from the vehicle while still remaining rules compliant.**

During our design phase we had to conform to multiple rules calling out spacing of high voltage and grounded low voltage components. After much deliberation we condensed the overall size of the accumulator to as small as we could fit it within the frame. Using 3-D modeling we could check spacing of the accumulator while attempting to place the container within the frame and while removing it. We worked with the frame designer to ensure that the accumulator could fit without issue. In future years it would be ideal to begin designing of the accumulator and the frame at around the same time. This way the integration can become more user friendly. At the moment it is difficult, but manageable to move the accumulator in and out of the frame. Features such as tightening of mounting bolts to the frame should also be considered, as it is difficult to reach the locations of the bolts in the current frame. There are also many other connectors designed by the electrical leads that protrude from the accumulator, that at the moment need removal of other subsystem components to reach. Sub system integration should be of high importance for future cars.

***EV.3.2.2* Every accumulator container must contain at least one fuse and at least two accumulator isolation relays, see EV.5 and EV.8.1.**

During our design phase we spent a considerable amount of time ensuring that all necessary components could fit within the accumulator. Some of these components include a single fuse, and two accumulator isolation relays or AIRs for short. The components are crucial to the safety of the electrical harness and need secure spots within the accumulator. The AIRs were placed within their own compartment separated from low voltage components. The fuse was also separated from any low voltage components as well as the AIRs themselves. Both the AIRs and the fuse are also connected in series with all of the batteries to create a cohesive system.

EV.3.2.3 ***Each segment must be electrically insulated by the use of suitable material between the segments in the container and on top of the segment to prevent arc flashes caused by inter segment contact or by parts/tools accidentally falling into the container during maintenance for example. Air is not considered to be a suitable insulation material in this case.***

The main container and internal walls are made using aluminum which is of course a conductive material so we used a thin insulative coating for all internal surfaces. This thin coating was chosen because it did not take up much internal space when applied, making it a great choice. We had the option of using a thicker foam barrier that is also rated for the maximum voltage but we decided that it was going to take up too much internal room. The material we used was applied using a spray adhesive to ensure a proper adhesion to the internal surfaces.

EV.3.2.7 ***Each accumulator container must have a prominent indicator, such as an LED that will illuminate, whenever a voltage greater than 60 V DC is present at the vehicle side of the AIRs.***

When voltage from any source exceeds 60V it is then considered to be high voltage, meaning extra rules are in place for anything that is considered high voltage. The accumulator contains much more than 60V but the AIRs prevent the main connector protruding from the container to have more than 60V running through it. If at any time the main connector is carrying anything above 60V then there is a bright red LED that will illuminate on the back side of the accumulator near the connector to warn anyone nearby that they accumulator is energized. There was not much that was considered when designing a place for this LED, it was quite small and there was plenty of room for it.

***EV.3.3.1* Maintenance plugs must allow electrical separation of the internal cell segments such that**

a. The separated cell segments meet voltage and energy limits of EV.3.1.2

b. The separation must affect both poles of the segment

This rule is a continuation off of **EV.3.1.2** where we were required to separate our battery packs into smaller segments. Once the packs are in separate segments of the accumulator there needs to by a physical way to link the segment in series with each other. There are a couple different ways we could have accomplished this, but we decided to go with positive locking maintenance plugs that would attach to each pole of the segments, ultimately linking them together, you can see the path of the voltage of the packs in series along with the maintenance plugs in Figure 1.

***EV.3.3.2* This separation method must be used whenever the accumulator containers are opened for maintenance and whenever accumulator segments are removed from the container.**

For safety reasons the maintenance plugs must be removed from the accumulator so that when working on or removing a segment from the accumulator the voltage will not be the entire tractive system voltage. Our design allows for this, by first removing the plugs from the accumulator.

<u>EV.3.3.3</u> Maintenance plugs must require the physical removal or separation of a component. Contactors or switches are not acceptable maintenance plugs.

This is more straightforward of a rule, simply meaning you need physical plugs that can be removed from the segments to separate the packs. As said earlier, our plugs can be physically removed, and there is nothing automated about it.

<u>EV.3.3.4</u> Maintenance plug physical requirements:

a. Must not be possible to connect in any way other than the design intended configuration

b. Must not require tools to install or remove

c. Must include a positive locking feature which prevents the plug from unintentionally becoming loose

d. Must be nonconductive on surfaces that do not provide any electrical connection

During our design of the maintenance plugs we ran across our first issue of ensuring the packs cannot be connected in the wrong order. There are 4 maintenance plugs and each one is unique in length. This means that each connector is only as long as it needs to be to plug one pack into the next. We knew that with our longer plugs, they could be forcibly bent to allow them to connect two segments together that should not be. Our solution was to use a rigid conduit around each plug that would restrain them from bending. We also took one extra precaution by raising the height of the internal walls that separate the segments and then cutting out small section that allow the plugs to only lay in one direction. The plugs have a positive locking mechanism that latches onto the terminals of the battery segments. This prevents them from coming loose. This latch can be operated by hand and does not require any tools to actuate. The maintenance plugs are made of plastic, with no exposed surfaces that could potential conduct electricity.

<u>EV.4.1.1</u> All accumulator containers must lie within the Primary Structure

The primary structure of the car in our case would be the floor, side impact pods, and main roll hoop. Our design began with using the initial constraint of the total amount of space given to us within the frame itself. This proved to be our biggest set back because when we began designing the accumulator the frame had already been designed. This meant that we did not have much creative freedom to design the shell of the container. In the future working closely with the frame lead and integrating the two should be a high priority.

<u>EV.4.1.2</u> Accumulator container(s) must be built of mechanically robust material.

This rule is very general in its wording, the accumulator can be made from metals, plastics, or even composites. We chose to go with aluminum because it would be much easier to work with and manufacture. We used the structural equivalency spreadsheet to ensure that our design would in fact be strong enough to endure racing conditions.

<u>EV.4.1.3</u> The container material must be fire resistant according to UL94-V0, FAR25 or equivalent.

We are not concerned with the container failing this rule because it is constructed from a single piece of aluminum. The main container was fabricated without using any flammable materials. Of course some components inside of the main container are flammable, but in the event of a internal fire the accumulator will contain the fire and prevent injury to anyone surrounding. This rule may become more of design concern if the container is made from a non metallic material.

<u>EV.4.1.5</u> All accumulator containers must be designed to withstand forces from deceleration in all directions

The accumulator needs to be mounted in such a way that under normal driving conditions the mounting points will not yield. We satisfied this rule by conforming to most other rules that relate to the overall build quality. In our design we sided more on simplistic designs that did not involve much optimization. This resulted in an accumulator with much room for improvement, but we are very confident in the structural stability of the container. We used Solidworks Finite Element Analysis to ensure that our design was going to remain stable under the harshest conditions. This will be elaborated on in the SES (structural equivalency spreadsheet) section of the rules.

<u>EV.4.1.7</u> A sticker according to ISO 7010-W012 (triangle with black lightning bolt on yellow background) with triangle side length of at least 100 mm and the text "Always Energized" must be applied on every accumulator container.

The sticker must also contain the text "High Voltage" if the voltage is more than 60 V DC or 25 V AC.

Considering the accumulator contains a large amount of energy, it is essential to have the proper precautions in place for safety. The container is safe to handle even when energized, but should not be handled if not trained. The labels on the accumulator were made using a vinyl cutter, that formed the shapes of all required stickers, and then placed on the accumulator. Making these stickers took a considerable amount of time to make as the cutting process is lengthy. Searching for a potential sponsor that would fabricate the stickers would be worth looking into.

<u>EV.4.2.1</u> Teams may use the following design guidelines or utilize a standard accumulator container.

a. Design of the accumulator container must be documented in the SES.

b. Documentation includes materials used, drawings/images, fastener locations, cell/segment weight and cell/segment position.

The Structural Equivalency Spreadsheet is used to determine if the accumulator design is rules compliant. It does not encompass all the rules for the accumulator; however, many of them are, and it is a helpful tool during the design phase. Many mechanical components of the car are included in the SES, such as the frame and welded inserts. This document is submitted to FSAE for approval. See the appendix for screenshots of the SES document. Each section of the SES has the rule it is associated with. If the top of the section is highlighted in light blue and shows EQ, it passes the rule.

<u>EV.4.2.2</u> Accumulator container design guidelines:

a. The floor or bottom of the accumulator container must be constructed of steel 1.25 mm (0.049 inch) minimum thickness or aluminum 3.2 mm (0.125 inch) minimum thickness.

b. The external vertical walls must be constructed of steel 0.9mm (0.035 inch) minimum thickness or aluminum 2.3 mm (0.090 inch) minimum thickness.

c. Internal vertical walls separating cells and/or segments must be: Minimum of 75 percent of the height of the external vertical walls Constructed of steel 0.9 mm (0.035 inch) minimum thickness or aluminum 2.3 mm (0.090 inch) minimum thickness

d. Covers and lids must be constructed of steel 0.9 mm (0.035 inch) minimum thickness or aluminum 2.3 mm (0.090 inch) minimum thickness.

e. The floor and walls of the accumulator container must be joined by welds and/or fasteners. Any fasteners must be 6 mm or 1/4" minimum diameter Critical Fasteners, see T.10.2 and T.10.3

f. Internal vertical walls divide the accumulator container into "sections" A maximum of 12 kg is allowed in any section of the accumulator container Fastened connections between the floor and any vertical wall of each section must have at least two fasteners. Fastened connections between internal vertical walls and external vertical walls must be located in the top half of the internal vertical wall. Sections containing 8 kg or less must have a minimum of two fasteners connecting any two vertical walls. Sections containing between 8 kg and 12 kg must have a minimum of three fasteners connecting any two vertical walls.

g. Folding or bending plate material to create flanges or to eliminate joints between walls is recommended.

h. Covers and lids must be fastened with a minimum of one fastener for each external vertical wall per section.

i. Alternate materials are allowed with proof of equivalency per T.2.31. Proof of equivalency must be documented in the SES and test samples must be available at technical inspection.

j. Substituting one 6 mm or 1/4" bolt with two 5 mm or #12 bolts or three 4 mm or #10 bolts is allowed.

The accumulator design guidelines are intended to generate a structure that does not fail under the following accelerations: 40 g in the longitudinal direction (forward/aft) 40 g in the lateral direction (left/right) 20 g in the vertical direction (up/down)

Many of these rules are captured in the SES. Both exterior and interior walls of the accumulator were manufactured using the minimum thickness. The lid of the accumulator was made from the same thickness, 0.125 in, and could be reduced to save weight. Since most of the accumulator was made from 0.125 in aluminum, it seemed more convenient for the manufacture to use the same sheet of aluminum to make container as well as the lid. The internal walls of the accumulator are at least 75 percent the height of the external walls. This ensures each segment of the accumulator is properly separated from one another. Each segment of the accumulator weighs a maximum of 20 lbs, or 9 kg. Since the internal walls were welded, it eliminated the need for fasteners and flanges for mounting. We decided to have the manufacture weld the container and interior walls. Our team felt reducing the amount of fasteners was critical for the design. This reduces the risk of fasteners becoming loose, less rules to consider, and allows for easier maintenance inside the accumulator. FEA was performed on the brackets used to hold the batteries. This was done to prove the brackets could withstand the required forces established by the FSAE rules.

<u>EV.4.2.3</u> The cells and/or segments must be appropriately secured against moving inside the container.

a. This mounting system must be designed to withstand the following accelerations: 40 g in the longitudinal direction (forward/aft) 40 g in the lateral direction (left/right) 20 g in the vertical direction (up/down)

b. Calculations and/or tests proving these requirements are met must be included in the SES.

c. Any fasteners must be 6 mm or 1/4" minimum diameter Critical Fasteners, see T.10.2 and T.10.3

FEA was done to prove the battery brackets could withstand the required forces. These were included in the SES as well. The material choice, thicknesses, and attachment methods all proved to be sufficient to withstand the proper forces. Screenshots of the SES can be found in the appendix.

<u>EV.4.2.4</u> The accumulator segments contained within the accumulator must be separated by an electrically insulating and fire resistant barrier (according to UL94-V0, FAR25 or equivalent). Documentation of segment separation must be provided in the ESF.

The interior walls of the accumulator were used to separate each pack. All interior walls of the accumulator were lined with an insulating fire resistant material called Formax. This helps to reduce the amount of exposed metal inside the accumulator that could lead to electrical failures.

<u>EV.4.2.5</u> Composite accumulator containers must satisfy the following requirements:

a. Data obtained from laminate perimeter shear strength and 3 point bending tests (T.2.31) must be used for any strength calculations.

b. The calculations and physical test results must be included in the SES.

Our accumulator was not made from composite materials. With our main objective to create a rules complaint accumulator, we chose aluminum as our material choice over composites due to time and budgetary constraints. Aluminum is easier to manufacture and perform load calculations on due to the large amount of information on the material. A composite material would have created additional work early in the design process that we did not have time for to meet deadlines. Future accumulator improvements could implement composites for further weight reduction, handling, rigidity and improved safety by not using a conductive material for the container.

***EV.4.3.7* Accumulator Attachment – Load Based**

a. The number of attachment points that must be used depends on the total mass of the container:

< 20 kg must have 4 brackets

20 – 30 kg must have 6 brackets

30 – 40 kg must have 8 brackets

> 40 kg must have 10 brackets

b. Any brackets which attach the accumulator container to the chassis must: Be made of steel 1.6 mm (0.063 inch) minimum thickness or aluminum 4 mm (0.157 inch) minimum thickness Have gussets to carry bending loads.

c. Each attachment point, including any brackets, backing plates and inserts, must be able to withstand 15 kN in any direction

There were two ways to determine how to mount the accumulator to the frame of the car, corner attachments or load based. We chose load based because the corner attachments required brackets on all sides of the accumulator. This added to the width of our accumulator, and we would not be able to take it in or out of the frame of the car. Our accumulator weighs 95 lbs or 43 kg meaning the accumulator needed 10 mounting brackets that would be fastened to the frame of the car. The original design of the mounting bracket thickness was 0.157 in thick aluminum; however, the manufacture made the brackets using 0.125 in thick aluminum. After telling the manufacture the brackets were not rules compliant, the mounting brackets were reworked. They had 0.1875 in aluminum in stock, and our team approved using the thicker material. FEA was also done on the mounting brackets to prove they could withstand 15 kN in any direction. To prove our mounting brackets were over designed with the thicker material, we did the FEA using 20 kN in all directions.

<u>EV.4.4.1</u> Holes, both internal and external, in the container are only allowed for the wiring harness, ventilation, cooling or fasteners. External holes must be sealed per EV.6.5.1 and EV.6.5.2

All external cutouts for the accumulator were cut using a water jet and designed to only be used for fastening, wire harnesses, and ventilation. Once assembly of the accumulator began there were some fitment issues with the battery bracket mounting hardware. Several holes needed to be enlarged to account for the variance in the sheet metal bends on the brackets. We did not account for this human error during the design process and should have waited until the brackets were bent, then drilled the holes after to ensure they would align with each other. Washers were used to account for the larger diameter holes and this did not compromise the structural rigidity of the accumulator. We also opted to drill new holes for several bracket mounts to increase the distance between the mounting hardware and the high voltage maintenance pins. This distance was difficult to measure on the 3D model and once we assembled the bus bars and pins, we made the decision to increase the distance of the fasteners to lean on the side of safety rather than taking a risk. The old holes were patched using JB Weld SteelStik Epoxy which is rated for tensile strength of 900 psi and 300 degrees F. This ensures the holes are filled properly with a rigid material that will adhere properly to the aluminum housing.

***EV.4.4.2* The container must be completely closed at all times when mounted to the vehicle and also when dismounted from the vehicle without the need to install extra protective covers. Openings for ventilation should be of reasonable size, completely open side pods containing accumulators are not allowed.**

The only open compartment on the accumulator is the detachable lid that is held on by bolts. The lid remains securely attached to the accumulator whether or not the accumulator is installed on the car or not. The physical act of installing or removing the accumulator also does not require the removal of the lid and the accumulator remains sealed the entire time. Ventilation openings were cut out small enough to prevent any fingers or body parts from accidentally entering the inside of the accumulator. The ventilation hole size leans more on the side of safety rather than high volume air flow to ensure it remains rules compliant.

***EV.5.1.1* Each accumulator must be monitored by an Accumulator Management System whenever the Tractive System is active or the accumulator is connected to the charger.**

The Accumulator Management System is also known as the Battery Management System or BMS. This was the largest single component that we needed to incorporate into the design. There are also multiple wiring harnesses that needed proper clearance around the BMS to ensure the bend radius of the wires was not too narrow. Theses issues were taken into account when designing the placement of the BMS.

<u>EV.6.1.5</u> Where both Tractive System and GLV are present within an enclosure, they must <u>EITHER</u>:

a. ***Be separated by insulating barriers made of moisture resistance, UL recognized or equivalent insulating materials rated for 150 deg C or higher (such as Nomex based electrical insulation)***
b. ***Maintain the following spacing through air, or over a surface (similar to those defined in UL1741):***

U < 100 V DC	***10 mm***
100 V DC < U < 200 V DC	***20 mm***
U > 200 V DC	***30 mm***

The separation between the tractive system and the low voltage components was done through integrated internal walls. The wall are made from the same aluminum as the enclosure and secured in place using a full weld around the perimeter of the wall. This ensures complete separation of high and low voltage components. The wall are then covered with an insulating material for further protection. In areas where tractive system and low voltage wires were wired next to one another, Kapton tape was used as an electrical insulator.

<u>EV.6.5.3</u> Tractive system components and containers must be protected from moisture in the form of rain or puddles.

The lid enclosure of the accumulator has no holes on the top and only side holes used for the mounting fasteners. The lid completely wraps over the top of the accumulator with a lip around all four sides to ensure water will not enter from the top. The rear ventilation holes are covered with a breathable waterproof mesh that allows for proper airflow and cooling but does not allow for the intrusion of water. The fans are also blowing air into the accumulator creating a positive pressure situation and will help prevent water intrusion in any of the fastener locations. The front side of the accumulator has is covered with the firewall, flooring, and water resistant cooling fans that will block any rain water from above as well as splashing puddles from below.

<u>T.10.2.1</u> Any critical fastener must meet, at minimum, one of the following:

a. ***SAE Grade 5***
b. ***Metric Grade 8.8***
c. ***AN/MS Specifications***

All critical fasteners in the accumulator are fully rules compliant and meet the Metric Grade 8.8 or SAE Grade 5 specification. This includes all mounting hardware for the accumulator itself as well as any internal components.

<u>T.10.2.2</u> All Critical Fasteners must be one of the following:

- ***Hex head***
- ***Hexagonal recessed drive (Socket Head Cap Screws or Allen screws/bolts)***

All critical fasteners, both internal and external, for all components and the housing are either hex head or hexagonal recessed drive fasteners. Even most fasteners that may not be considered critical still followed this rule to lean on the side of safety and rules compliance. The only non hex or hexagonal recessed fasteners are the philips pan head sex screws used for "pinching" together the battery mounting brackets when installing into the accumulator. Rules compliant critical fasteners were not used for this due to the extreme difficulty finding a supplier for these fasteners. The application for these screws are not considered critical fasteners because their purpose is to only hold the packs together until they're installed into the accumulator where the battery bracket mounting bolts (which are rules compliant critical fasteners) then take over the task of holding the backs together.

***T.10.3.1* Positive Locking Mechanisms are defined as those which:**

- ***a.*** ***The Technical Inspectors (and the team members) are able to see that the device/ system is in place (visible).***
- ***b.*** ***The Positive Locking Mechanism does not rely on the clamping force to apply the locking or anti vibration feature. (If it loosens a bit, it still prevents the nut or bolt coming completely loose)***

All positive locking mechanisms in the accumulator are either nylon nuts, safety wire, tabbed washers, or top lock nuts. All of these systems are clearly visible by all people when the accumulator is assembled. All locking mechanisms are rules compliant as they physically prevent the nut from coming loose on its own. None of the nuts are simply tightened on and only relying on the clamping force of the nut for security.

***T.10.3.2* Acceptable Positive Locking Mechanisms include:**

- ***a.*** ***Correctly installed safety wiring***

b. ***Cotter pins***

c. ***Nylon lock nuts (where temperature does not exceed 80 degrees C)***

d. ***Prevailing torque lock nuts***

As stated in the previous rule explanation, all positive locking mechanisms use either nylon nuts, safety wire, tabbed washers, or top lock nuts. The safety wire was installed properly with the help of another student who is familiar with the proper uses for safety wire and has installed it in a rules compliant manner multiple times before. This ensured all critical fasteners were installed using rules compliant fastening practices to prevent loosening.

T.10.4.1 A minimum of two full threads must project from any lock nut.

All fasteners, both critical and not, use properly specified bolts to ensure the correct length is used. A minimum of two threads can be seen protruding from all fasteners to ensure safety and rules compliance. The only fastener that was very close to not passing this rule are the maintenance plug pins through the bus bars with the top lock fasteners. The length of the pins was just long enough to show two threads. To fix this issue in the future, the bus bars need to be made slightly thinner while still remaining electrically safe as determined by the electrical team.

Conclusion

After one year of hard work we were able to design, manufacture, and assemble an accumulator for the Zips Electric Racing team from scratch. Due to the lack of previous knowledge from past years or a rules compliant accumulator, we were tasked to sort through the rule book to ensure we were designing a safe and functioning accumulator. We began with several different designs that were reviewed with the team to narrow down on the best option. After an option was chosen we then worked with the frame team and the electrical team to double check the accumulator would fit into the frame and all electrical components were accounted for. After everything was manufactured we then assembled all the components. We ran into some issues with components not lining up but we were able to work through all the problems that were presented to us. Now that the accumulator is assembled we are excited to have it race for the first time ever at competitions this summer.

Appendix

EQ **Accumulator Segments**

The segment structures carry the load to the accumulator container and mounts.
This information will help develop FSAE standards for accumulator and segment internal structure

Note: Compliance with EV.3.1.2 requires additional documentation in the EVSE.
Nominal values reported here are for approximation only.

		EQ		
	Cell type:	Cylindrical		EQ
	Maximum Voltage:	4.2	V	EQ
	Nominal Voltage:	3.7	V	EQ
	Nominal Capacity:	2500	mAh	EQ
	Maximum segment cells in series:	18		EQ
	Maximum segment cells in parallel:	6		EQ
EV.3.1.2	Maximum segment voltage:	75.6	V	EQ
EV.3.1.2	Nominal segment capacity:	3.5964	MJ	EQ
	Total accumulator cells in series:	72		EQ
	Total accumulator cells in parallel:	6		EQ
EV.1.3.2	Maximum accumulator voltage:	302.4	V	EQ
	Nominal accumulator capacity:	3.996	kWh	EQ
		EQ		
EV.4.2.3 Cell mounting and bracing mate	E:	6.89E+10	Pa	EQ
	UTS:	310000000	Pa	EQ
	Shear:	207000000	Pa	EQ
	Segment Izz Lateral:	5706.43	**mm^4**	EQ
	Segment Izz Longitudinal:	2238.18	**mm^4**	EQ
	Maximum segment length:	**22.86**	mm	EQ
	Maximum segment width:	15.88	mm	EQ
	Maximum segment height:	108.72	mm	EQ
		EQ		
EV.4.2.3 Installation Me		Bolted		EQ

Figure 14 *- SES Accumulator Segments*

EQ Accumulator Container

EV.4.3.6 Corner Attachment:

The internal segment structures carry the load to the accumulator container and mounts.
Corner attachments are located at the structural limits of the assembled segments.
Rectangular segment arrangements have mounts at all eight corners:
Front, Back, Top, Bottom, Left, Right
Fasteners may be offset up to 50mm in each orthogonal direction.
Panel thickness does not count toward this limit.

Corner attachment locations are determined by the internal segment structure, not the external container.
Additional container walls or volumes are not counted.
A 1-tube thick exoskeleton with a direct load path around the perimeter of the assembled segments may be used to define the structural limits and corners.
Minimum tube sizes are given by T.2.5-7.
The structural dimensions of a composite container are best increased with core size.
Composite panels with a core are preferred.
A subframe may be used to bring nodes to the accumulator if the tubes meet T.2.5-7.

	EQ			
	Minimum segment mass:	5	kg	EQ
EV.4.2.2f	Maximum segment mass:	10	kg	EQ
	Number of segments <= 8kg:	1		EQ
	Number of 8kg < segments <= 12kg:	4		EQ
.4.2.2f Baseline: 3 x 6mm (1/4in) fasteners connecting vertical wa				3

	EQ		
EV.4.2.2h	Number of segment external vertical walls:	4	EQ
	Number of cover fasteners:	12	EQ

Make sure at least 1 fastener is used per segment external wall.
Indicate weld paths in image.

	EQ			
EV.4.2.2e	Vertical wall joining method:	Welded		EQ
		>= 6mm (1/4in)		N/A
				N/A
			N	N/A
			N/mm^2	N/A
			mm^2	N/A
				N/A

Figure 15 *- SES Accumulator Container*

ACCUMULATOR FLOOR

EQ

	Floor width:	889	mm	EQ
	Floor length:	260	mm	EQ
EV.4.2.2	Accumulator Floor Construction:	Aluminum		EQ
	Steel: 1.25mm (0.049in), Aluminum: 3.2mm (.125in):	3.2	mm	EQ
	Material Used:	T.2.31 SIS Layup		N/A
	Panel thickness:	0	mm	N/A
	Core thickness:		mm	N/A
	Outer skin thickness:		mm	N/A
	Inner skin thickness:		mm	N/A

Flat Panel Properties			Flat Panel Properties			Flat Panel Properties		
Outer (b)	0.26	m	A_1	######	m^2	I_1	######	m^4
Outer (h)	0	m	A_2	######	m^2	I_2	######	m^4
Thicknes	0	m	y_1	0	m	Ic_1		m^4
Inner (b)	0.26	m	y_2	0.000	m	Ic_2		m^4
Inner (h)	0	m	Centroid		m	Ic_{12}		m^4

		Baseline Steel	Aluminum		
	Thickness:	0.0013	0	m	N/A
	Cross sectional area (A):	######	######	m^2	N/A
	Second moment of inertia (I):	4.23E-11		m^4	N/A
T.2.5.3a	Young's Modulus (E):	######		Pa	N/A
	Ultimate Tensile and Bending Strength (S):	######			N/A
	Shear:	######			N/A
Buckling Modul	E_1*L_1<= E_2*L_2:	######			N/A

Figure 16 *- SES Accumulator Floor*

ACCUMULATOR EXTERIOR WALLS

EQ

	Exterior wall height:	193.7	mm	EQ
EV.4.2.2	Exterior Wall Construction:	Aluminum		EQ
	Steel: 0.90mm (0.035in), Aluminum: 2.3mm (0.090in):	3.2	mm	EQ
	Material Used:	T.2.31 SIS Layup		N/A
	Panel thickness:	0	mm	N/A
	Core thickness:		mm	N/A
	Outer skin thickness:		mm	N/A
	Inner skin thickness:		mm	N/A

Flat Panel Properties			Flat Panel Properties			Flat Panel Properties		
Outer (b)	0.1937	m	A_1	######	m^2	I_1	######	m^4
Outer (h)	0	m	A_2	######	m^2	I_2	######	m^4
Thicknes	0	m	y_1	0	m	Ic_1		m^4
Inner (b)	0.1937	m	y_2	0.000	m	Ic_2		m^4
Inner (h)	0	m	Centroid		m	Ic_{12}		m^4

		Baseline Steel	Aluminum		
	Thickness:	0.0009	0	m	N/A
	Cross sectional area (A):	1.74E-01	######	m^2	N/A
	Second moment of inertia (I):	1.18E-11		m^4	N/A
T.2.5.3a	Young's Modulus (E):	######		Pa	N/A
	Ultimate Tensile and Bending Strength (S):	######			N/A
	Shear:	######			N/A
Buckling Modul	E_1*L_1<= E_2*L_2:	######			N/A

Figure 17 *- SES Accumulator Walls*

ACCUMULATOR COVER/LID

EQ

Cover width:	903.4	mm	EQ
Cover length:	270.4	mm	EQ
EV.4.2.2 **Exterior Wall Construction:**	Aluminum		EQ
Steel: 0.90mm (0.035in), Aluminum: 2.3mm (0.090in):	4	mm	EQ
Material Used:	T.2.31 SIS Layup		N/A
Panel thickness:	0	mm	N/A
Core thickness:		mm	N/A
Outer skin thickness:		mm	N/A
Inner skin thickness:		mm	N/A

Flat Panel Properties			**Flat Panel Properties**			**Flat Panel Properties**		
Outer (b)	0.2704	m	A_1	######	m^2	I_1	######	m^4
Outer (h)	0	m	A_2	######	m^2	I_2	######	m^4
Thicknes	0	m	y_1	0	m	Ic_1		m^4
Inner (b)	0.2704	m	y_2	0.000	m	Ic_2		m^4
Inner (h)	0	m	Centroid		m	Ic_{12}		m^4

		Baseline Steel	**Aluminum**		
	Thickness:	0.0009	0	m	N/A
	Cross sectional area (A):	######	######	m^2	N/A
	Second moment of inertia (I):	1.64E-11		m^4	N/A
T.2.5.3a	Young's Modulus (E):	######		Pa	N/A
	Ultimate Tensile and Bending Strength (S):	######			N/A
	Shear:	######			N/A
Buckling Modul	E_1*L_1<= E_2*L_2:	######			N/A

Figure 18 *- SES Accumulator Cover Lid*

EQ — Accumulator Mount 1

Accumulator Mount where Chassis Mount meets

				EQ
Outside	the front/rear surfaces of the segment structures	30.76	mm	EQ
Outside	the top/bottom surfaces of the segment structu	4	mm	EQ
Outside	the left/right surfaces of the segment structures	47.05	mm	EQ
	Total Surface Offset:	56.355	mm	EQ
	Mount material (Accumulator skin if directly mounted):	Steel (No Welding)		EQ
	Young's Modulus (E):	#####	Pa	EQ
	Ultimate Tensile and Bending Strength (S):	#####	Pa	EQ
	Shear:	#####	Pa	EQ
	Mount total skin/wall thickness (Do not include core.):	4	mm	EQ
	Minimum - Fastener spacing or edge distance:	12	mm	EQ
	Number of fasteners used (2x if in double shear):	1		EQ
	Fastener diameter:	8	mm	EQ
	Threads in shear:	No		EQ
	Fastener shear capability:	25000	N	EQ
	Shear perimeter:	25.12	mm	EQ
	Fastener shear >= Test Load:	25000	166.7%	EQ
	Fastener Pullout >= Test Load:	21162	141.1%	EQ
	Fastener Tearout >= Test Load:	20218	134.8%	EQ

Accumulator Mount Braces

Enter 2*tube wall for thickness. Do not enter a skin/wall thickness > fastener diameter.

			EQ
Lateral bracing total skin/wall thickness:	4	mm	EQ
Lateral brace total length:	47.05	mm	EQ
Bending M*y / I <= UTS:	#####	13.1%	EQ
Parabolic shear 3*Test Load/2*b*h <= Shear:	#####	56.8%	EQ
Longitudinal bracing total skin/wall thickness:	4	mm	EQ
Longitudinal brace total length:	30.76	mm	EQ
Bending M*y / I <= UTS:	#####	30.6%	EQ
Parabolic shear 3*Test Load/2*b*h <= Shear:	#####	86.8%	EQ
Vertical bracing total skin/wall thickness:	4	mm	EQ
Vertical brace total length:	34.76	mm	EQ
Bending M*y / I <= UTS:	#####	24.0%	EQ
Parabolic shear 3*Test Load/2*b*h <= Shear:	#####	76.8%	EQ

Accumulator Mount to Accumulator Skin interface

			EQ
Accumulator skin at mount interface:	Steel (Welded)		EQ
Young's Modulus (E):	#####	Pa	EQ
Ultimate Tensile and Bending Strength (S):	#####	Pa	EQ
Shear:	#####	Pa	EQ
Accumulator total skin/wall thickness:	3.176	mm	EQ
Mount interface with accumulator:	Welded		EQ
		mm	N/A
			N/A
		mm	N/A
			N/A
		N	N/A
		mm	N/A
	0		N/A
	0		N/A
	0		N/A
Max bending load <= Shear strength:	#####	64.5%	EQ
Total weld perimeter:	224.0	mm	EQ
Weld thickness is assumed = skin thickness:	3.176	mm	EQ
Shear strength >= Test Load:	123147	821.0%	EQ
		N/mm^2	N/A
		N/mm^2	N/A
		mm^2	N/A
			N/A
			N/A

Figure 19 *- SES Accumulator Front Mounting Bracket*

EQ	Accumulator Mount 2		

Accumulator Mount where Chassis Mount meets

EQ			
Outside the front/rear surfaces of the segment structures	31.62	mm	EQ
Outside the top/bottom surfaces of the segment structur	4	mm	EQ
Outside the left/right surfaces of the segment structures:	47.05	mm	EQ
Total Surface Offset:	56.829	mm	EQ
Mount material (Accumulator skin if directly mounted):	Steel (No Welding)		EQ
Young's Modulus (E):	#####	Pa	EQ
Ultimate Tensile and Bending Strength (S):	#####	Pa	EQ
Shear:	#####	Pa	EQ
Mount total skin/wall thickness (Do not include core.):	4	mm	EQ
Minimum - Fastener spacing or edge distance:	15	mm	EQ
Number of fasteners used (2x if in double shear):	1		EQ
Fastener diameter:	8	mm	EQ
Threads in shear:	No		EQ
Fastener shear capability:	25000	N	EQ
Shear perimeter:	25.12	mm	EQ
Fastener shear >= Test Load:	25000	166.7%	EQ
Fastener Pullout >= Test Load:	21162	141.1%	EQ
Fastener Tearout >= Test Load:	25273	168.5%	EQ

Accumulator Mount Braces

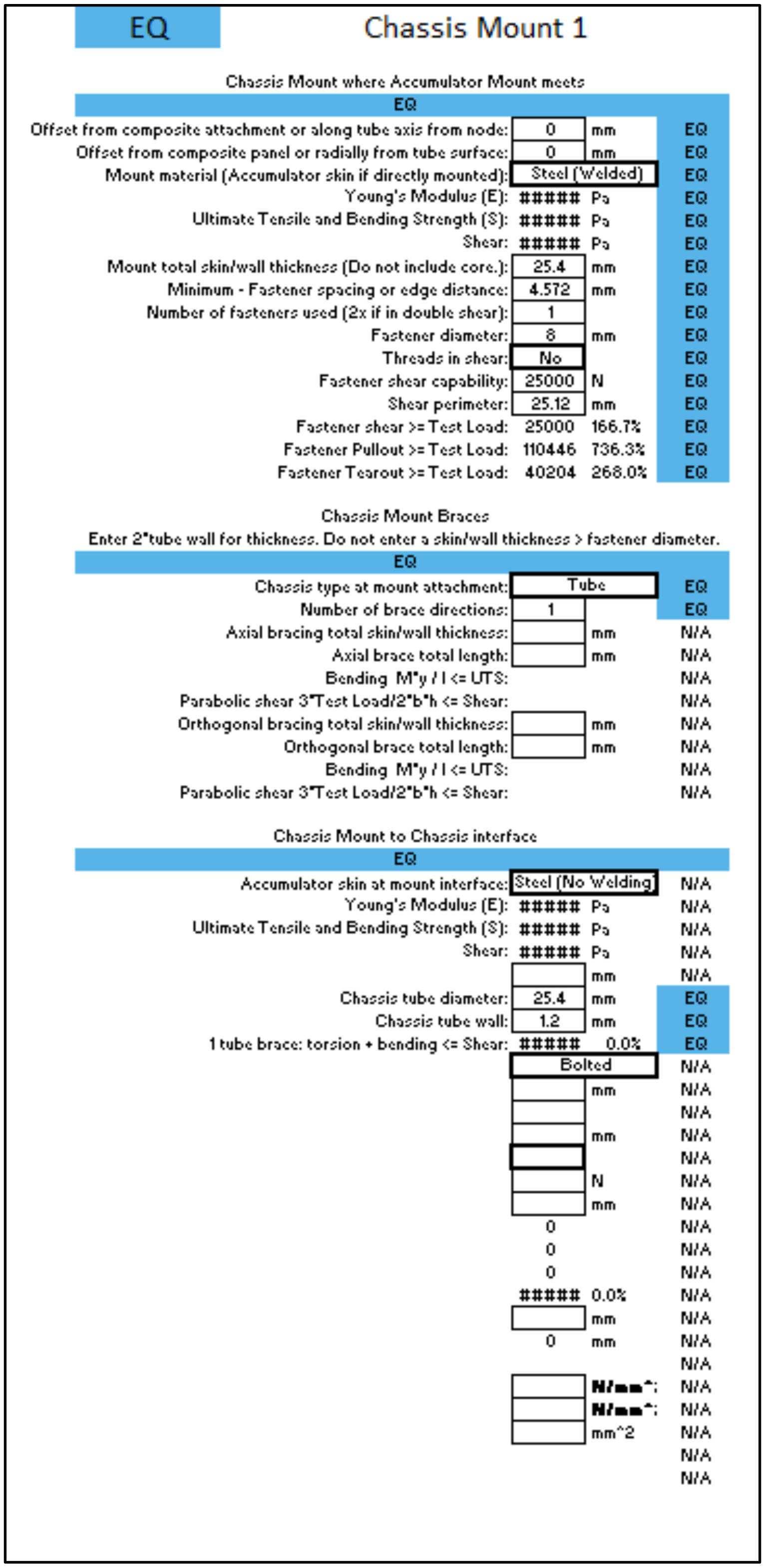
Enter 2*tube wall for thickness. Do not enter a skin/wall thickness > fastener diameter.

EQ			
Lateral bracing total skin/wall thickness:	4	mm	EQ
Lateral brace total length:	47.05	mm	EQ
Bending M*y / I <= UTS:	#####	13.2%	EQ
Parabolic shear 3*Test Load/2*b*h <= Shear:	#####	56.8%	EQ
Longitudinal bracing total skin/wall thickness:	4	mm	EQ
Longitudinal brace total length:	31.62	mm	EQ
Bending M*y / I <= UTS:	#####	29.2%	EQ
Parabolic shear 3*Test Load/2*b*h <= Shear:	#####	84.5%	EQ
Vertical bracing total skin/wall thickness:	4	mm	EQ
Vertical brace total length:	33.91	mm	EQ
Bending M*y / I <= UTS:	#####	25.4%	EQ
Parabolic shear 3*Test Load/2*b*h <= Shear:	#####	78.8%	EQ

Accumulator Mount to Accumulator Skin interface

EQ			
Accumulator skin at mount interface:	Steel (Welded)		EQ
Young's Modulus (E):	#####	Pa	EQ
Ultimate Tensile and Bending Strength (S):	#####	Pa	EQ
Shear:	#####	Pa	EQ
Accumulator total skin/wall thickness:	3.176	mm	EQ
Mount interface with accumulator:	Welded		EQ
		mm	N/A
			N/A
		mm	N/A
			N/A
		N	N/A
		mm	N/A
	0		N/A
	0		N/A
	0		N/A
Max bending load <= Shear strength:	#####	61.6%	EQ
Total weld perimeter:	244.0	mm	EQ
Weld thickness is assumed = skin thickness:	3.176	mm	EQ
Shear strength >= Test Load:	134143	894.3%	EQ
		N/mm^:	N/A
		N/mm^:	N/A
		mm^2	N/A
			N/A
			N/A

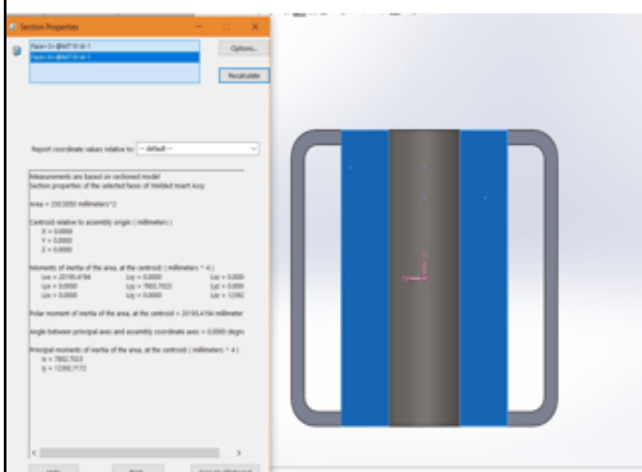
***Figure 20** - SES Accumulator Rear Mounting Bracket*



EQ	Chassis Mount 1		
Chassis Mount where Accumulator Mount meets			
EQ			
Offset from composite attachment or along tube axis from node:	0	mm	EQ
Offset from composite panel or radially from tube surface:	0	mm	EQ
Mount material (Accumulator skin if directly mounted):	Steel (Welded)		EQ
Young's Modulus (E):	#####	Pa	EQ
Ultimate Tensile and Bending Strength (S):	#####	Pa	EQ
Shear:	#####	Pa	EQ
Mount total skin/wall thickness (Do not include core.):	25.4	mm	EQ
Minimum - Fastener spacing or edge distance:	4.572	mm	EQ
Number of fasteners used (2x if in double shear):	1		EQ
Fastener diameter:	8	mm	EQ
Threads in shear:	No		EQ
Fastener shear capability:	25000	N	EQ
Shear perimeter:	25.12	mm	EQ
Fastener shear >= Test Load:	25000	166.7%	EQ
Fastener Pullout >= Test Load:	110446	736.3%	EQ
Fastener Tearout >= Test Load:	40204	268.0%	EQ
Chassis Mount Braces			
Enter 2*tube wall for thickness. Do not enter a skin/wall thickness > fastener diameter.			
EQ			
Chassis type at mount attachment:	Tube		EQ
Number of brace directions:	1		EQ
Axial bracing total skin/wall thickness:		mm	N/A
Axial brace total length:		mm	N/A
Bending M*y / I <= UTS:			N/A
Parabolic shear 3*Test Load/2*b*h <= Shear:			N/A
Orthogonal bracing total skin/wall thickness:		mm	N/A
Orthogonal brace total length:		mm	N/A
Bending M*y / I <= UTS:			N/A
Parabolic shear 3*Test Load/2*b*h <= Shear:			N/A
Chassis Mount to Chassis interface			
EQ			
Accumulator skin at mount interface:	Steel (No Welding)		N/A
Young's Modulus (E):	#####	Pa	N/A
Ultimate Tensile and Bending Strength (S):	#####	Pa	N/A
Shear:	#####	Pa	N/A
		mm	N/A
Chassis tube diameter:	25.4	mm	EQ
Chassis tube wall:	1.2	mm	EQ
1 tube brace: torsion + bending <= Shear:	#####	0.0%	EQ
	Bolted		N/A
		mm	N/A
			N/A
		mm	N/A
			N/A
		N	N/A
		mm	N/A
	0		N/A
	0		N/A
	0		N/A
	#####	0.0%	N/A
		mm	N/A
	0	mm	N/A
			N/A
		N/mm^:	N/A
		N/mm^:	N/A
		mm^2	N/A
			N/A
			N/A

Figure 21 *- SES Accumulator Fastener for Mounting to the Frame*

EQ	Welded Tube Insert				
	Note: Young's Modulus is given in MPa, not Gpa.				
	EQ				
		Original	Insert _2 +		EQ
r	Material:	Steel			EQ
	Original tube:	Square	Square		EQ
	Wall thickness:	1.2	1.2	mm	EQ
	Square side:	25.4	25.4	mm	EQ
	Tube cross sectional area (A_1):	#####	-	mm^2	EQ
	Tube second moment of inertia (I_1):	#####	-	mm^4	EQ
	Insert/Collar cross sectional area (A_2):		230.51	mm^2	EQ
	Insert/Collar second moment of inertia (I_2):		7820.7	mm^4	EQ
	Tube with Hole cross sectional area (A_3):		77.638	mm^2	EQ
	Tube with Hole second moment of inertia (I_3):		5461	mm^4	EQ
T.2.5.3a	Young's Modulus (E):	#####	#####	Pa	EQ
	Yield Strength (Sy):	#####	#####	Pa	EQ
	Ultimate Strength (Su):	#####	#####	Pa	EQ
Buckling Mode	E_1*I_1 <= E_2*I_2 + E_1*I_3:	#####	#####	116.9%	EQ
Yield	Sy_1*A_1 <= Sy_2*A_2 + Sy_1*A_3:	#####	#####	183.9%	EQ
Ultimate	Su_1*A_1 <= Su_2*A_2 + Su_1*A_3:	#####	#####	229.9%	EQ
Bending	4*Su_1*I_1/r <= 4*Su_1*(I_2+I_3)/r:	1.31E+12	#####	116.9%	EQ
eflectio	Bending_1/(48*EI):	#####	#####	85.6%	EQ
Energy	0.5*Bending^2/(48*EI):	#####	#####	116.9%	EQ



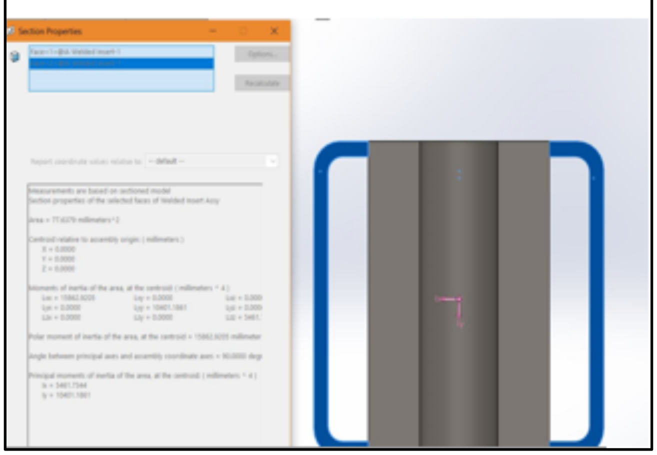


Figure 22 *- SES Accumulator Welded Inserts for Mounting to the Frame*

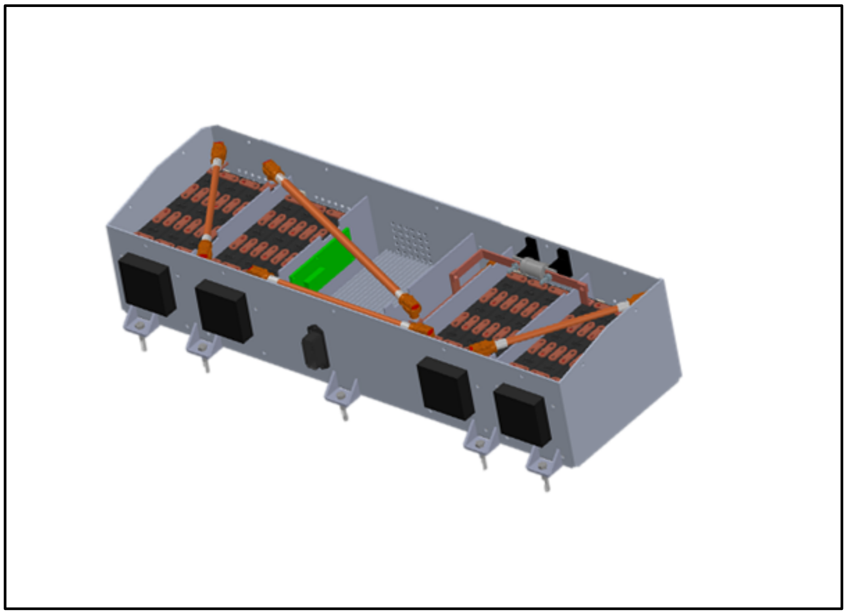


Figure 23 *- Final Design of Accumulator*

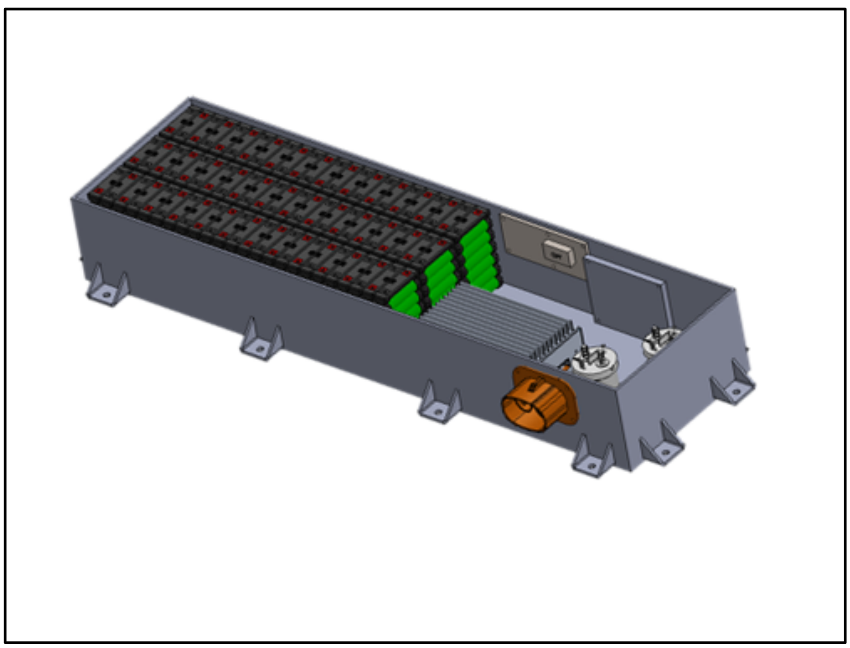


Figure 24 *- Concept Design 1*

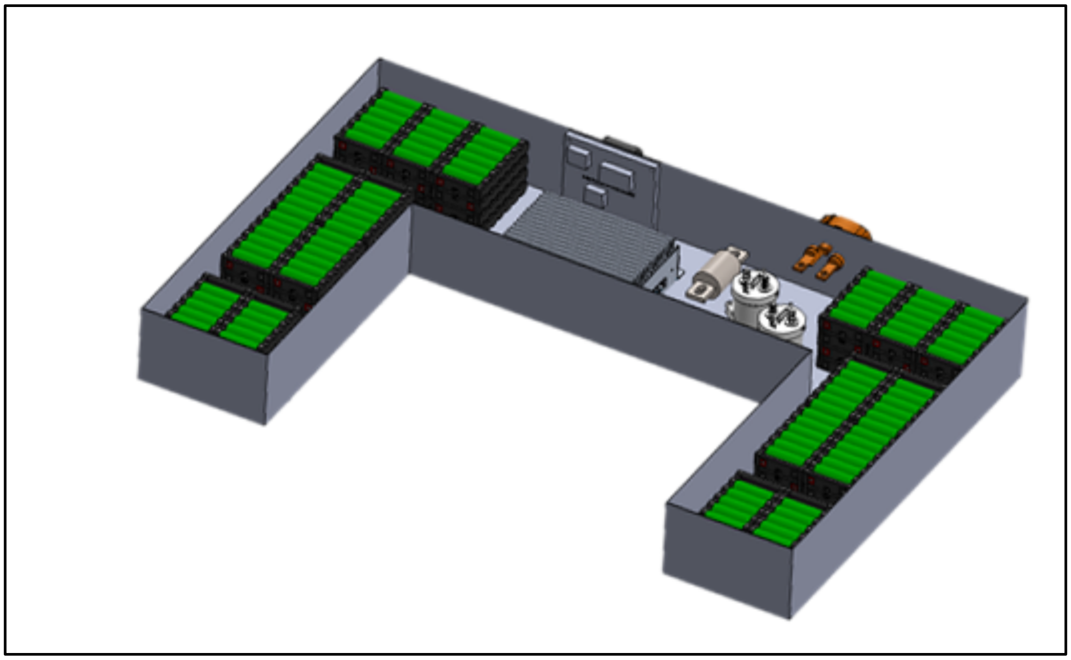


Figure 25 *- Concept Design 2*

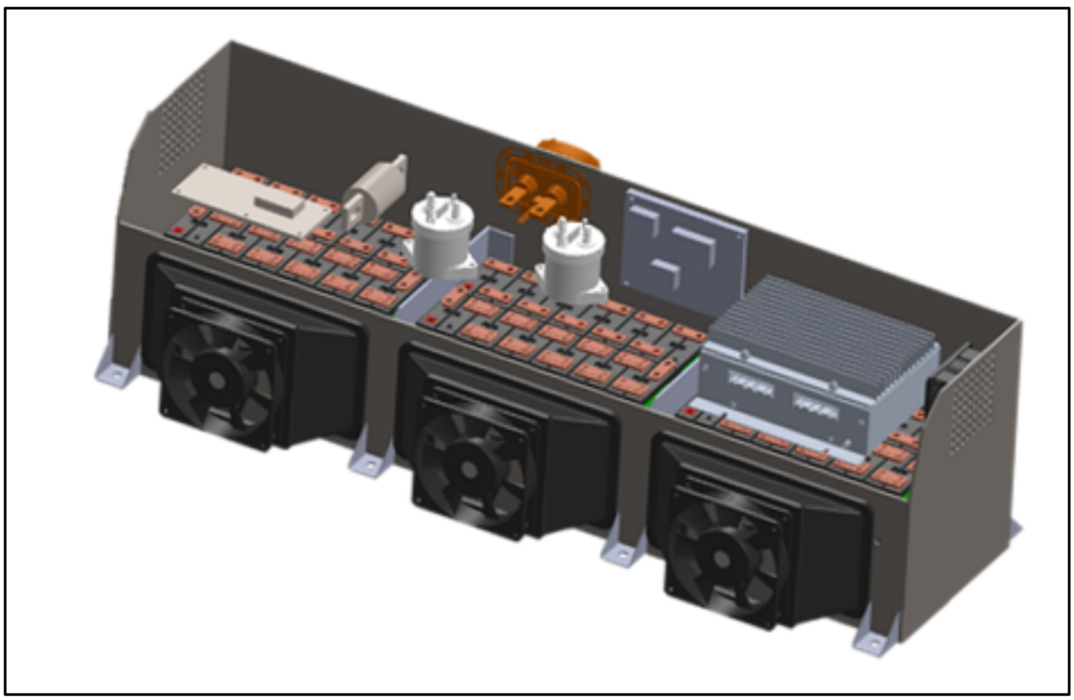


Figure 26 *- Concept Design 3*

Closing Remarks Following Formula North

Formula North was the first SAE competition that Zips electric racing passed all technical inspections. These inspections included accumulator, electrical, mechanical, tilt, rain, and brake inspections. Regarding the accumulator, it was the first inspection we passed. The mechanical inspection of the accumulator was captured in the SES. Judges were mainly concerned the SES was accepted and not many questions were asked about the structural rigidity of the accumulator. The judge did make some comments. He liked that our internal walls were next to the mounting brackets for maintaining rigidity. The mounting brackets had gussets to handle bending loads. The accumulator added rigidity to the frame, especially with side bending loads. During the design presentations I wish I had displayed more of the FEA simulations I did to prove the brackets could withstand the required forced. During the design presentations there was not a dedicated judge to answer questions specifically about the accumulator; however, I chimed in to all judges especially those standing by themselves. Future designs of the accumulator do not need fans to cool batteries (could change during extremely hot climates at Formula Lincoln; however, TDB). Using internal walls and pack mounting brackets as heat sinks may be enough to draw heat from the batteries. The heat sink on the BMS should stay on as it will become hot if taken off to improve packing. Michigan experienced thermal issues after removing the BMS heat sink. Future frame designs need to better accommodate the design of the accumulator, especially when it comes to the overall size, and removing it from the frame during charging. Many teams have access to the accumulator from underneath the frame. The more simulations to show off the better, which goes for all systems of the car.