Design Expo

Systems Integration for Columbia's First FSAE Electric Vehicle

Mechanical Engineering

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May 9th, 2019

FAHK

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PROJECT OVERVIEW AND CONTEXT

Systems Integration for Columbia's First FSAE Electric Vehicle

- First Formula SAE competition held in 1981
- First Formula SAE Electric competition held in 2013
- 2019 FSAE Electric to host 30 teams in Lincoln, Nebraska

- Columbia's FSAE team, Knickerbocker Motorsports, was founded in 1997
- 2020 is first year Columbia hopes to compete in EV racing

FSAE President: Mark Hellinger
EV Presidents: Max Möller & Nico Hoernle
EV Advisor: Professor Preindl
FSAE Advisor: Professor Browne

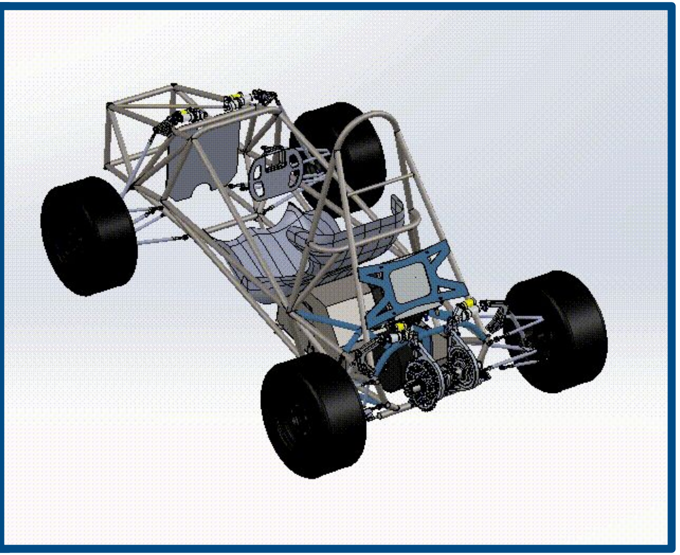
Systems integration in existing chassis:

- House batteries and high and low voltage systems
- Package motor and integrate differential
- Structure and mounting in compliance with FSAE rules

CAD OVERVIEW

CAD OVERVIEW

Systems Integration for Columbia's First FSAE Electric Vehicle



LITERATURE REVIEW

Journals and filed patents we researched for our project

- **FSAE Rules 2019:** The definitive ruleset and guidelines for building an FSAE Electric Car
- **Penn Electric Racing:** Used as inspiration, benchmark for car specifications, and to determine maximum motor speed used in calculations for Final Drive Ratio
- **Wisconsin Accumulator Paper:** Accumulator space management, conforming to standards, mounting, and FEA
- **UConn Accumulator Paper:** Accumulator space management & conforming to standards
- **Oakridge National Laboratory:** Thermal Properties of Sony Li-Ion Batteries, rationale for cooling system
- **IIT Armour College of Engineering:** Design of a gearbox for an electric vehicle
- **Undergraduate Journal of Mathematical Modeling:** Optimum gear ratios for an electric vehicle
- **Relevant Patents:** US20110083449 (Cooling cabin and electrical components of vehicles)
US20120070724A1 (Buffering structure for lead accumulator)
CN105114590B (Limited slip differential on FSAE car)

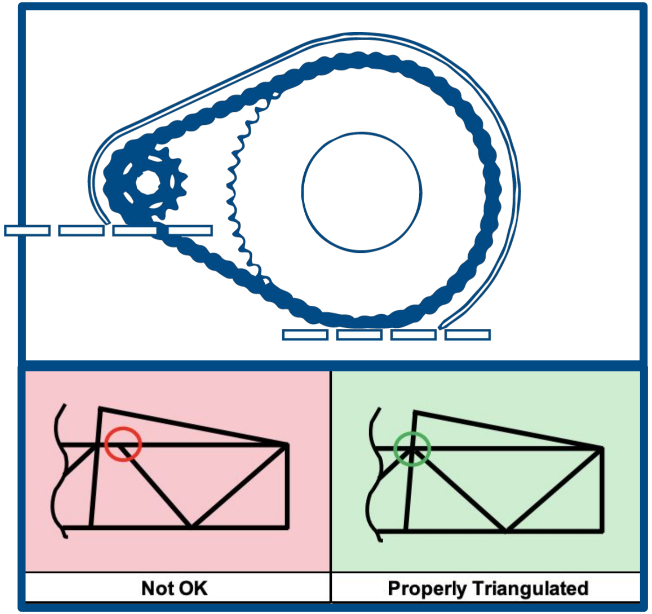
STANDARDS & CODES

The regulations and guidelines pertinent to our project

FSAE Rulebook & SES (Highest level of standards)

- Accumulator Design
  - Battery segment requirements: mass/voltage
  - Wall structure, internal structure, and mounting
  - Insulated and water resistant
- Drivetrain
  - Any transmission and drive
  - Chain guard must be made of solid material
  - Chain guard must start and end parallel
- Chassis
  - Triangulation from the side, not top
  - Tube sizing
  - Max insert sizes and bracketing

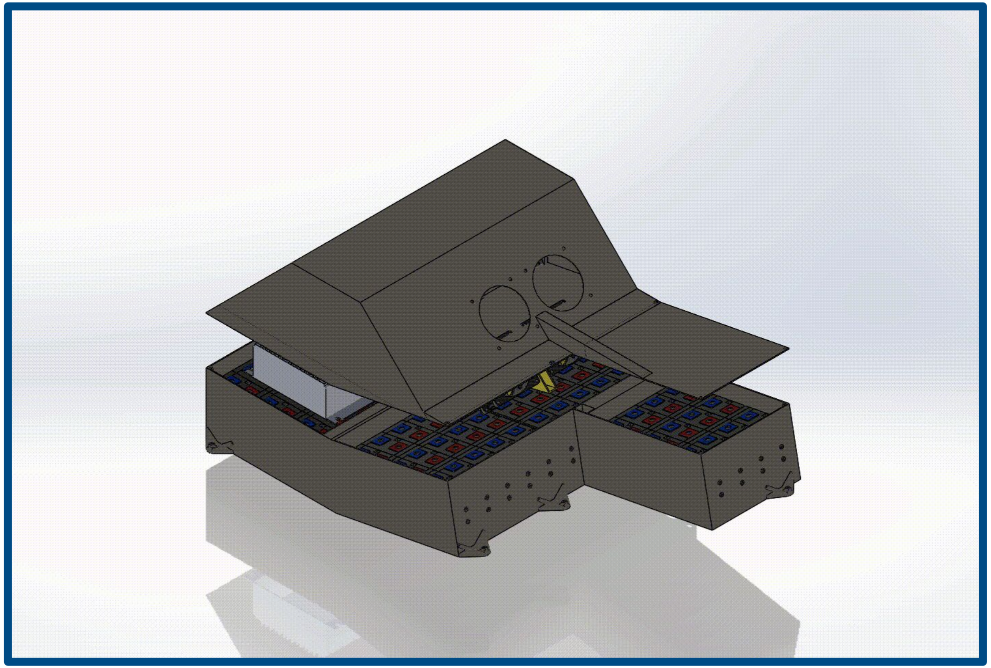
ASME (Y 14.5-2009: Tolerancing)



SYSTEM INTEGRATION:

ACCUMULATOR HOUSING

Designing the accumulator housing for batteries and BMS



SYSTEM INTEGRATION:

ACCUMULATOR HOUSING

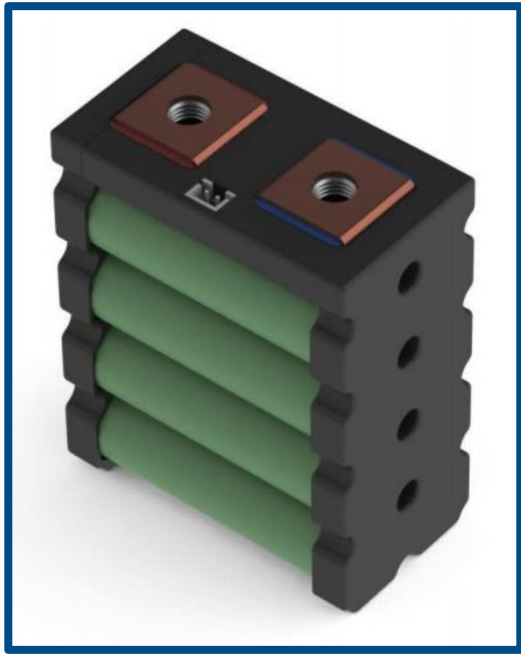
Designing the accumulator housing for batteries and BMS

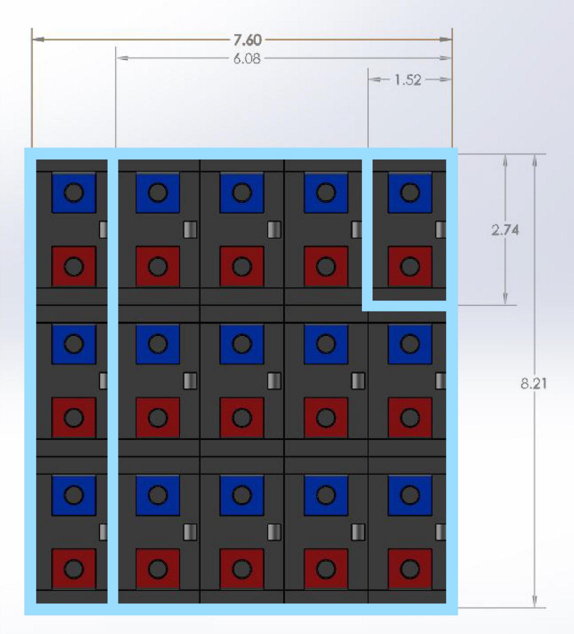
Maximal Battery Voltage	4.2 V DC
Weight	0.427 kg
Dimensions	39×69.5×87 mm
Max Working Temperature	60º Celcius

Table 1: LI8P25RT Lithium-Ion Battery

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.





SYSTEM INTEGRATION:

ACCUMULATOR HOUSING

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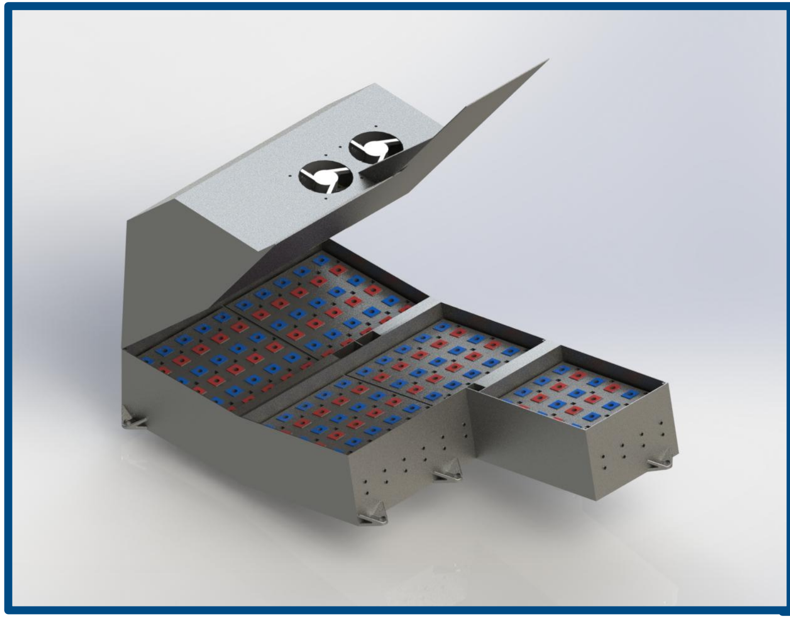
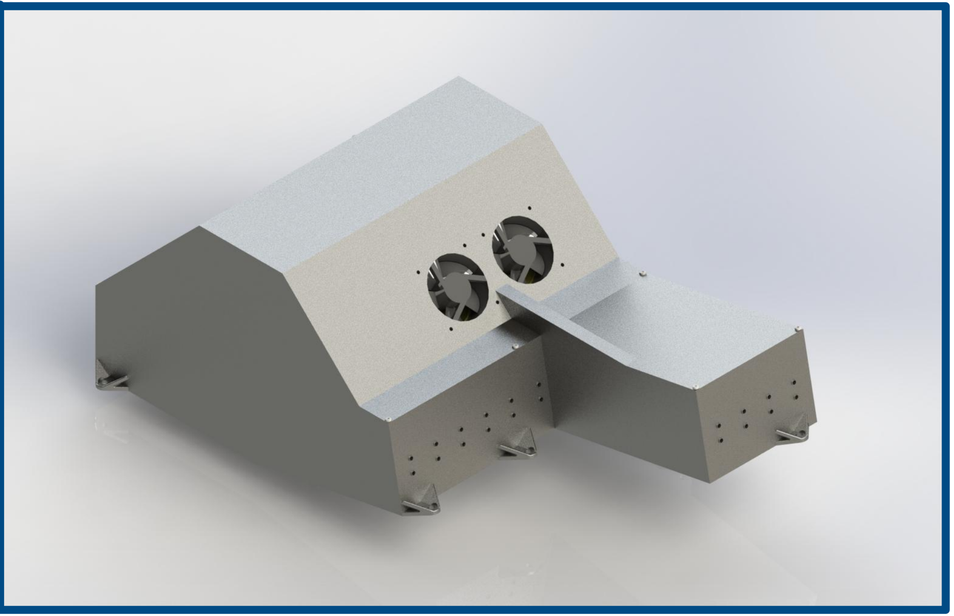


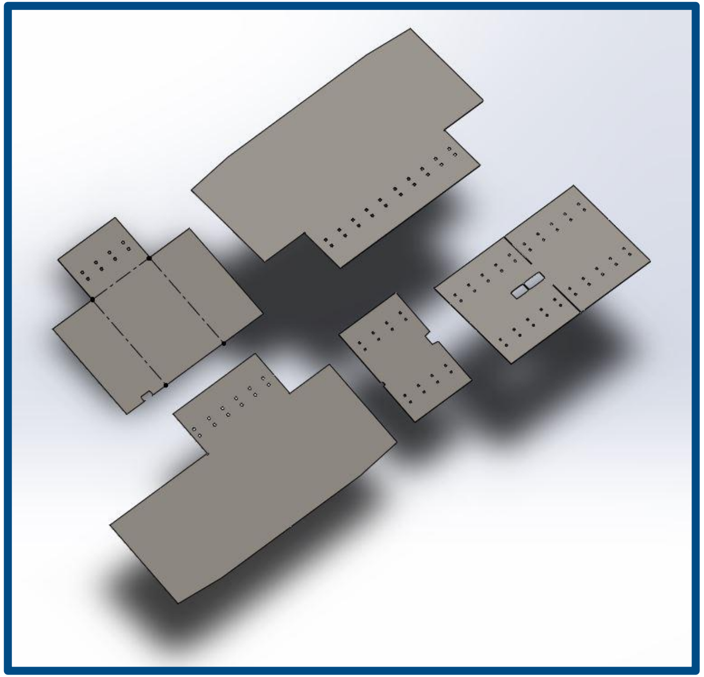


SYSTEM INTEGRATION:

ACCUMULATOR HOUSING

Sheet metal fabrication example

Sheet Thickness	0.06”
Sheet Size	24” x 36”
Sheet Quantity	7
Parts to Cut	Upper - 6 Lower - 7

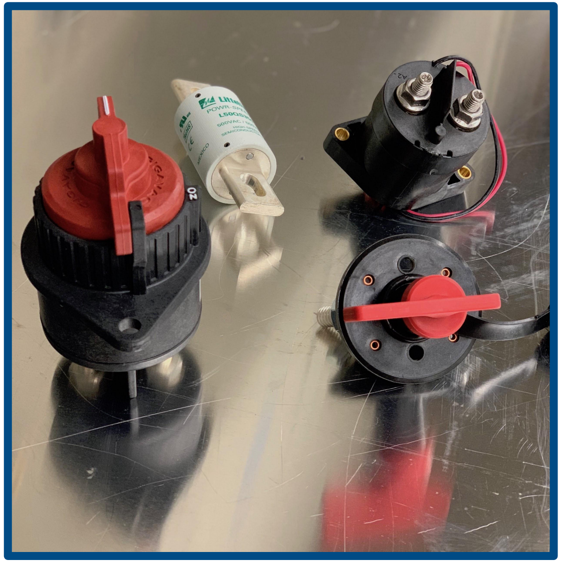


SYSTEM INTEGRATION:

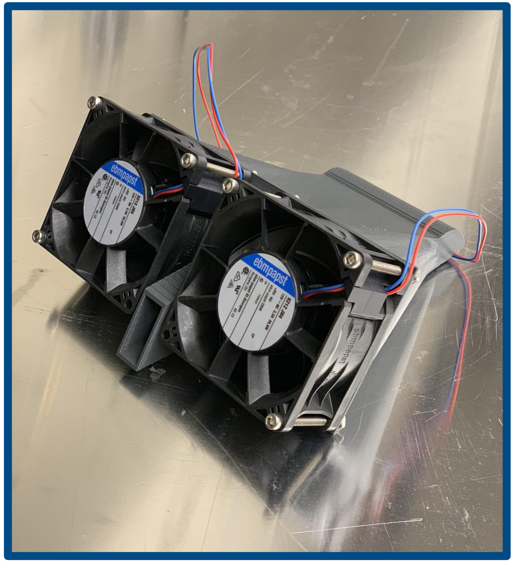
ACCUMULATOR HOUSING

Components housed inside accumulator

Orion Battery Management System

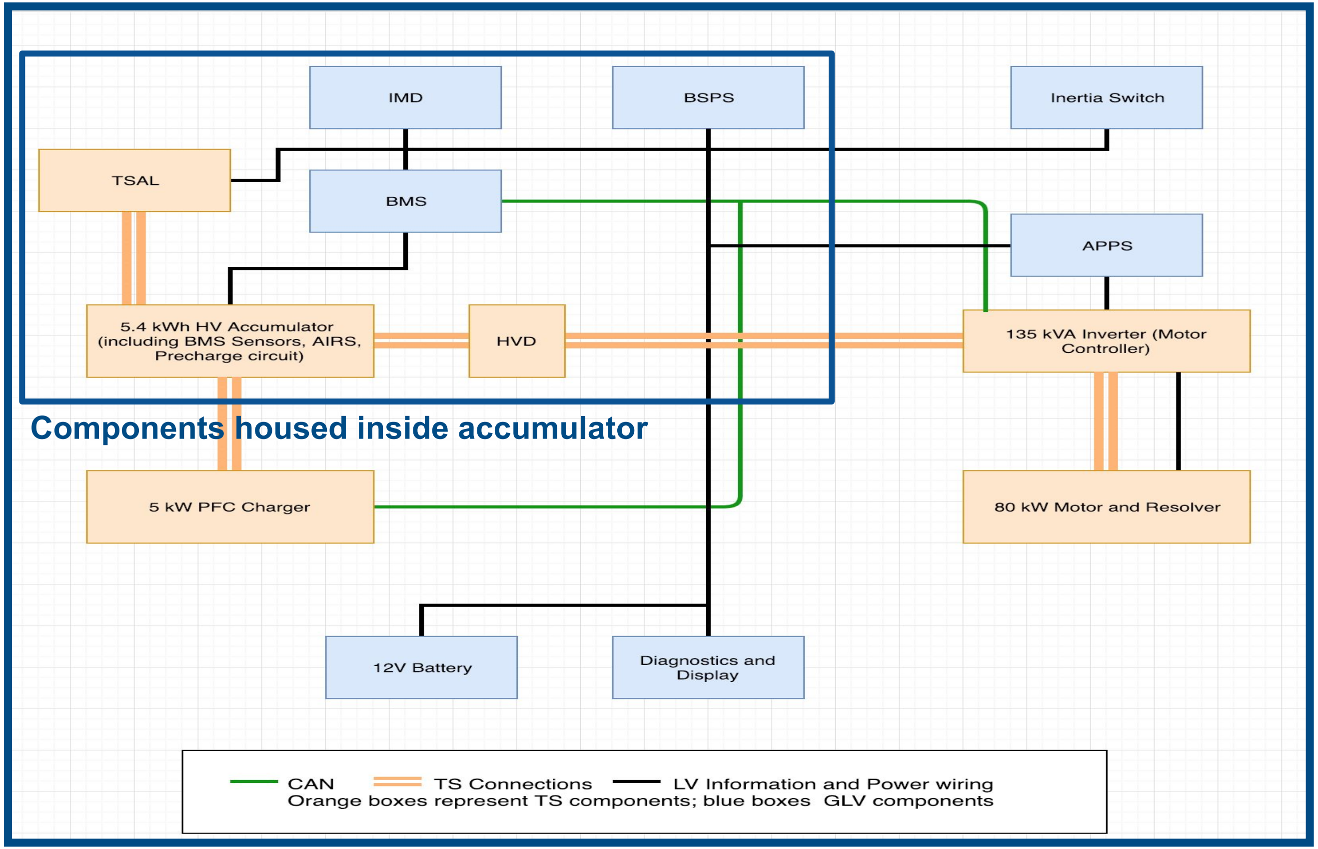


CLOCKWISE: Accumulator Isolator Relay (AIR), Maintenance Plug, HV Shutdown Switch, Fuse



Cooling Fans and 3D Printed Vent

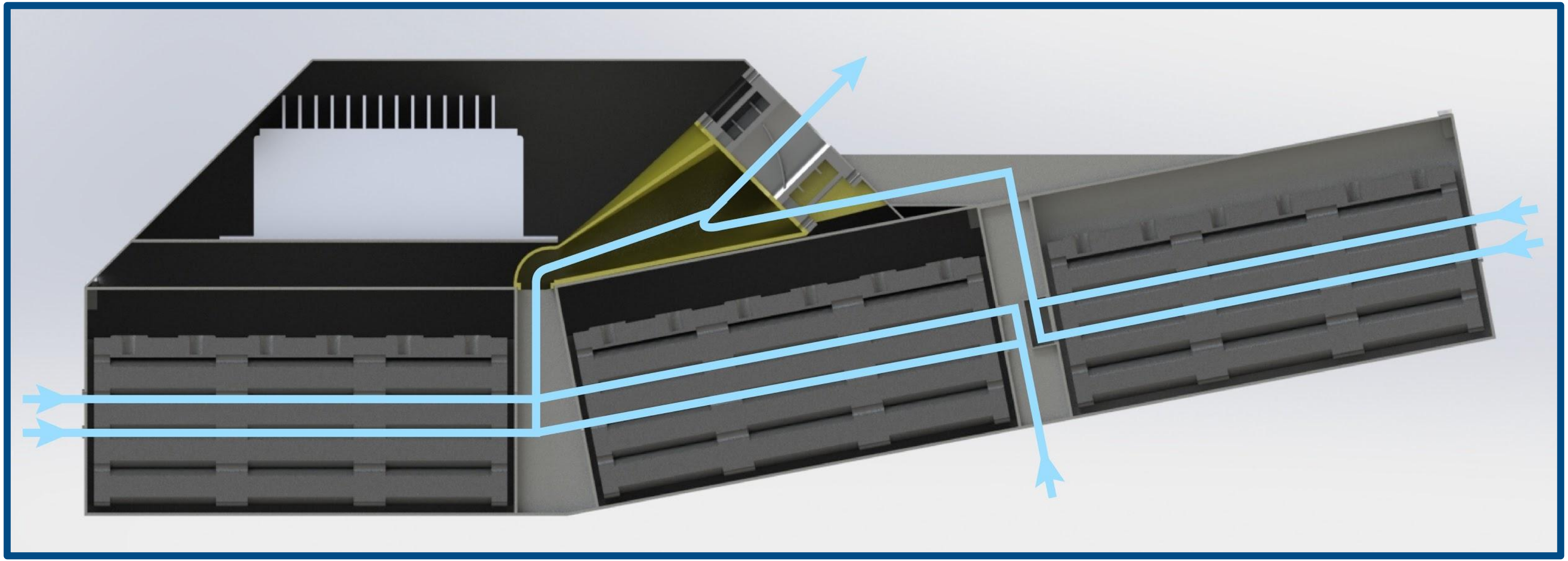
Electrical Systems Block Diagram



SYSTEM INTEGRATION:

ACCUMULATOR HOUSING

Air Cooling

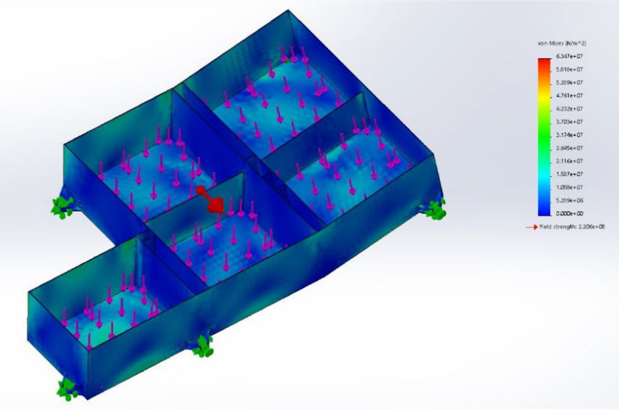


SYSTEM INTEGRATION:

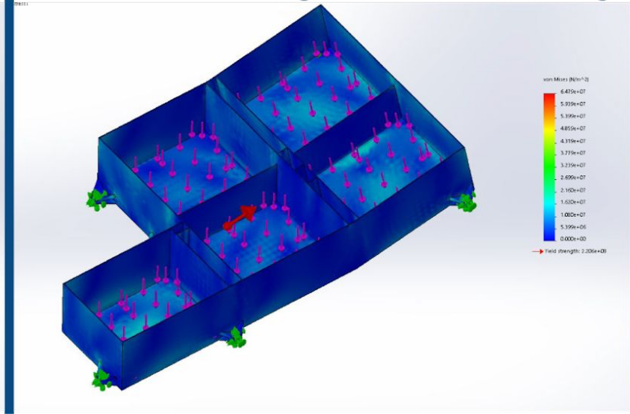
ACCUMULATOR HOUSING

Analyzing structural soundness according to FSAE rules

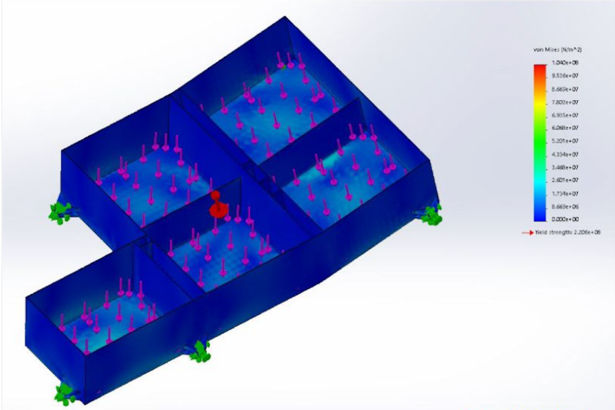
Accumulator: Lateral Load of 40 g



Accumulator: Longitudinal Load of 40 g



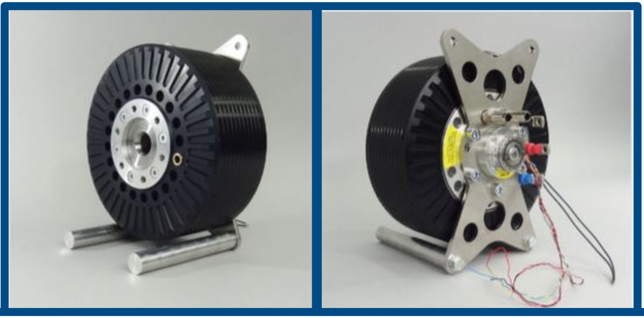
Accumulator: Vertical Load of 20 g



SYSTEM INTEGRATION:

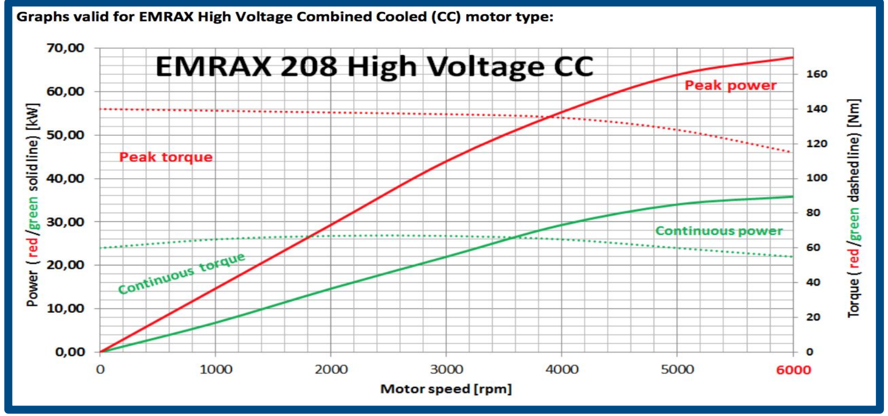
MOTOR & DIFFERENTIAL

EMRAX 208 Motor



Maximal Battery Voltage	470 Vdc (Medium Voltage)
Weight	9.4 kg
Diameter / width	208 / 85 mm
Peak Power at Max RPM	75 kW
Continuous Power	20-32 kW
Peak Motor Torque	140 Nm
Continuous Motor Torque	80 Nm
Motor Efficiency	92-97%

Table 2: EMRAX 208 Technical Data Table



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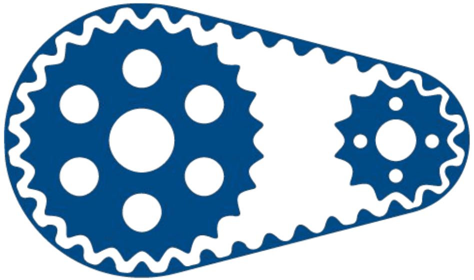
SYSTEM INTEGRATION:

MOTOR & DIFFERENTIAL

Determining drive ratio

Maximum Motor Velocity (ω)	6000 rpm
Maximum Desired Velocity (v)	130 km/hr
Wheel Radius (r)	10.4 in
Final Drive Ratio (FDR)	4.60

Parkinson, Scott (2016) "Optimum Gear Ratios for an Electric Vehicle," Undergraduate Journal of Mathematical Modeling: One + Two: Vol. 7: Iss. 1, Article 4.



$$v = \frac{\omega \times r}{FDR} \quad (1)$$

$$FDR = \frac{\omega \times r}{v} \quad (2)$$

$$\omega = 6000\frac{rev}{min} \times \frac{1min}{60s} \times \frac{2\pi rad}{1rev} = 628.32\frac{rad}{s} \quad (3)$$

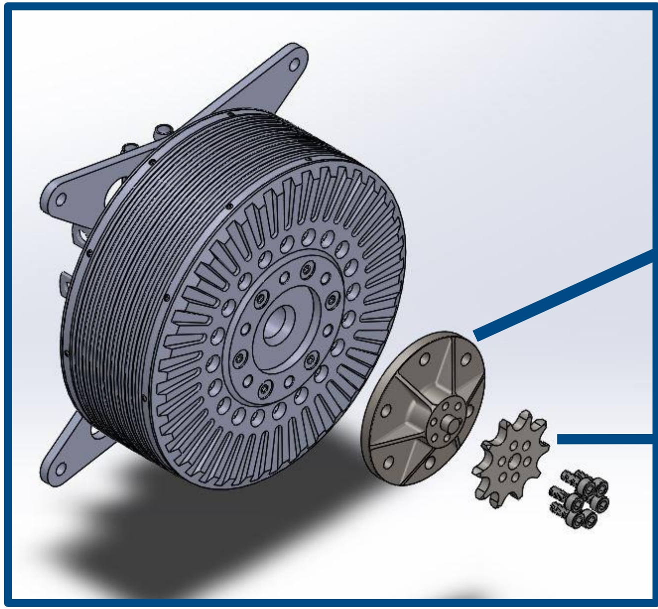
$$v = 130.0\frac{km}{hr} \times \frac{1000m}{km} \times \frac{1hr}{3600s} = 36.11\frac{m}{s} \quad (4)$$

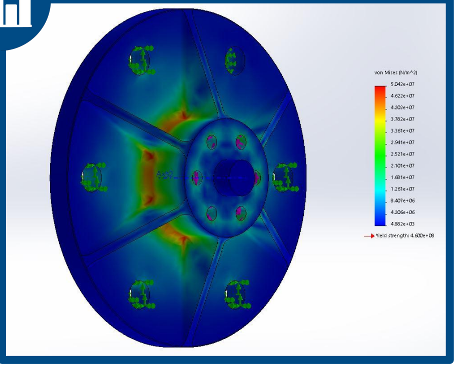
$$FDR = \frac{628.32rad/s \times 10.4in \times 1m/39.37in}{36.11m/s} = 4.60 \quad (5)$$

SYSTEM INTEGRATION:

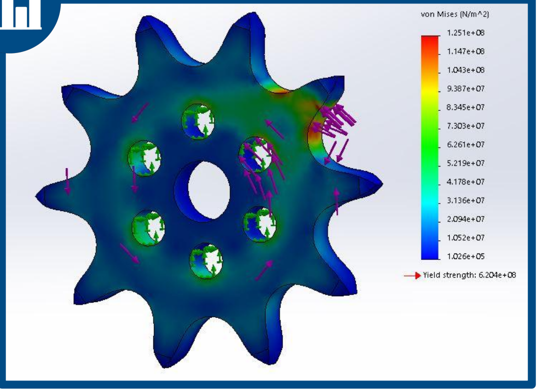
MOTOR & DIFFERENTIAL

Drive sprocket CAD and FEA



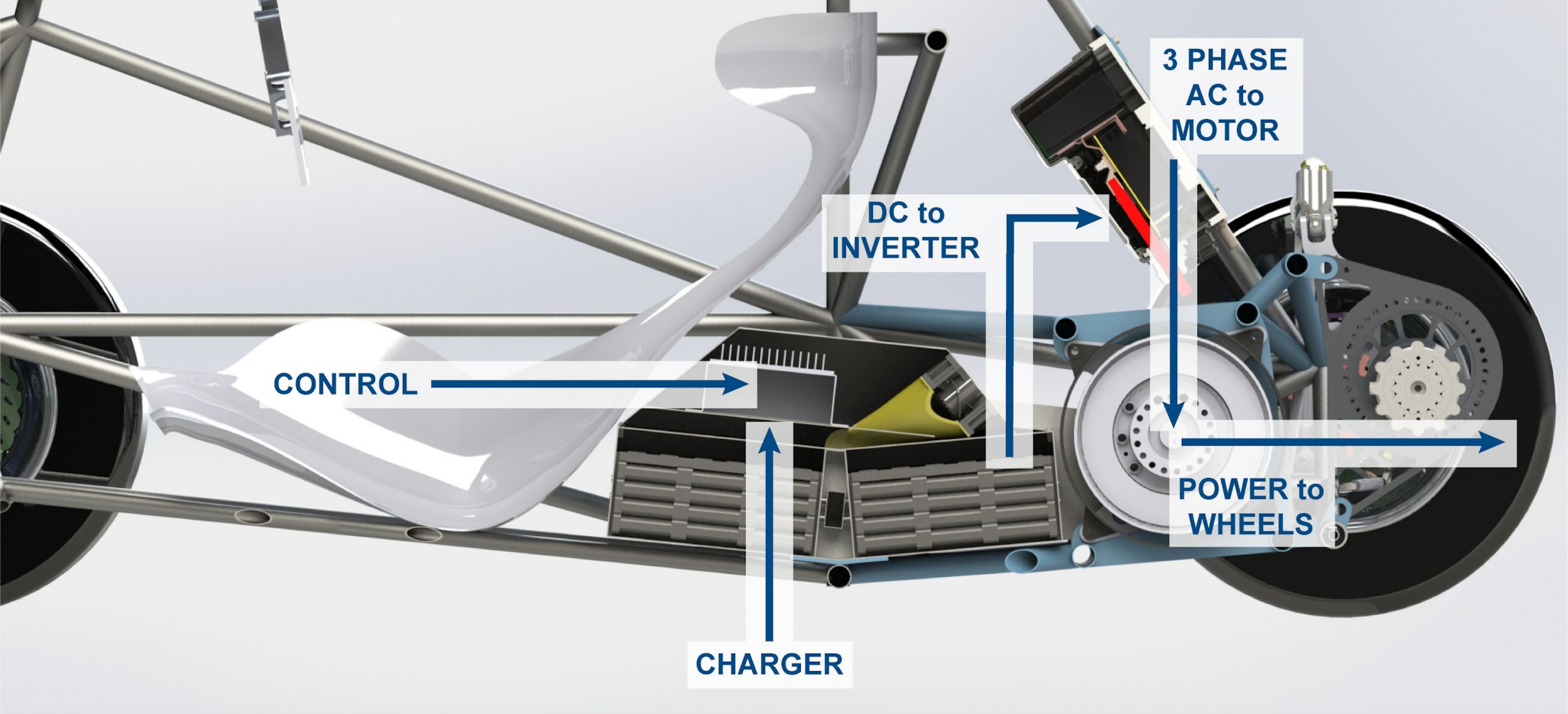


Torque of 140 Nm

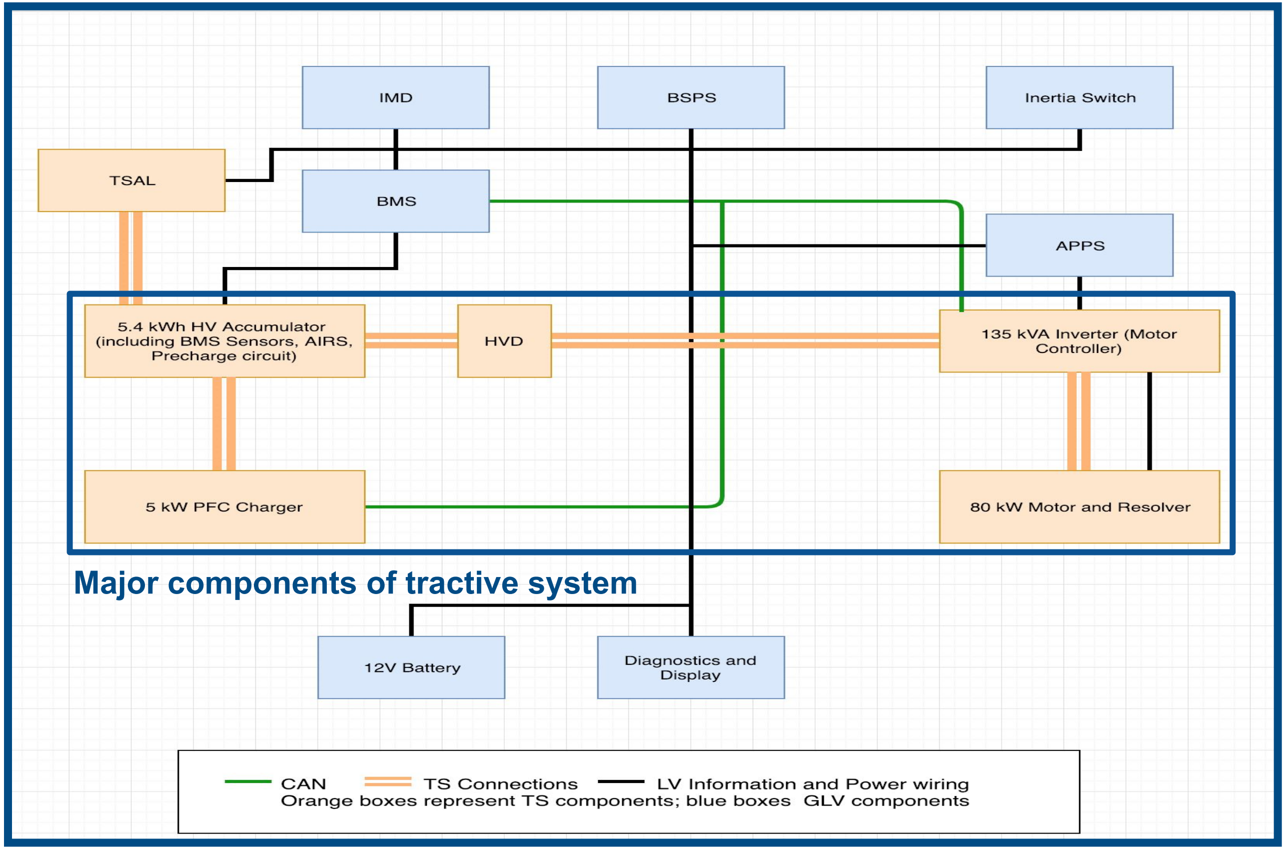


Force of 660 N applied to one tooth

TRACTIVE SYSTEM OVERVIEW



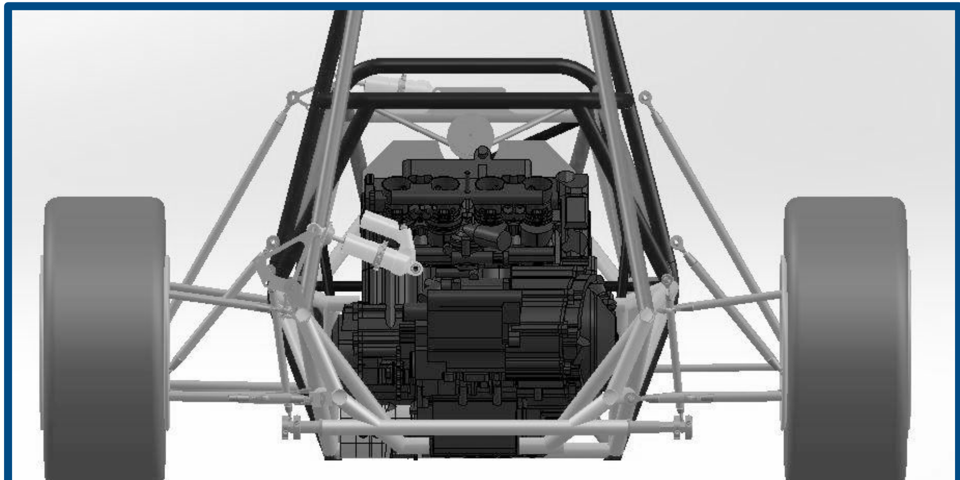
Electrical Systems Block Diagram



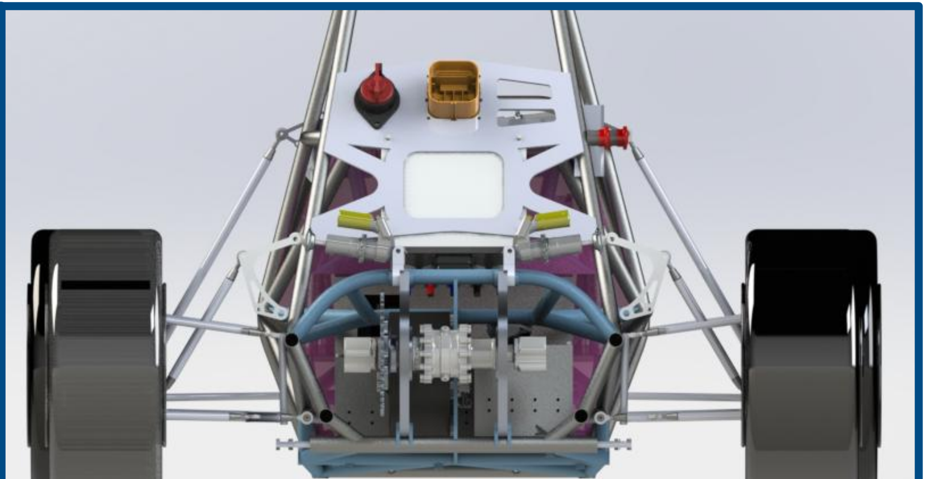
SYSTEM INTEGRATION:

STRUCTURE & MOUNTS

Adapting the chassis to accommodate for removed IC engine



BEFORE: Internal Combustion

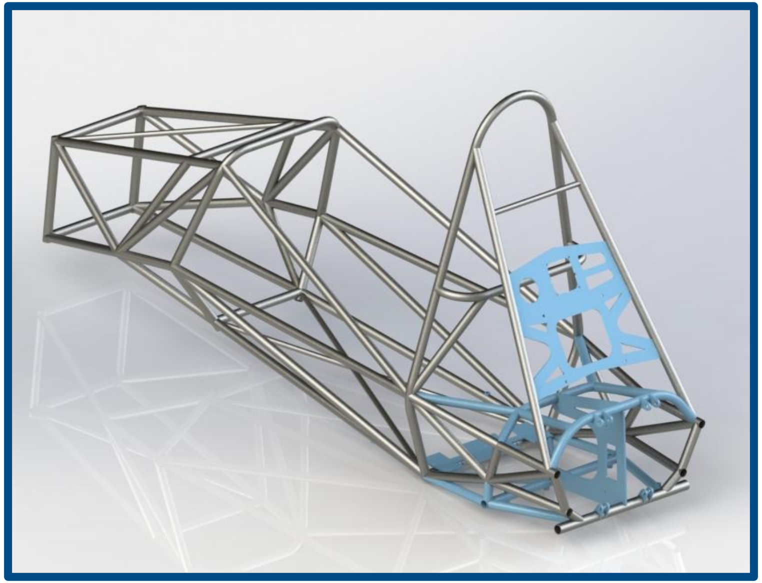


AFTER: Electric Vehicle

SYSTEM INTEGRATION:

STRUCTURE & MOUNTS

Adapting the chassis to accommodate for removed IC engine

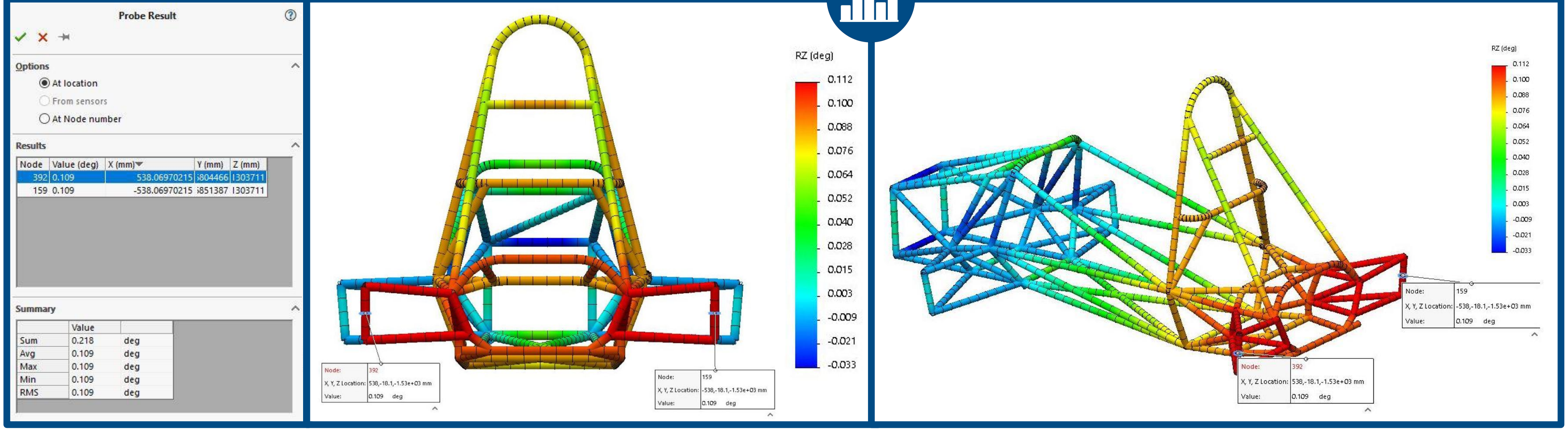


STRUCTURAL ADDITION TO CHASSIS

SYSTEM INTEGRATION:

STRUCTURE & MOUNTS

Evaluating torsional stiffness of modified chassis



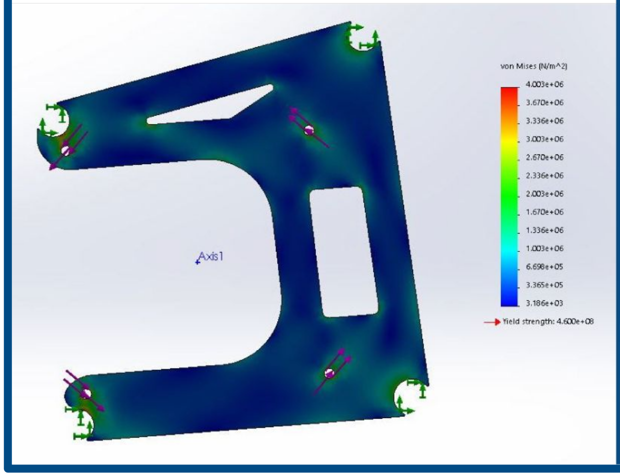
(100 lbs * 1.77 ft) / 0.109 degrees = 1619.35 ft*lb /degree → +15% = 1905 ft*lb /degree

SYSTEM INTEGRATION:

STRUCTURE & MOUNTS

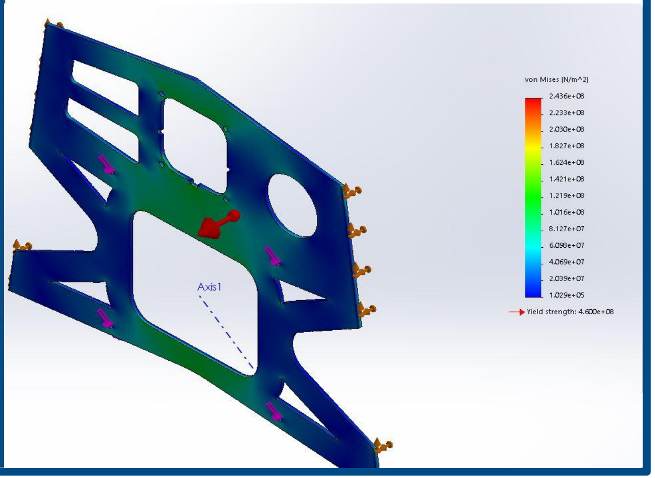
Evaluating structural soundness of motor and inverter mounts

Motor Clevis: Torque of 150 Nm



12” x 12” 4130 Steel, 0.25” Thick

Inverter Mount: Torque of 1500 Nm



15” x 12” 4130 Steel, 0.16” Thick

SYSTEM INTEGRATION:

STRUCTURE & MOUNTS

(SES)

EQ — Accumulator Side Protection

From the side, below 350mm, the HV components must be protected with:
1. An upper tube, generally at Upper SIS height.
2. A lower tube.
3. A diagonal tube or tubes completely triangulating the upper and lower tubes.

A 10" diameter impactor shall not pass anywhere between these tubes.
The SES can calculate equivalence for a panel replacing the diagonal tube.
Composite equivalence is located below tube equivalence.

					EQ
EV.6.2.3	Accumulator Side Protection:	Tube			EQ
		Baseline	Tube Used		EQ
	Accumulator Protection Tube Material:	Steel	Steel		EQ
T.2.5.1	Accumulator Protection Minimum Tube:	Round	Round		EQ
	Wall thickness:	0.063	0.065	in	EQ
T.2.5.4	Outer Diameter (OD):	1	1	in	EQ
	Wall thickness:	0.063	0.065	in	EQ
	Outer Diameter (OD):	1	1	in	EQ
	Tube cross sectional area (A):	1.85E-01	1.91E-01	in^2	EQ
	Tube second moment of inertia (I):	2.04E-02	2.10E-02	in^4	EQ
T.2.5.3a	Young's Modulus (E):	2.90E+07	2.90E+07	psi	EQ
	Ultimate	5.29E+04	5.29E+04	psi	EQ
Buckling Modulus	E_1*I_1 <= E_2*I_2:	5.93E+05	6.08E+05	102.5%	EQ
Ultimate	S_1*A_1 <= S_2*A_2:	9.81E+03	1.01E+04	103.0%	EQ
Bending	4*S_1*I_1/r <= 4*S_2*I_2/r:	8.65E+03	8.87E+03	102.5%	EQ
Deflection	Bending_1/(48*EI):	3.04E-04	2.96E-04	97.5%	EQ
Energy	0.5*Bending^2/(48*EI):	1.32E+00	1.35E+00	102.5%	EQ

EQ — Rear Impact Protection

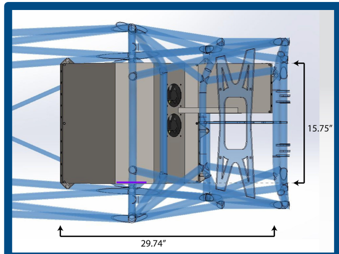
From the rear, below 350mm, the HV components must be protected against:
1. The intrusion of a 10" diameter impactor
2. The intrusion of components mounted behind the rear impact protection, such as a differential.
3. The Rear Protection must connect to the rear of the Accumulator or Tractive Side Protection.

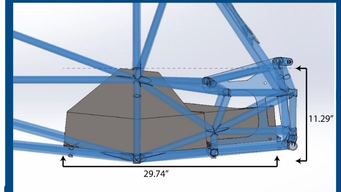
Example Solutions:
A. Two 25.4mm x 1.2mm horizontal tubes < 10" apart.
B. Two horizontal tubes with additional vertical or diagonal tubing.
C. Carbon or metallic panel equivalent to two 25.4mm x 1.2mm tubes.
D. Differential mounts equivalent to a 25.4mm x 1.2mm tube to prevent differential intrusion.
E. An X-configuration without top or bottom tubes **will not be accepted.**

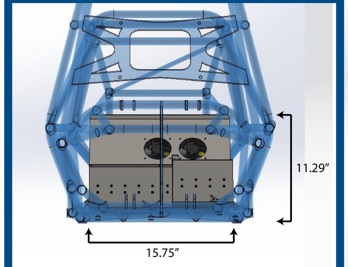
Select hybrid construction if differential mounts form part of the anti-intrusion structure.
Select composite construction if a metallic shear plate is used instead of horizontal tubing.
Non-composites may be entered in the Hybrid/Compositetable for these purposes.
Composite equivalence is located below tube equivalence.

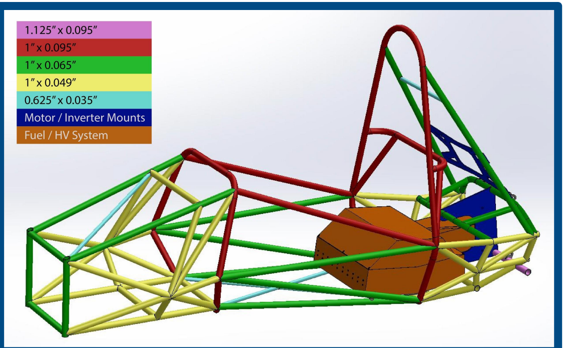
Bolted joints must be documented if a removable panel or tube is used.

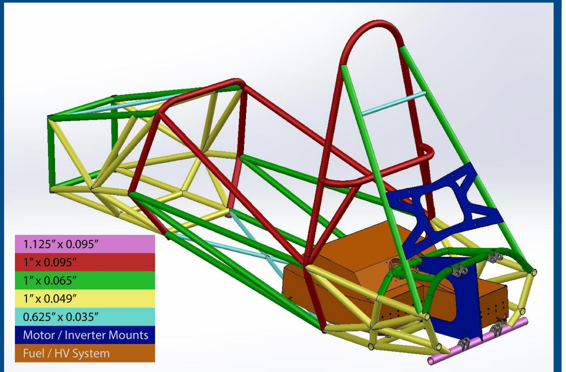
					EQ
EV.6.2.3	Rear Impact Construction:	Tube			EQ
		Baseline	Tube Used		EQ
	Rear Impact Tube Material:	Steel	Steel		EQ
T.2.5.1	Rear Impact Minimum Tube:	Round	Round		EQ
	Wall thickness:	0.047	0.049	in	EQ
T.2.5.4	Outer Diameter (OD):	1	1	in	EQ
	Wall thickness:	0.047	0.049	in	EQ
	Outer Diameter (OD):	1	1	in	EQ
	Tube cross sectional area (A):	1.41E-01	1.46E-01	in^2	EQ
	Tube second moment of inertia (I):	1.60E-02	1.66E-02	in^4	EQ
T.2.5.3a	Young's Modulus (E):	2.90E+07	2.90E+07	psi	EQ
	Ultimate	5.29E+04	5.29E+04	psi	EQ
Buckling Modulus	E_1*I_1 <= E_2*I_2:	4.64E+05	4.81E+05	103.6%	EQ
Ultimate	S_1*A_1 <= S_2*A_2:	7.44E+03	7.74E+03	104.0%	EQ
Bending	4*S_1*I_1/r <= 4*S_2*I_2/r:	6.78E+03	7.02E+03	103.6%	EQ
Deflection	Bending_1/(48*EI):	3.04E-04	2.93E-04	96.5%	EQ
Energy	0.5*Bending^2/(48*EI):	1.03E+00	1.07E+00	103.6%	EQ







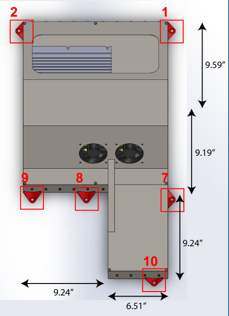


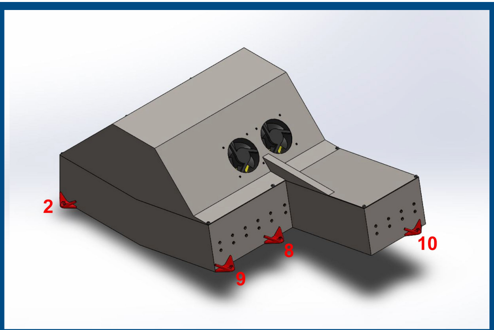


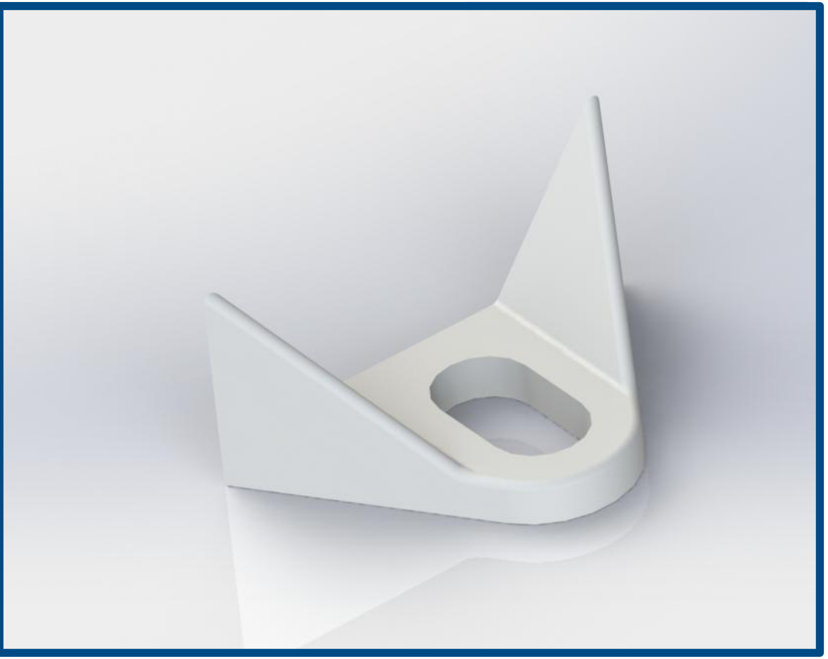
SYSTEM INTEGRATION:

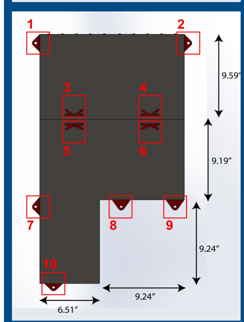
STRUCTURE & MOUNTS

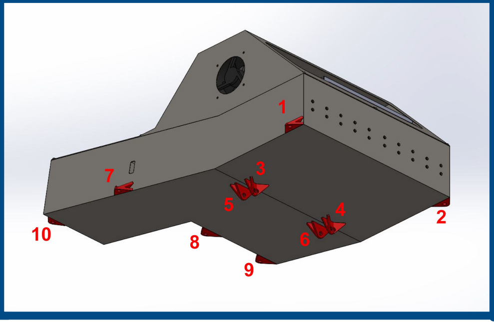
Accumulator mounts and mounting points







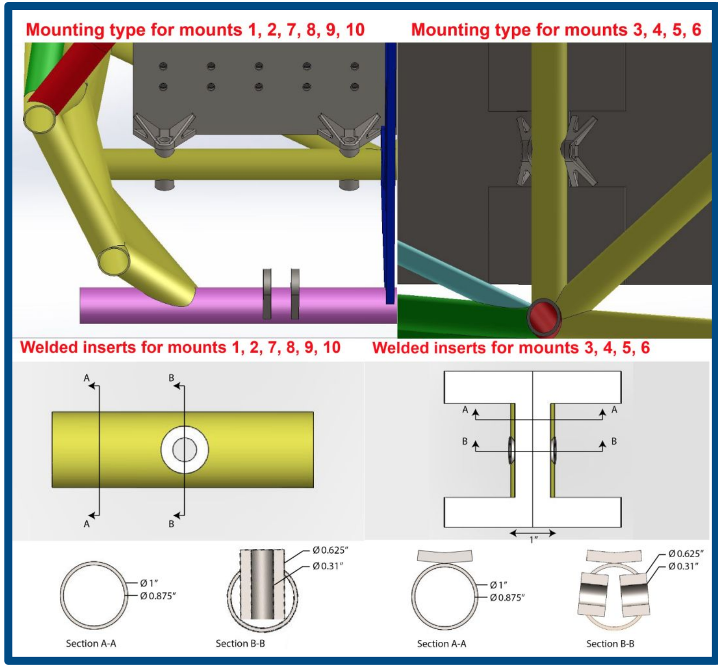


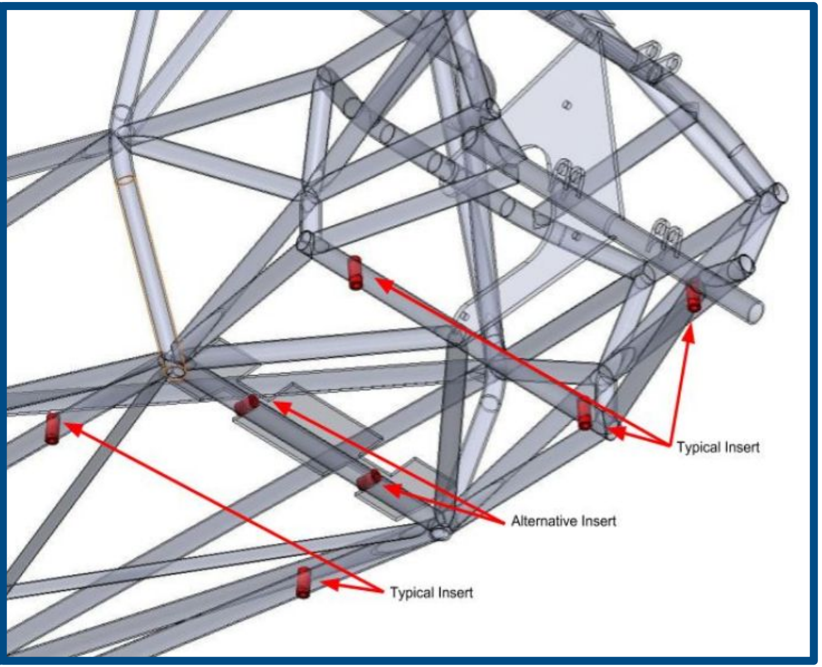


SYSTEM INTEGRATION:

STRUCTURE & MOUNTS

Welded inserts and insert locations





CAD OVERVIEW

PROGRESS & LEVELS OF SUCCESS

Outlining team goals and what makes for a successful project

1

- Successful design and integration of all systems and mounts into chassis, compliant with FSAE standards, with accompanying engineering analysis
- Successful manufacturing, purchasing, and sourcing of all required parts

2

- Testing of this integration to ensure structural soundness and functionality
- Running, functional car — this will require success from entire FSAE EV team

3

- Columbia passes FSAE Electric technical inspection and participates in competition
- Our team travels to competition

4

- Optimization suggestions for next year's EV car
- Detailed reports of our methodology and process to use as a resource for future teams

ACKNOWLEDGEMENTS

- From Senior Design: Josh Browne, Veronica Over, and Joni Mici
- From FSAE IC team: Mark Hellinger, Mikhail Sigalov, Andrew Chuka, Jon Katz, and Michael Harriss
- From EV team: Max Moeller, Daniel Halmos, Matthias Preindl, and many others for powering the car
- From Mechanical Engineering Shop: Andrei Shylo, Bill Miller, Bob Stark
- Carleton Laboratory for access to welder

THANK YOU!

Mechanical Engineering

Professor Josh Browne

May 9th, 2019

FAHK

Fernando A. Pascual

Austen Paris

Henry Tucher

Katherine Guan