eCFR-23 Design Briefing

COLUMBIA UNIVERSITY
FORMULA RACING

Car #243

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Columbia FSAE at Michigan International Speedway (May 2022)

FORMULA SAE®

Executive Summary

Overview of our team, approach to engineering and administrative workflow, and the process of building our vehicle.

Executive Summary

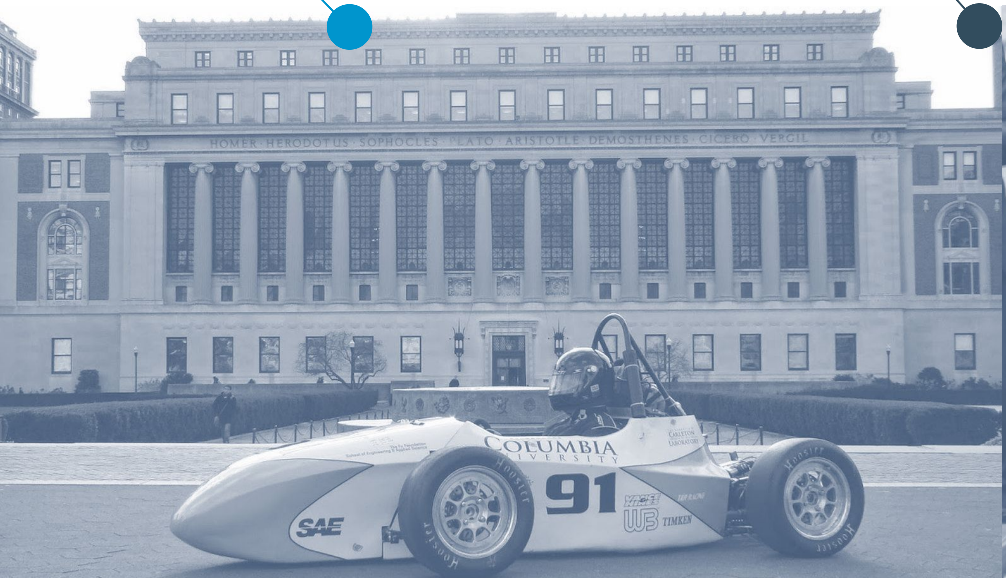
For the first 20 years, we raced as an internal combustion team.
This year, we are transitioning to an exclusively electric vehicle team, and eCFR-23 will be the first electric car we race in this new era.

1997-2000
The Early Teams

2000-2008
The First Decade

2008-2019
Superleggera

2019- Future
eCFR-23

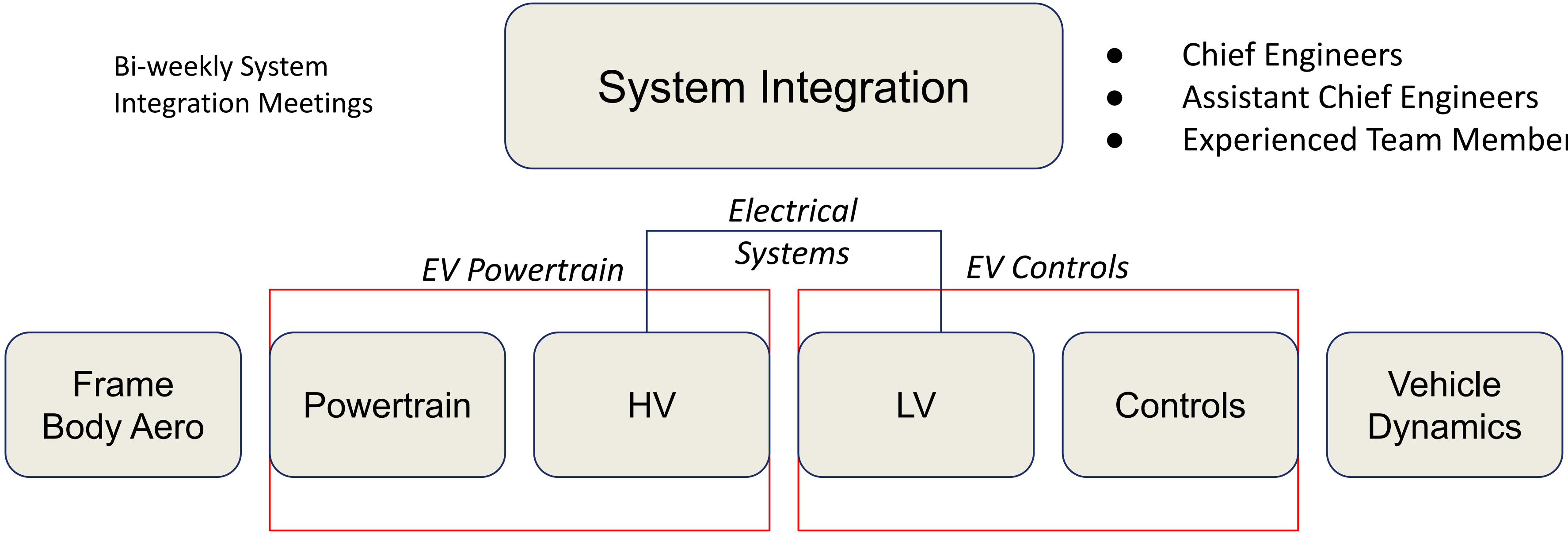


Team Structure

Bi-weekly System Integration Meetings

- Chief Engineers
- Assistant Chief Engineers
- Experienced Team Members

Weekly System Meetings



Frame Body Aero
Chassis
Body
Aero
Cooling Airflow

Powertrain
Drivetrain
Cooling Hardware
Accumulator
Hardware

HV
Tractive System
Battery Pack
Charging
HV Electronics

LV
Software
Wiring Harness
Shutdown System
Enclosure boards
Telemetry

Controls
Pedals
Dashboard
Ergonomics
Steering Control

Vehicle Dynamics
Suspension
Hubs and Uprights
Brakes
Steering Geometry

*Tractive system refers to delivery of motor current
*Body refers to the carbon fiber bodywork housing the chassis
*Aero refers to aerodynamic simulation, design, and in future years, downforce components

Team Mission

Our team mission is to educate and develop the next generation of engineers and managers while building a racecar for the Formula SAE competition.

The past year has given us time to adequately plan for the transition from IC to EV, and we are proud to present the design for our first electric car.

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Design Overview

Vehicle overview, mass breakdown, system goals, event capabilities and predicted outcomes, design highlights.

eCFR-23 By the Numbers

68kW Drivetrain

18” 300V, 5.4kWh battery pack

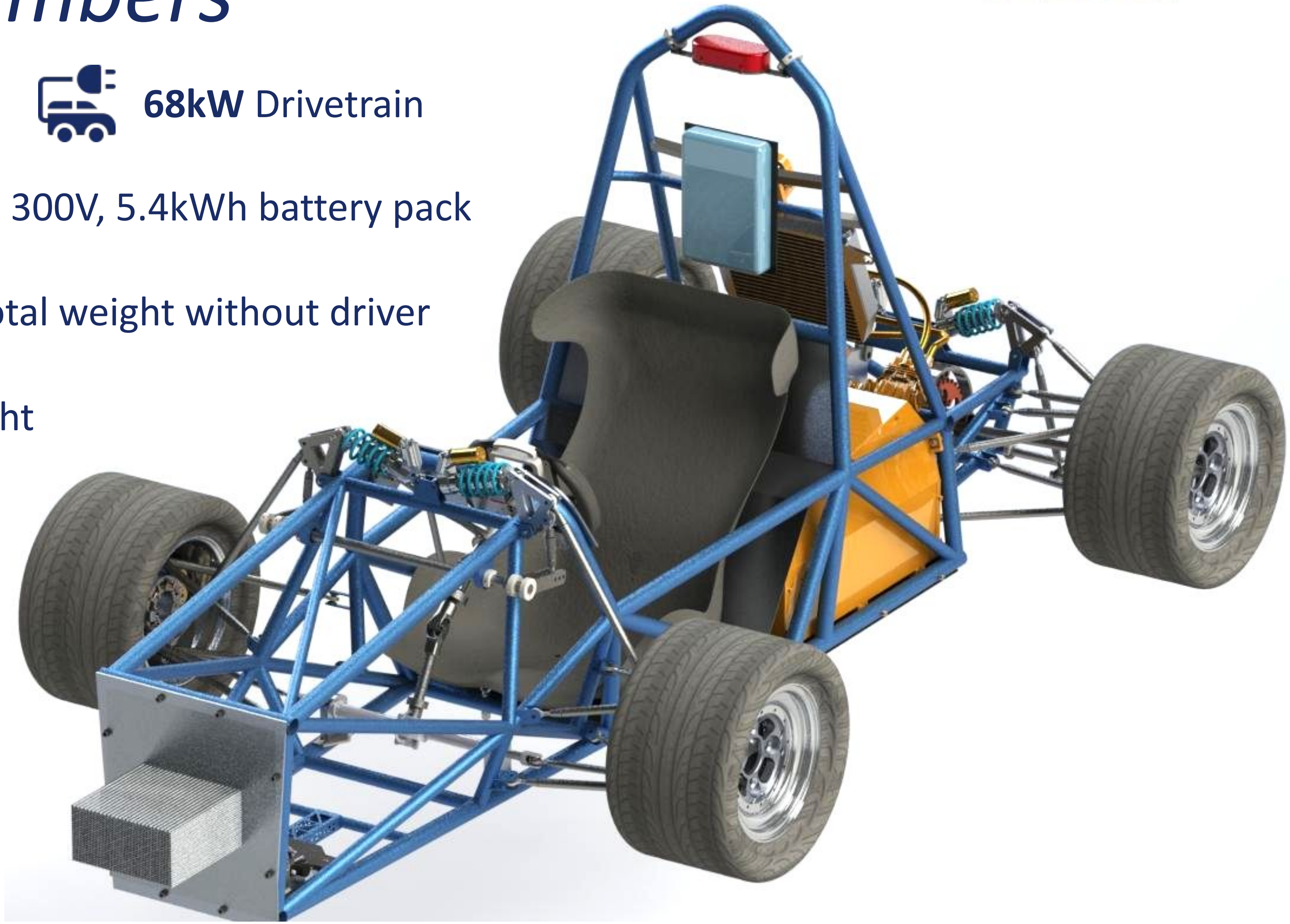
485 lb. Total weight without driver

1.25” Ride height

9.83” CoG height

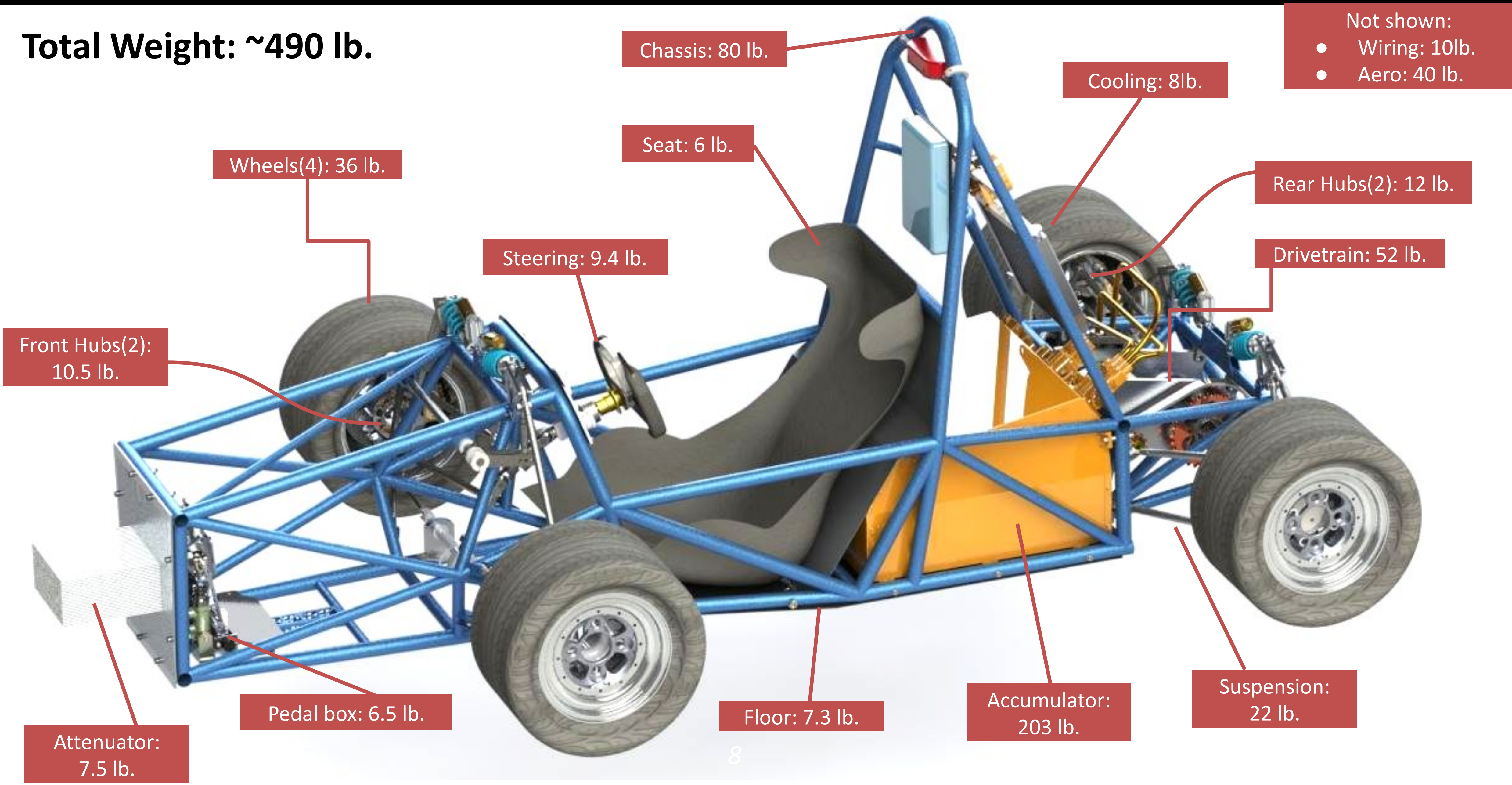
47”/47” TW Front / Rear

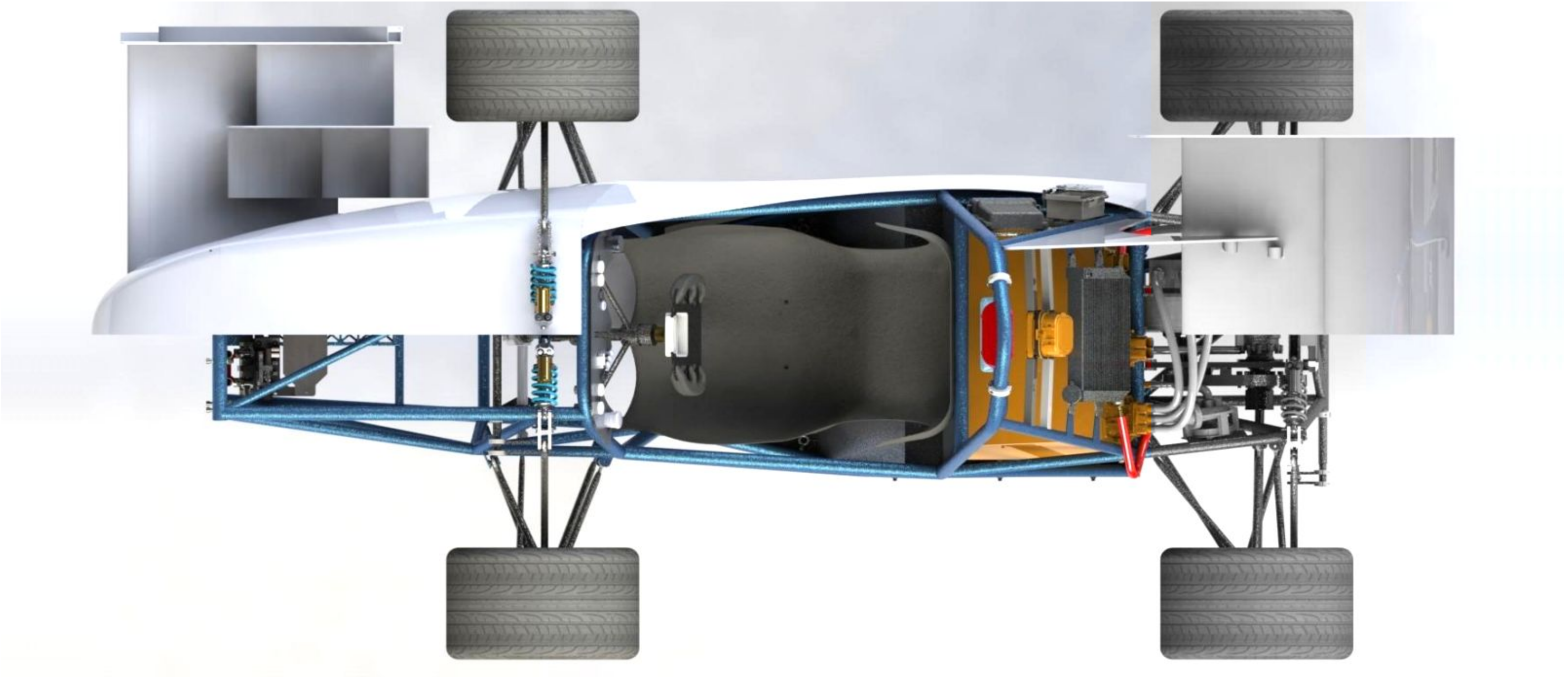
4130 steel space-frame chassis

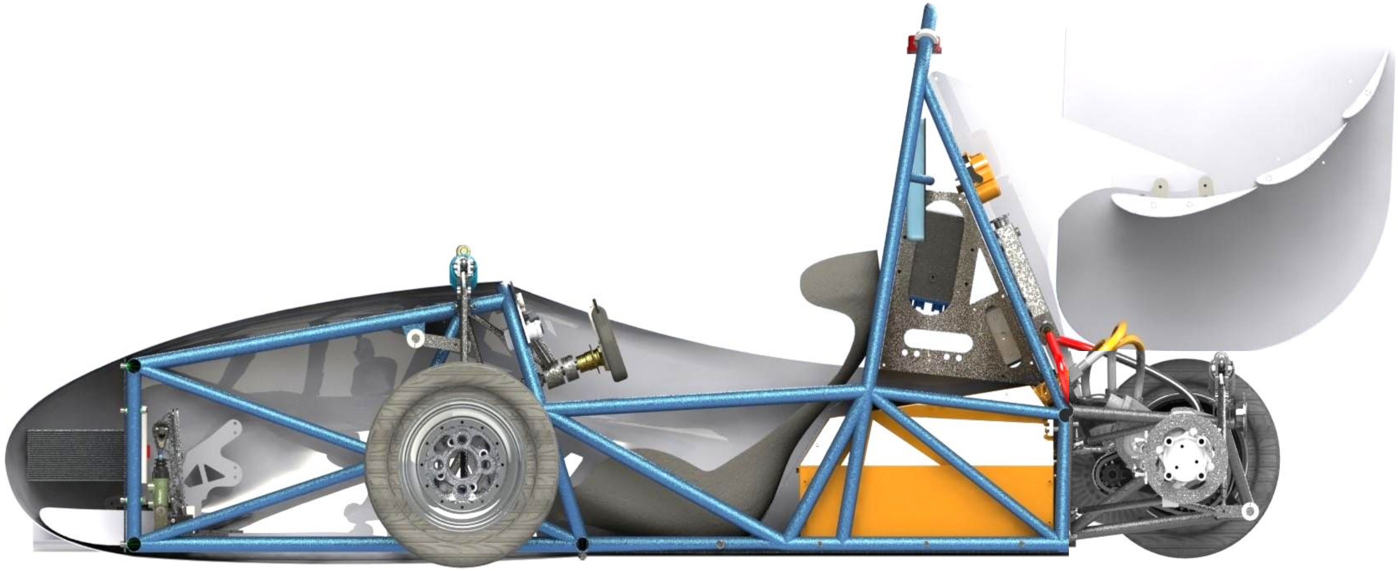


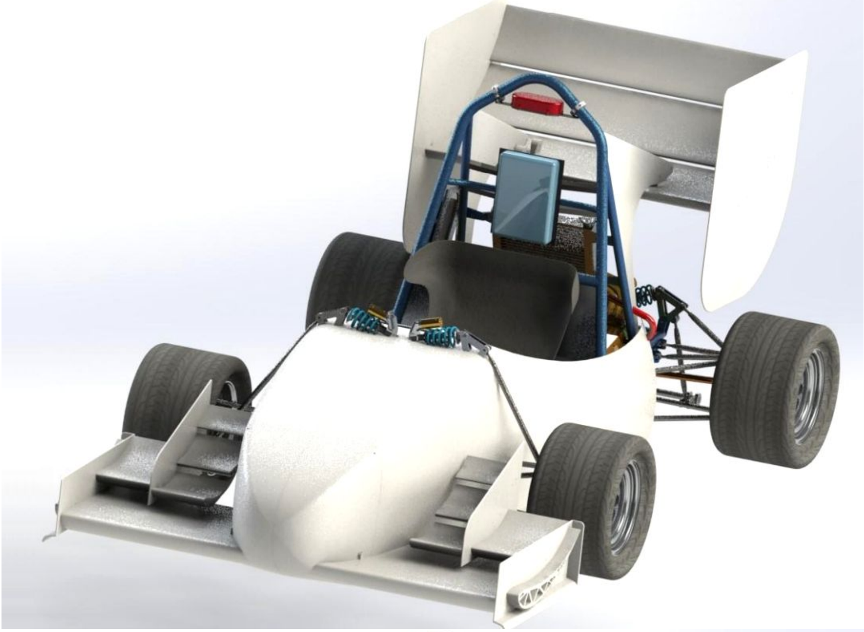
Vehicle Weight Breakdown

Total Weight: ~490 lb.









System Goals

Main Goal: Finish Endurance

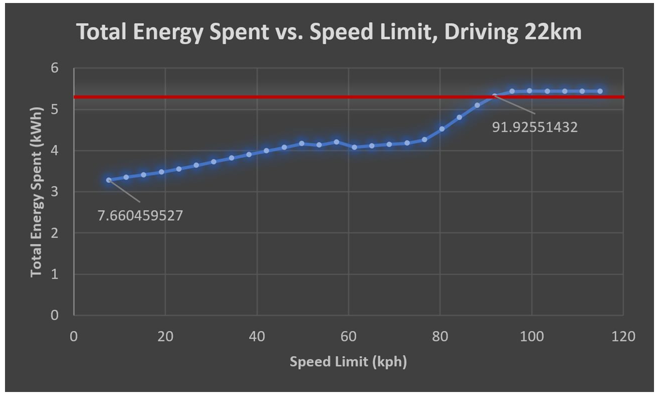
Create a reliable vehicle that will pass technical inspection, complete the dynamic events, and finish endurance at our first EV competition. We accomplished this by focusing on race car vehicle dynamics fundamentals and maintaining simplicity throughout the design process.

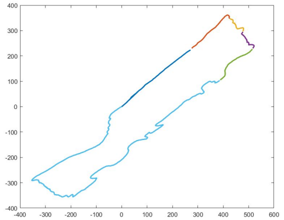
Chassis: Lower chassis CG as much as possible and prioritize torsional stiffness in order to realize cornering gains.	**Suspension:** Design a suspension that can accommodate low CG & optimizes cornering performance.
Accumulator: Design a safe and reliable system that is accessible and easy to remove, as well as low to the ground and near the CG.	**Body:** Prevent debris from entering the vehicle and minimize drag.
Drivetrain: Design a simple fixed gear drivetrain that strikes a good balance between torque & speed. Low to the ground & structurally stiff to avoid drivetrain losses.	**Cooling:** Design a system that keeps the motor, inverter (liquid cooled) & batteries at operating temperature in order to maximize efficiency of motor.
Steering: Minimize steering column slop in order to maximize slip angle gains & improve cornering potential of the car.	**Brakes:** Create a reliable braking system that also reduces the unsprung mass of the car.
Cockpit & Controls: Driver / pit crew interaction with the car should be safe and easy. Drivers of different sizes should be accommodated.	**Wiring:** Harness should be robust and serviceable. Minimize stray wiring and prevent user error.

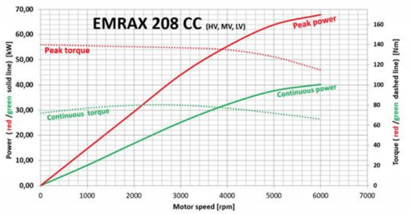
Goals and Capabilities

Points Goal by Event		2022
Endurance	60	NA
Autocross	60	NA
Skidpad	45	NA
Acceleration	90	NA
Efficiency	88	NA
Design	110	80(IC)
Presentation	70	62.5
Cost	90	81.4(IC)
Overall	**613**	

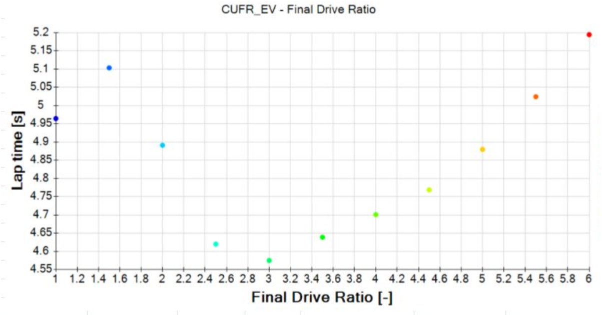
Endurance
Lap time analysis used to determine the average speed that can be used for endurance without batteries running out of energy. **Avg Speed Limit: 91kph**

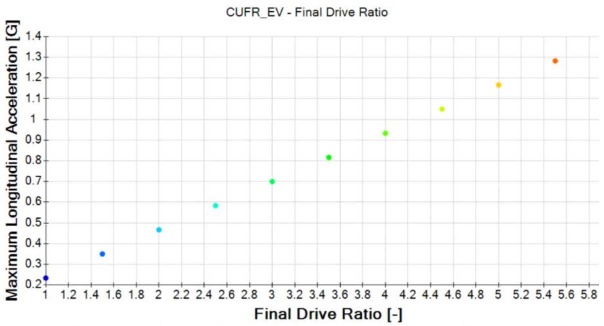






Acceleration
A parameter sweep of various drive ratios was done in OptimumLap with 16” tires. A drive ratio of 3.2 yielded best results.





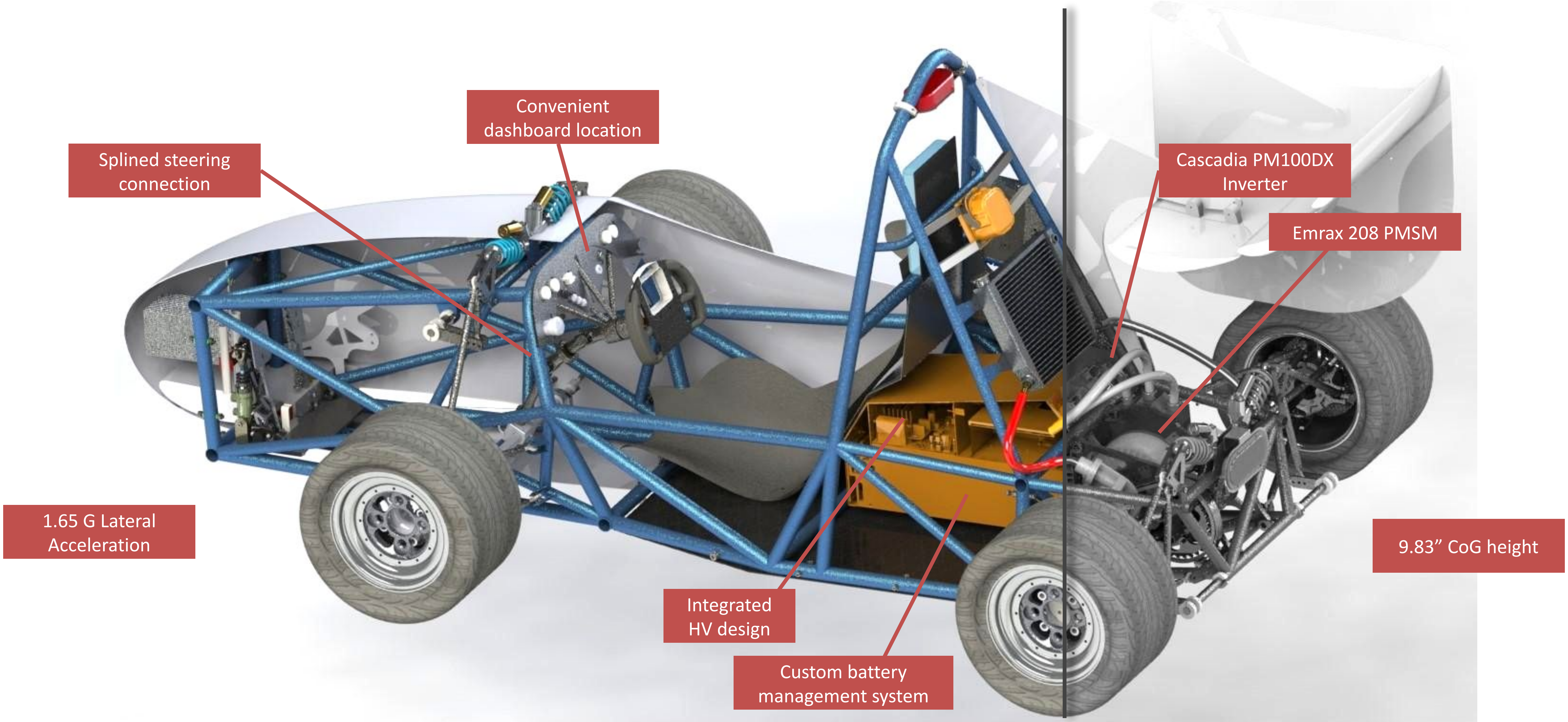
Skid pad
An Excel calculator is used that accounts for static & dynamic corner weights, aerodynamic contributions & tire friction coefficients to produce skid pad time under ideal conditions.
Skid pad time: **4.75s** (under ideal conditions)
~**5.2s** (with FOS)

Static Corner Balance (lbs)	
170	170
170	170
Dynamic Corner Balance (lbs)	
108.4635153	231.5364847
108.4635153	231.5364847
Post-Aerodynamic Dynamic Fz (lbs	
111.4329153	234.5058847
111.4941153	234.5670847
Post Aerodynamic Fy Gains (lbs)	
13.1857998	11.20362074
13.45756209	11.43452988

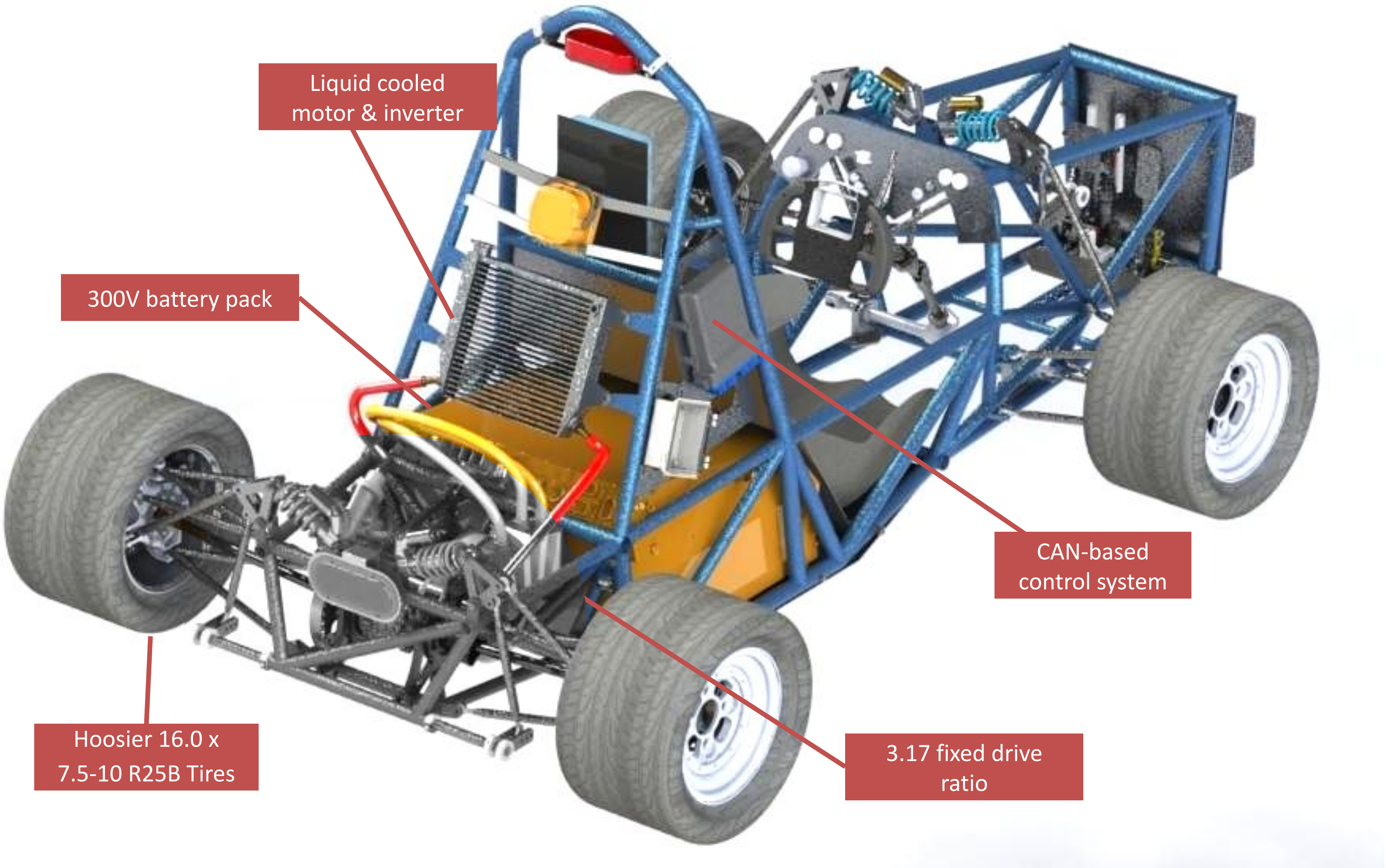
Autocross
Due to time constraints, autocross was not directly analyzed. Based on results from skid pad and acceleration simulations, we concluded that the car will have a great lateral acceleration and a fair longitudinal acceleration. Thus, we believe our autocross performance will be average.

At the North America EV competitions, a score of 613 would place us in the top 10 teams (based on 2022 results), as most teams have trouble passing tech inspection and the dynamic events.

Highlights


Convenient dashboard location
Splined steering connection
Cascadia PM100DX Inverter
Emrax 208 PMSM
1.65 G Lateral Acceleration
9.83” CoG height
Integrated HV design
Custom battery management system

Highlights


Liquid cooled
motor & inverter
300V battery pack
CAN-based
control system
Hoosier 16.0 x
7.5-10 R25B Tires
3.17 fixed drive
ratio

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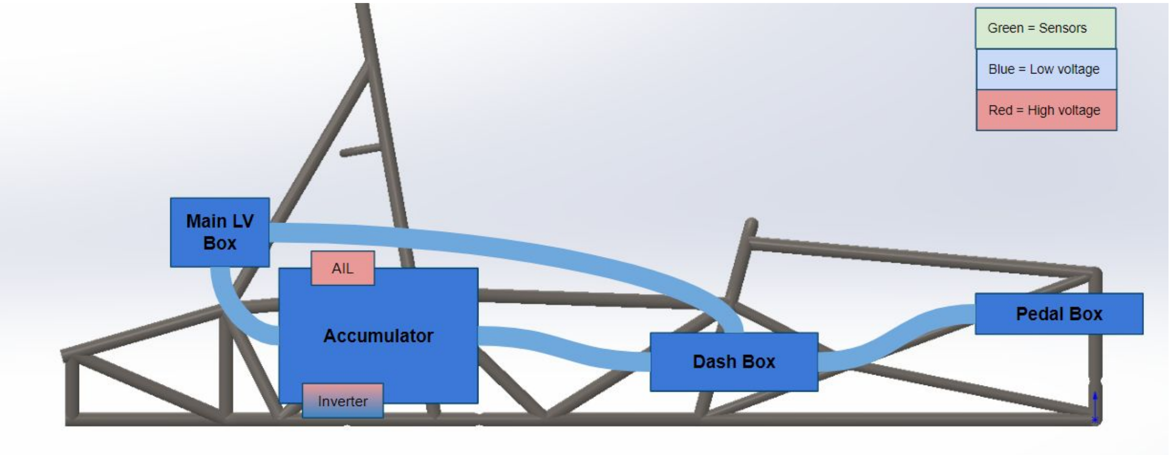
Systems Management Integration

Design integration, plumbing/wiring, power management, schematics. Are sensitive items protected? Proper use of data? Do systems compliment another? Are progressive project management/ organization methods evident? Special communication tools utilized? What testing/development tools have been used or created?

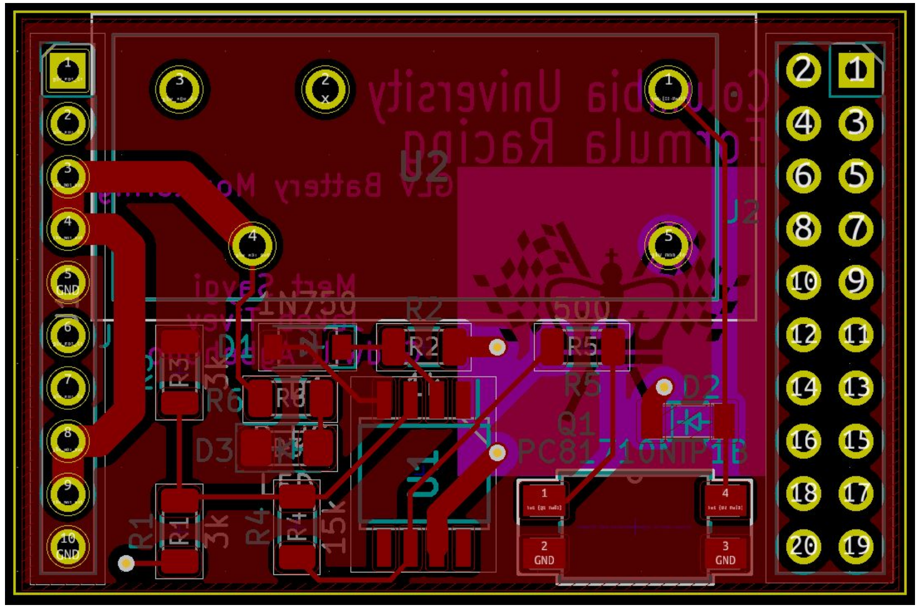
Wiring Harness and Power Management

EV Integration



- Decentralized and modular LV circuits allow for subsystem testing and redesign to happen in parallel
- 4 MCUs (one per LV enclosure and one in Accumulator) all responsible for nearby peripherals and subsystems -> allows for shorter individual wire lengths
- A CAN Bus allows for communication between MCUs and subsystems

Power Management



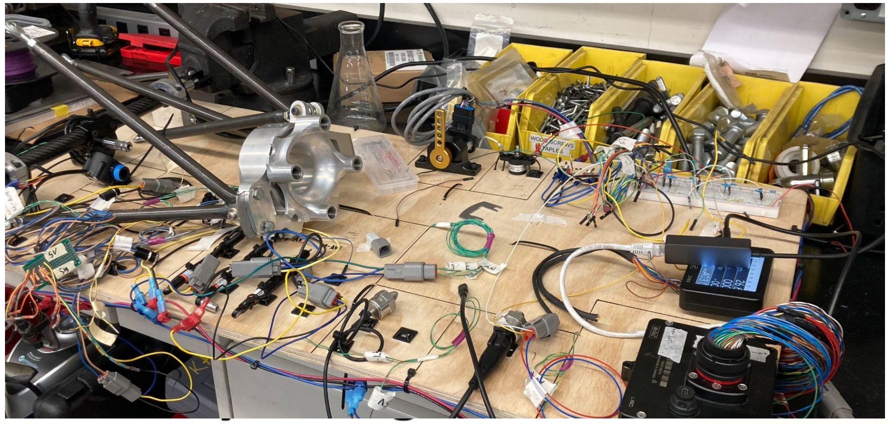
- Shorai 12V, 12Ah battery for low-power LV systems
- Subsystems fused in each enclosure
- A Low Voltage Battery Monitoring Board (pictured above) ensures that the battery does not discharge below the rated 12V to ensure a long lifetime

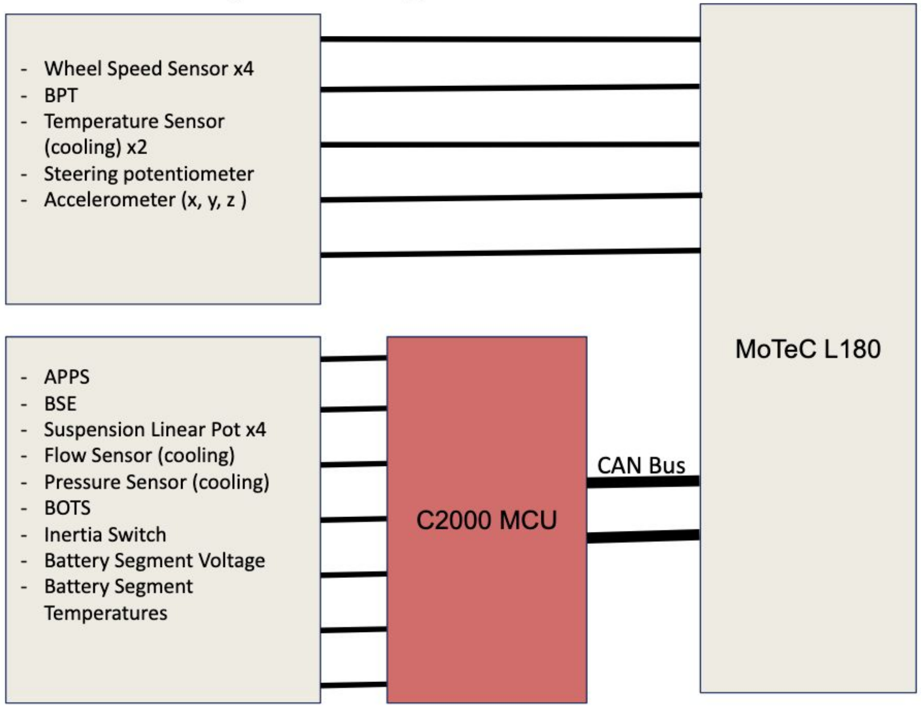
Data and Communication

- A MoTeC L180 data acquisition module is used to store data from sensors

- To increase the number of sensors that can connect to the MoTeC and to act on sensor data in real time some sensors are routed to an MCU and transferred to the MoTeC over the CAN bus

- A testing board for all of our sensors and the MoTeC was used to test the data acquisition system in parallel with car development





- A MoTeC D153 display screen is mounted on the dashboard

- Critical information (ie. battery pack voltage and velocity) will be displayed to the driver

Wiring Harness Software: RapidHarness

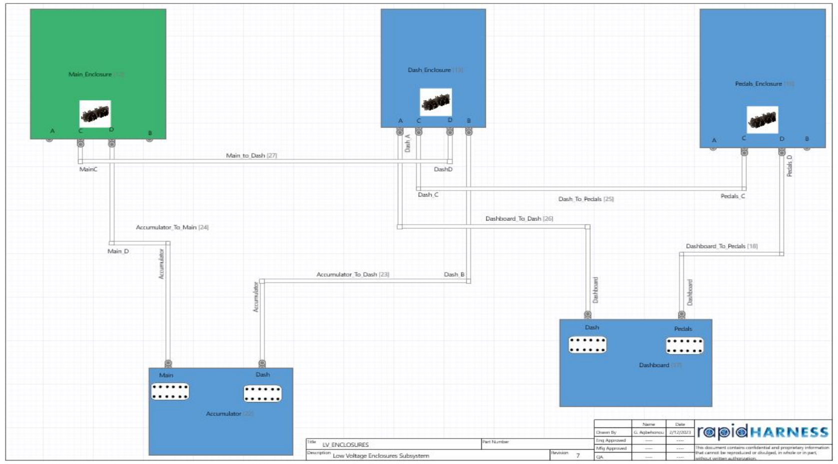
- Creates a digital mockup of wiring harnesses and the connections on the car
- Harnesses are created from connectors and wires and can store the data about each of its wires within said harness
- Devices are used to show an electrical component that has a connection to a harness (i.e. PCB Boards)
- Harness and devices make up a system, which can use signals created by the harnesses and devices to show a complete connection net of the system
- RapidHarness allows for easier and more localized access to wiring schematics and other data regarding the wiring harness for testing and presentation

Dash_to_Main Harness (Main C to Dash D)

Notes	From	To	Conductor	Color	Gauge
PWR_12V	MainC.1	DashD.1	W5.Red		18 AWG
PWR_GND	MainC.2	DashD.2	W11.Black		18 AWG
SDS+	MainC.3	DashD.3	W6.Blue		18 AWG
SSOK_SIG	MainC.4	DashD.4	W7.Blue		18 AWG
CANH	MainC.5	DashD.5	W8.Green		18 AWG
CANL	MainC.6	DashD.6	W9.Green		18 AWG
CAN_GND	MainC.7	DashD.7	W10.Black		18 AWG
APPS_SIG	MainC.8	DashD.8	W12.Green		18 AWG
APPS_5V	MainC.9	DashD.9	W13.Red		18 AWG
APPS_GND	MainC.10	DashD.10	W14.Black		18 AWG

Notes	From	To	Conductor	Color	Gauge
PWR_12V	DashD.1	MainC.1	W5.Red		18 AWG
PWR_GND	DashD.2	MainC.2	W11.Black		18 AWG
SDS+	DashD.3	MainC.3	W6.Blue		18 AWG
SSOK_SIG	DashD.4	MainC.4	W7.Blue		18 AWG
CANH	DashD.5	MainC.5	W8.Green		18 AWG
CANL	DashD.6	MainC.6	W9.Green		18 AWG
CAN_GND	DashD.7	MainC.7	W10.Black		18 AWG
APPS_SIG	DashD.8	MainC.8	W12.Green		18 AWG
APPS_5V	DashD.9	MainC.9	W13.Red		18 AWG
APPS_GND	DashD.10	MainC.10	W14.Black		18 AWG

LV_ENCLOSURES System



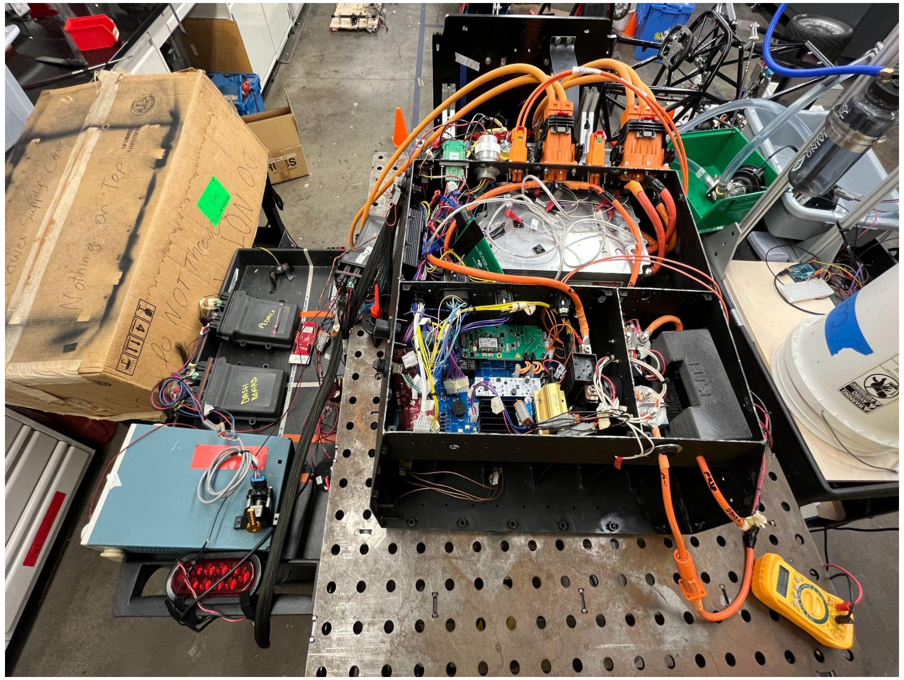
LV_ENCLOSURES Connection Signal Net

Device / Harness	Endpoint	Signal
Accumulator	Dash.1	DCDC_ON
Accumulator_To_Dash	Accumulator.1	
Accumulator_To_Dash	Dash_B.7	
Dash_Enclosure	B.7	DCDC_EN_ACC
Accumulator	Dash.2	RTD_DASH
Accumulator_To_Dash	Accumulator.2	
Accumulator_To_Dash	Dash_B.8	
Dash_Enclosure	B.8	RTD_SIG
Accumulator	Dash.3	LED_SDC
Accumulator_To_Dash	Accumulator.3	
Accumulator_To_Dash	Dash_B.4	
Dash_Enclosure	B.4	LED_SDC_ACC
Accumulator	Dash.4	CURRENT_SENS
Accumulator_To_Dash	Accumulator.4	
Accumulator_To_Dash	Dash_B.6	
Dash_Enclosure	B.6	CT_ACC
Accumulator	Dash.5	BPT_SIG
Accumulator_To_Dash	Accumulator.5	
Accumulator_To_Dash	Dash_B.12	
Dash_Enclosure	B.12	BPT_SIG_ACC
Accumulator	Dash.6	SDS_OUT
Accumulator_To_Dash	Accumulator.6	
Accumulator_To_Dash	Dash_B.11	
Dash_Enclosure	B.11	SDS_OUT

Isolated Testing

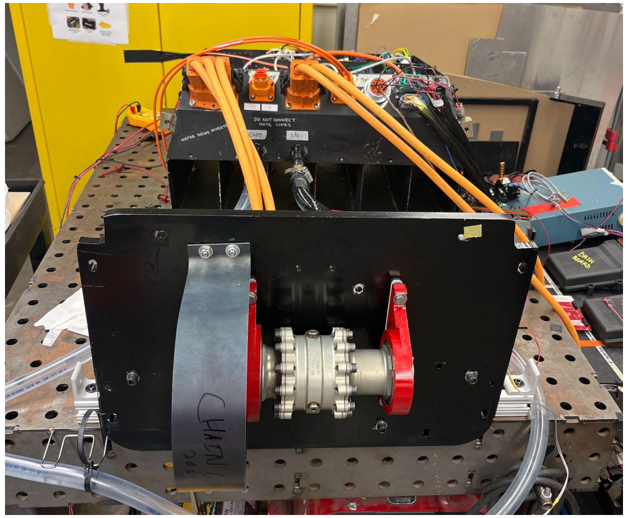
- Subteams (ie. cooling, HV, LV) had specific testing carts for a pipelined testing program and easy integration and troubleshooting off the chassis
- This allowed ups to isolate problems such as the motor plate flexing and the AIRs not flipping due to high resistance in the shutdown loop
- PCBs designed for standalone testing without the need of integrated sensors and systems

HV and LV Test Cart

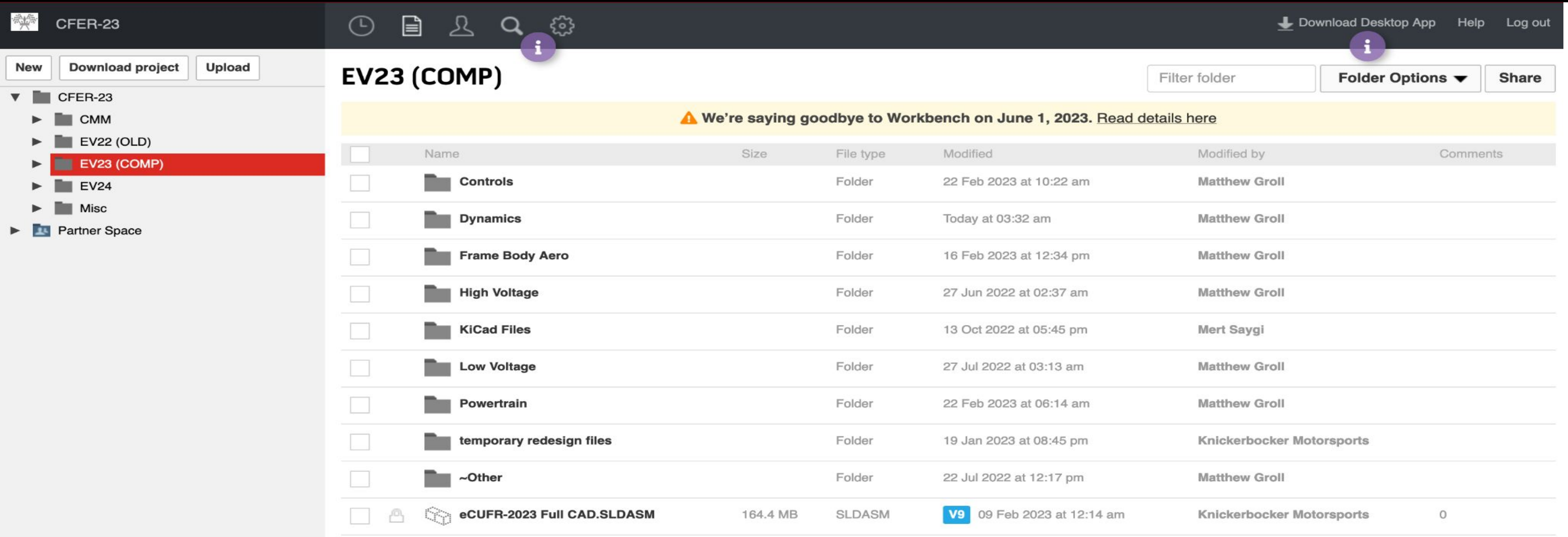


Cooling Test Cart

Drivetrain Test Bench



Development Tools: GitHub and GrabCad



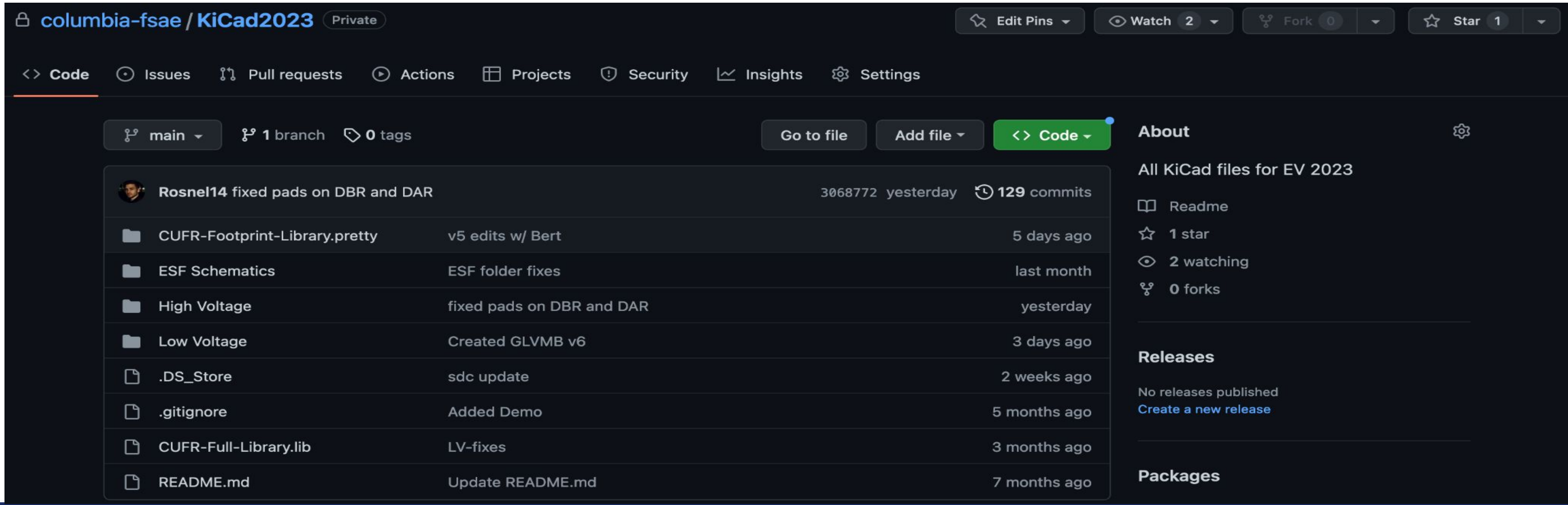
GrabCad:

- Store and version control all CAD models

GitHub:

- Store and version control all electrical schematics, PCB designs and software

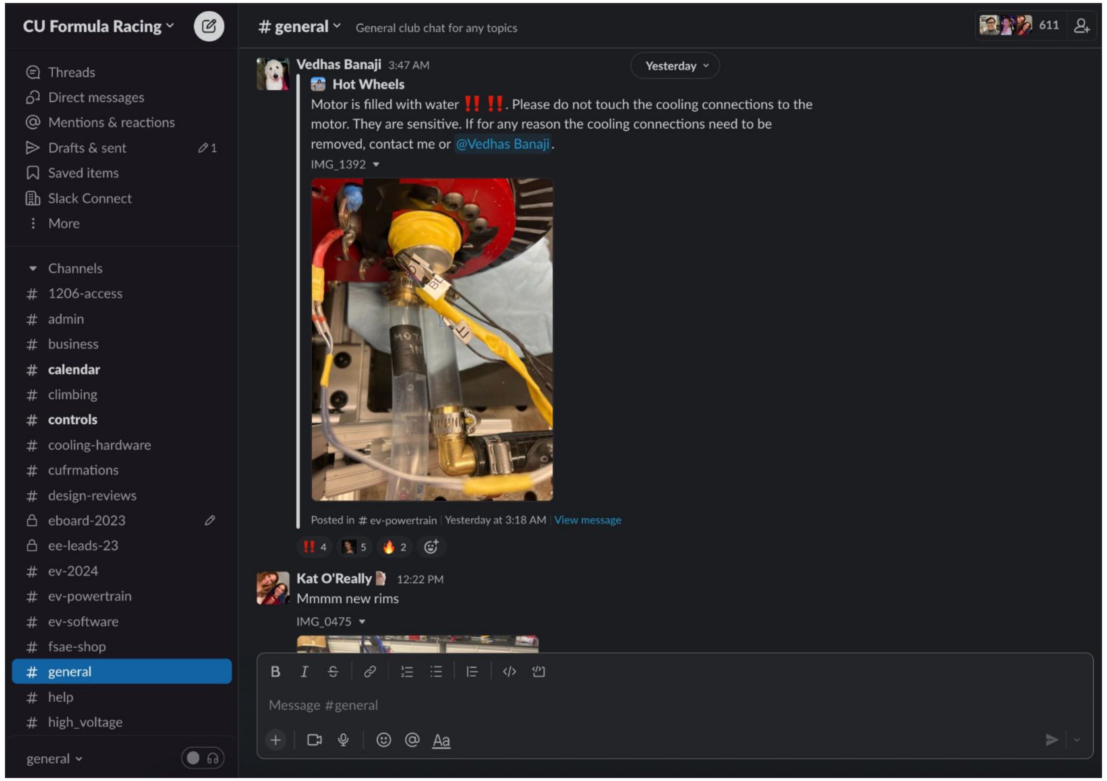
- Desktop Application allows for instant update of project folders on local device



Communication: Slack and Google Suite

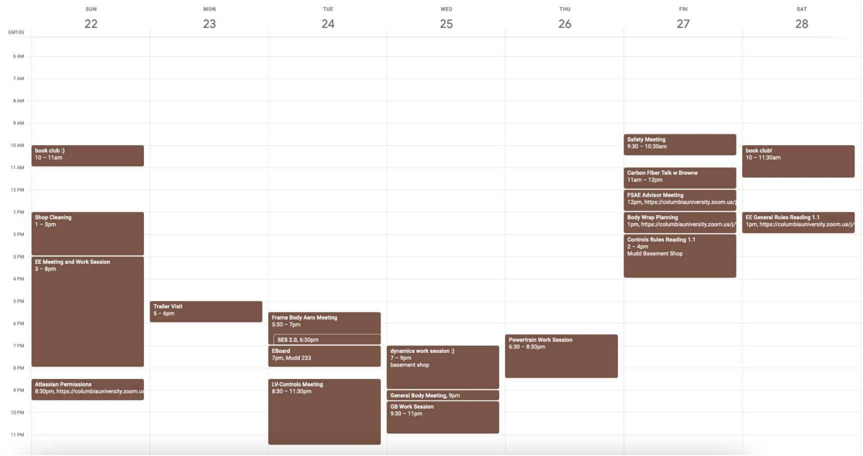
Slack:

- Fast and urgent messaging
- Topic-specific channels
- Integrated with apps for productivity



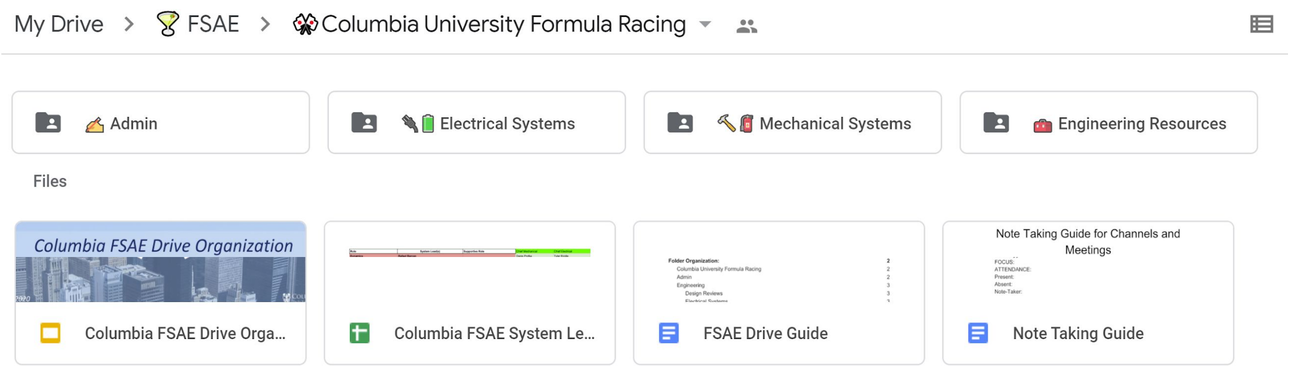
Google Calendar:

- Displays designated meeting
- Allows for integration of systems to take place in parallel with individual subteam developments



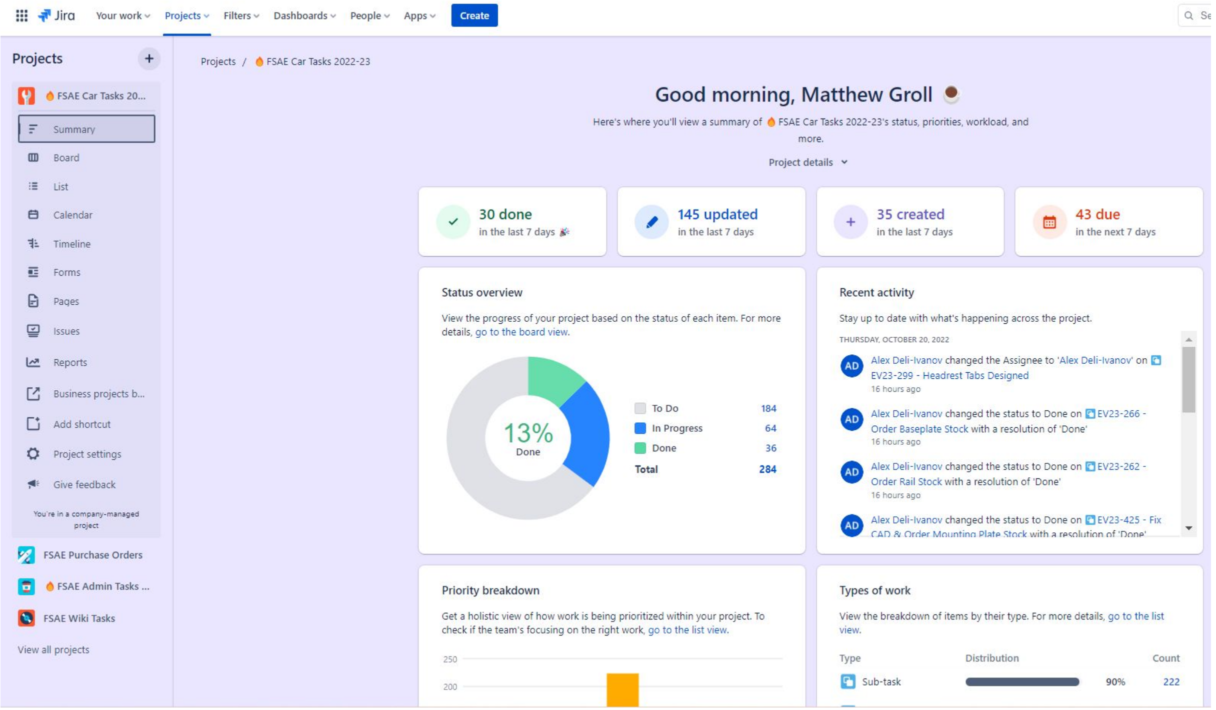
Google Drive:

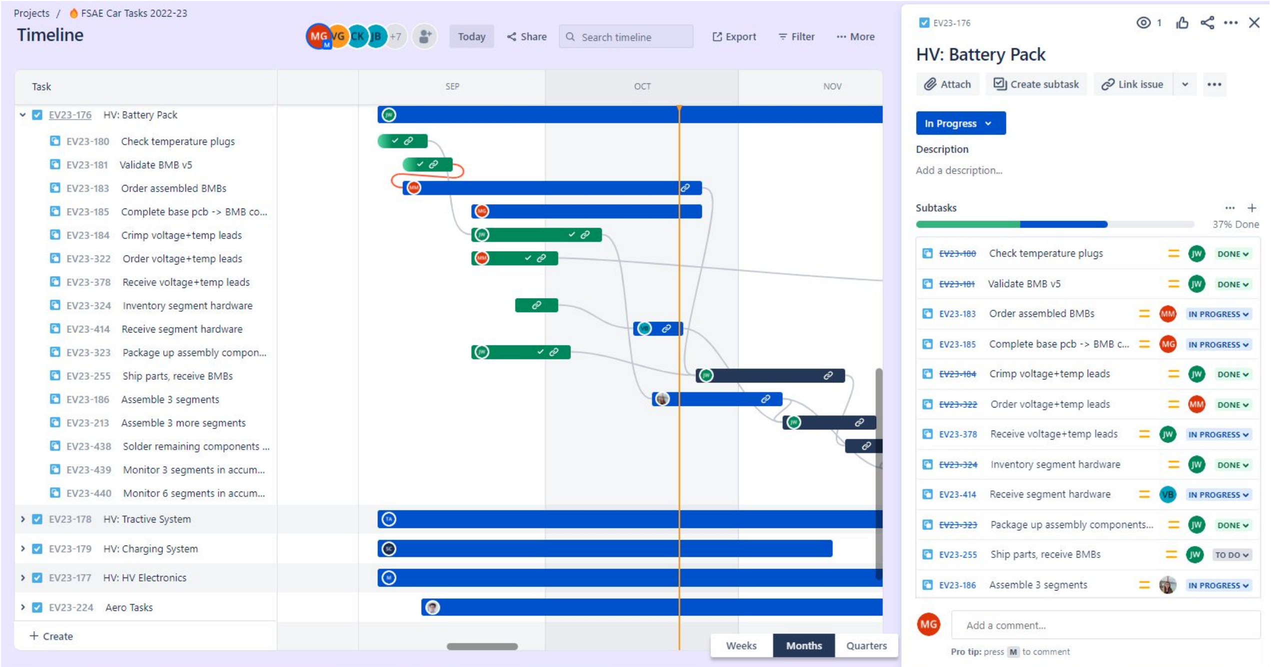
- File sharing: notes, competition documents, testing plans, data sets, reference documents, and more



Management Tools: Jira

Jira allows our team to coordinate project work on subteam, system, and component level. Task dependency can be tracked as well as progress. Updates can be communicated.





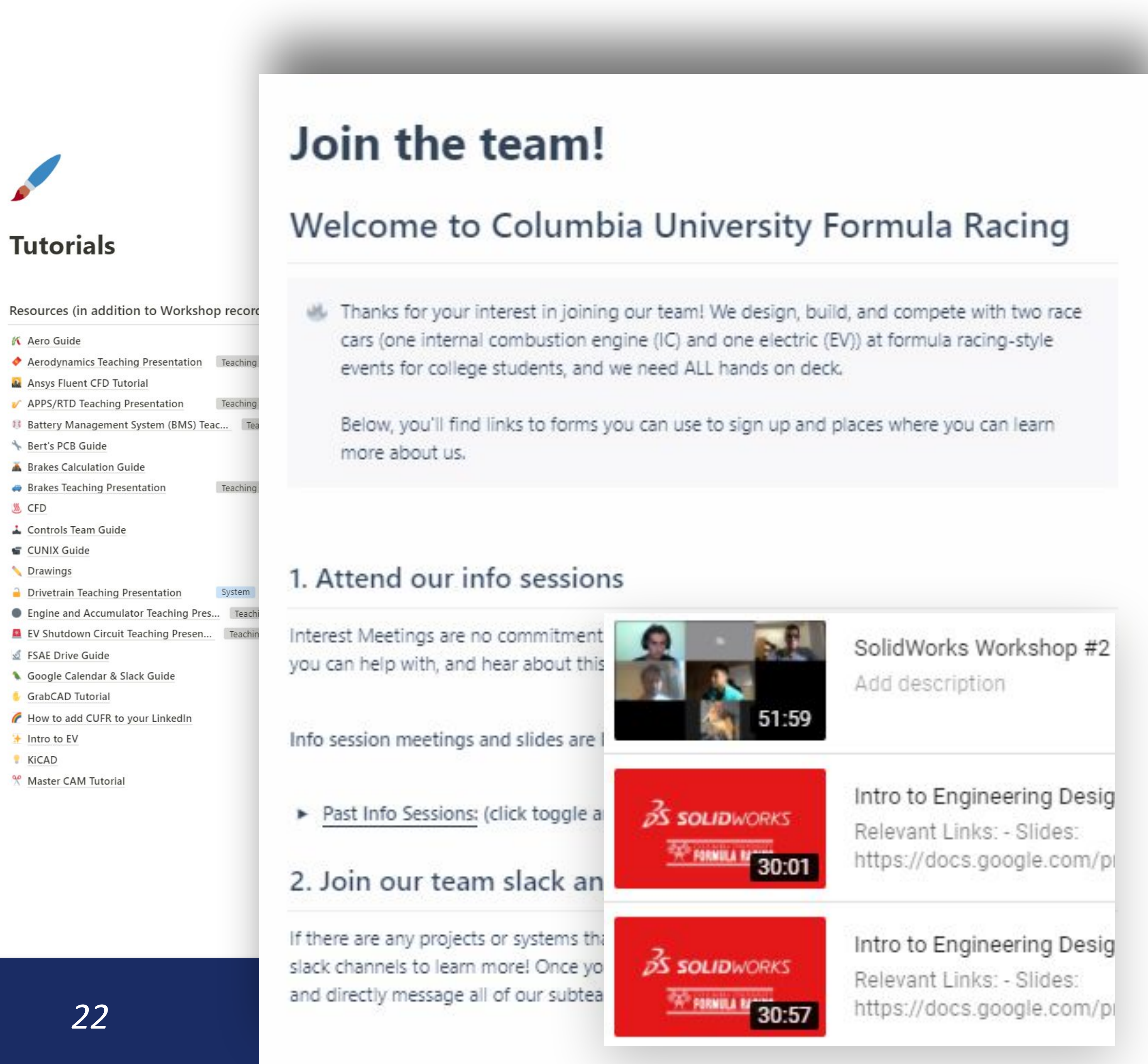
Onboarding & Knowledge Transfer

The team invests heavily in new member recruitment and retention for long-term success of our car and engineering program.

We use Confluence as a wiki to easily share information.

Process:

- Subteam-level introduction meet & greets
- “Shopping” Period with open work sessions
- Becoming an official member guarantees you access to club-wide events
- Year-long support program by the executive board
- Workshops, Office Hours, & Teaching Presentations



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Suspension

Suspension Overview

Goals:

- Reliability: the vehicle must consistently complete the 22 km endurance event
  - minimum FOS of 2 for all parts

- reduce design complexity, ensure serviceability

General:

- Hoosier 16-7.5x10, R25B tires with 10” Keizer aluminum rims

- track width/wheelbase: 46.9”, 60.2”

- 50 % FLLTD

front left suspension assembly

rear left suspension assembly

Kinematics

Static Front Parameters:

FVSA Length	53.7”
FVSA Angle	2.96^{o}
Roll Center height	1.21”
Scrub Radius:	0.22”
Mechanical trail:	0.87”
Camber:	-2^{o}
Caster:	8.7^{o}
KPI:	2.82^{o}

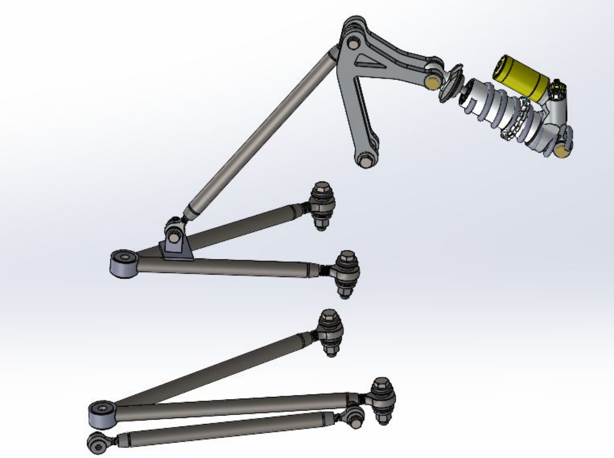
Static Rear Parameters:

FVSA Length	146.56”
FVSA Angle	1.56^{o}
Roll Center height	0.638”
Scrub Radius:	0.620”
Mechanical trail:	0”
Camber:	-2^{o}
KPI:	11.0^{o}

Suspension/Steering Linkages

- Short long arm (SLA) double wishbone suspension setup
- 4130 Steel Tubes, 0.058" Wall Thickness, 5/8" OD
    - Min FOS 2, Pacejka tire curves used to find forces
- Welding Cups used for rear suspension A-Arms
- Double Shear Joints for all suspension chassis attachment points
- Threaded rod-ends w/ jam nuts used for ease of adjusting lengths
- Serviceability and Accessibility
    - Maximum 4 washers per bolt
    - Access to bolt heads and nuts

Forces Experienced by Suspension Arms (N)			
	Left Hand Corner at 1.5g	Accelerate at 1g	5g Bump
Lower A-Arm Fore	507.990	707.887	3800.592
Lower A-Arm Aft	8007.604	1607.887	3268.360
Upper A-Arm Fore	422.256	664.079	1337.469
Upper A-Arm Aft	6282.909	2497.043	656.867
Tierod	38.812	686.475	241.701
Pushrod	1289.109	4661.308	965.303



Left Rear Suspension Assembly

Left Front Suspension Assembly

Rockers and Dampers

Rear rocker loads:

- Pushrod Force: 2265 N bearing load
- Shock Absorber Force: 400 N bearing load

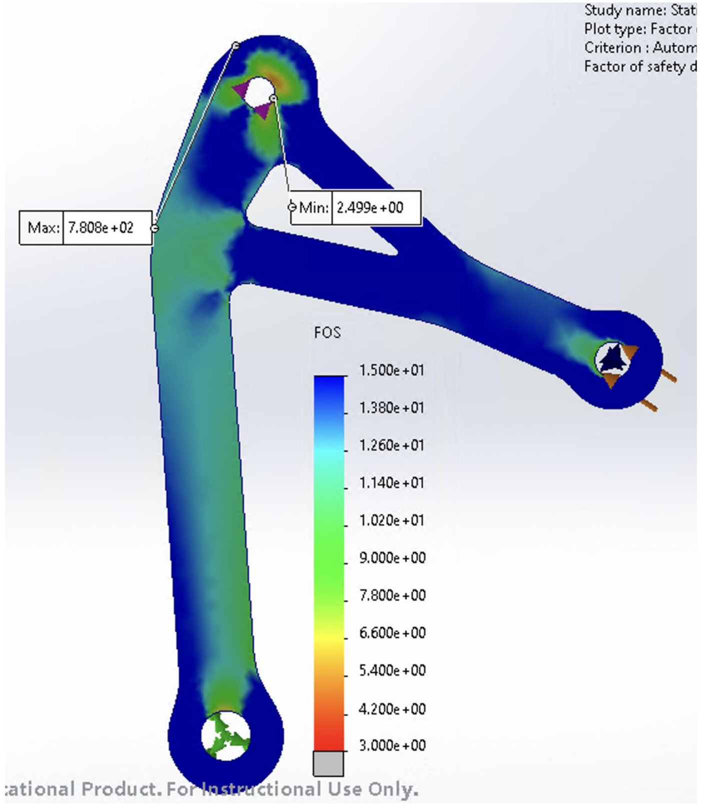
Material:

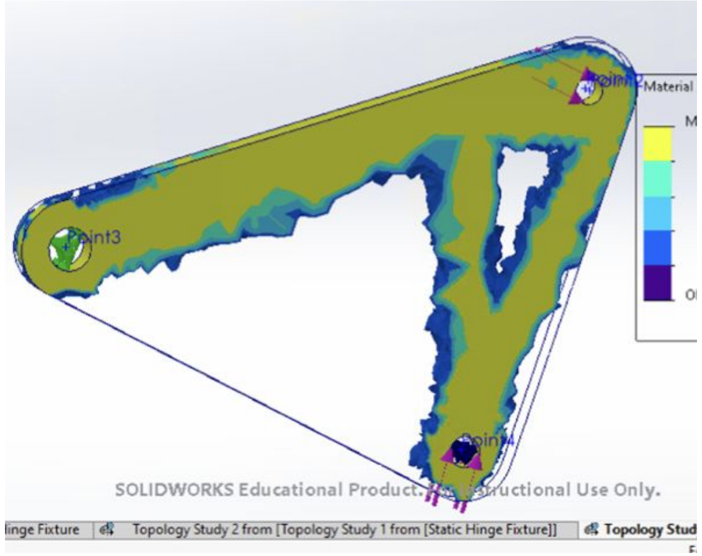
- Aluminum 6061 T6
- Yield Strength: 2.4 x 10^8 N/m^2

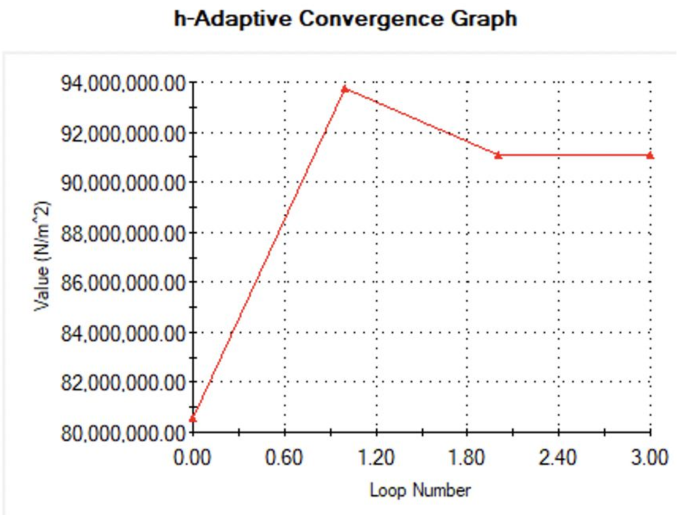
Final design min FOS: 2.5

	Front	Rear
Roll Center Height (in)	1.212	0.638
Ride Rate (lb/in)	155.84	159.25
Motion Ratio*	1.1442	0.8985

*Motion ratio is defined as wheel displacement/spring displacement

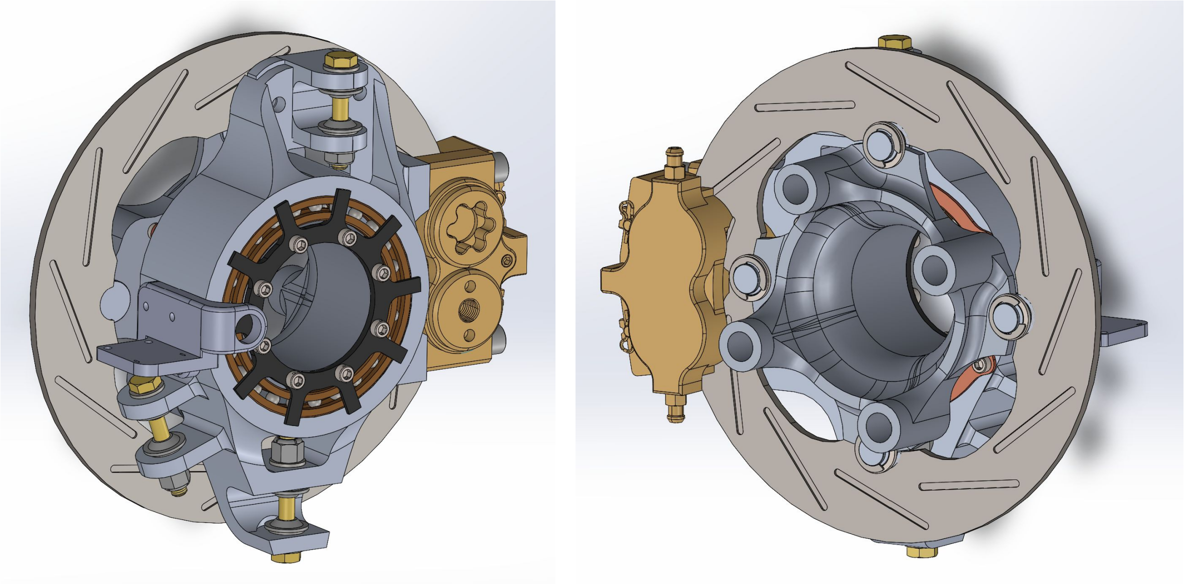






Hubs & Uprights

- 7075-T6 was selected for hubs and uprights due to its high strength-to-weight ratio
- Uprights allow for camber adjustment with addition of shims
- Minimum factor of safety: 2
- Rims attach to the hubs with lug bolts
- Double bearing arrangement, a bearing press-fit and further secured with retainers on each side of the hub to mitigate cantilever effect
- Deep groove non-contact sealed bearings



Front Right Hubright Assembly

Roll Rates and Dampers

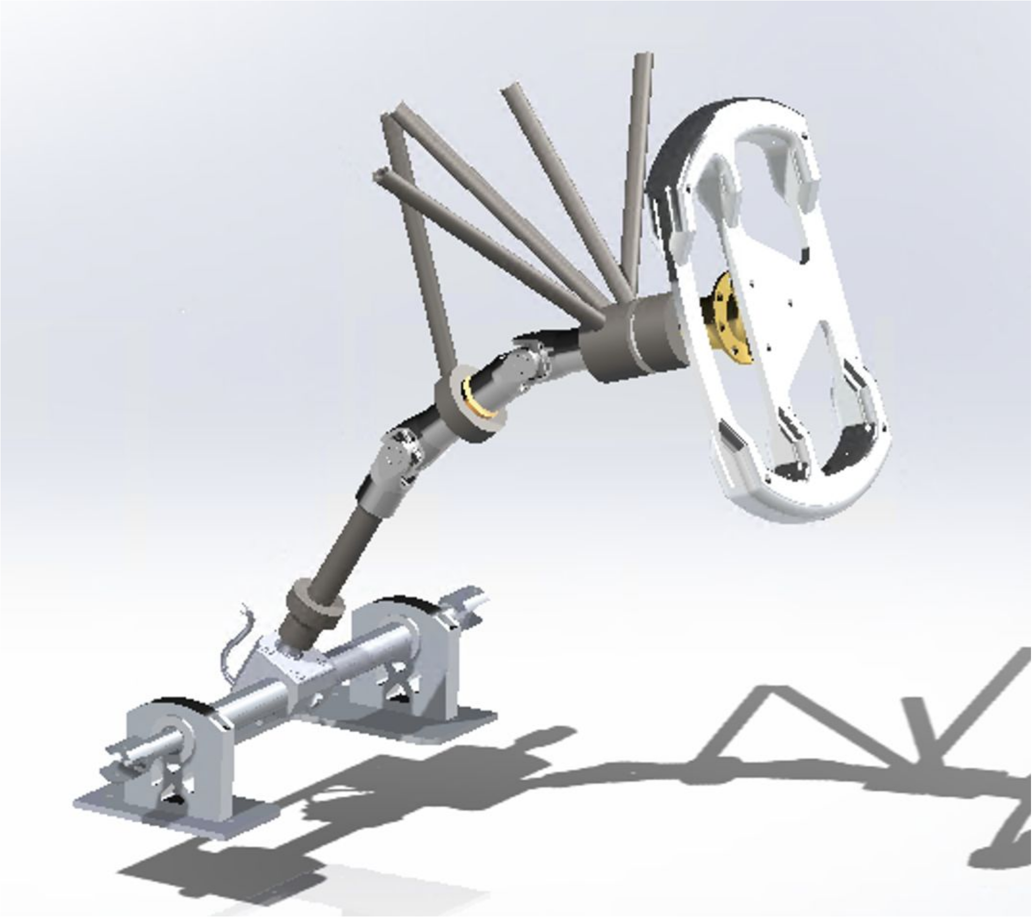
	Front	Rear
Roll Stiffness (lb-ft/deg)	249.17	254.63
Spring Stiffness (lb/in)	150	250

- TTX25 MkII Öhlins dampers
- Roll gradient: 1.0 deg/g

Steering

Goal: reduce compliance, maintain consistent driver feel/control

- Steering ratio: 4.79
- Positive ackermann
- Two u-joint design in column
  - max 30 degree operating angle for each
  - constant linear velocity
- Splined column connections
- Unibody mounting system
- Minimum FOS of 3
- Tuneable bump steer/ackermann



Data Acquisition, Testing and Validation

Sensors

- Linear potentiometers for damper length
- Wheel speed sensors
- Steering angle sensor
- 3 axis accelerometer

Future plans:

- Instron testing
- dynamic testing (to validate/correlate with our tire models)

Frame/Body/Aero

Primary structure/tub/tubing, body, and aerodynamic/ductwork systems. Rigidity and stress-relief methods. Load analyses. Fasteners. Selection and use of materials.

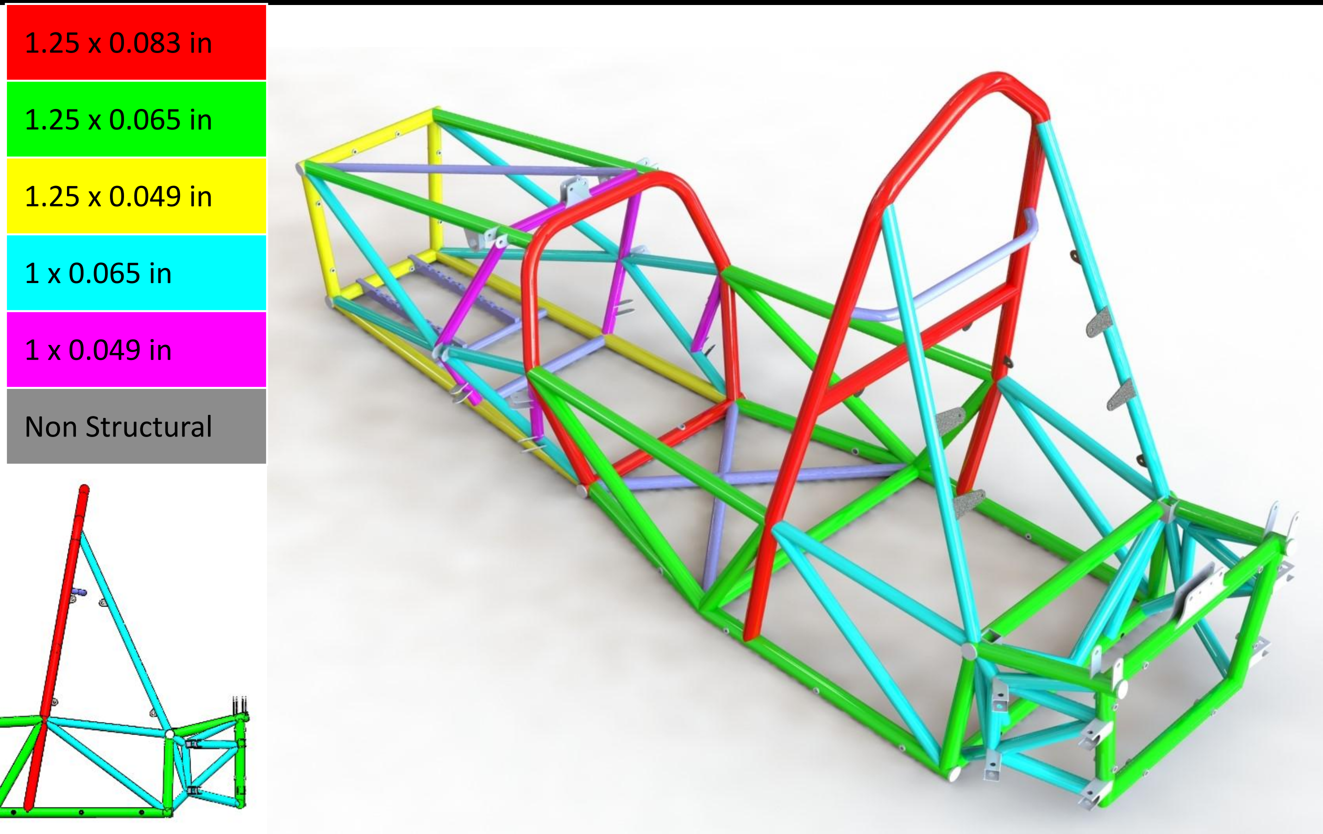
Chassis Design Goals

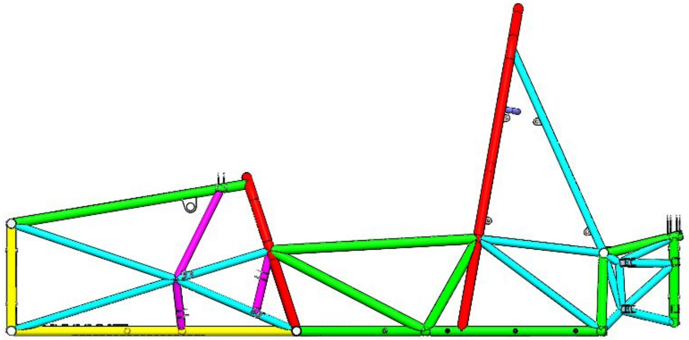
Goals:

- Lower CG
- Optimize chassis torsional stiffness
- Optimize the geometry for EV systems

Important Requirements:

- Passes structural equivalence for a hanging differential
- Accommodate drivetrain packaging with the Emrax 208 Motor and the High Voltage Enclosure
- Accommodate suspension pick up points





- In order to get triangulation and the points to sit at nodes, we created the geometry and tabs shown above.
- In addition, having a hanging differential necessitated larger tubes in the rear, and the inclusion of welded inserts.

Weight Analysis (for CG)

CG Height: 9.831 in

Front/Rear weight distribution:

- 48.94/51.06 (static)
- 73.42/26.58 (dynamic)
  under a breaking acceleration of 1.5g's

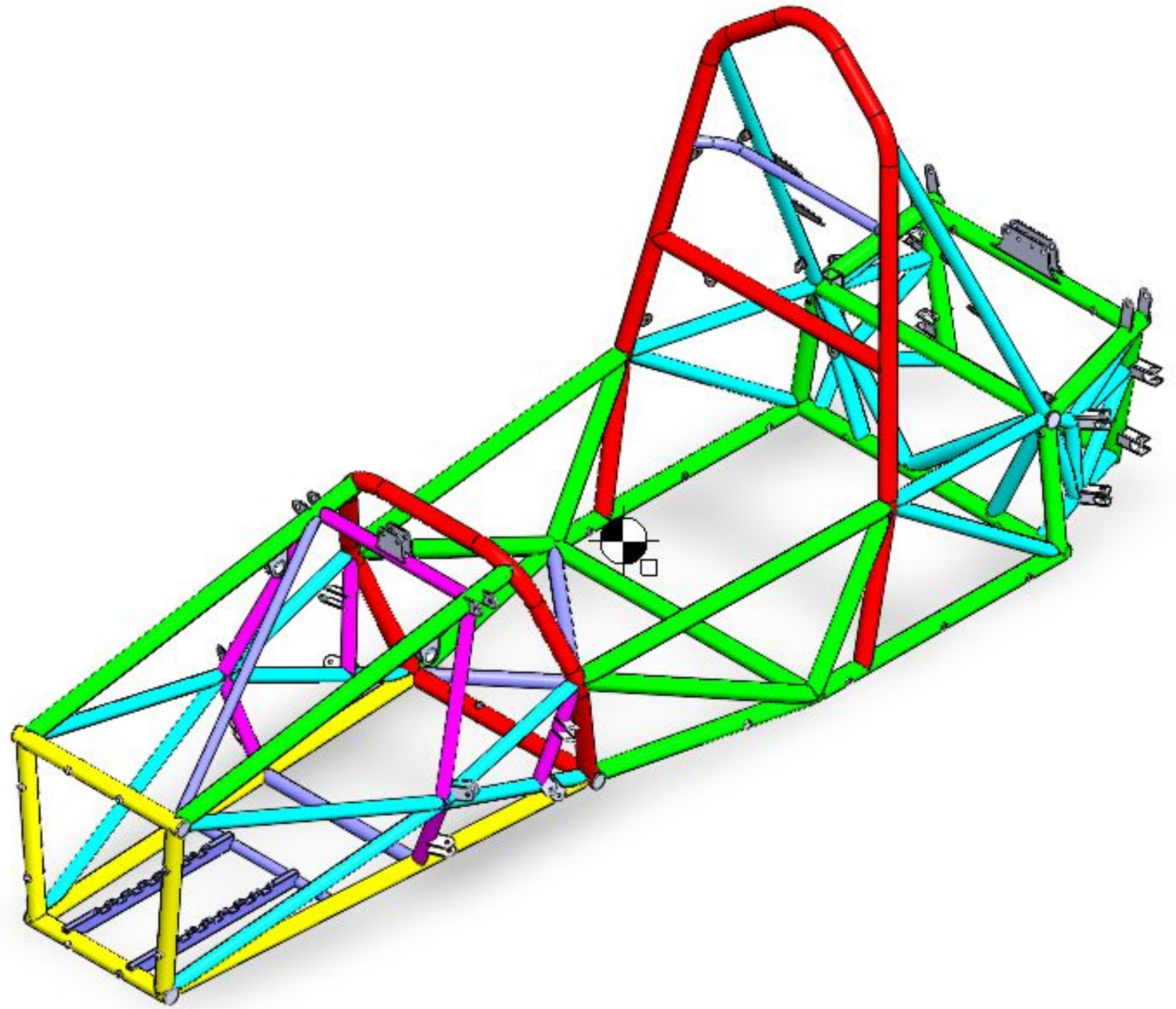
Chassis weight: 93.41 pounds

Ride height: 1.25 inches

Unique Features: Welded Inserts, Rear Clip, Geometry

Material: 4130 Steel
(2x the amount of yield strength, ultimate strength as 1020 steel due to increased Cr content in 4130)

Alternative materials considered (Aluminum) but not used based on price.



Torsional Stiffness

Simulation setup:

- Got a working mesh by combining bodies
- Constrained the rear pick up points
- Added a force component to the front suspension points in equal and opposite directions
- Ran Mesh and took notes of the Z-Deflection. Solved a triangle for degrees and for N*M, and N*M/degs

Stress concentrations:

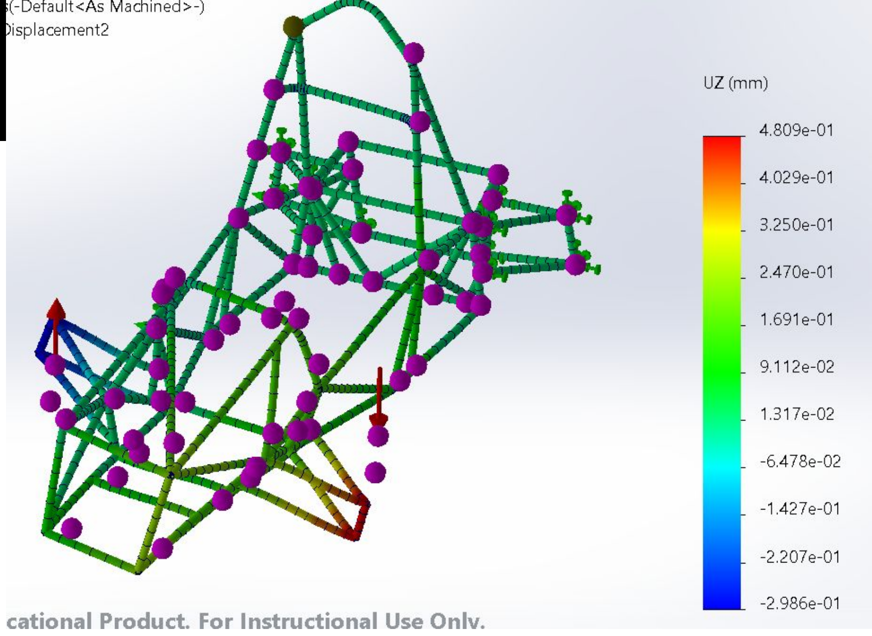
- 50 N at each of the front suspension pick up points. Going down in the Z on positive x side and the opposite on the negative x side
- Only a force component to simulate load

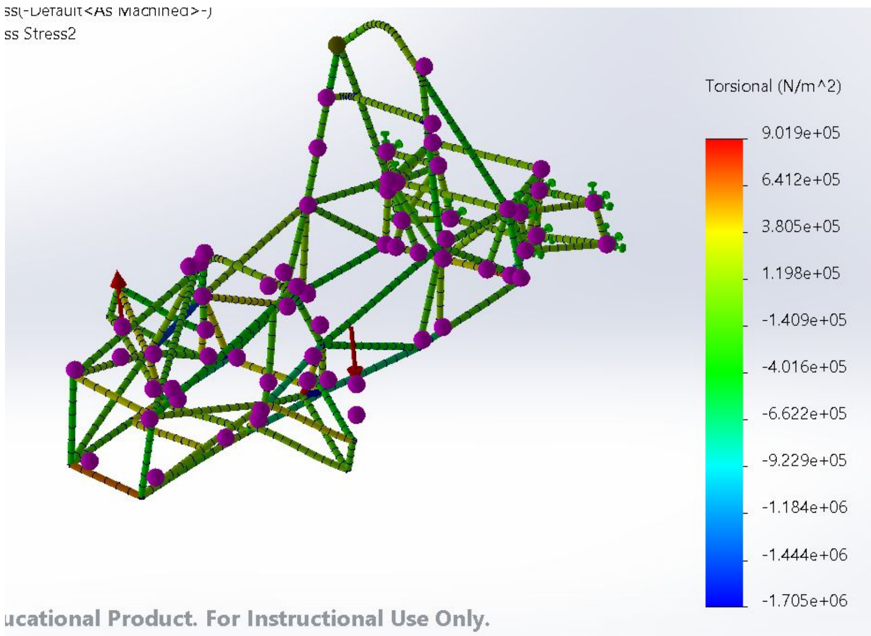
Sampling:

- From the point of deflection to the midplane
- You could also sample along an originally horizontal bar as a reference point

Results/conclusions:

- 1506.79 Ft*Lbs/ Deg
- More samples need to be taken and compared with suspension stiffness in series

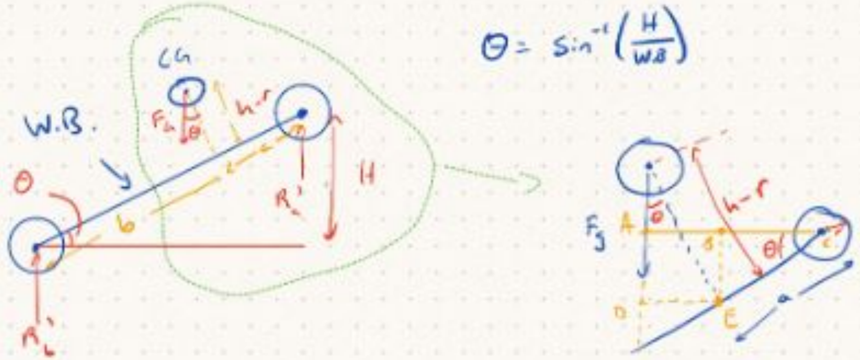




Weight Distribution

- Measure & Calculate Static Weight Distribution
  - Static F/R: 48.94/51.06
  - CG Height: 0.2497m (9.831 in)

- Calculate Dynamic Weight Distribution
  - Braking acceleration: -1.5g
  - **Dynamic F/R:** 73.42/26.58



$$\Sigma M_A : R_a'(0) + R_b' \cos\Theta\,(W.B) - F_G\left|\overline{AC}\right| = 0$$

$$|AB| = |DE| = (h-r)\sin\theta$$

$$|AD| = |BE| = a\sin\Theta$$

So $|AC| = |AB| + |BC| = (h-r)\sin\theta + a\cos\theta$

Inserting back into the original sum of moments:

$$R_b'\cos\theta\,(W.B) - F_G\left((h-r)\sin\theta + a\cos\theta\right) = 0$$

rearrange $(h-r)\sin\Theta + a\cos\Theta = \frac{R_b'}{F_G}\cos\theta\,(W.B)$

$$(h-r) = \cot\Theta\left(\frac{R_b'}{F_G}(W.B) - a\right)$$

also $= WB\left(\frac{R_b}{F_G}\right)$

So: $\boxed{(h-r) = \cot\theta\left(\frac{R_b' - R_b}{F_G}\right)(W.B.)}$ where $\Theta = \sin^{-1}\left(\frac{H}{WB}\right)$

raised height

C.G. height from ground

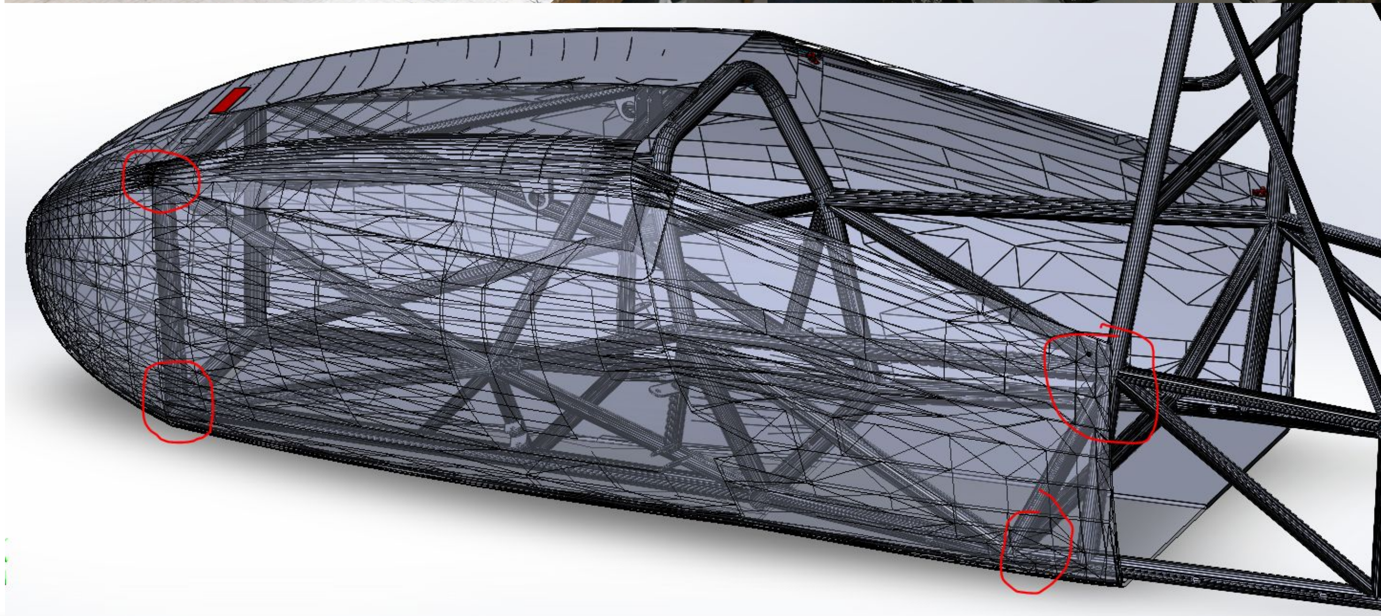
tire radius

wheel base

Body Design Goals

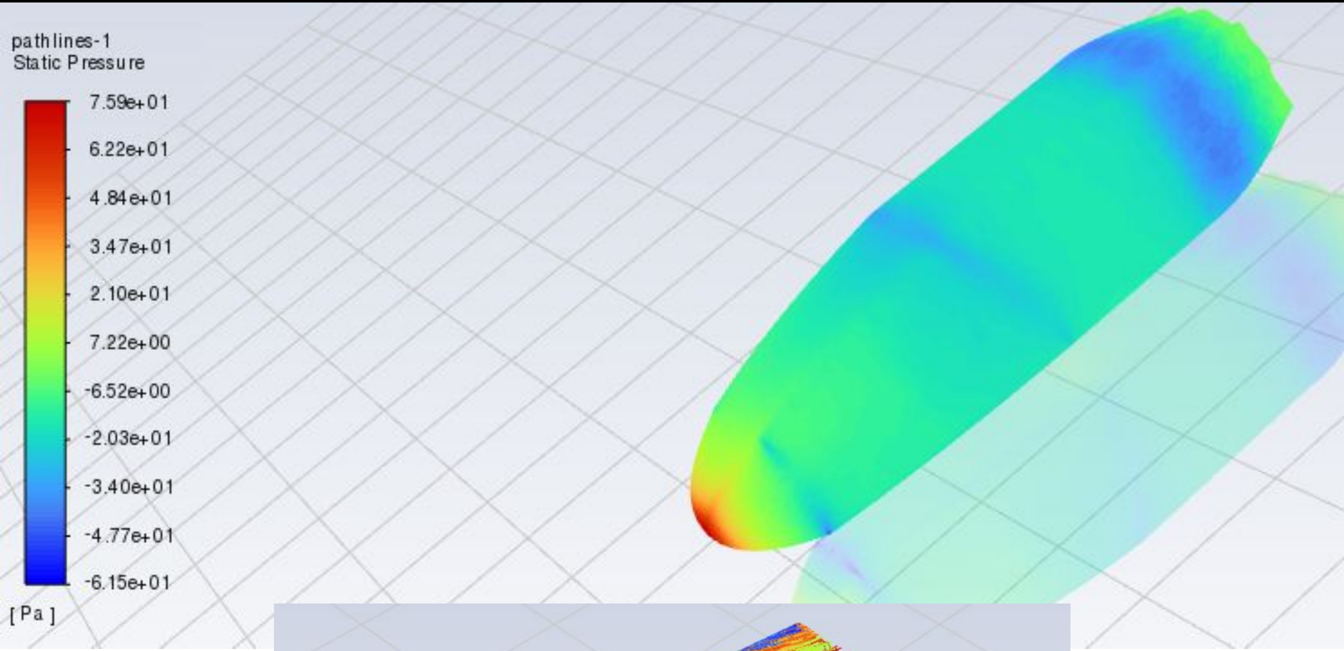
Click to add title

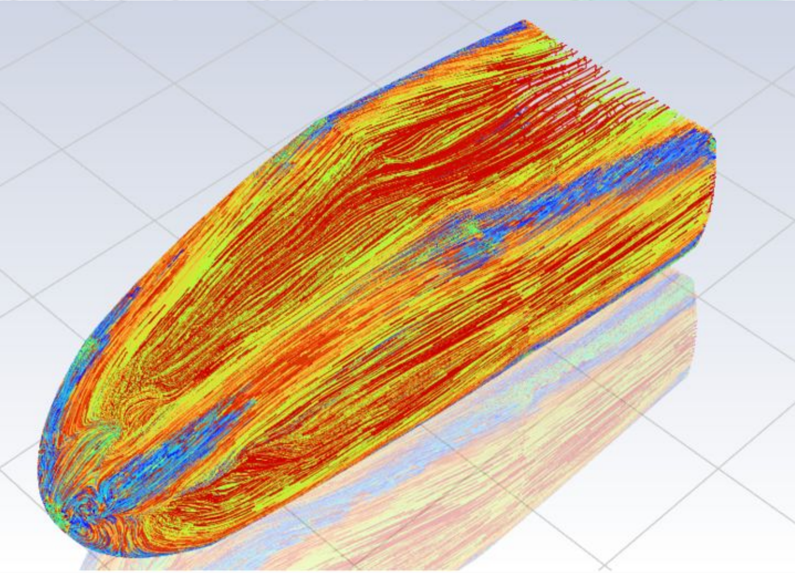
- Body directs air over the chassis to reduce drag coefficient and air resistance
- Lower drag reduces force required to move car forward and produces less strain on powertrain components
- Body cuts to allow accessibility
- Secure mounting to chassis
- Aerodynamic simulations for drag coefficient verification
- T.7.2.3. [No Opening to the Cockpit]
- T.7.2.4. [Forward Facing Edge Radii]
- Prevent debris from entering the cockpit



Body Analysis

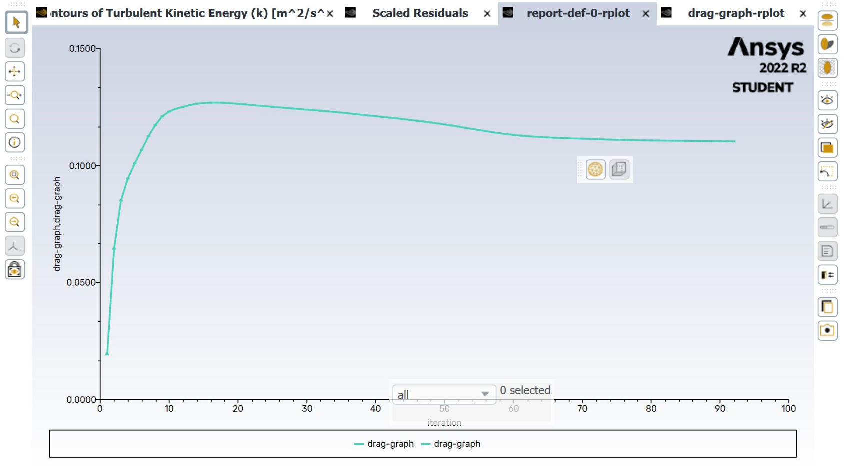
- Designed to be as aerodynamic as possible with regards to contours of chassis
- Frontal Area Minimization
- Nose is detachable to access pedals
- Multiple forms of attachment (e.g. quarter turns, velcro)
- A smooth curve on the body prevents flow separation and reduces pressure which lowers air resistance
- ANSYS pressure and drag simulation
- Currently, we have a physically impossible drag coefficient





Body Analysis

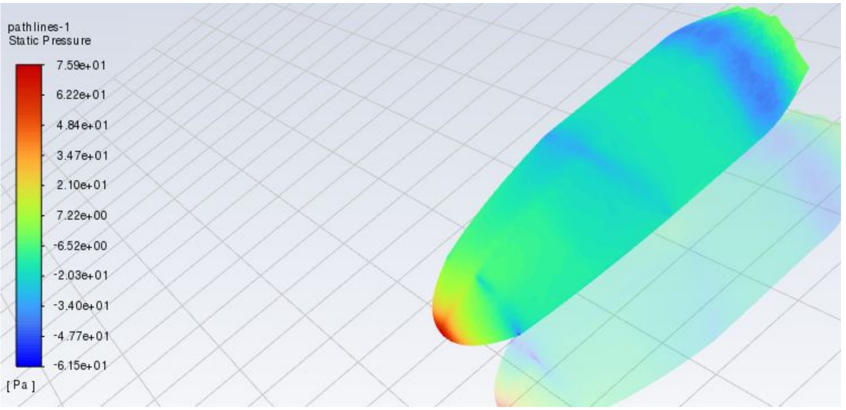
Drag Analysis of 2D Body



Frontal Area Calculation

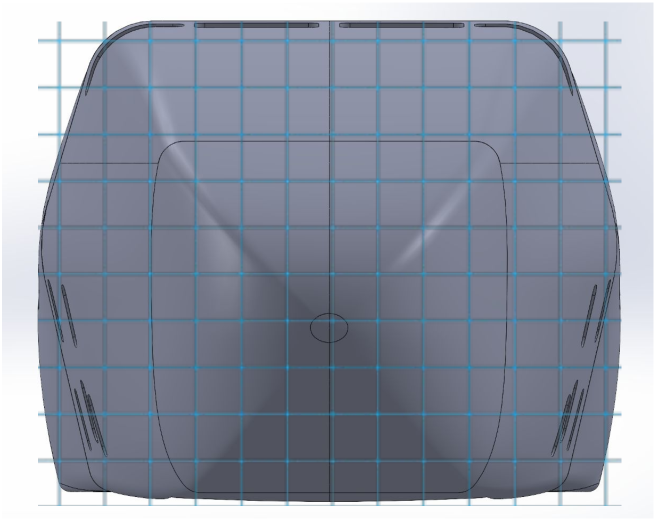
Approximately constant pressure throughout the body

- No unnecessary lift created



Frontal Area Calculation

Height: 27.5 in
Width: 21.87 in
Square Area: 601.43 in^2
Percent coverage: 94%
Frontal Area: 3.97 ft^2

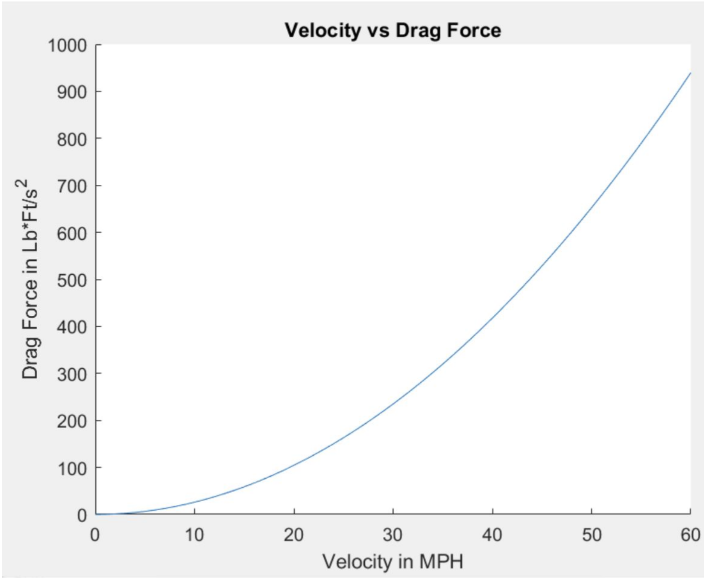


Velocity vs Drag Force

$$Area = 3.96527\ ft^2$$

$$C_d = 0.8$$

$$\rho = 0.0765\ \frac{lb}{ft^3}$$



Aerodynamics

Why we chose not to run an Aero kit:

- Heavy
- Slow
- Shaky
- Complex
- Expensive
- Bad
- Manufacturing, time, mounting are main difficulties

- An aero kit would most likely increase the lateral load transfer because the CG would go up and so would the weight.
- The downforce produced would only marginally decrease the time on a skidpad event if it produced enough load to keep the tire contact patch in contact with the road taking into account increased CG and Weight.
- In the future, the goal is to validate a full aero kit that would help with endurance, skidpad, and autocross.

FORMULA SAE

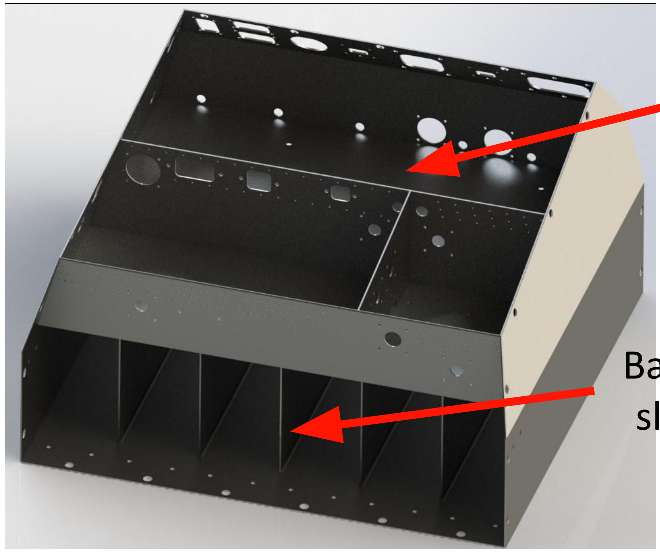
Powertrain

Accumulator, Power conversion, motor/controller selection/design, wiring considerations, transmission. Torque vectoring. Gearing. Regenerative braking. Selection/use of materials.

HV Enclosure: Design Goals and Highlights

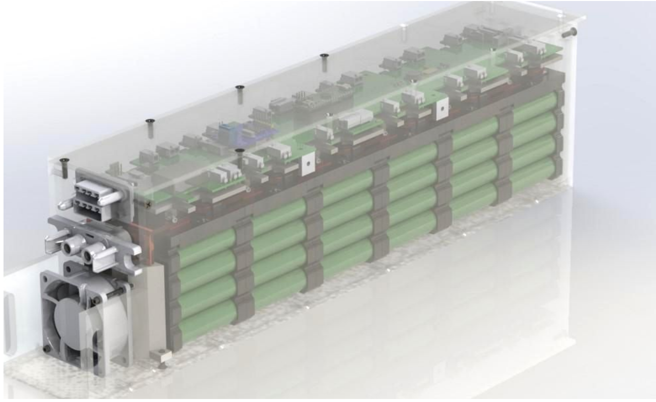
Design Goals:

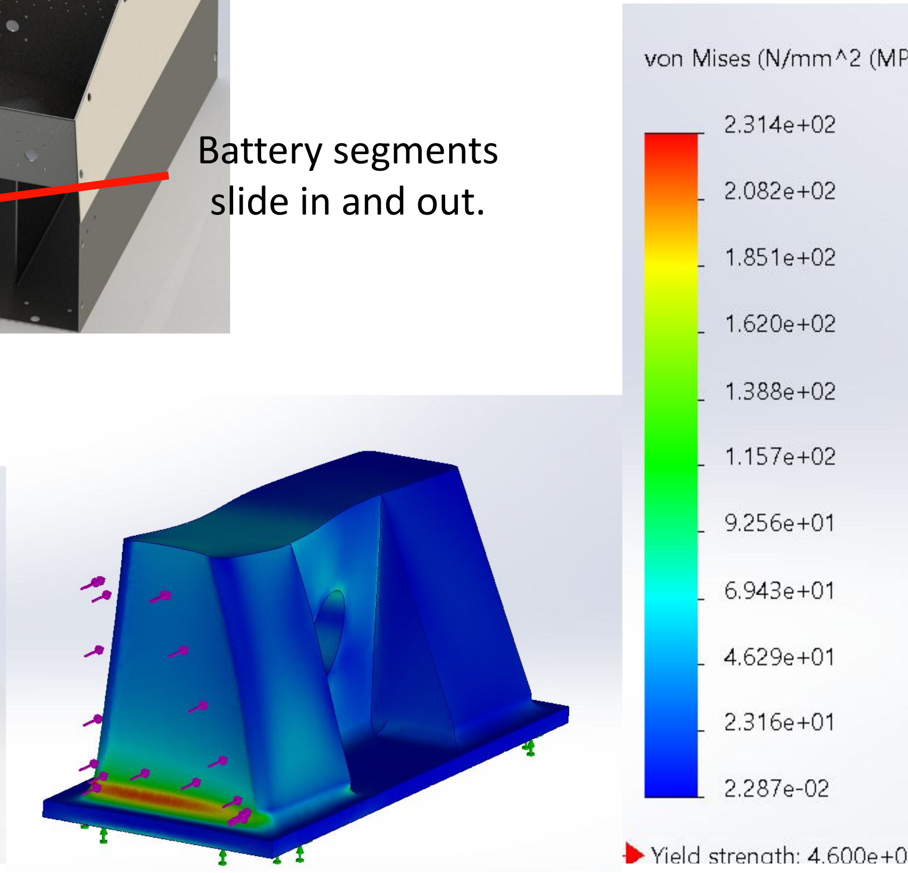
- **Accessibility**
  - Easy removal from car
  - Segments & peripherals
- **Packaging**
  - Reduce exterior HV wiring, consolidate electrical systems
- **Low CG goal**
  - Pack as many components as allowed by rules inside
  - Place low to the ground & near the COM
- **Safety**
  - Tab mount analysis
  - Secure battery casings



Separate electronics compartments.

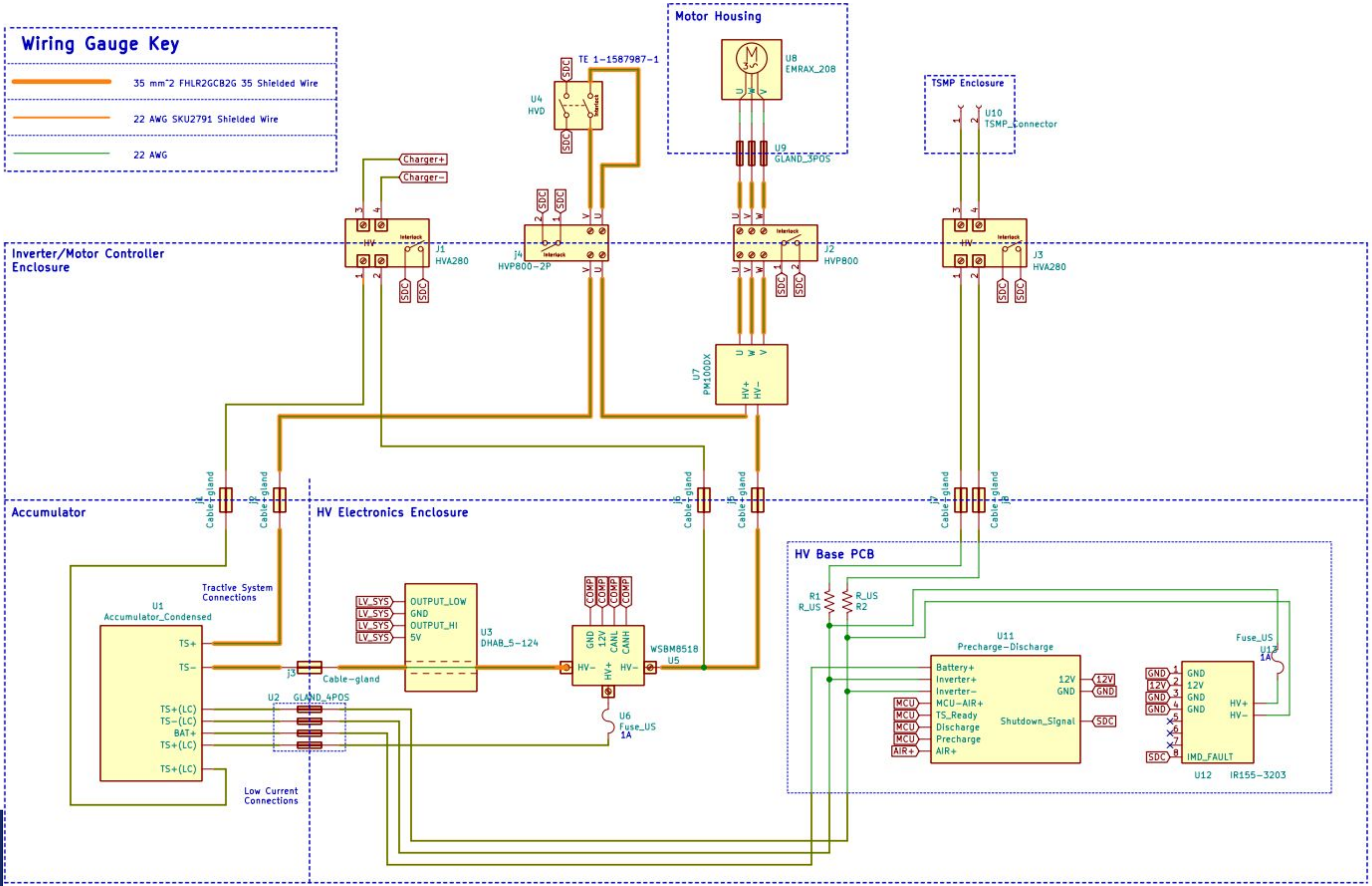
Battery segments slide in and out.





Tractive System

- 72s8p Li-Ion battery pack
  - **Max. Voltage: 302V**
  - **Nominal Voltage: 259V**
- Team-designed BMS
- 110A slow-blow fuse
- Cascadia PM100DX inverter
- Emrax 208 PMSM



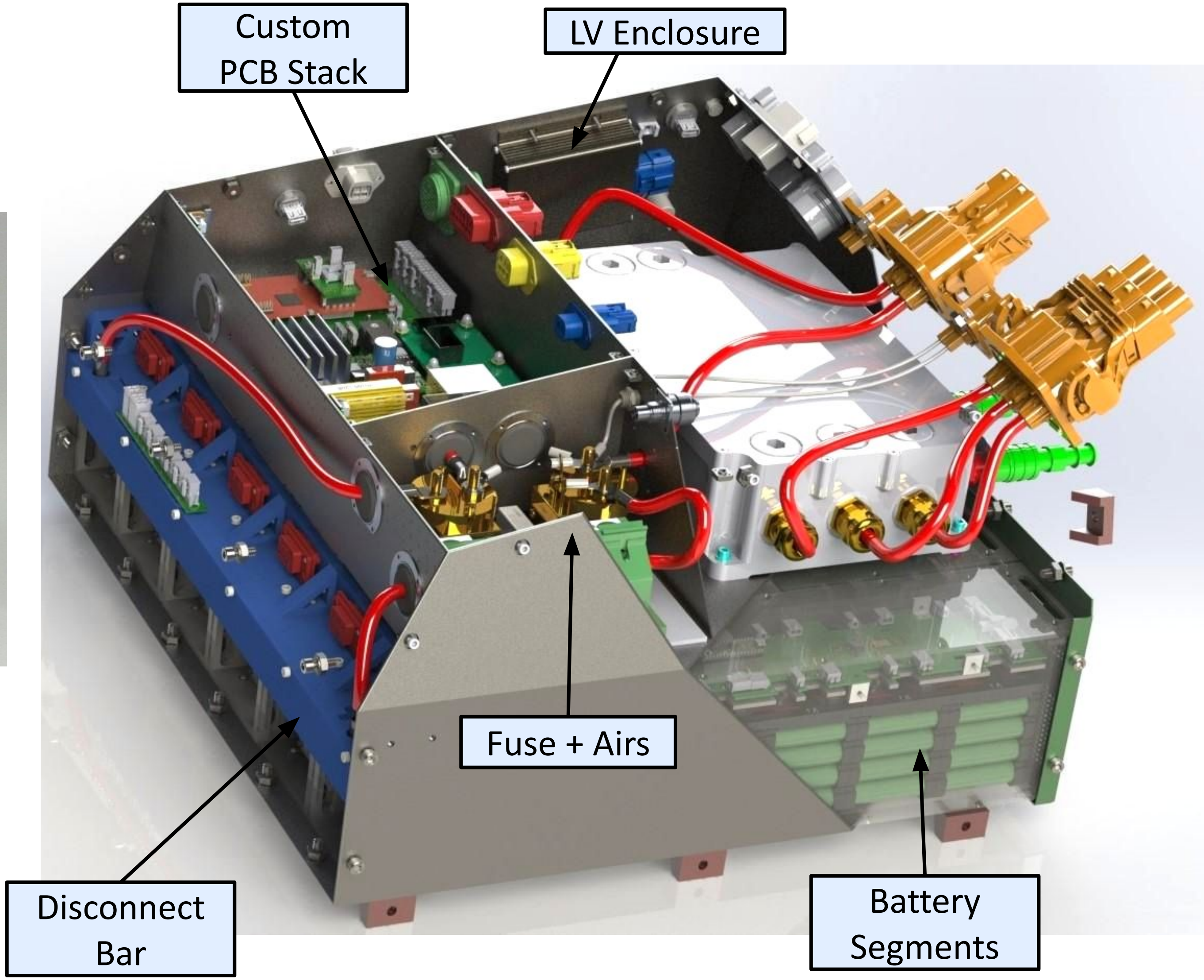
HV Electronics

Four distinct chambers

- Battery Pack
- AIRs + HV Fuse
- PCB Stack
- Inverter

Motor

- Emrax 208 Motor
- 302V Max, 259V Nominal Voltage
- 448 Nm Max Torque
- 350 A Current Rating



Energy Consumption Simulations

Simulation Goals:

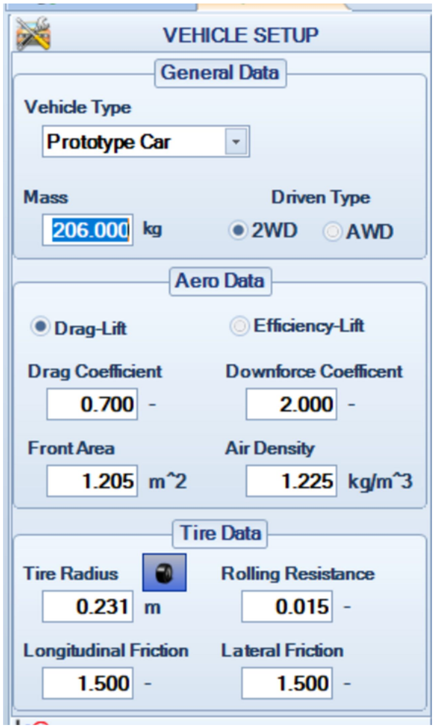
- Verify accumulator capacity
- Ideally enough power to last the endurance race (22km)
- Determine maximum speed to complete the race

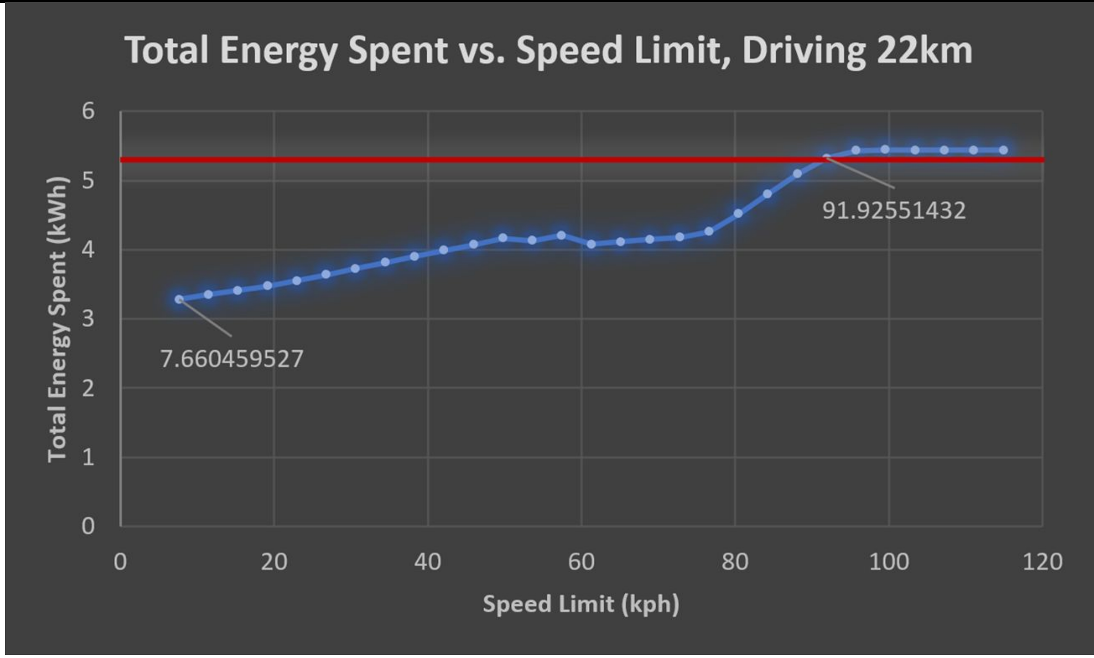
Process:

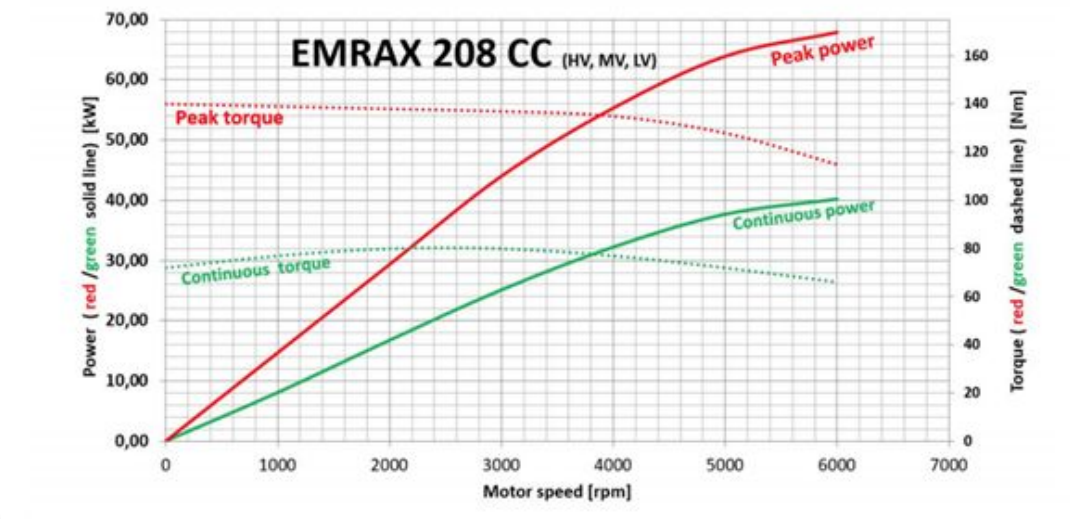
- Use OptimumLap software
- Input vehicle parameters
  - Mass, aero, motor curves
- Simulate energy consumption at different speeds

Result:

- Speed limit: 91 kph (ideal), 76 kph (realistic)







Accumulator & Battery Management System

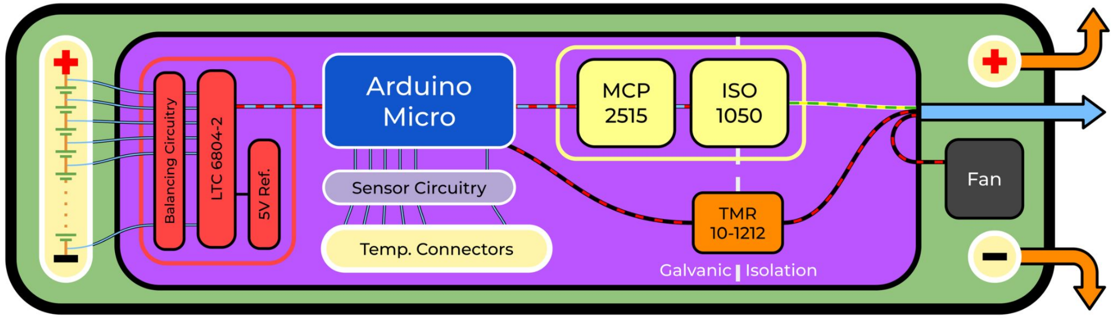
Design & Build:

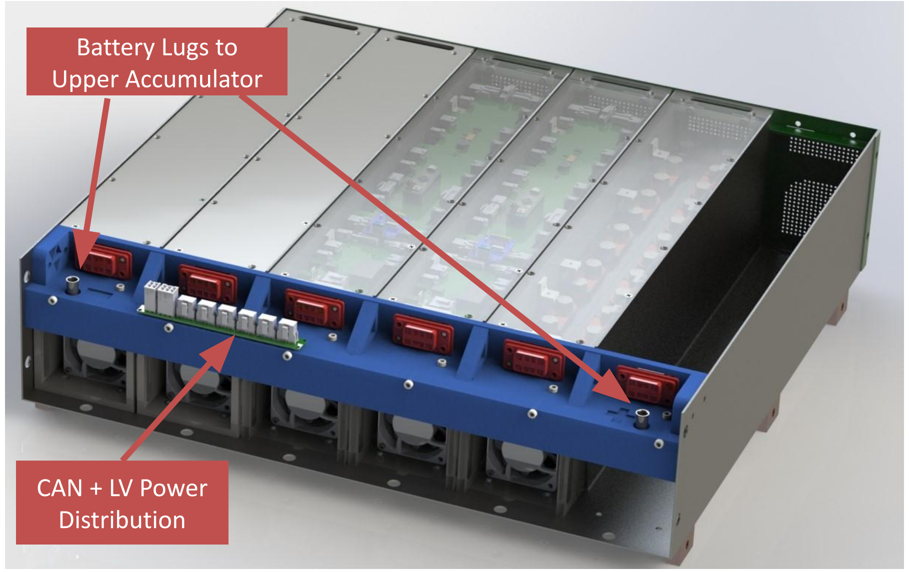
- 6 Segments, each < 60V
- Blind mate connectors on the back side (BMS and HV Path)
- Team-designed BMS with separate monitoring boards in each segment, on top of batteries

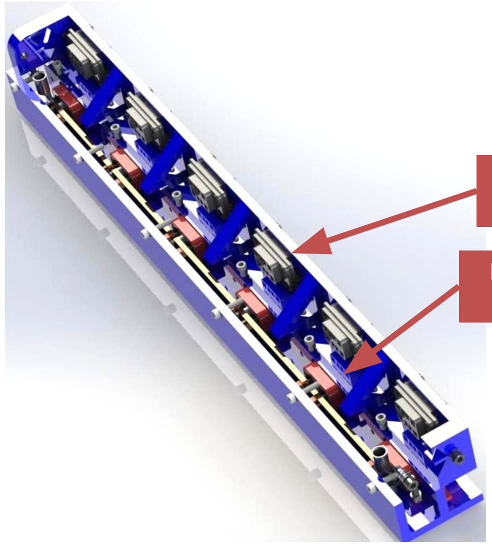
Integration & Testing:

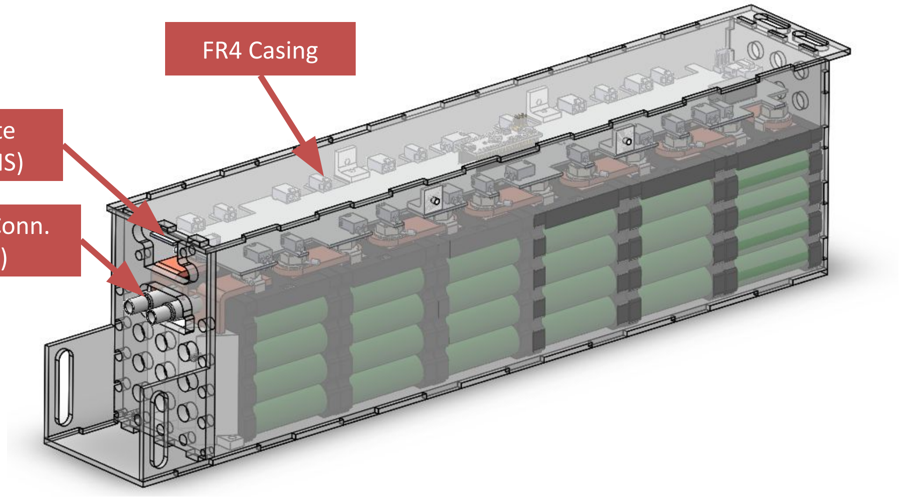
- All data on the CAN bus, logged and analyzed
- Thermal experiments completed to justify no cooling

BMS Board Design:









Drivetrain Design Goals and Highlights

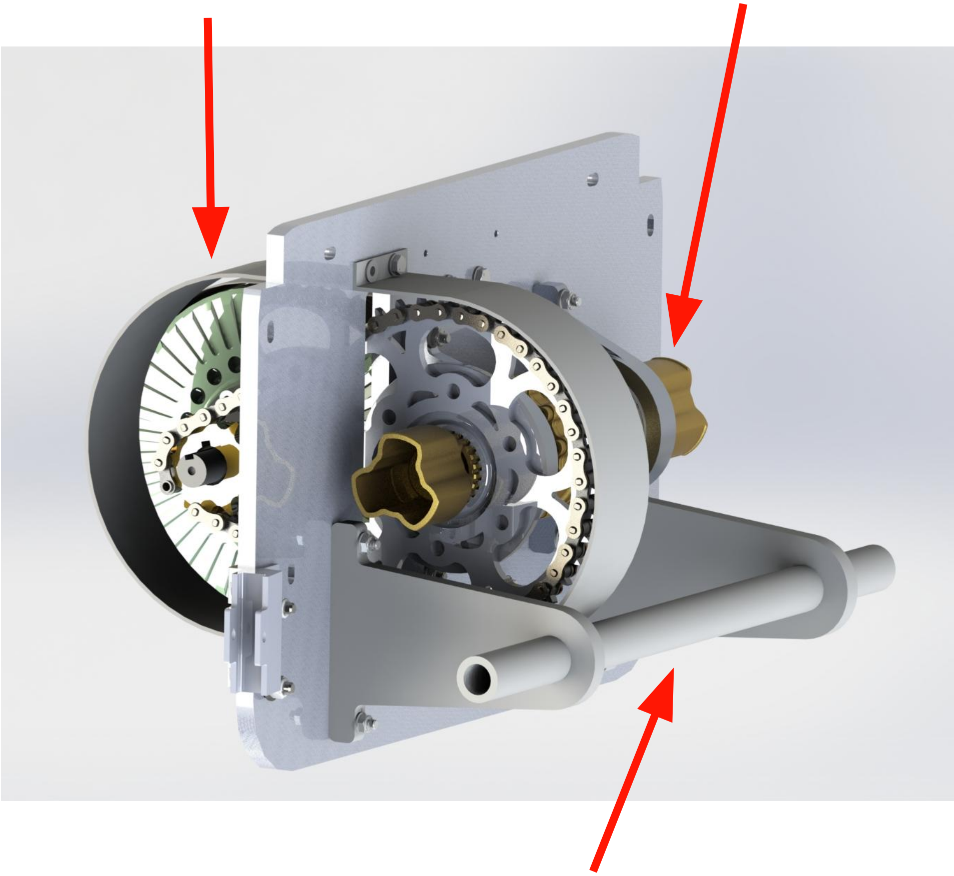
The drivetrain system includes an Emrax 208 motor, 2 fixed chain-driven gears, as well as a Drexler Salisbury differential.

Design Goals:

- Accessibility
- Manufacturability
  - In house production
  - Simplicity of mounting
- Structural Rigidity
  - Limit deflection of rotating components

Drivetrain Specs:

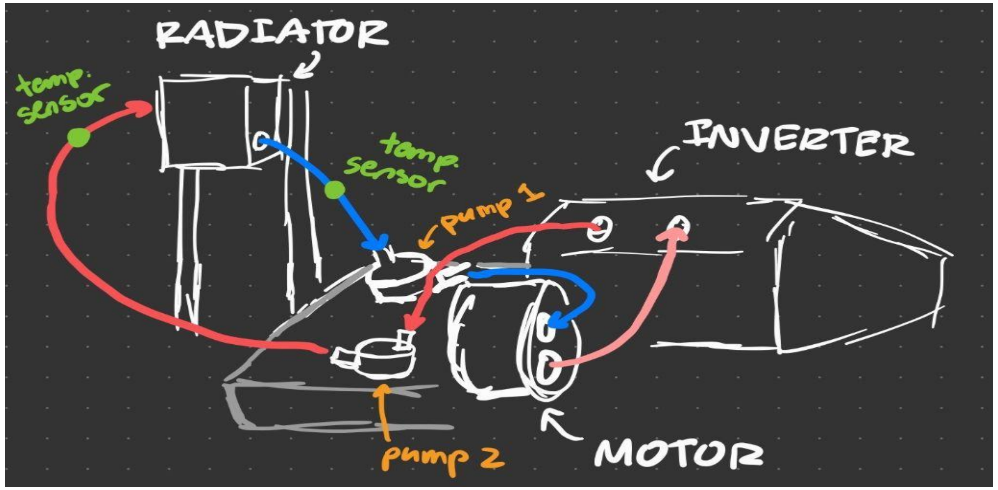
- 3.7 Drive Ratio
  (32t driven, 10t driving)
- 10.5° Max Half Shaft Angle
- 65 mph Max Velocity
- Drexler Salisbury Differential
- ¼" 7075 Aluminum Driven Sprocket
- 520 Motorcycle Chain
- 7075 Aluminum Chain Tensioning Guide

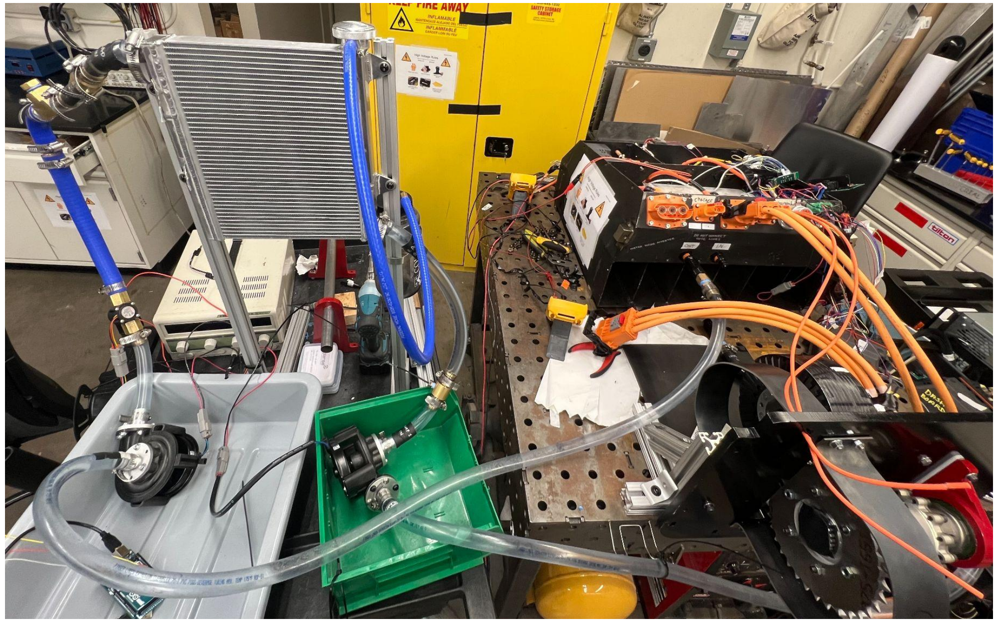


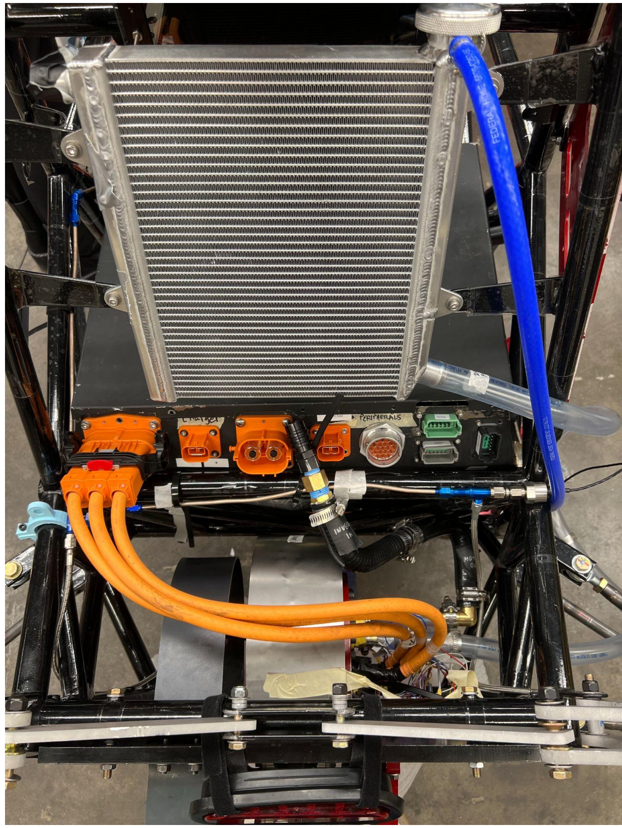
Cooling System

Loops Specifications:

- Operating Temp = **50 deg C** (122 deg F)
- Flow Rate = **6-8 LPM**
- Heat Input at peak power
  - Motor (95% efficiency) = 3.5kW
  - Inverter (97% efficiency) = 2kW
- Radiator -> Triple bypass for maximum cooling performance
- Sensor Data on Test Bench
  - Flow Rate = 6.34 - 7.29 LPM
  - Temp Increase while Spinning Motor (No load) = 26→31 deg C
  - Pressure = Pending data collection







Cockpit/Controls/ Brakes/Safety

Driver interfaces, seat, belts, steering wheel, steering column, control panel/dash, cockpit sizing & protection, driver comfort/ease of control, shifter, pedals, braking system. Safety considerations. Selection and material use.

Pedals

Design Goals

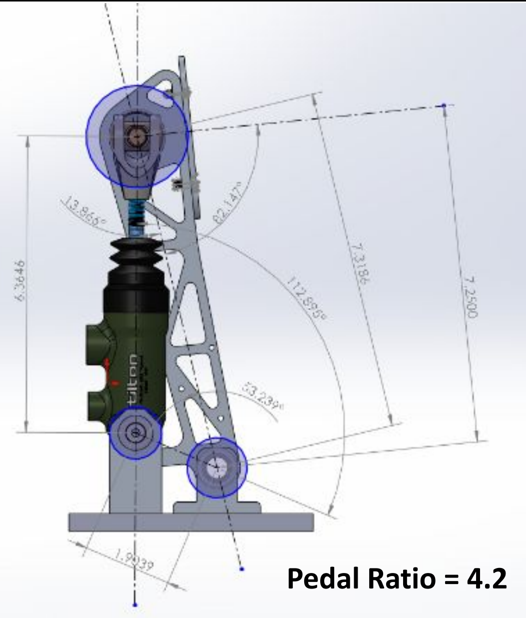
- **Meet Packaging Restraints:** 11x6 Baseplate, 98th percentile tall male & 5th percentile short female
- **Adjustability/Serviceability:** pedal rails allow easy movement for different height drivers, standard bolt size
- **Ergonomics/Simplicity:** initial pedal angles, pedal pad area
- **Reliability/Safe:** BOTS, sensor protectors, FEA's

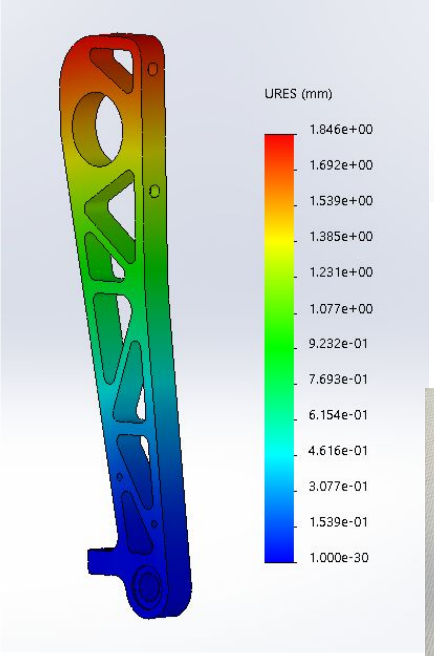
Materials

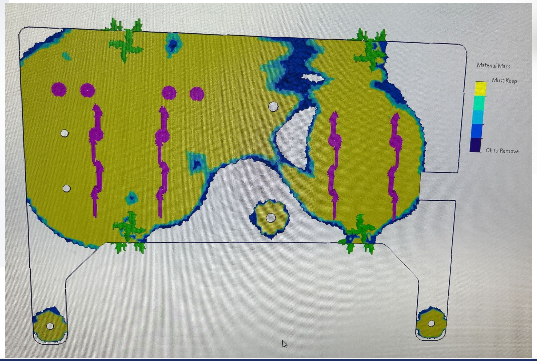
- 6061 aluminum baseplate
- Stainless steel pedal rails
- Carbon fibre heel rest
- EV West Billet Al APPS Sensor
- Brake System Encoder (BSE)
- Break Over Travel Switch (BOTS)
- Tilton 78-Series Master Cylinders

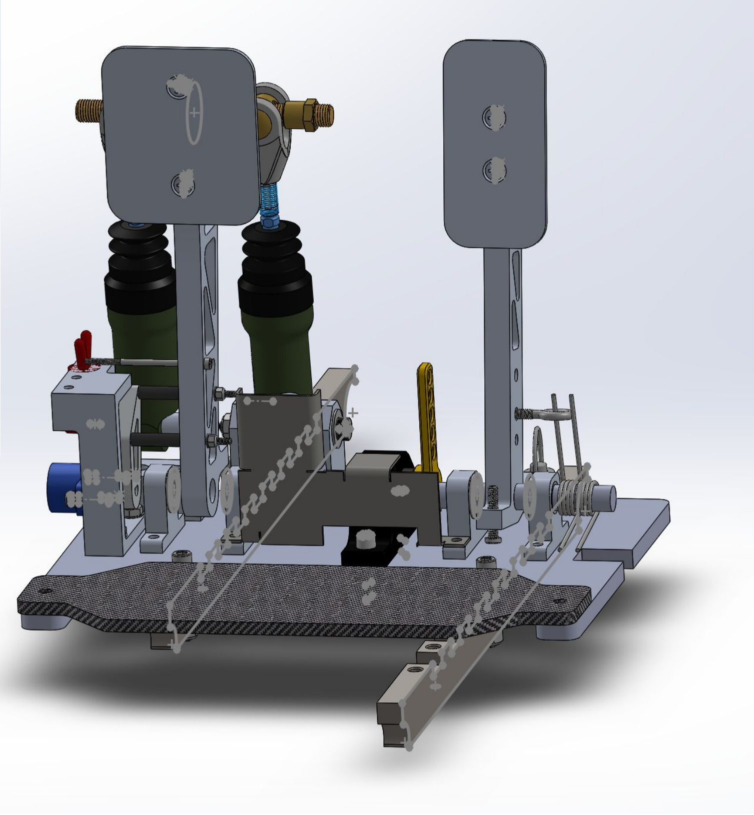
Analysis/Testing

- Minimum factor of safety: 2
  - Topology optimization test
- Driver's comfortability test, reasonably stiff throttle









Dashboard and Peripherals (LV Mounting)

Goals:

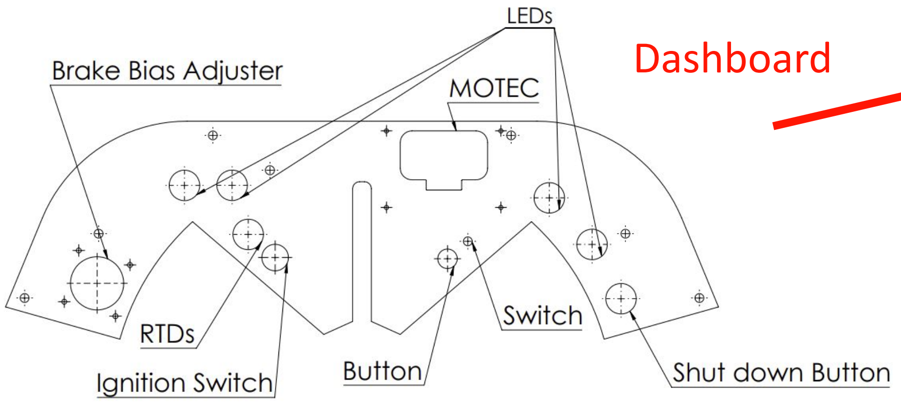
- Rigider mounting
- Waterproofing
- Stronger mounting material

Implementations:

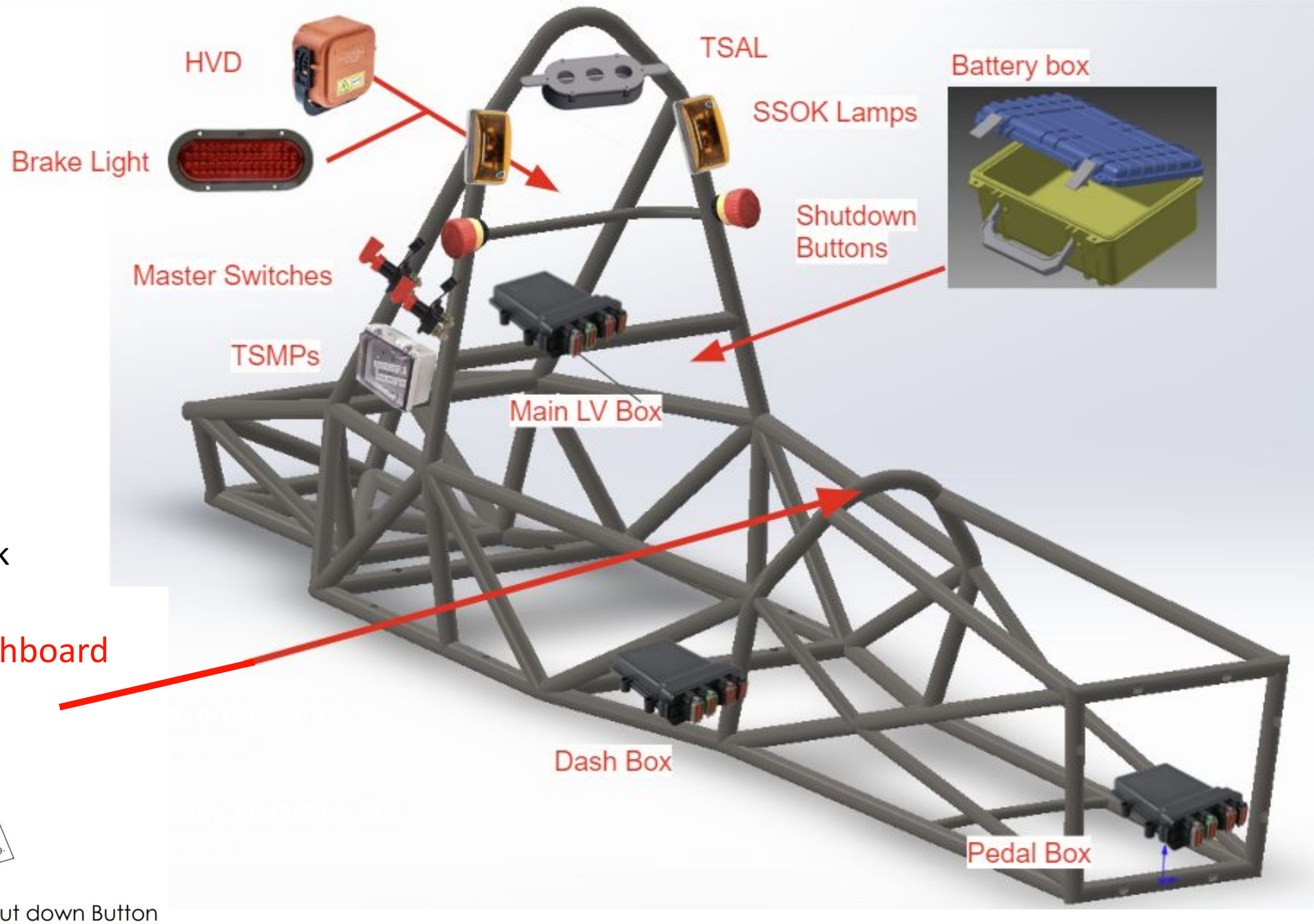
- Aluminum 6061 → dashboard
- Welded tabs over zip-tie

Test:

- Test LV components fit before machining final stock



Dashboard



Cockpit

Headrest

Carbon Fiber Backing
Foam Headrest

Goals:

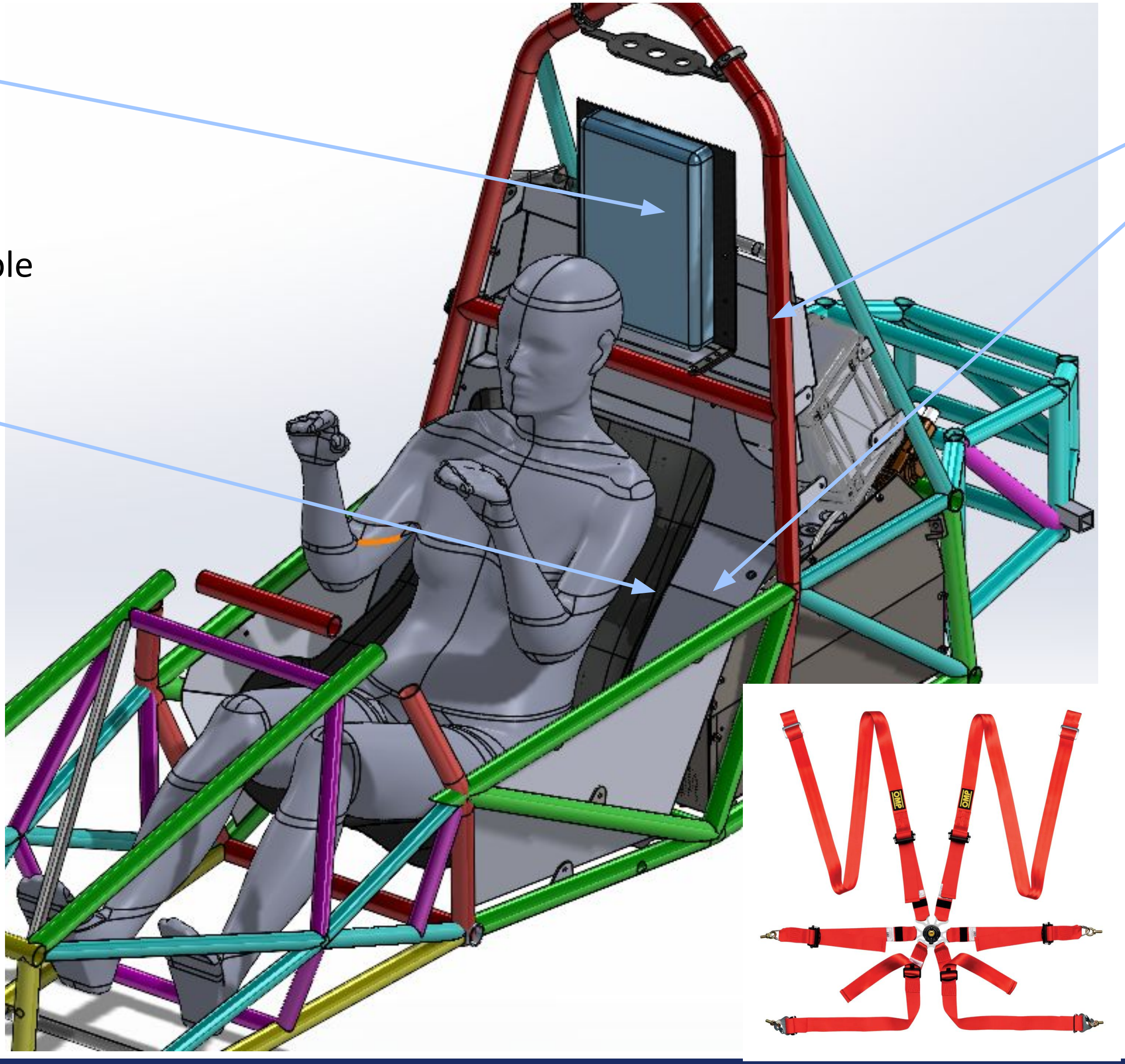
- Sturdily mounted and adjustable

Seat

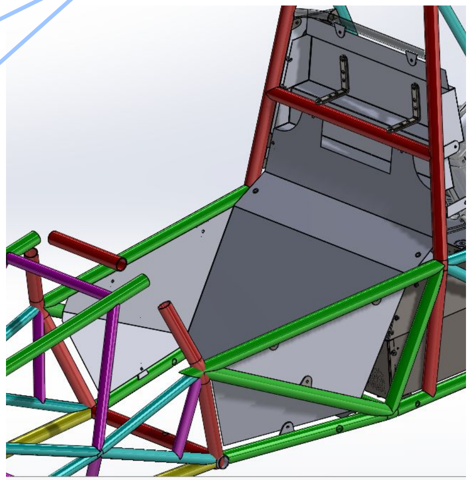
Carbon Fiber Shell w/ Creaform Molded Seat

Goals:

- Seatbelt is accessible
- No interference with belt and mounting points



Firewall



5052 Aluminum
Kydex 100 Insulation Material

Goals:

- Full coverage of cooling, electrical components and others for driver safety
- Accomodations for seatbelt and brake line routing and headrest mounting

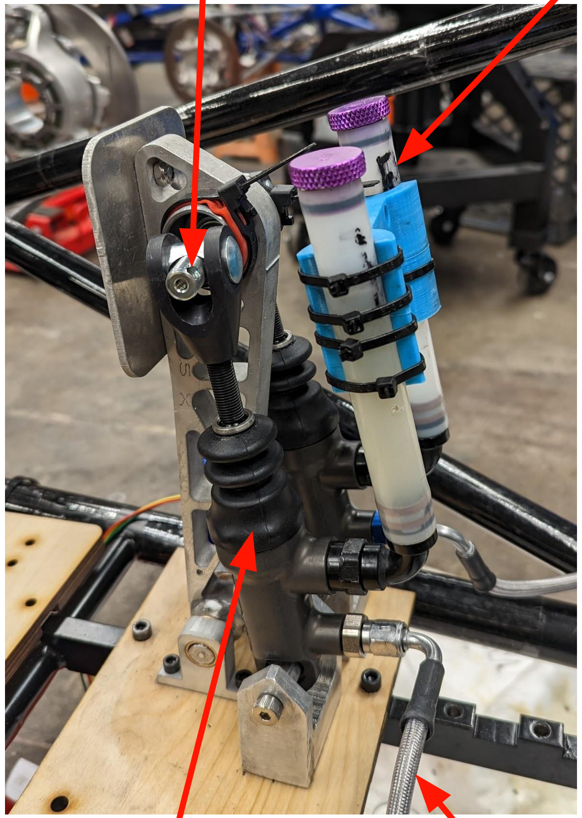
Brakes

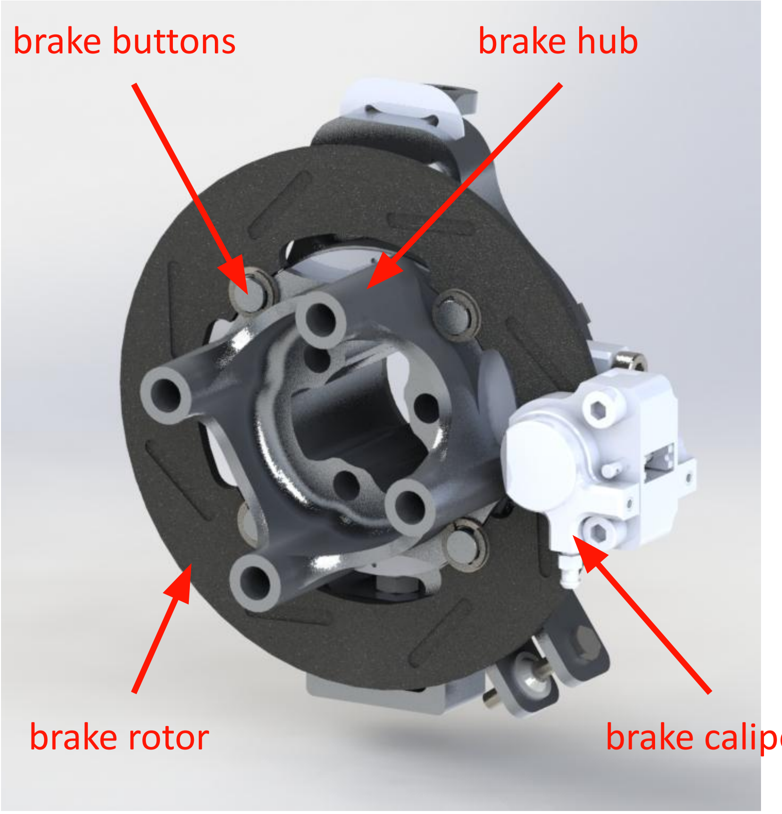
Design Goals:

1. Pass the Formula SAE IN.12 Brake Test
2. Robust and Reliable System

Hardware Specifications and Vehicle Spec/Parameters:

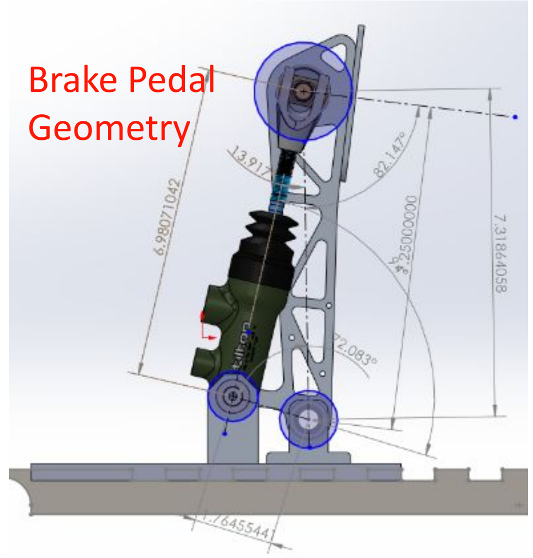
- Brake Calipers:
  - Front: 4 Piston, 25mm dia.
  - Rear: 2 Piston, 25mm dia.
- Rotors
  - 4.75mm Dura-Bar G2 Cast Iron

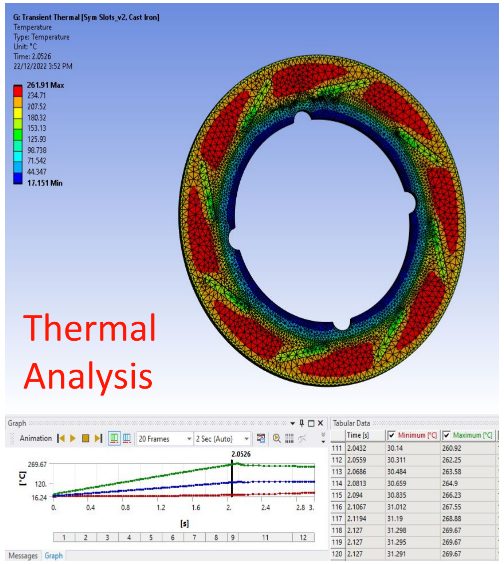


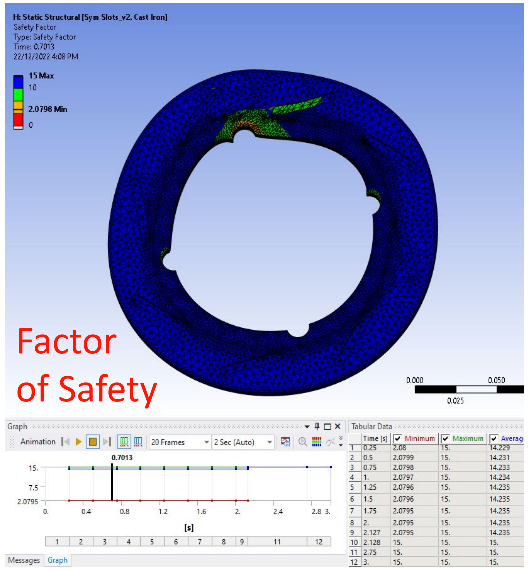


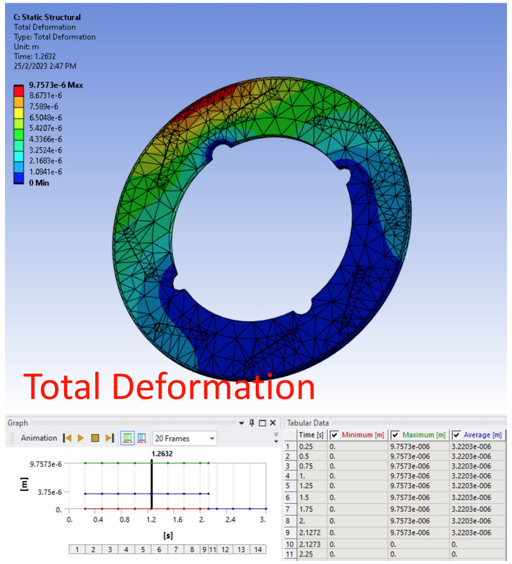
Brakes Analysis

- Master Cylinder (MC) specs:
  - front: 7/10” diameter
  - rear: 13/16” diameter
- MC Mounting
  - pedal geometry
    - pedal ratio: 4.16
    - Angle/mounting of master cylinder determines pedal ratio geometry
- Rotor analysis – minimum safety factor
  - Front: **2.309**
  - Rear: **4.8648**
  - Safety Requirement is met



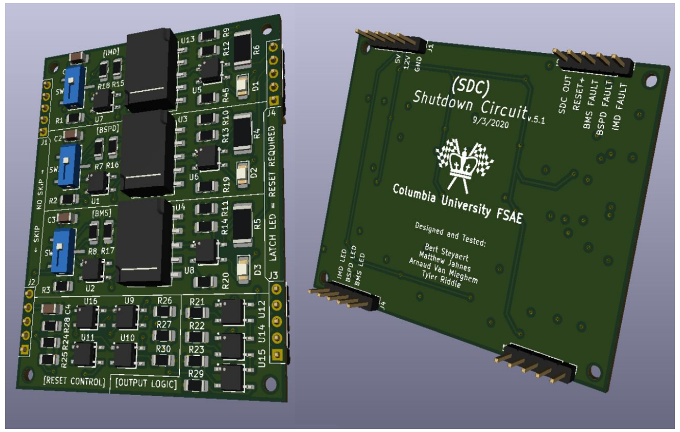


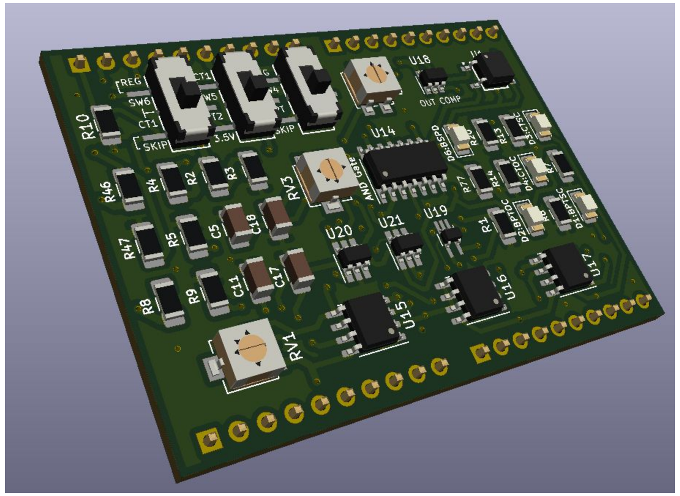




Shutdown Module and Switches

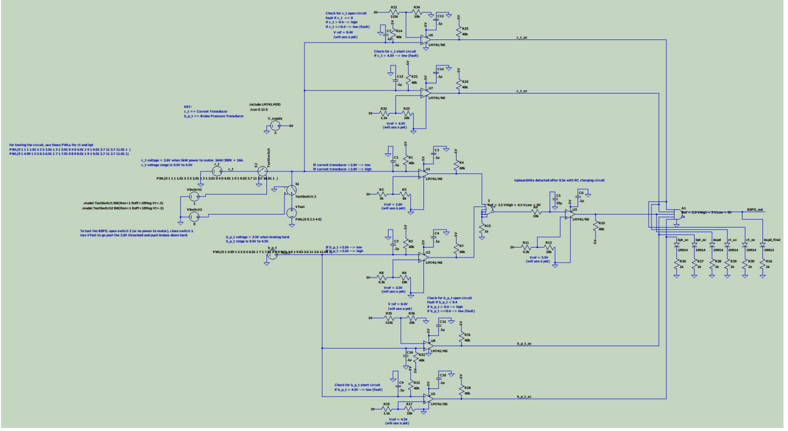
SDC and BSPD Circuits



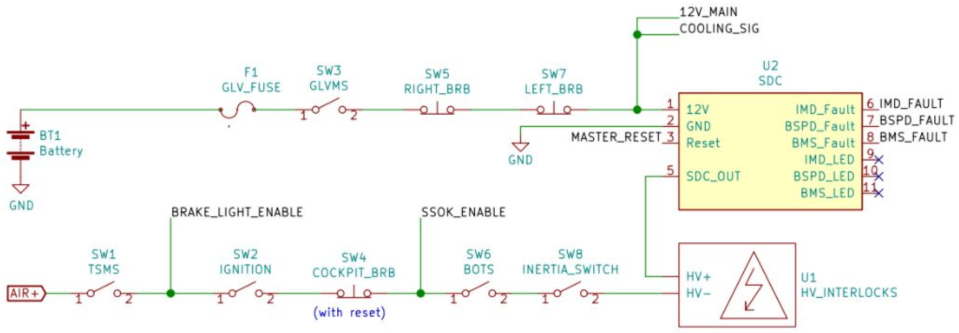


- Both the SDC (top) and BSPD (bottom) are designed with testing and packaging in mind
  - Switches and potentiometers allow for sensor simulation
  - SMT components and multilayer design allows for smaller packaging

- Operation of both boards verified on LTSpice with all possible fault conditions checked



Shutdown Loop



- Includes a car key switch for added safety

- A capacitor bank was added to the shutdown circuit to help provide the 100ms 1.3A spike required to initially flip the AIRs

- Faults on the shutdown loop are displayed to the driver through LEDs on the dashboard

Thank you!

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