ENGINEERING DESIGN PRESENTATION

FORMULA BHARAT 2025

E13-IITK MOTORSPORTS

Supporting Document

Insights from first FSEV testing (FB24)

Issues faced - FB24	Alterations - FB25
Steering geometry - The choice of 100% anti-Ackermann geometry caused excessive tire wear and made low-speed turning difficult.	Steering geometry was designed to obtain optimal slip angles during cornering by using tyre data.
Manufacturing errors - Error in chassis parameters, such as overall length and inaccurate tyre angles.	Improved manufacturing processes, such as laser cut metal fixtures and shims, to achieve accurate tyre angles.
Mechanical failure - Hub failure during cornering, rotor failure during braking (improper mounting) and rod end failure in control arms.	Designing was done while accounting for these and all other possible failure cases and maintaining an FOS>1.5.
Compliance issues - Poor routing of low voltage and high voltage wire harness, causing interference with mechanical components and accumulator.	Using motion planning for better routing the harness to increase reliability of low voltage connections.

Vehicle Goals

Dynamically Balanced Vehicle

- Unsprung mass reduction by ~ **4 Kg**
- Ride frequency set to **1.9 Hz**
- Increasing straight line stability for better handling
- Reduction in CG height by **22%**

Reliability and Efficiency

Acceleration and Speed

Vehicle Goals

Dynamically Balanced Vehicle

Reliability and Efficiency

- Fatigue life > **10^6** for all major moving components
- FOS > **1.5** for all primary components
- Endurance energy consumptions < **3.7 Kwh**
- Improved **thermal management** of accumulator

Acceleration and Speed

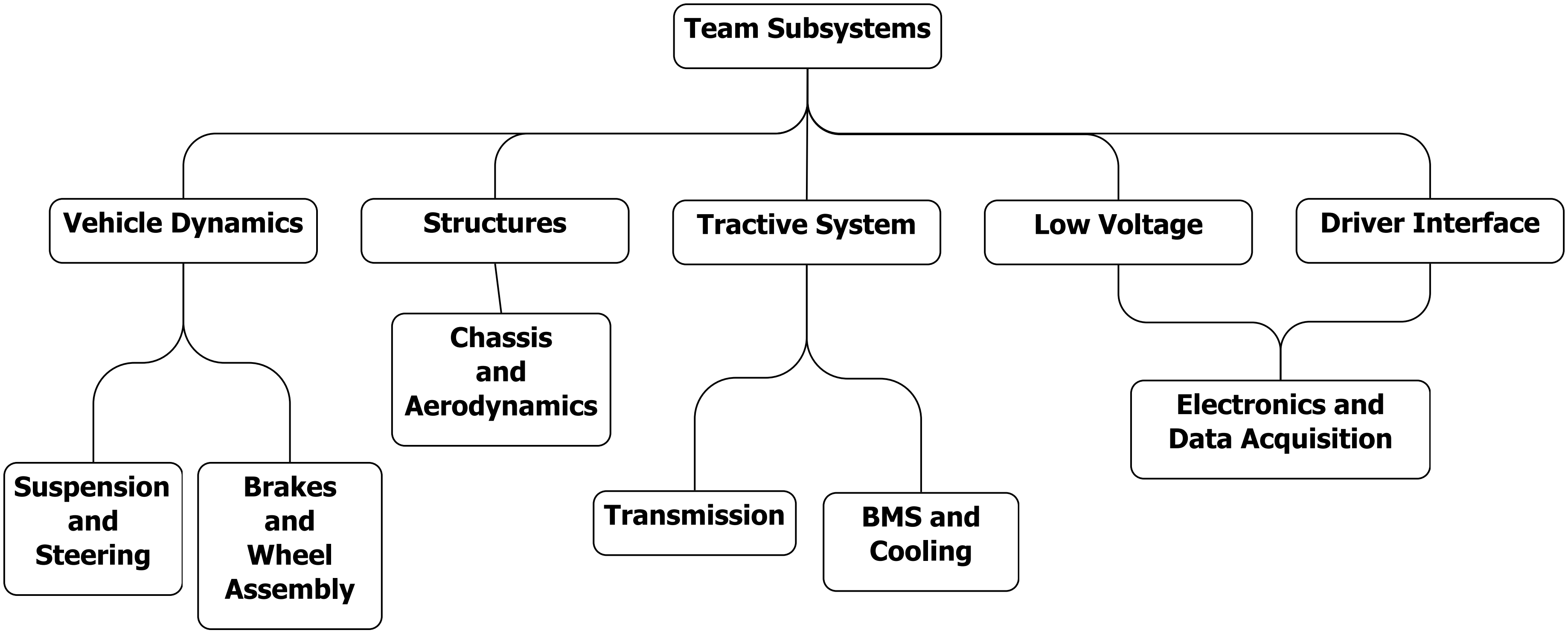
Vehicle Goals

Dynamically Balanced Vehicle

Reliability and Efficiency

Acceleration and Speed

- Weight reduction by ~ **20 Kg**
- Gear ratio of **4.7** for better acceleration
- Optimal slip angles for better cornering resulting in better skidpad and autocross times
- Drag coefficient of **- 0.58** for better acceleration and efficiency


Team Subsystems
Vehicle Dynamics
Structures
Tractive System
Low Voltage
Driver Interface
Suspension and Steering
Brakes and Wheel Assembly
Chassis and Aerodynamics
Transmission
BMS and Cooling
Electronics and Data Acquisition

Subsystem Vehicle Coherence

Vehicle Goals ⟶ **Constraints** ⟶ **Derived Subsystem Goals**

Vehicle Goals

1. **Dynamically Balanced Vehicle**
2. **Reliability and Efficiency**
3. **Acceleration and Speed**

Constraints

1. **Reuse Decisions** :
   a. Dampers, Master cylinders, Calipers
   b. Motor and differential
   c. Same cells and capacity
   d. BMS
2. **Availability of raw materials**
3. **Technical Limitations**
4. **Financial Constraints**

Derived Subsystem Goals

Chassis And Aerodynamics
- Compact packaging
- CG height reduction **50 mm**
- Minimizing manufacturing errors
- Reducing drag coefficient

Brakes And Wheel Assembly
- Factor of safety > **1.5**
- Unsprung mass reduction by **~ 4 Kg**
- Increasing peak deceleration to **1.6 g**
- Effective thermal management

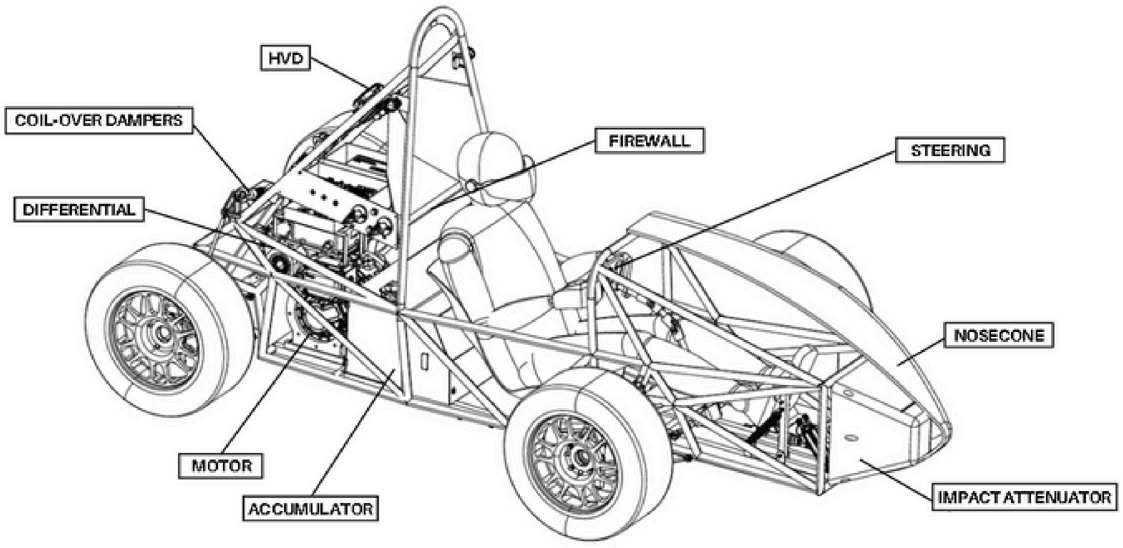
BMS and Cooling
- Weight reduction by ~ **9 kg**
- Ease of maintenance
- Rapid troubleshooting
- Effective thermal management
- Optimal packaging of segments

Suspension And Steering
- Minimum turning radius< **3 m**
- Peak steering torque<**7.5 Nm**
- Optimal slip angles during turning
- Preventing bottoming out

Powertrain
- Optimal gear ratio selection for finishing endurance with 3.7kWh
- Acceleration time < **6 seconds**
- Weight reduction by ~ **2 Kgs**
- fatigue life > **10^6 cycles**

Electronics + DAQ
- Reliable PCB design and **signal integrity**
- Robust wiring and connections
- Reliable **data acquisition** and displaying relevant data

Overall System Specifications

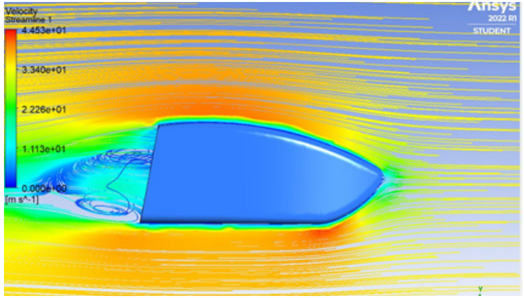


Overall Vehicle CAD

Car Parameters	Specification
Top Speed (simulated)	100 km/h
Maximum Acceleration/Deceleration	0.7 G/1.6 G
Motor Torque/Power	140 Nm/30 kW
Vehicle weight	230 Kg
Battery Voltage	100.8 V (Peak)
Battery Capacity	3.7 kWh
Battery Configuration	24s2p in 3 segments
Final Drive Ratio	4.7

Tools

Computational and Analytical Tools



Experimental Validation

Computational and Analytical Tools

- **Design, Assembly and Analysis** — Solidworks and Ansys
- **Ensuring Structural integrity** — Ansys
- **Mathematical modelling of suspension, brakes, cooling systems** — MATLAB
- **Dynamic modelling and simulation** — Lotus Shark, OptimumLap, MicroCap
- **Configuration** — Orion CAN, Tsuyo Controller Software

Experimantal Validation

- **Individual components testing** — Material strength, cell performance, circuits, dampers
- **Prototype model** — PVC tubes chassis, 3D printed components
- **Integration** — Motor <---> Accumulator integration, circuits integration, suspension system
- **Complete vehicle testing** — Using DAQ to analyse performance validating overall vehicle concept

Some Notable Experiments

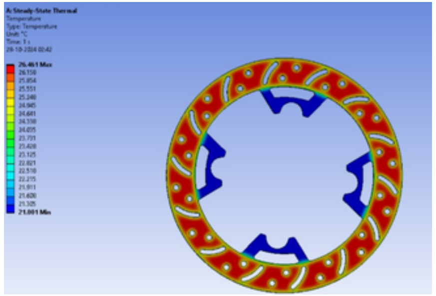
Endurance Testing

Aim: To check the maximum drivable range on full charge for our first FSEV (FB24)

Initial Voltage - 96V
Final Voltage - 83V
Total distance driven - 25km
Average speed ~ 6.5 m/s

Thermal Validation Of Rotor

Aim: To validate the thermal model for rotor temperature via brake test of our first FSEV (FB24)



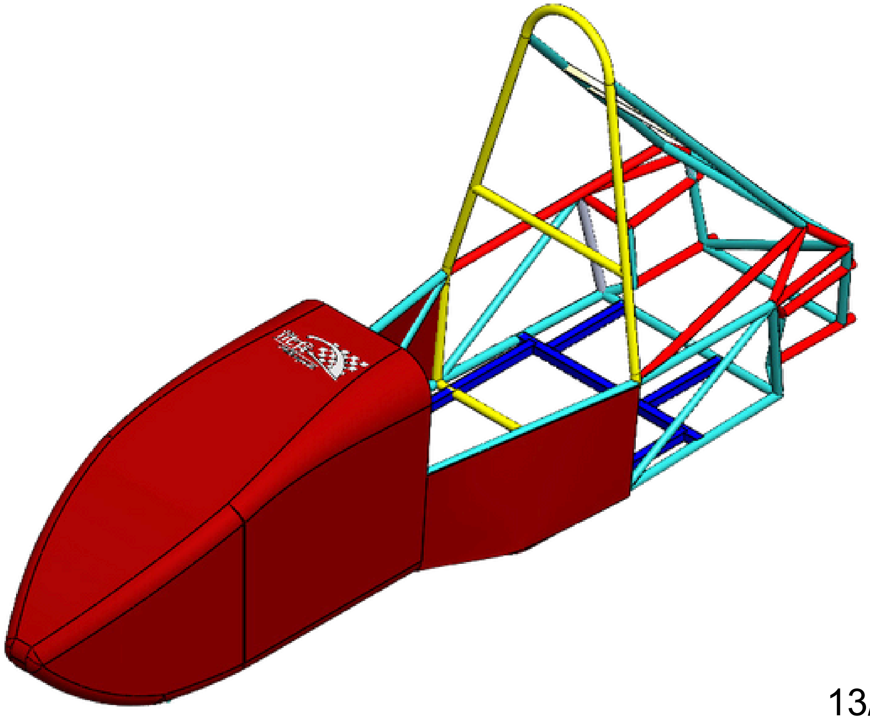
Initial Temp - 22 C (ambient)
Simulated Temp - 26 C
Actual Temp - 25 C

PVC Chassis

Aim: To check ergonomics and rulebook compliance of our chassis

Link to Vidyut's testing datasheet

CHASSIS AND AERODYNAMICS



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Vehicle Goals → **Constraints** → **Derived Subsystem Goals**

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Design Methodology

Feedback from last year :

- Manufacturing errors
- Packaging issues
- Driver ergonomics

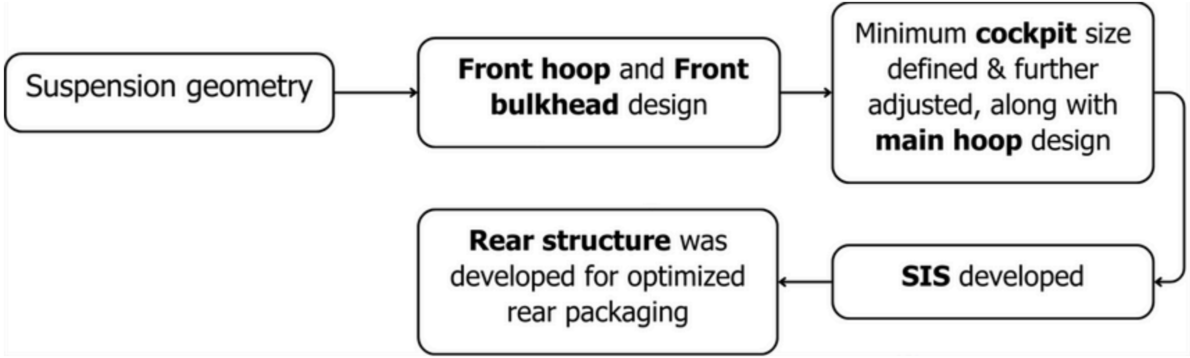
Chassis Material Selection

To determine the material for the chassis, we assigned weightages to the various factors of judgement for available materials

Alloy	Density (0.25)	Yield strength (0.35)	Availability and Price (0.25)	Weldability (0.15)	Score
AISI4130	**10**	**10**	**9**	**8**	**9.45**
AISI1018	10	8	10	10	9.3
AISI1015	10	7	5	9	7.55

*The multi-criteria-decision-making (**MCDM**) process was employed to evaluate the alternatives

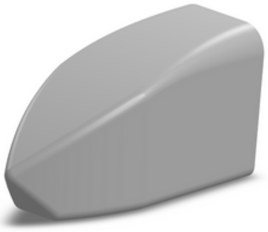
Design process:



Bodyworks (Nose Cone & Side Panel)

Lowering the height of the tip

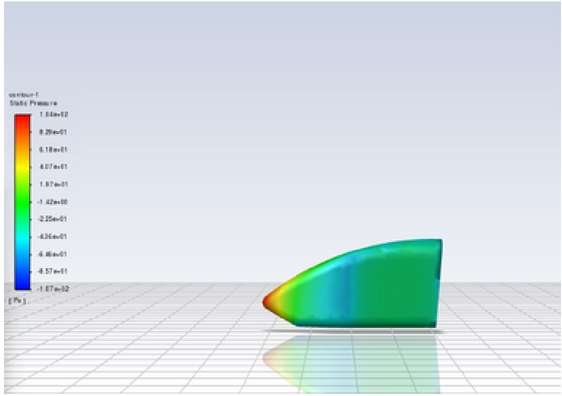
Reducing the frontal area

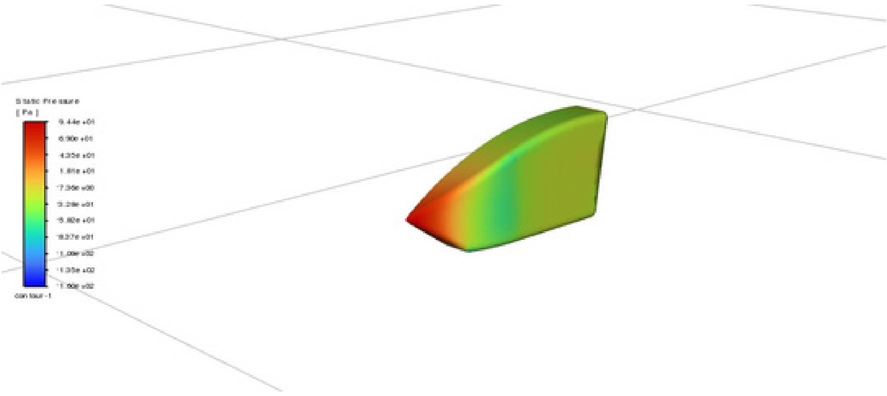


Rounding lower surface

Adding more fillets for smoothness

Simulations





pressure contours around nose cone

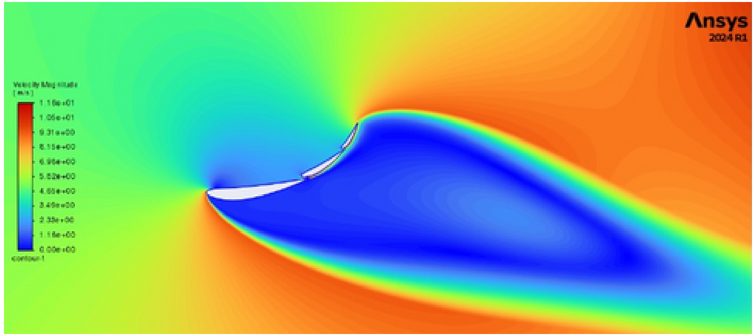
Rear Wing and Front Wing

Rear Wing profile
Using NACA 6412 airfoil profile

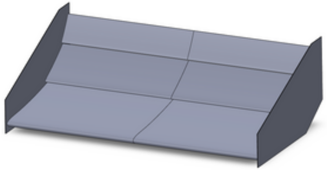
Front Wing profille
Using NACA 4412 airfoil profile

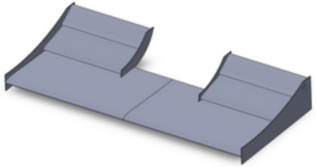
- NACA 6412 and NACA 4412 airfoil profiles were chosen for Rear Wing and Front Wing respectively.
- Profiles with large thickness and camber were avoided to reduce overall weight and for manufacturing ease.

Simulations



Velocity contour on rear wing





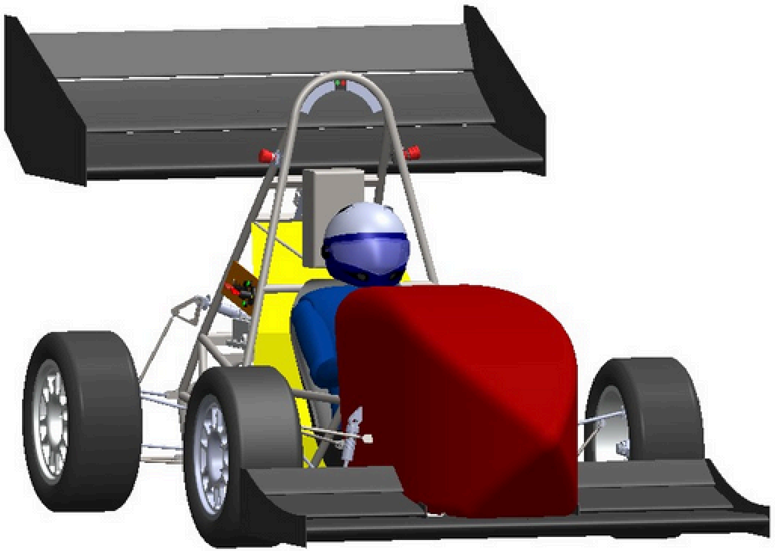
Rear Wing	
Cl	**-2.47**
Cd	**1.01**
Cl/Cd	-2.45

Front Wing	
Cl	**-2.13**
Cd	0.88
Cl/Cd	-2.42

Rear Wing and Front Wing Limitations

While the wing designs yielded some satisfactory results, the **disadvantages outweighed the benefits** due to the following factors :

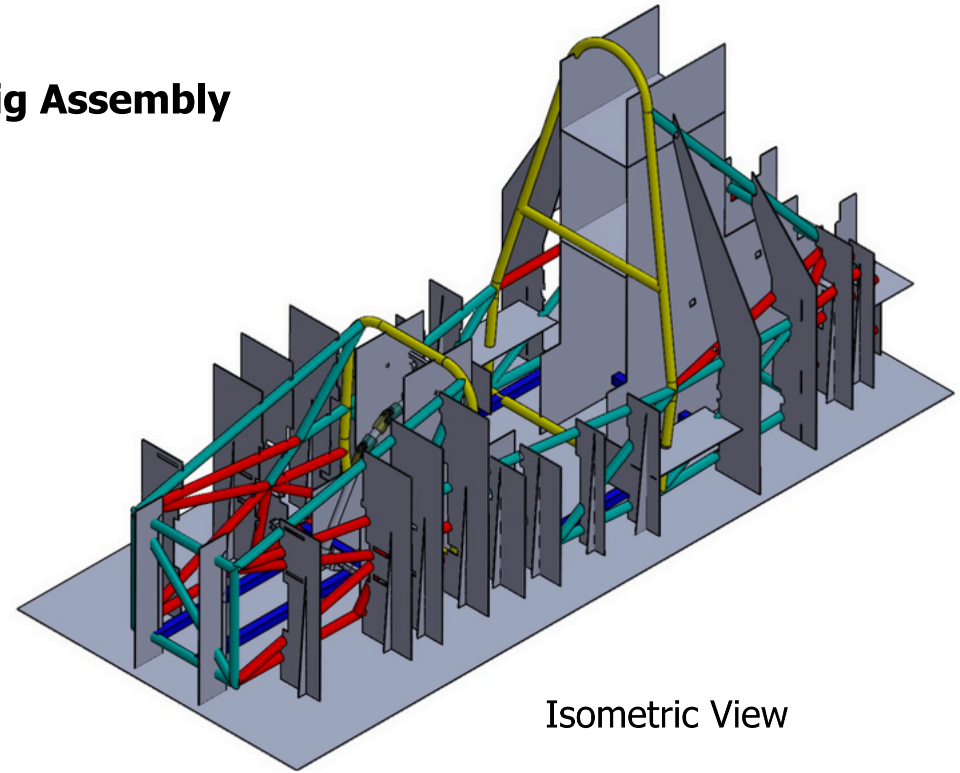
- Increased drag force along with limited energy capacity, led to increased energy consumption **~ 0.3 kWh** for endurance.
- Minimal lap time improvement, offset by additional weight **~ 0.2 second (per lap)**
- Budgetary and manufacturing constraints.



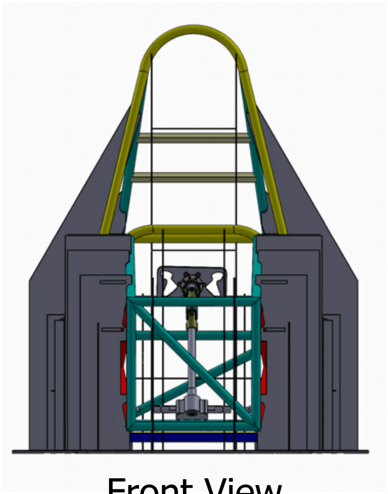
Our team has chosen **not** to use the front and rear wings.

Metal Jigs Design for Manufacturing

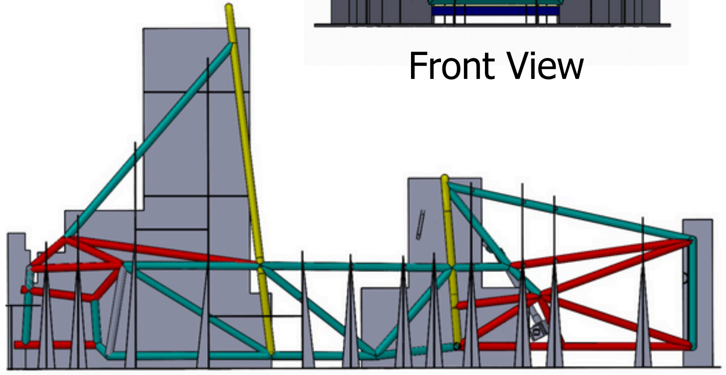
Jig Assembly



Isometric View



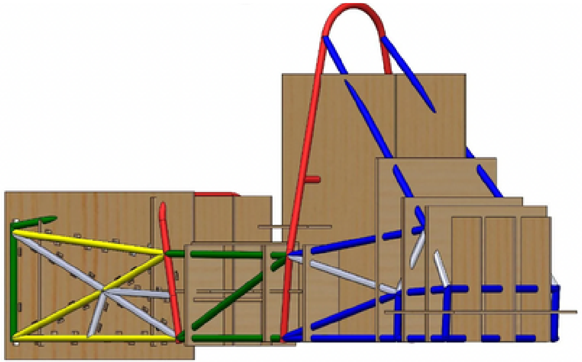
Front View



Side View

Shift to Metal Jigs

	Chassis FB24	Chassis FB25
Dimension	Error Percentage (%)	
Chassis length	0.8904	0.1580
Main hoop bottom to rear most point	1.4475	0.4149
Front bulkhead bottom to bottom of front hoop	2.09329	0.4804
Height of front hoop	5.0098	0.6139
Height of main hoop	12.7452	0.6320

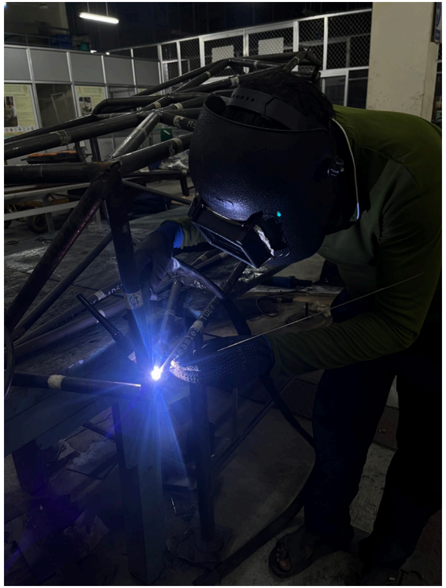


Wooden Jigs (FB24)

Metal Jigs (FB25)

Design for Manufacture

Assemble Front Bulkhead and FBHS jigs → Assemble Front Bulkhead and FBHS tubes → Assemble SIS Jigs along with placement of Main Hoop → Assemble SIS tubes along with jigs behind Main Hoop → Assemble Rear Bulkhead and Impact structures tubes



TIG Welding

- TIG welding with **ER70S-2** filler rods for chassis tubes, enhancing weld quality

Node optimisation using MATLAB

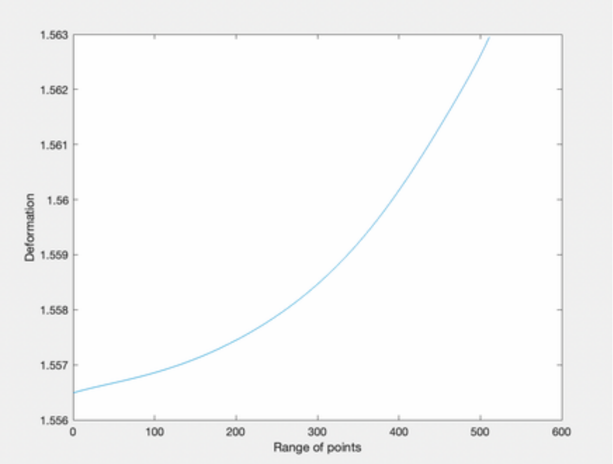
Code iterations to obtain positions of nodes with least deformation

Outputs:

Q: internal forces and moments in the local coordinate system at end and beginning nodes (for chassis members)

V: deflections in global coordinate system (for each node)

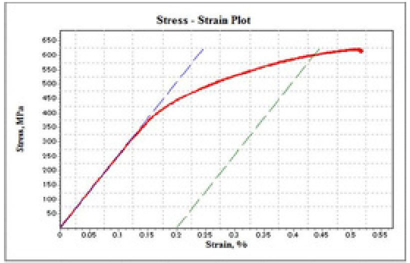
R: reactions at each node in global coordinate system



Deformation Vs Node position

Validation Emphasizing Physical Testing

Peak Stress	301.5 MPa
Peak Load	51.714 kN
0.2% Offset Yield Stress	210.858 MPa
Yield Strain	0.345 %
Yield Load	36.584 kN
Modulus	146.29 GPa
Elongation at Break (Using Strain)	11.949 %

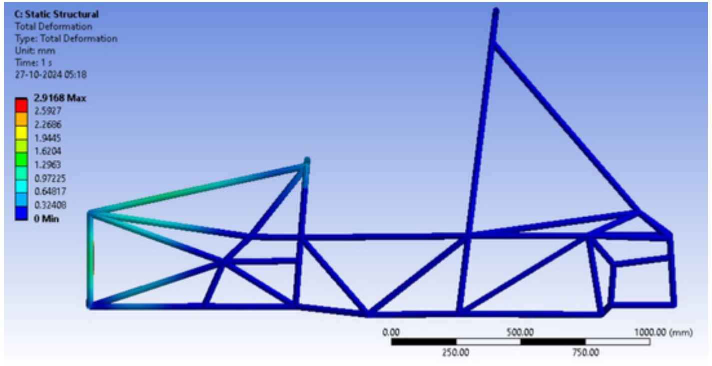


Peak Stress	624.785 MPa
Peak Load	59.399 kN
0.2% Offset Yield Stress	602.709 MPa
Yield Strain	0.436 %
Yield Load	57.3 kN
Modulus	254.011 GPa

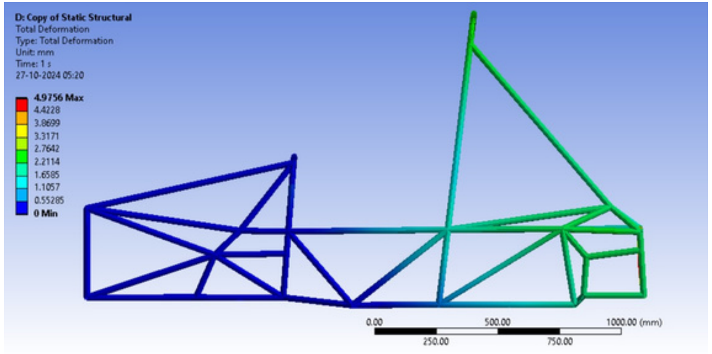
The testing was done on a BiSS 100 kN UTM Hydraulic Machine

FEA Frame Impact Analysis

Type of Test	Loading Conditions	Boundary Conditions	Max. Deformation	Max. Stress	Factor of Safety
Front	27.78 kN at Front Bulkhead	Simply supported at Rear Bulkhead	2.9 mm	363.62 MPa	1.7
Rear	27.78 kN at Rear Bulkhead	Simply supported at front VD points	4.9 mm	355.3 MPa	1.5

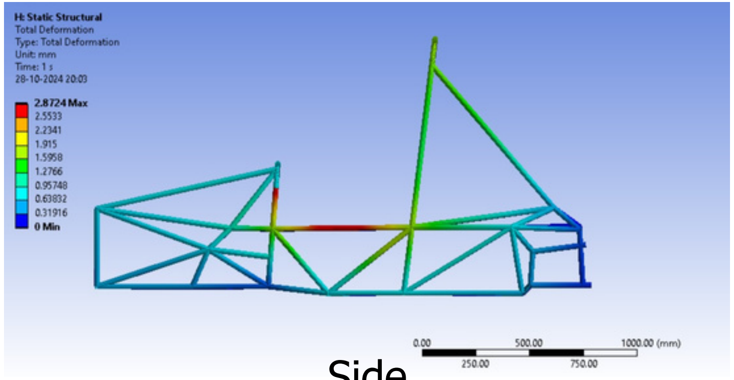


Front

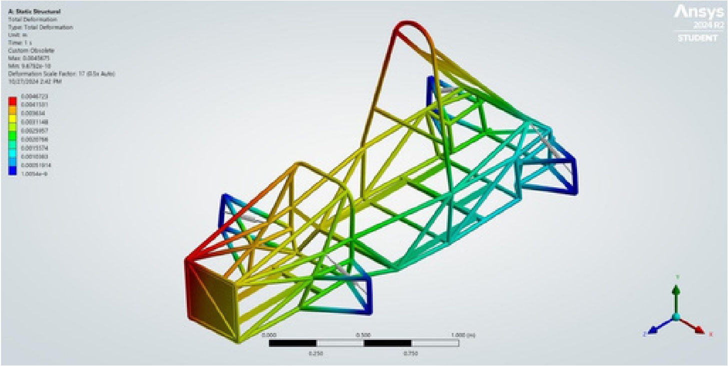


Rear

Type of Test	Loading Conditions	Boundary Conditions	Max. Deformation	Max. Stress	Factor of Safety
Side	18.05 kN at critical locations in Side structure	Simple support at other side inboard points	2.8mm	211.2 MPa	2.4
Cornering & Braking	1.5 G lateral acceleration	Uprights fixed	4.6 mm	362.2 MPa	1.5



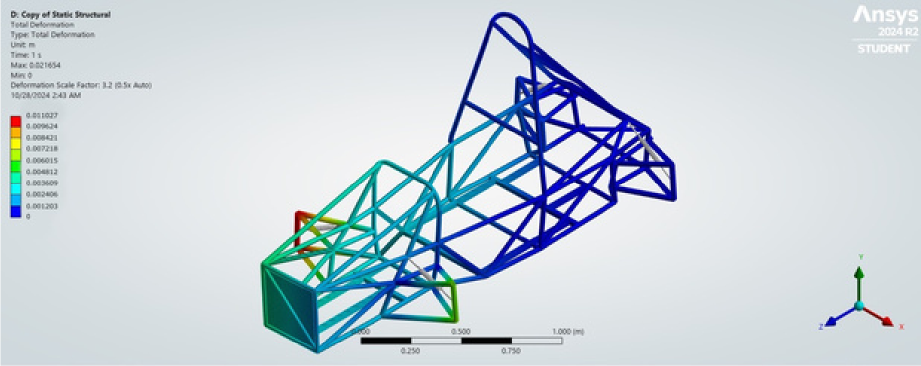
Side

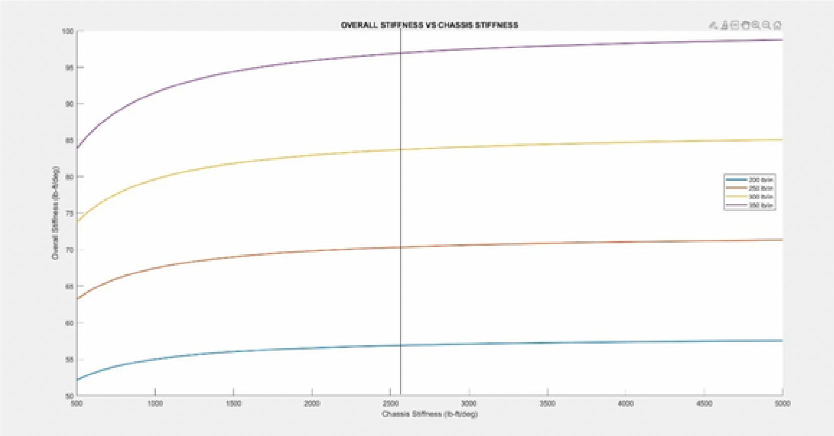


Cornnering & Braking

Torsional Stiffness

Applying coupled force of 3000N through remote force on the A arms





$\theta =$ *Angle of Deflection*

= tan-1 (Vertical displacement / 0.5* Track width)

= tan-1 (11 / 585)

= `1.07 degree

Torsional Stiffness (k) = Torque/ Angle of deflection

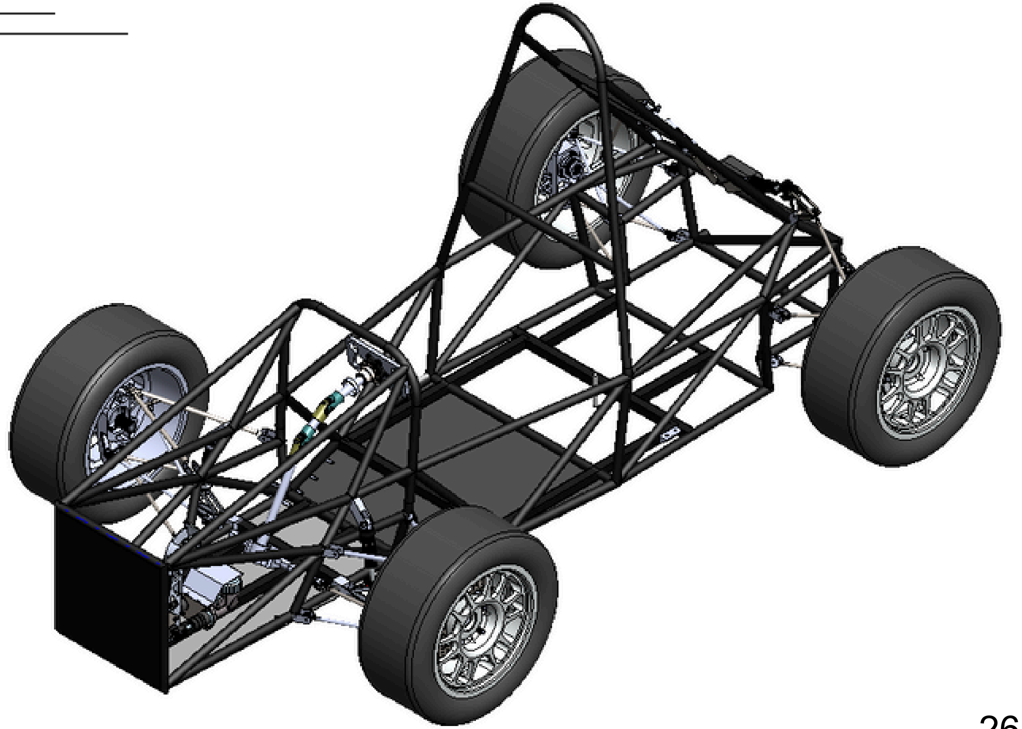
= 3510/ 1.07 = 3259 Nm/degree

Torsional Stiffness (k) = **2401** lb-ft/degree

Overall Stiffness vs Chassis Torsional Rigidity
This shows the saturation where stiffness remains unaffected with increase in torsional rigidity

200 lb/in
250 lb/in
300 lb/in
350 lb/in

SUSPENSION AND STEERING



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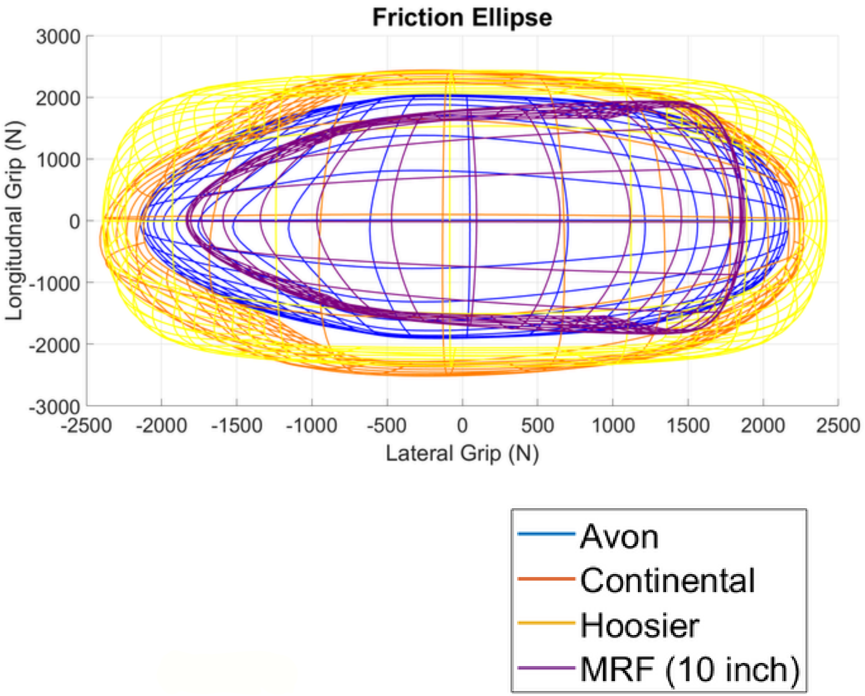
Tire Selection Process

	Hoosier	Continental	Avon	MRF
Lateral Grip	**10**	8	6	5
Longitudinal Grip	**9**	10	8	7
Combined Grip	**10**	8	7	8
Cornering Stiffness	**10**	7	6	9
Load Sensitivity	**10**	5	9	9
Total	**49**	38	36	38

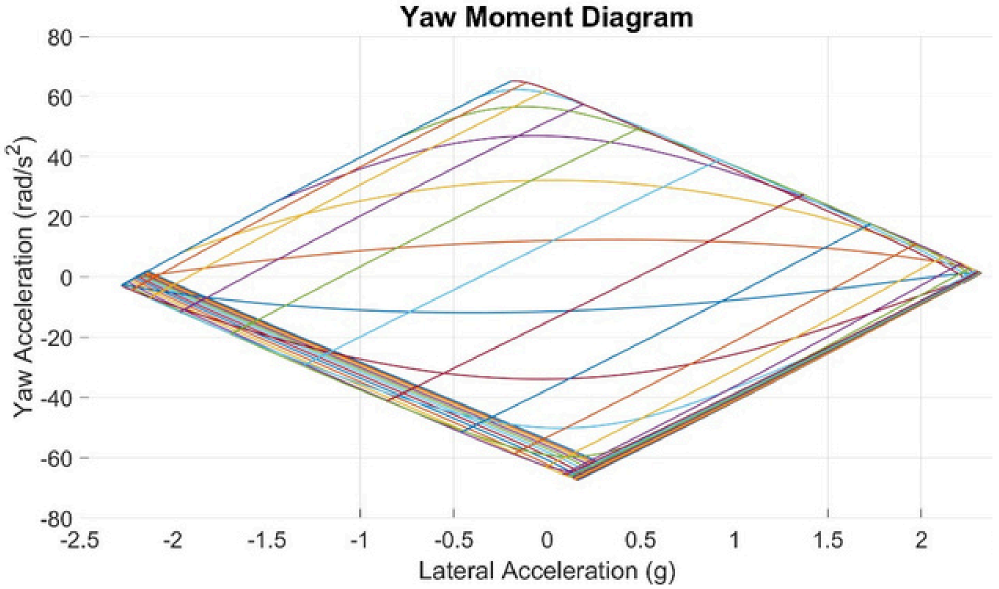
Hoosier 20.5 x 7.0 – 13 R20 were chosen following the above Co-factor Table

Friction Ellipse for normal Force of 1000N



YMD and Derived Parameters

Track Width	1170 mm (front) 1160 mm (rear)
Wheelbase	1545 mm
% Ackermann	-30%
Centre of Gravity	173 mm (height) 831 mm (distance from front axle)



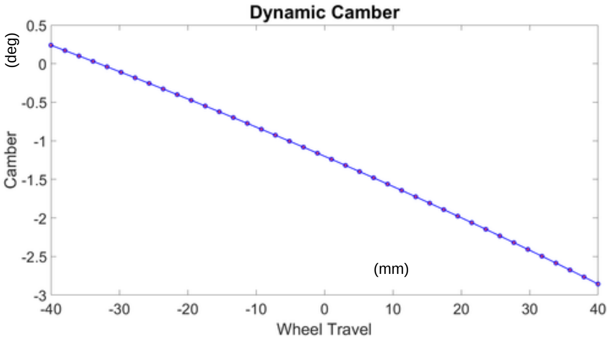
Yaw Moment Diagram generated for a constant radius equivalent to a skidpad circle

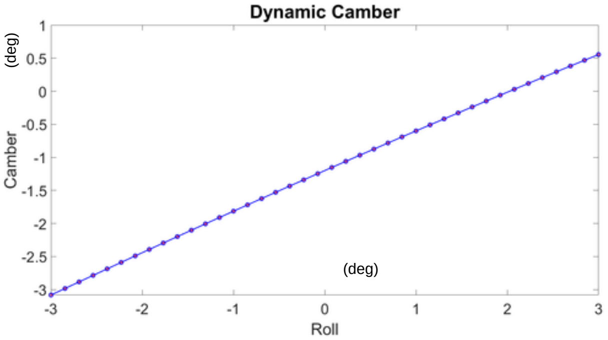
Selection of Suspension Concept

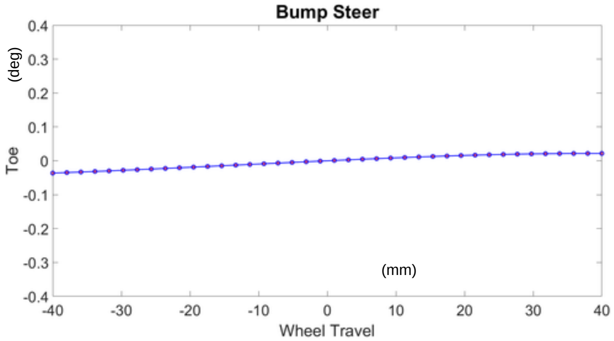
Aspect	MacPherson Strut	Double Wishbone	Multi-Link
Complexity	Simple and compact with fewer components	**More complex than MacPherson Strut; requires additional components**	Most complex; includes multiple links and pivot points
Handling & Stability	Adequate handling but may have more body roll	**Excellent handling with good stability during cornering**	Best handling; allows fine-tuning of suspension for specific conditions
Adjustability	Limited adjustability; mainly for camber and height	**Highly adjustable, allowing fine-tuning of camber, castor and toe**	Extremely adjustable, suitable for advanced suspension tuning

Kinematic Analysis of Suspension Geometry

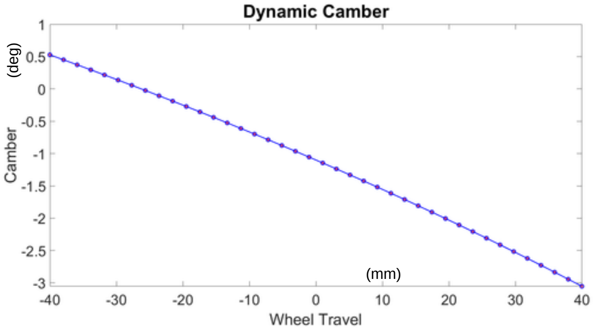
Front Geometry

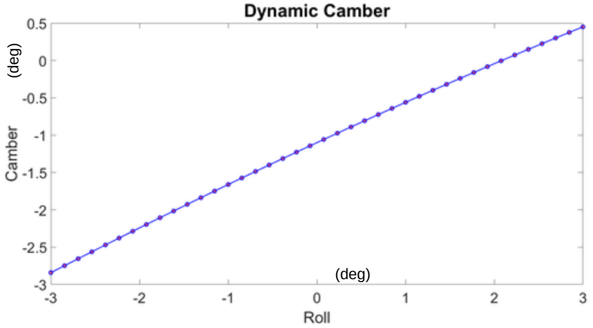


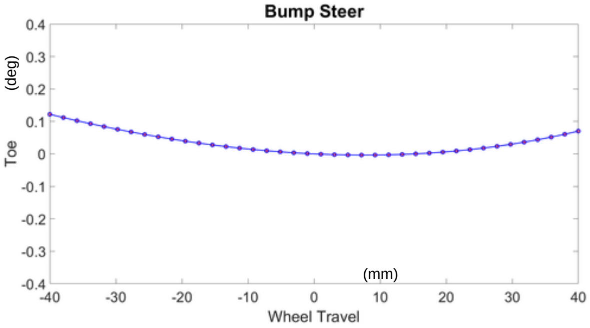




Rear Geometry







Kinematic Parameters

Wheel Alignment

Side	KPI	Camber	Castor	Static Toe
Front	3.9°	-1.1°	2.8°	0°
Rear	3.3°	-1.1°	0°	0°

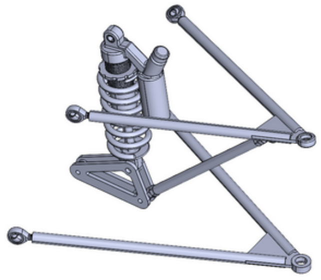
Car Parameters

Side	Roll Center	Pitch Center	Ride Height
Front	28mm	75mm	71.3mm
Rear	33mm	75mm	71.3mm

Selection of Spring Damper Assembly

Aspect	Direct Actuation	Push/Pull Rod
Adjustability	Less adjustable; changes require part replacement and offers limited motion ratio	**Highly adjustable for ride height and motion ratio**
Weight and Complexity	Heavier and simpler with fewer components	**Lighter but more complex with additional rods and parts**
Load Distribution	Load is directly transferred to the damper	**Distributes load more evenly through rods, reducing stress on specific points**

The team opted for a **pull rod assembly** in the front and a **push rod assembly** in the rear



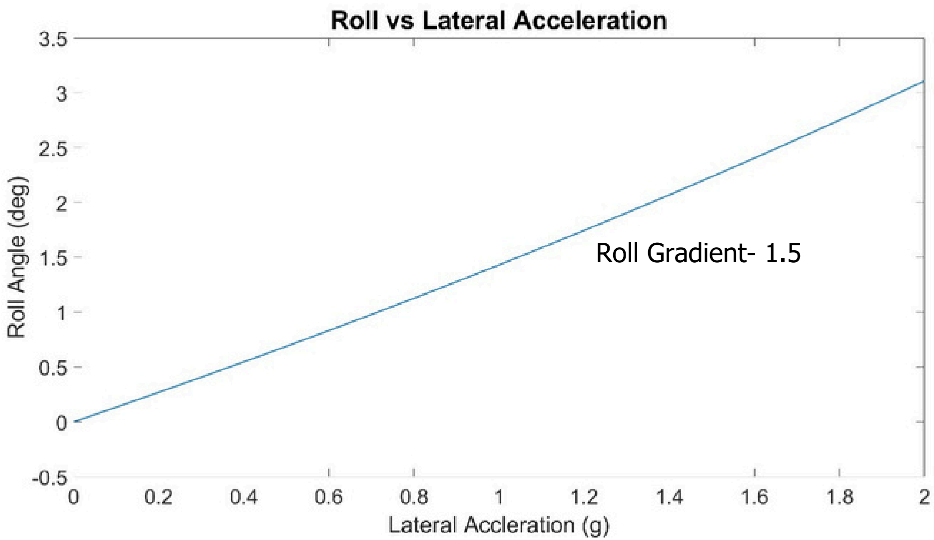
Front Assembly

Rear Assembly

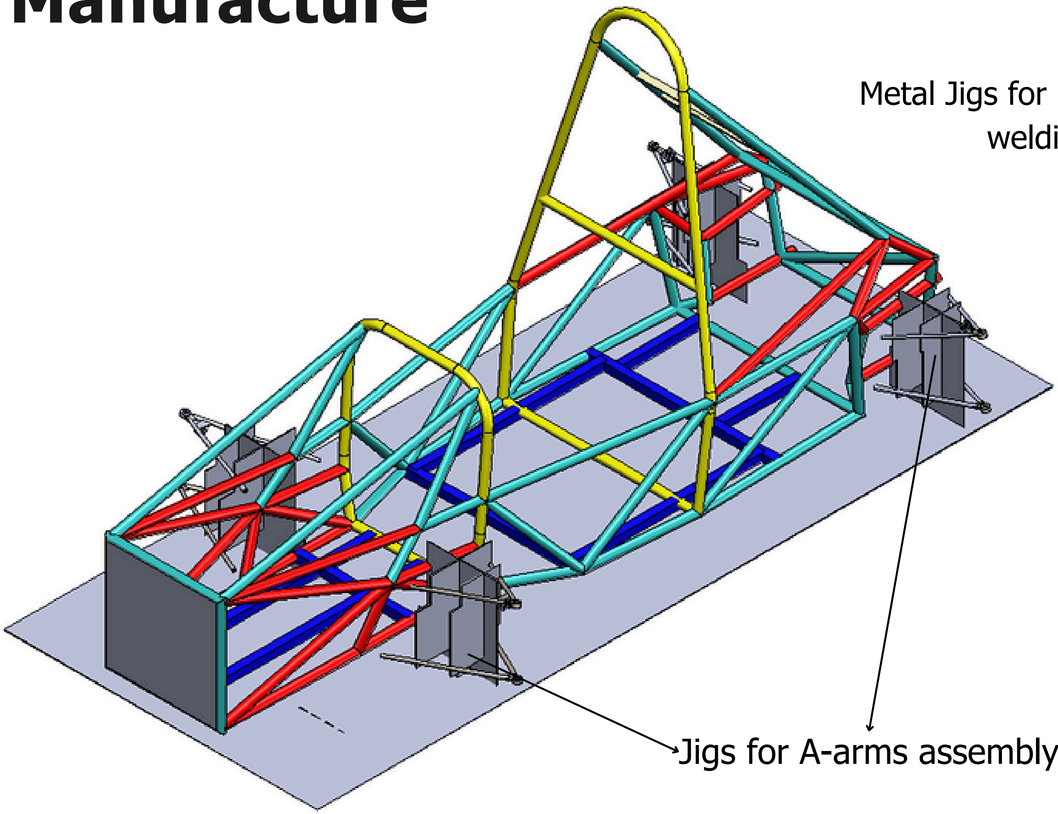
Vertical Dynamics

Quasi-static analysis of the actuation geometry was performed utilizing kinematic results which gave us the ideal spring constant, along with ride and roll rates for the same.

	Front	**Rear**
Motion Ratio	0.615	0.61
Spring Stiffness	225 lbs/in	250 lbs/in
Ride Stiffness	14858 N/m	16504 N/m
Roll Stiffness	10035 Nm/rad	11104 Nm/rad
Anti Geometry	30%	40%



Design for Manufacture



Metal Jigs for improved accuracy and ease of welding of suspension tabs

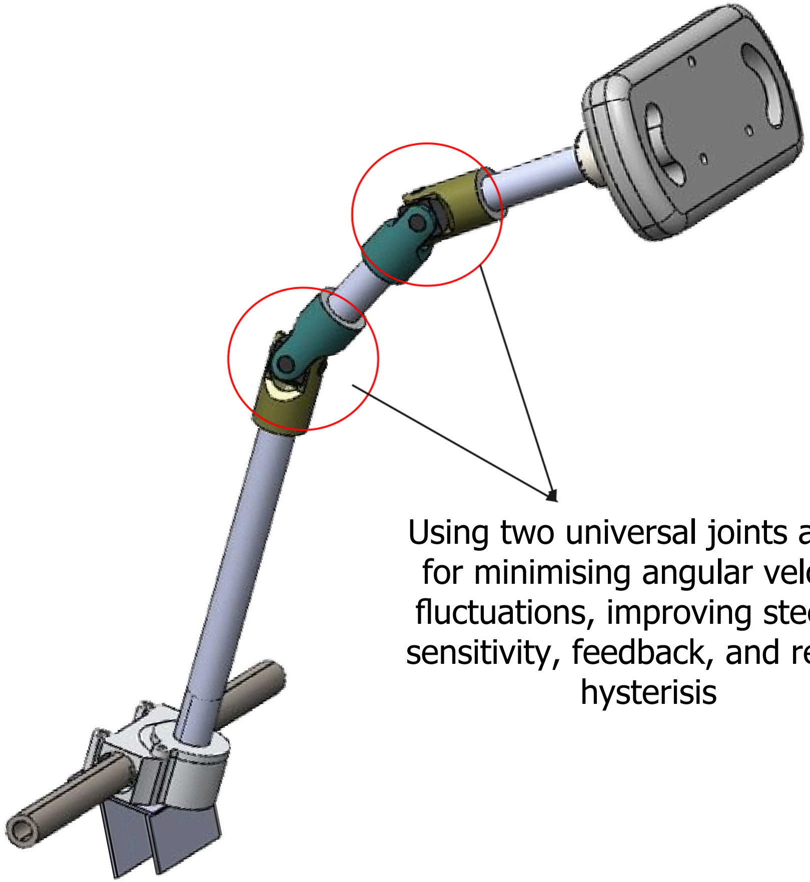
Jigs for A-arms assembly

Selection of Steering System

Aspect	Rack and Pinion Steering	Worm Gear Steering	Recirculating Ball Steering
Complexity	**Simple design with fewer components**	Simple and robust, but requires a large gearbox	More complex due to the ball bearings and internal mechanisms
Steering Precision	**Highly precise with direct response**	Less precise due to the mechanical play in the worm gear	Good precision; less direct than rack and pinion but better than worm gear
Size and Weight	**Compact and lightweight, ideal for smaller vehicles**	Larger and heavier; used in older or heavy vehicles	Bulkier than rack and pinion, but more compact than worm gear systems

Steering Assembly

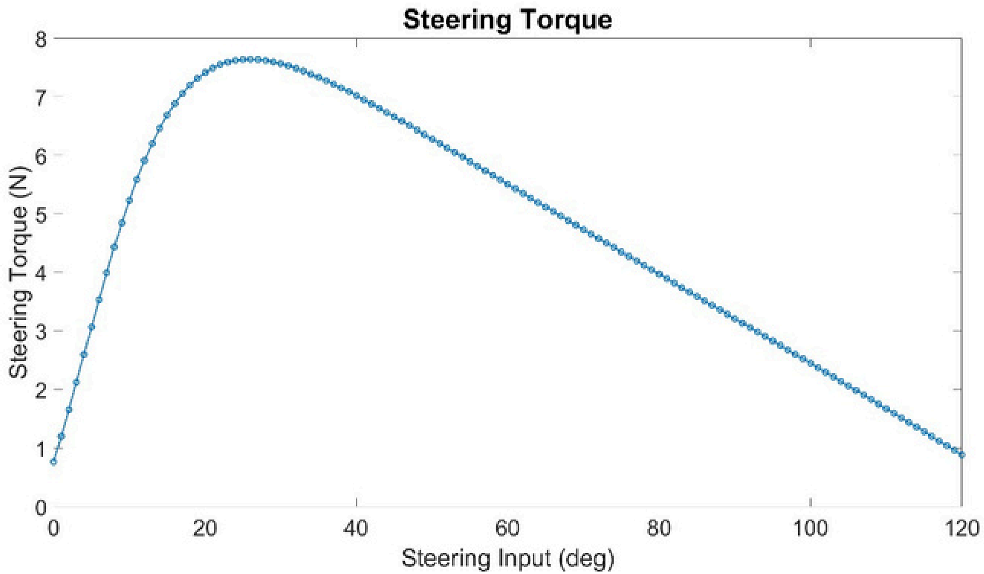
Minum Turning Radius	2.9 m
Eye-to-Eye Distance	397 mm
C-Factor	120 mm/rev
Rack Displacement (Lock to Lock)	80 mm
Steering Wheel Diameter	200 mm
Steering Ratio	3.93



Using two universal joints allows for minimising angular velocity fluctuations, improving steering sensitivity, feedback, and reduce hysterisis

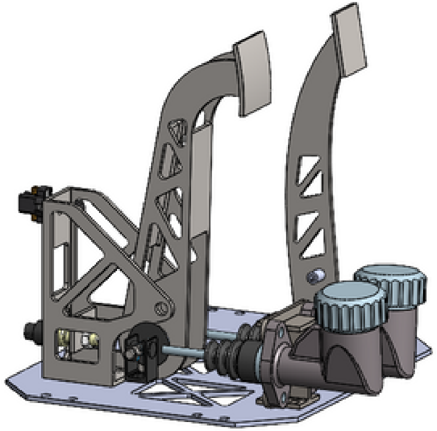
Minimizing Steering Torque

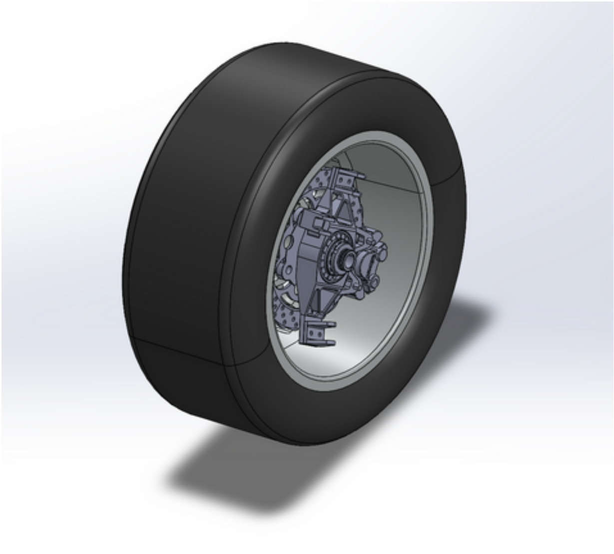
- Steering torque assessed via rack force and self-balancing torque
- Optimized to stay below 7.5 Nm during max cornering
- Adjusted steering ratio and C-factor for lower torque and sufficient driver feedback



Steering torque vs Steering angle

BRAKES AND WHEEL ASSEMBLY





Subsystem Vehicle Coherence

Vehicle Goals → **Constraints** → **Derived Subsystem Goals**

Vehicle Goals

1. **Dynamically Balanced Vehicle**
2. **Reliability and Efficiency**
3. **Acceleration and Speed**

Constraints

1. **Reuse Decisions** :
   a. Dampers, Master cylinders, Calipers
   b. Motor and differential
   c. Same cells and capacity
   d. BMS
2. **Availability of raw materials**
3. **Technical Limitations**
4. **Financial Constraints**

Derived Subsystem Goals

Chassis And Aerodynamics
- Compact packaging
- CG height reduction **50 mm**
- Minimizing manufacturing errors
- Reducing drag coefficient

Brakes And Wheel Assembly
- Factor of safety > **1.5**
- Unsprung mass reduction by **~ 4 Kg**
- Increasing peak deceleration to **1.6 G**
- Effective thermal management

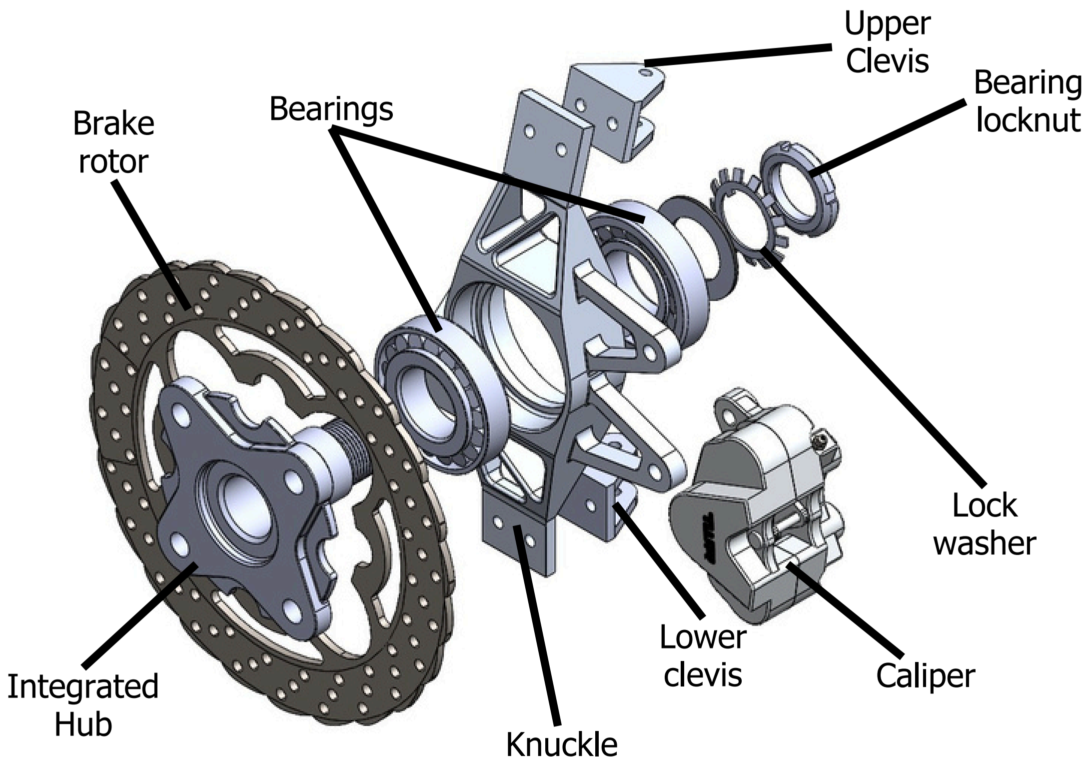
BMS and Cooling
- Weight reduction by ~ **9 kg**
- Ease of maintenance
- Rapid troubleshooting
- Effective thermal management
- Optimal packaging of segments

Suspension And Steering
- Minimum turning radius< **3 m**
- Peak steering torque<**7.5 Nm**
- Optimal slip angles during turning
- Preventing bottoming out

Powertrain
- **O**ptimal gear ratio selection for finishing endurance with 3.7kWh
- Acceleration time < **6 seconds**
- Weight reduction by ~ **2 Kgs**
- fatigue life > **10^6 cycles**

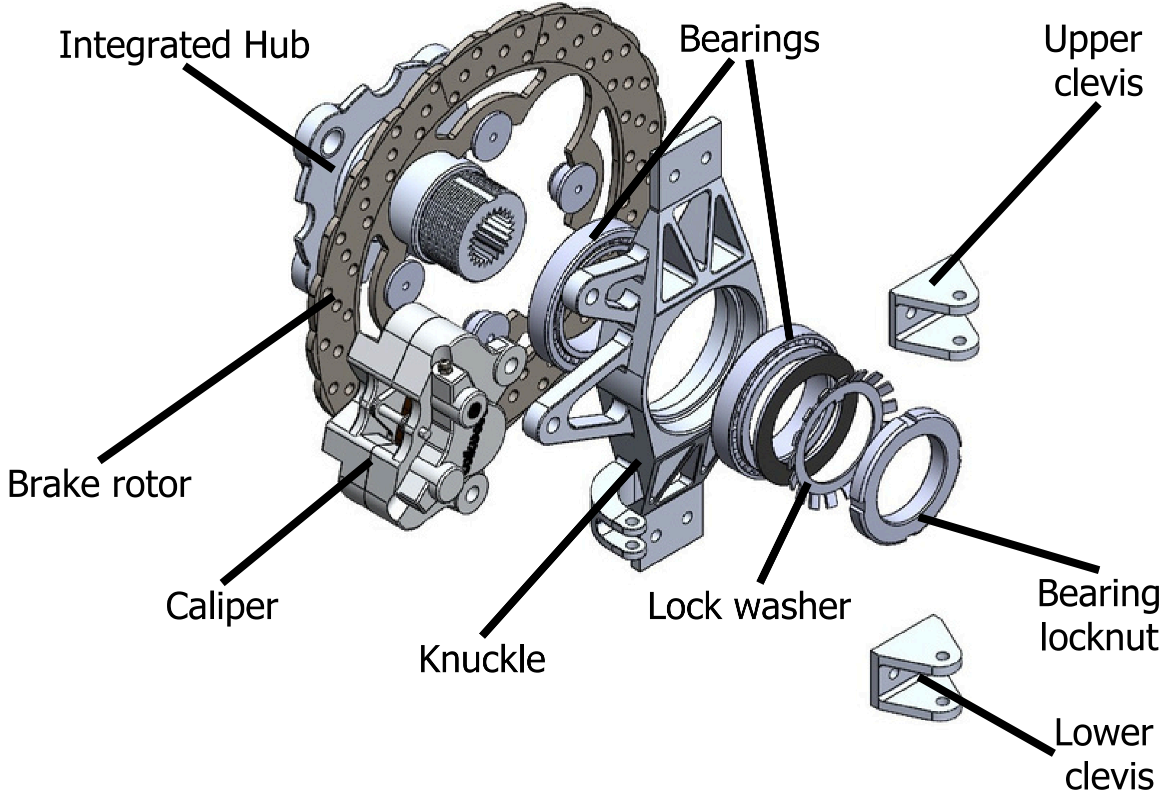
Electronics + DAQ
- Reliable PCB design and **signal integrity**
- Robust wiring and connections
- Reliable **data acquisition** and displaying relevant data

Front Wheel Assembly



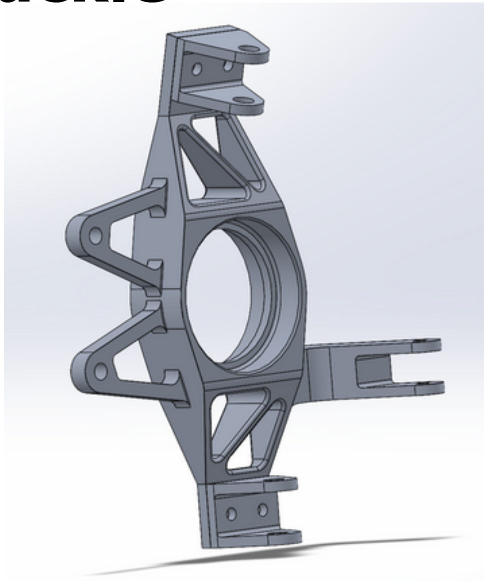
Mass = 2056.59 grams
Bearings used:
SKF 30207* 2 (Tapered roller)
Locknut: SKF KM6
Lock Washer: SKF MB6

Rear Wheel Assembly

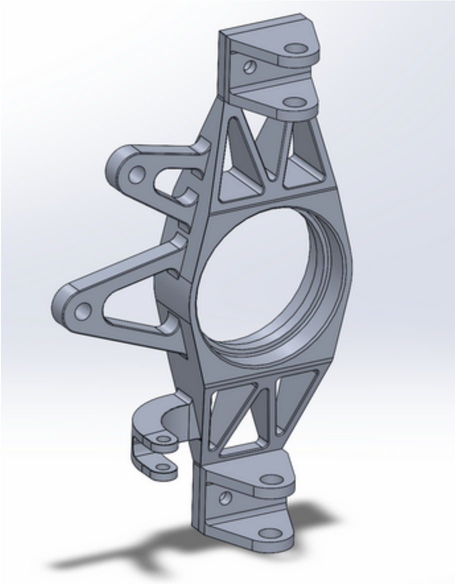


Mass = 2573.15 grams
Bearings used:
SKF 32910 * 2 (Tapered roller)
Locknut: SKF KM9
Lock Washer: SKF MB9

Knuckle



Front Knuckle:
Castor = 2.8°
Camber = -1.1°
Mass = 523.96 g
FOS = 1.70 (Cornering + Braking)



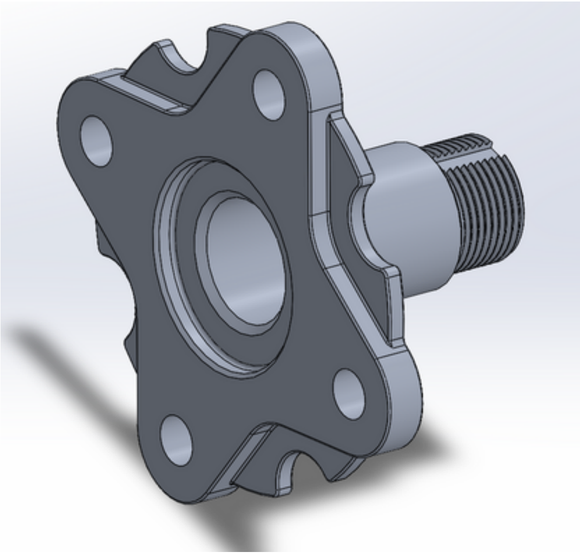
Rear Knuckle:
Castor = 0°
Camber= -1.1°
Mass = 383.60 g
FOS = 2.08

Why Al 7075 T6?

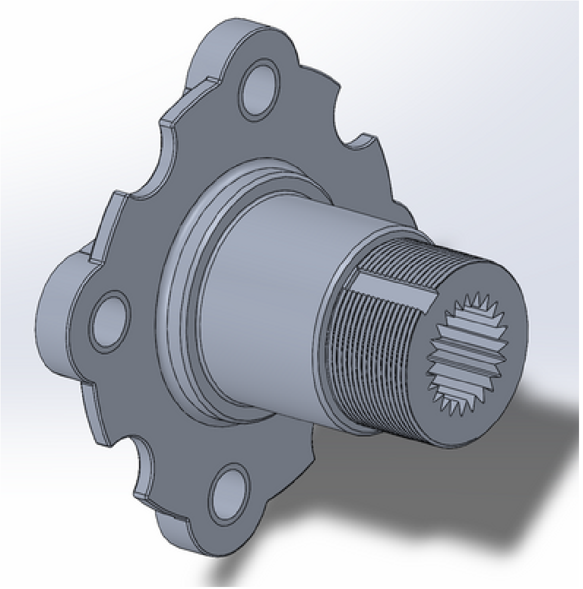
- Higher strength-to-weight ratio
- Surface finish
- Machinability

Detachable tabs for the upper and lower wishbone connections for improved tunability of camber angle.

Integrated Wheel Hub



Front
Mass: 268.56 g
Min FOS: 1.56



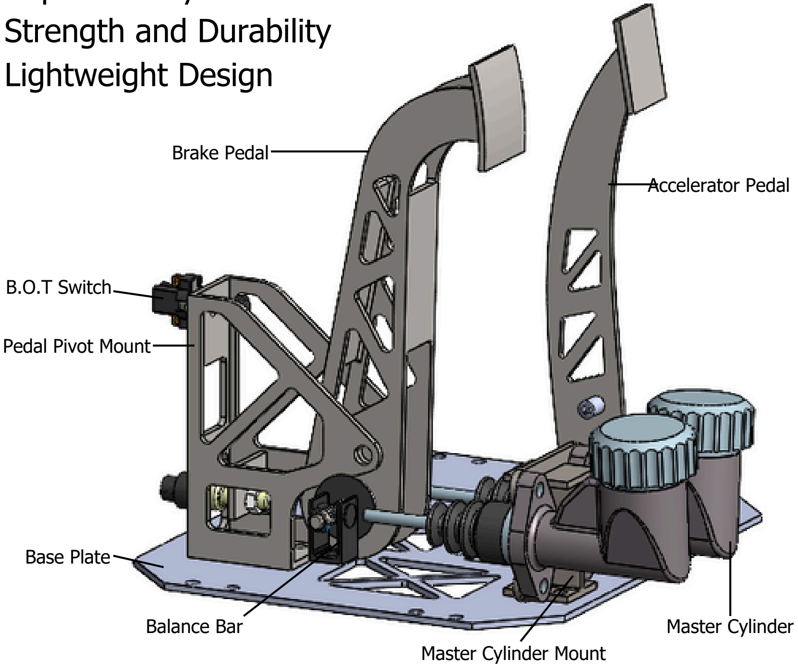
Rear
Mass: 441.55 g
Min FOS: 1.57

- Material: **Al 7075 T6**
- Outboard **floating brake rotor** attached to hub using a set of brake bobbins.
- Pros of integrated wheel hub
  - Reduced weight
  - Simplified assembly

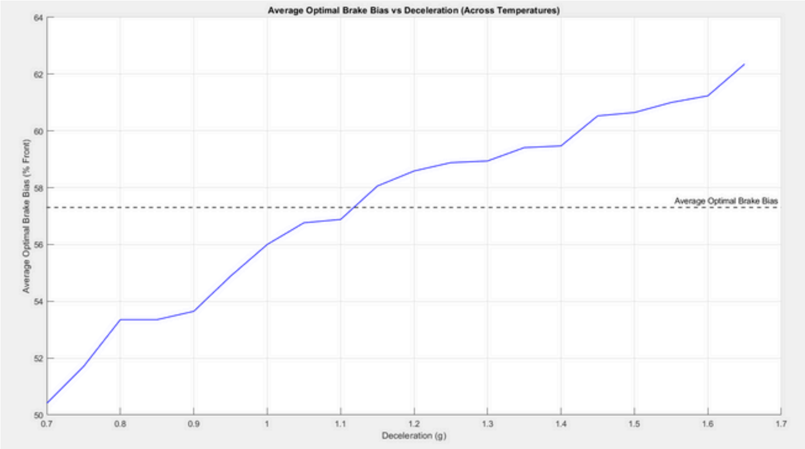
Pedal Box Assembly

The main focus while designing were:

- Replaceability
- Strength and Durability
- Lightweight Design



Brake Bias vs Deceleration



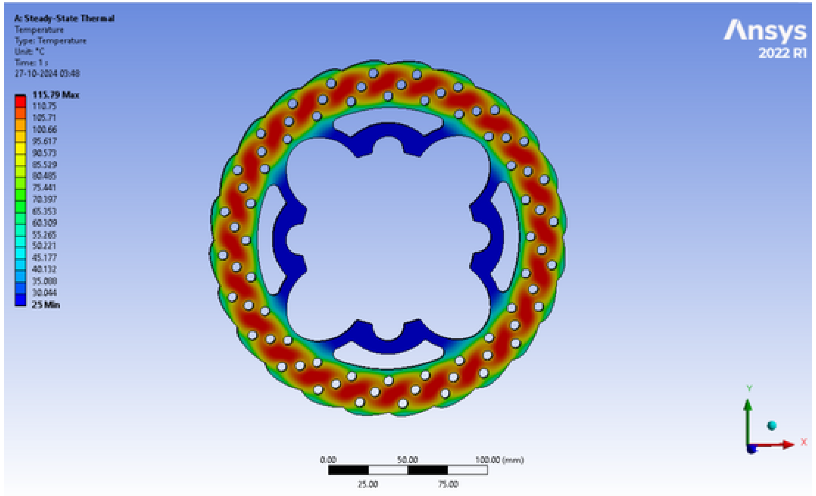
- Pedal Ratio: **6.5**
- Brake Bias (front : rear): **60:40**
- The assembly has been designed to sustain a force of **2400 N** on Pedal.
- Material : **AISI 1020**
- Master Cylinder: Wilwood GS Compact Integral
- Brake Over-travel switch: Push-Pull Switch

Brake Rotor

The main focus while designing were:

- Thermal Management
- Weight Optimization

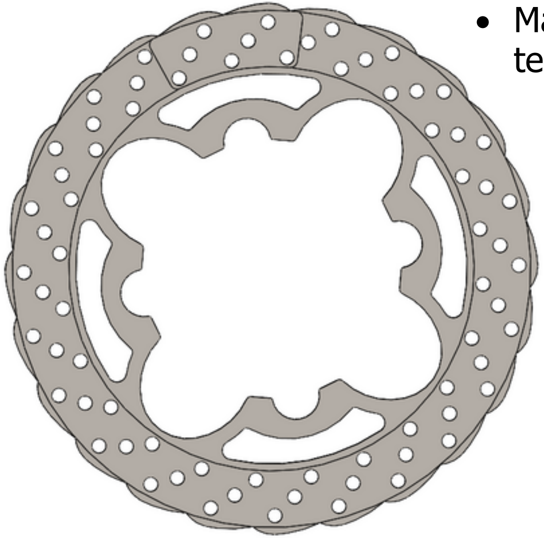
Identified hole incorporation as the most effective for heat dissipation.



Thermal analysis of Rotor

Calipers:

- Wilwood **PS1 Caliper** 2 pistons (0.99 in² each)
- Sintered metallic brake pads

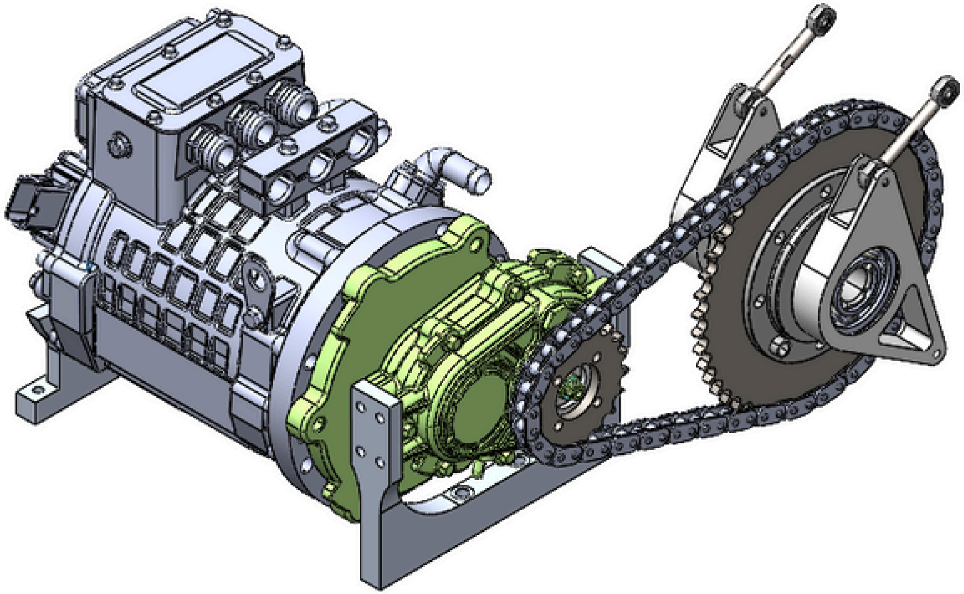


Rotor CAD

Brake Rotor (outboard)

- Floating Rotor
- Thickness: **4mm**
- Material: **AISI 4340**
- Min. FOS: **1.16**
- Maximum temperature:**115.8ºC**

TRANSMISSION



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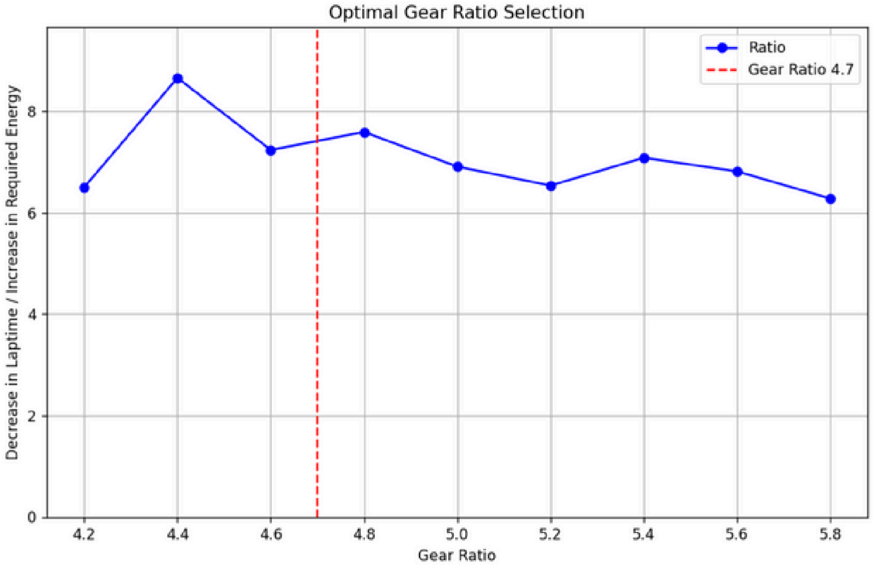
- fatigue life > **10^6 cycles**

Electronics + DAQ
- Reliable PCB design and **signal integrity**
- Robust wiring and connections
- Reliable **data acquisition** and displaying relevant data

Optimal Gear ratio selection parameters:-

1. Constraint on the Accumulator energy capacity - 3.7kWh
2. Reducing lap time while increasing acceleration of the car

gear ratio	laptime	energy	delta energy	delta time	ratio
4	100.81	3.08	0	0	0
4.2	100.03	3.2	0.12	-0.78	6.5
4.4	98.56	3.34	0.26	-2.25	8.65385
4.6	98.01	3.467	0.387	-2.8	7.23514
4.8	97	3.59	0.51	-3.87	7.58824
5	96.39	3.72	0.64	-4.42	6.90625
5.2	95.78	3.85	0.77	-5.03	6.53247
5.4	94.58	3.96	0.88	-6.23	7.07955
5.6	94.056	4.0714	0.9914	-6.754	6.81259
5.8	94.03	4.16	1.08	-6.78	6.27778
			(using gear ratio of 4 as refference)		



Final reduction ratio = 4.7

Reduction ratio of gearbox = 2

Reduction further required from transmission = 2.35

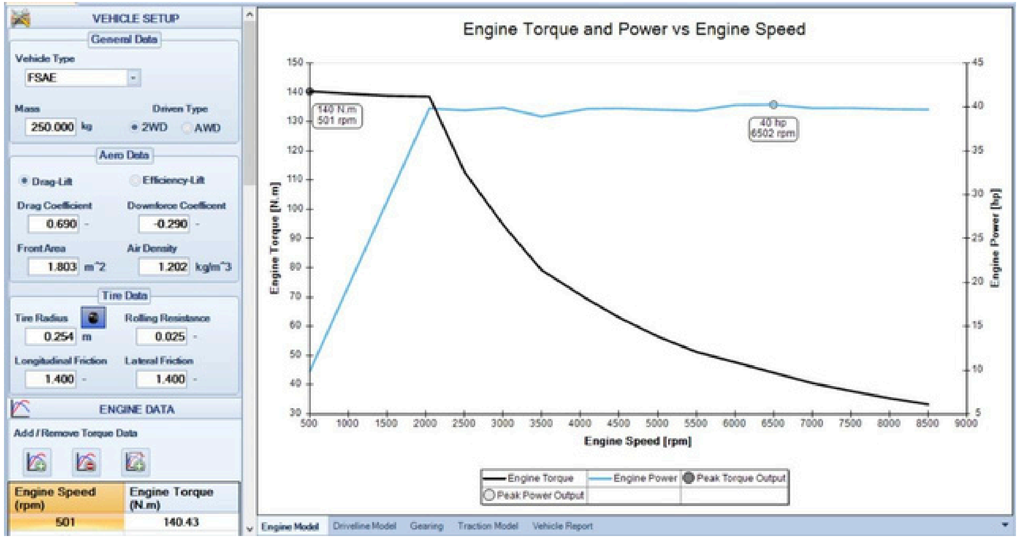
Lap time simulations

Inputs:

1. Vehicle parameters (mass, drag coefficient, tyre data)
2. Motor torque and speed characteristics
3. Track layout - Kari Motorway

Output:

1. Final gear ratio = **4.7**
2. Lap time = **97.03 s**
3. Energy required per lap = **0.13 kWh**
4. Peak longitudinal acceleration = **6.10 m/s2**
5. Acceleration event time = **5.4 s**

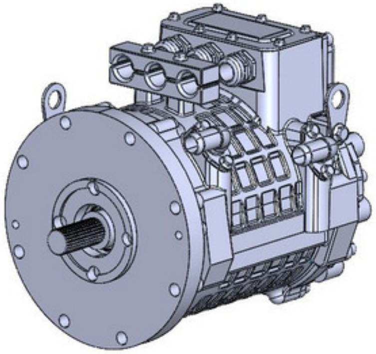


Optimum Lap simulations

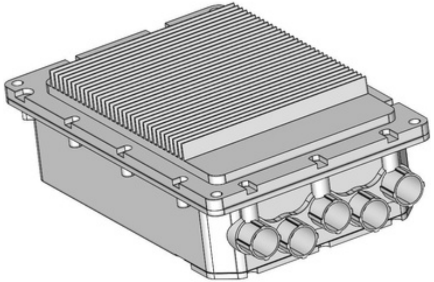
Motor & Motor Controller

Motor model	Tsuyo PHWM-P-J-96
Motor type	Permanent Magnet Synchronous Motor
Peak power	30kW
Continuous power	15 kW
Peak power	140 Nm
Continuous torque	35 Nm
Efficiency	85-92%
Controller model	TEVD410X58F2
Communication	CANBUS enabled

Target top speed = **120 km/hr**
Power required to overcome drag and rolling friction at the given top speed = **30.8 kW**

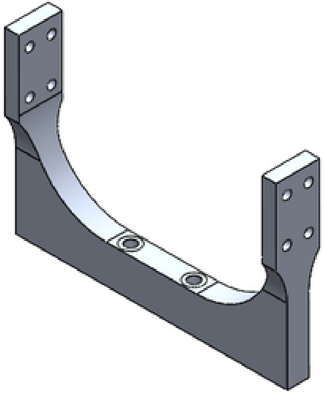


Motor

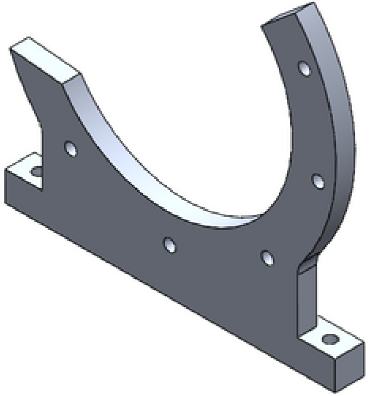


Motor Controller

Motor Mounts



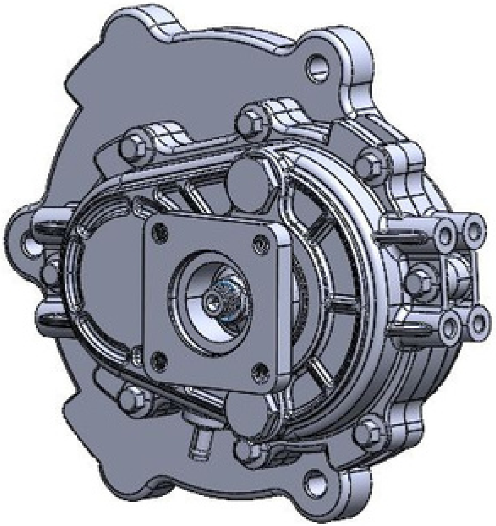
Reducer mount



Motor mount

Material	AL 7075 T6
Weight of Motor mount	~ 687.24 g
Weight of Reducer mount	~ 891.64 g
Minimum FOS	1.93

Reducer



- Reduction ratio = 2
- Splined output shaft
- Involute spline profile

Comparison of different drive systems

Chain and Sprocket

- Simple and lightweight
- Moderate life expectancy
- Requires periodic lubrication and maintenance
- High performance

Planetary Gearbox

- Complex and compact
- High life expectancy
- Regular maintenance
- Smooth power transfer

Belt drive

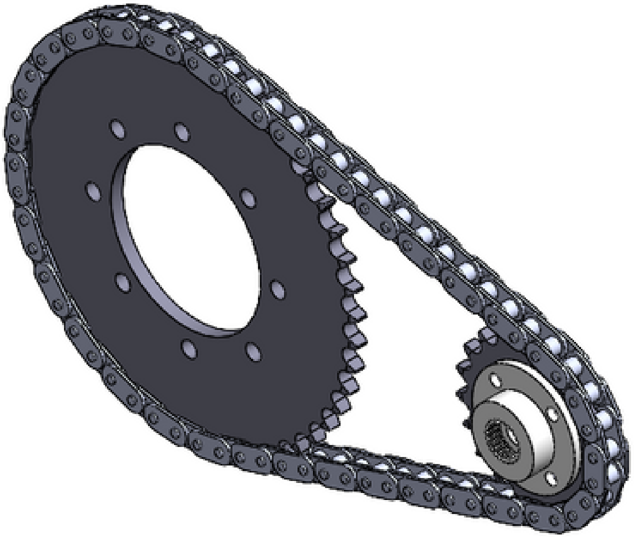
- Simple with few components
- low to moderate life expectancy
- occasional maintenance
- Quieter and has less vibrations

CVT

- Complex and lightweight
- High life expectancy
- Needs expensive and regular servicing
- Offers infinite gear ratios

Chain drive was selected due to its efficient power transmission, capability to handle high torque, and its reliability, as well as ease of assembly and maintenance.

Chain & Sprocket



Reduction ratio = 2.35
Sprocket to sprocket distance ~ 248.60 mm

Driving Sprocket	
Number of teeth	20
Weight	392.37 g
Heat treatment	Carburizing
Material	20MnCr5

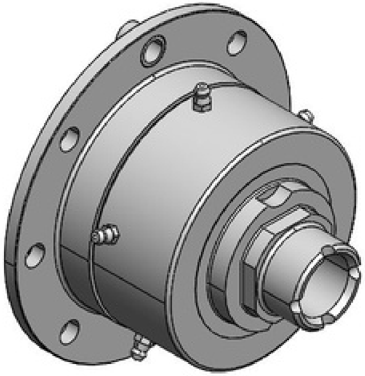
Driven Sprocket	
Number of teeth	47
Weight	2269.56 g
Heat Treatment	Induction hardening
Material	20MnCr5

Roller Chain	
Chain Number	520
Chain pitch	5/8 inch

Flange	
Material	EN24 Involute
Splines	No. of teeth=23

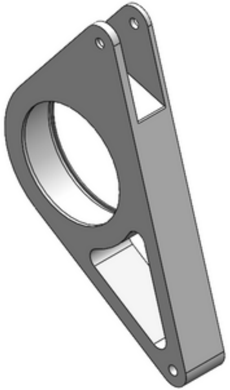
Differential

Company	Quaifie
Model No.	QDF7ZR
Load Bearing capacity	15,000 Nm



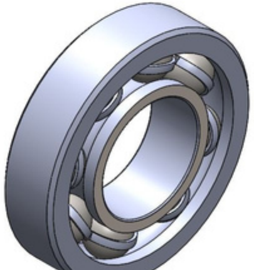
Differential Mount

Material	AL 7075 T6
Weight	~ 455 g
FOS	1.9



Bearing

Type of Bearing	Deep Groove Bearing
Model No.	SKF RLS 12
Dynamic Load Capacity	30.7 kN
Static Load Capacity	19 kN



Turnbuckle

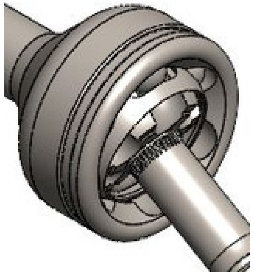
Material	Mild Steel
Load bearing capacity	Static = 4.25 kN Dynamic = 6.8 kN
Rod end type	POS6

Driveshaft

Material	EN24
Outer Diameter	26 mm (rod)
Spline profile	Involute
No. of teeth	23
Module	1 mm

CV Joint

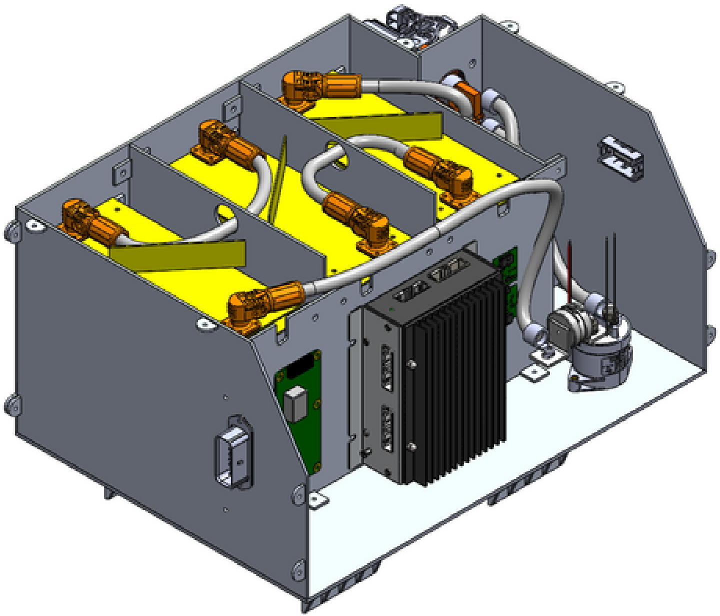
Joint type	Rzeppa (outboard)
Max articulation angle	45^{o}



Joint type	Tripod (inboard)
Max articulation angle	45^{o}

We are using tripod joints to accommodate linear movement resulting from wheel travel.

HIGH VOLTAGE



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Comparative Analysis of Cells

Types of Cell	Melasta Li-ion 3.7V 21Ah 8C Pouch Cell:	Samsung INR18650-25R 2.5Ah Cylindrical Cell:	Panasonic Li-ion NCA596080 3.6V 4.04Ah Prismatic Cell:
Configuration	24s2p=48 cells	29s14p=406 cells	43s6p=258 cells
Total Energy	3.7 kWh	3.7 kWh	3.7 kWh
Density (g/cm3)	2.28	2.63	2.38
Volume occupied by all cells in accumulator	7838.21 cm^3	16938.9 cm^3	208010 cm^3
Cell Life	>100	>250	<50
Energy Density	0.476 Wh/cm^3	0.526 Wh/cm^3	0.506 Wh/cm^3

Comparative analysis of Cells

Cell and HV Accumulator Specifications

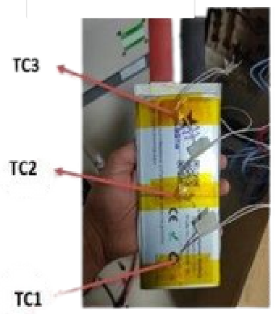
Cell Parameters

Manufacturer	SHENZHEN Melasta
Cell Cathode Material	$LiCoO_2$
Nominal Voltage	3.7 V
Maximum Voltage	4.2 V
Capacity	21 Ah
Nominal Discharge Current	150 Amps

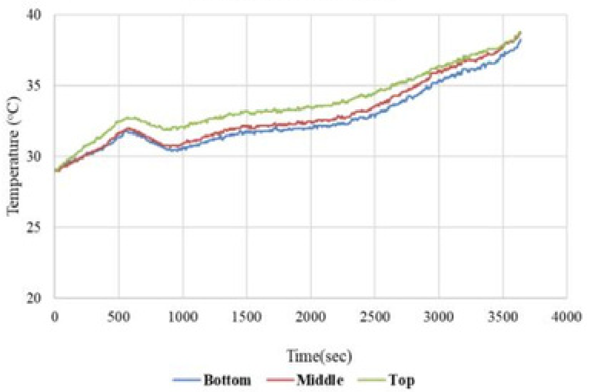
HV Accumulator Parameters

Nominal Voltage	88.8V
Maximum Voltage	100.8V
Configuration	24s2p
Energy	3.7 kWh
Nominal Discharge Current	125 Amps
Nominal Power	8.8 kW

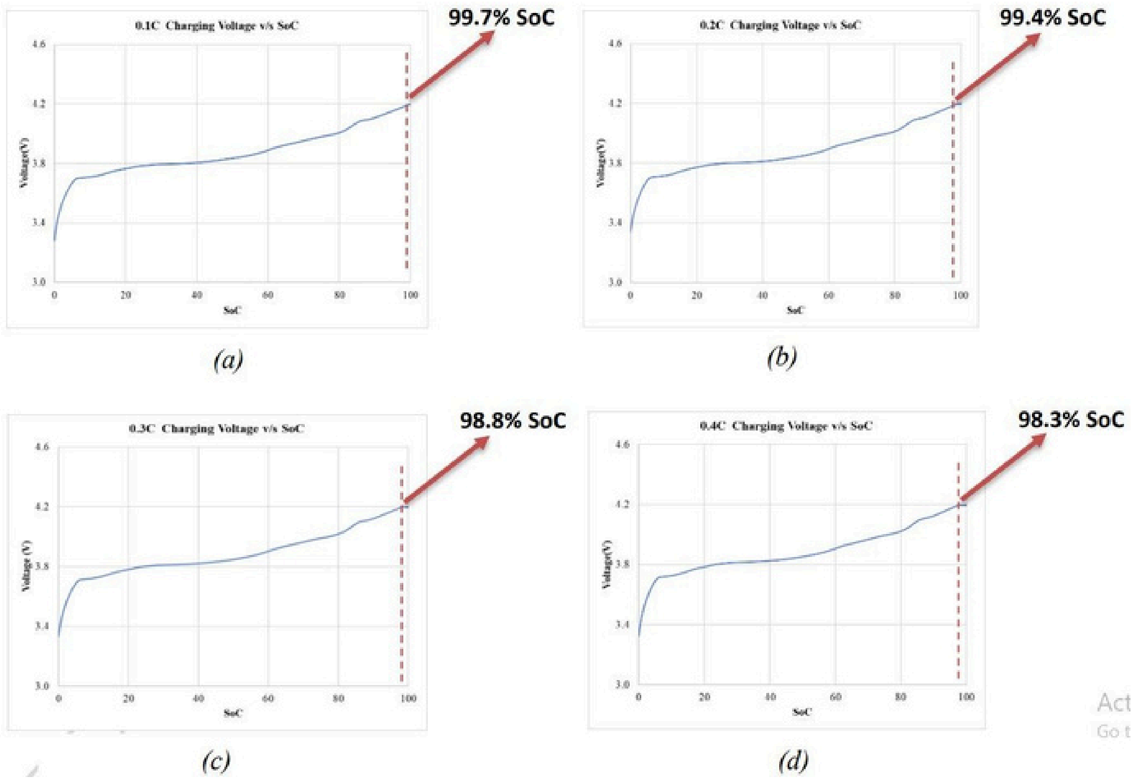
Cell Testing



Thermistor Sensor Position



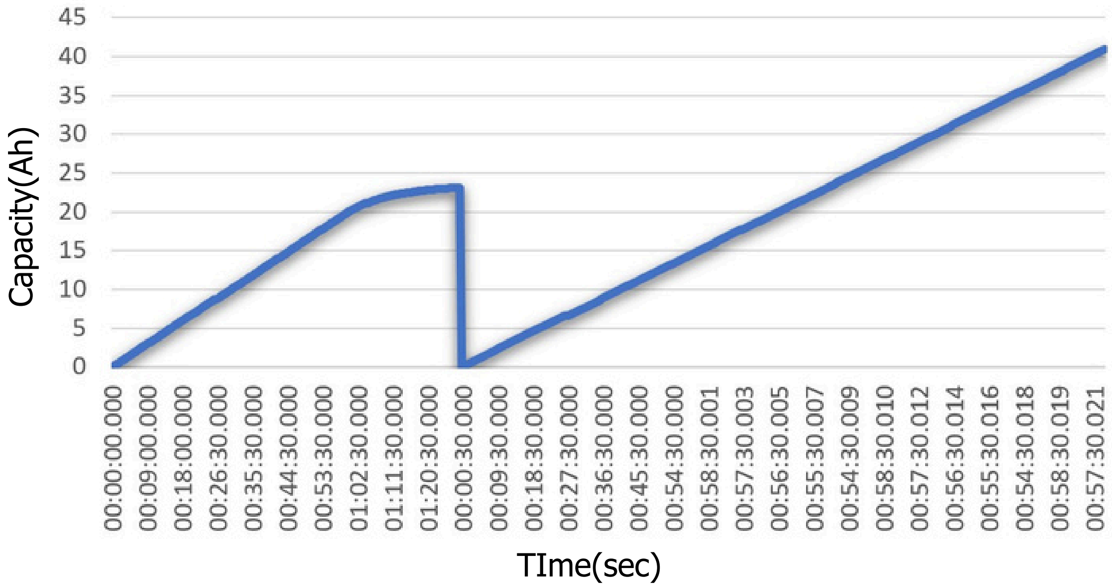
1 C discharge

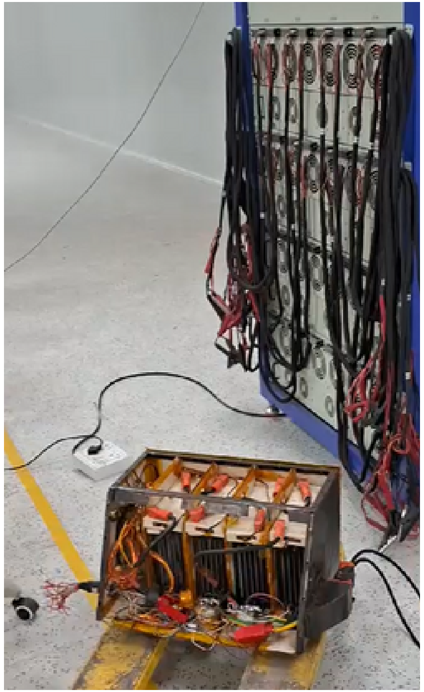


Voltage v/s SoC (a) 0.1C Charge (b) 0.2C Charge (c) 0.3C charge (d) 0.4C Charge

Accumulator Testing

- Since we are using previous year's cell, we carried out capacity testing of the accumulator and the capacity obtained was 41Ah.

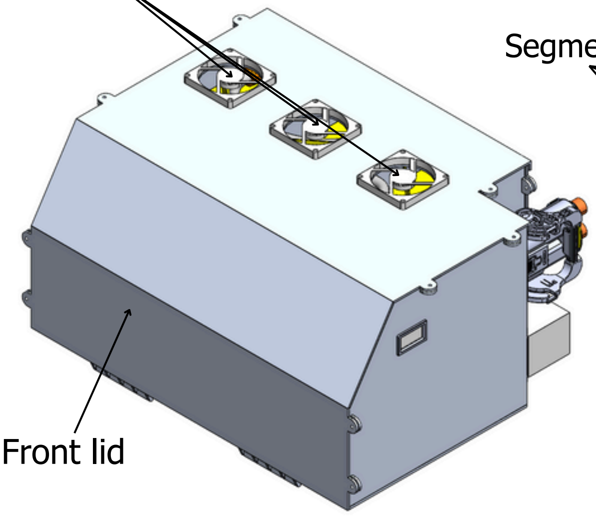


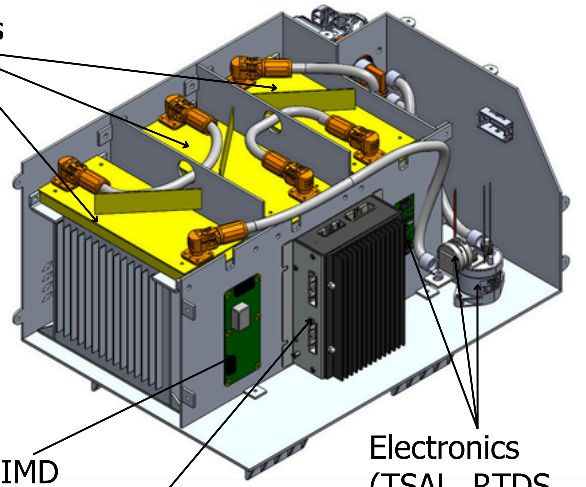


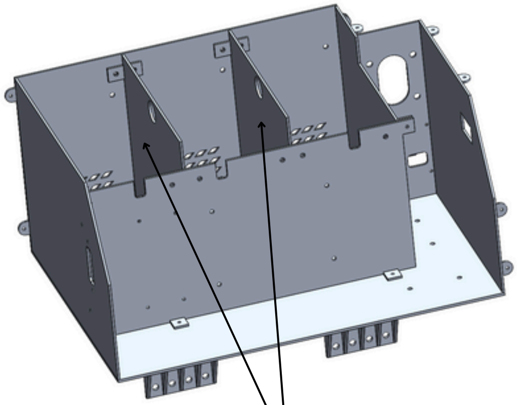
Accumulator Testing

TSAC Design and Orientation

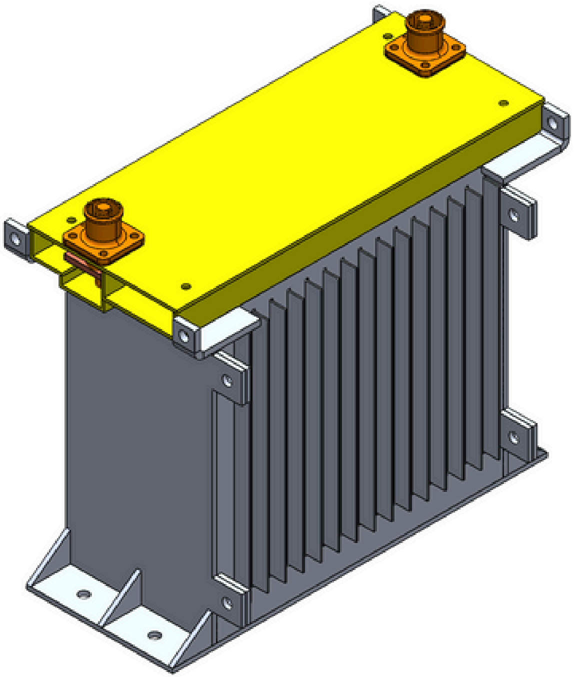
- **Dimensions:** Length - 390mm
  Width - 534mm
  Height - 260mm







Segment Construction



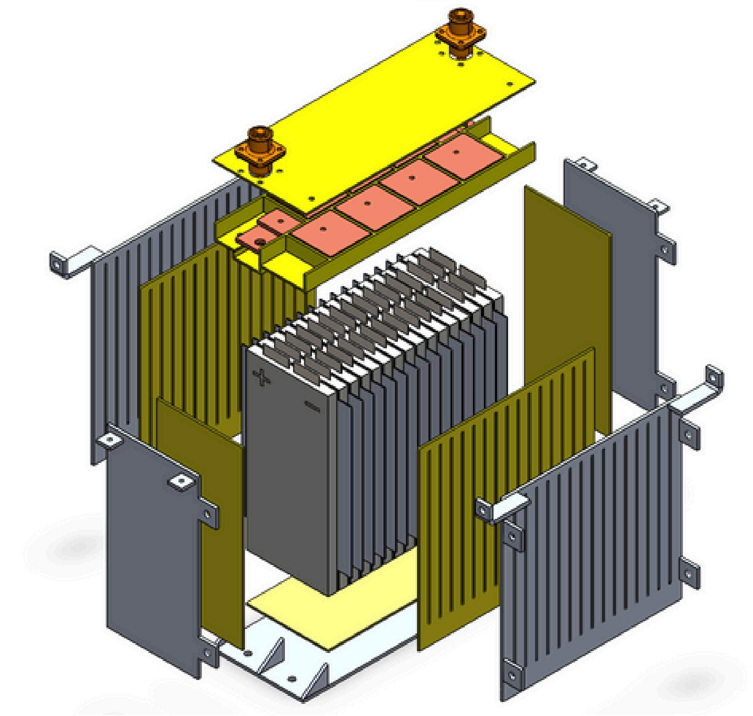
Segment

- **Modular Segment Design for Smooth Assembly**
  - Prevents individual cells from rubbing against the aluminum surface.
  - Ensures consistent spacing between cooling fins, improving cell packing and heat transfer.

- **Improved Busbar Attachment**
  - Busbars now slide in from one side instead of being cut to precise lengths and placed top-down.
  - With the fans mounted on the top, it also helps in cooling of busbars

Segment Stack Construction

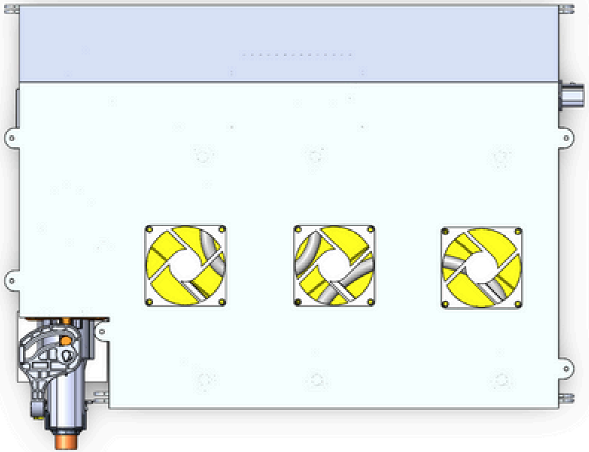
- **Segment Assembly Process**
  - Each segment is stacked with cells, thermal pads, and cooling fins, then surrounded by FR4 sheet on all sides.
  - The segment holder casing is tightened before sliding it into the accumulator container.



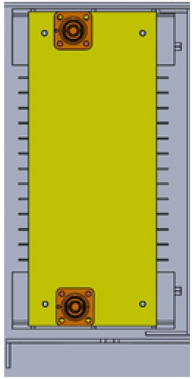
Exploded view of segment

Packing Improvements

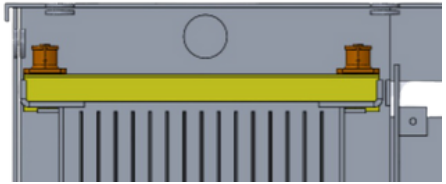
- **Enhanced Support Structure**
  - The new support structures are added at the top of the segment to prevent vibration and provide extra stability.
- **Change in number of Segment**
  - For better packaging, we chose to have 3 segments rather than 4 (as used in FB24).



Top view of TSAC



Top view of segment



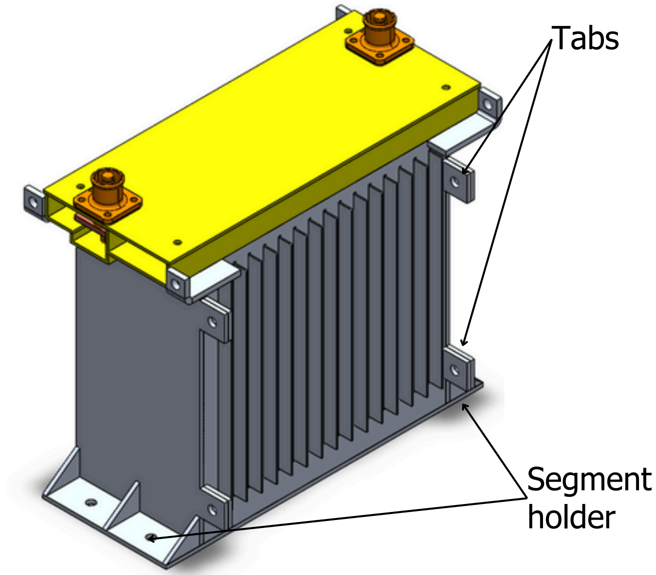
Side view of segment

Material Used

Part Name	Materials used in TSAC
TSAC	Aluminium (Al 6061 T6 3mm)
Segment	Aluminium (Al 6061 T6 3mm)
Insulation Cover	FR-4 Epoxy Glass sheets
Busbar	Copper
TSAC Tabs	Aluminium (Al 6061 T6 3mm)
Fins	Aluminium (Al 7075 T6 1mm)

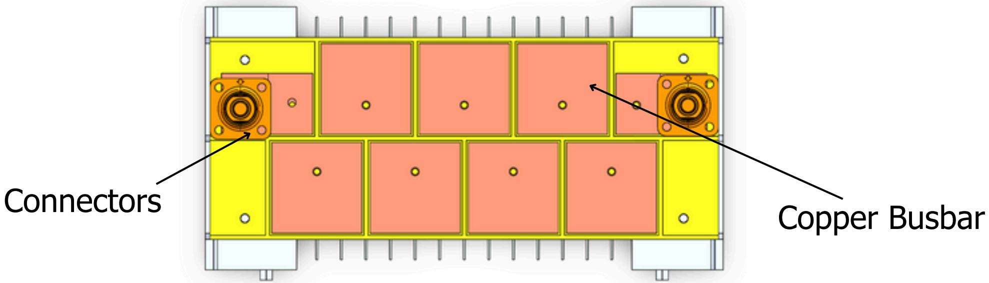
- A weight reduction of 9.8Kg is achieved by using aluminum as compared to the FB24 accumulator.
- The aluminum fins are used instead of copper due to their lightweight, corrosion resistance, low electrical conductivity and low cost.

Cell Segment and Connections



A segment containing 16 cells

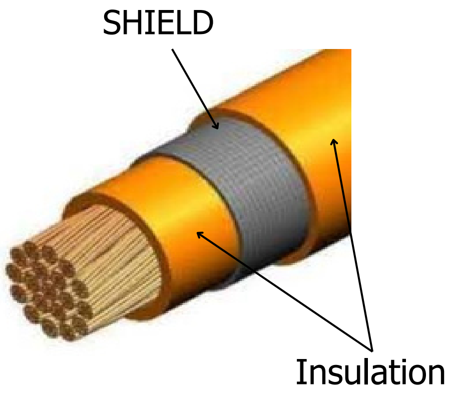
Segment Configuration	8 modules in series per segment
Module Configuration	1 module contains 2 cells in parallel
Thermal Exchange	Fins placed between two consecutive cells
Maintenance	2 maintenance plugs at the top of each segment
Module Fixation	Modules are fixed to the bottom plate using tabs
Cell Connection	Cells are packed together and connected using copper busbar



Sectional top view of segment

HV Wiring

- Maximum Current : 600 Amp
- Contact Cross-section Area : 50 mm2
- Approximate Length : 1 m



Receptacle

Plug

HVIL

- Positive Locking at Accumulator
- Terminals: 180° Plug and Receptacle
- UL94V-0 Rated Shielded 250 A

Battery Management System

Orion Centralized BMS

Centralized BMS over Master-Slave AMS

- Easier to set up and maintain.
- Reduces latency.
- Better suited for compact battery packs.
- Fewer components and connections simplify the system architecture.

Specifications

- Dual (x2) CANBUS 2.0B interfaces that are fully programmable.
- Performs intelligent cell balancing (passive).
- Calculates state of charge (SOC).
- Uses professional automotive-grade locking connectors.
- Calculates discharge current limit (DCL) and charge current limit (CCL).
- Can measure cell voltages between 0.5V and 5.0V.

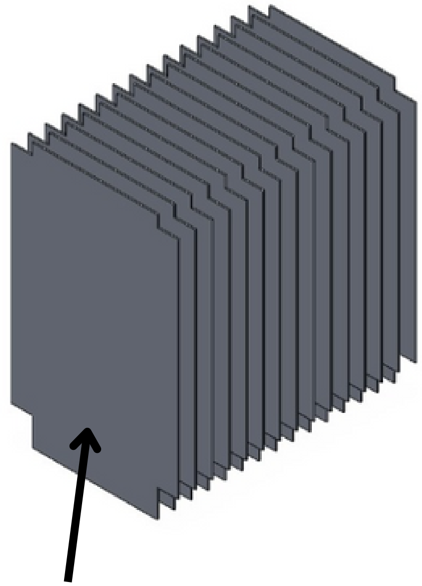
Charger

AC Input wide voltage	AC90V~264V
DC Output Voltage	96V
Efficiency	>93%
Maximum Charging Current	32 Amp
Operating Temperature	-40°C~60°C
Storage Temperature	-55°C~100°C
CAN Communication Function	Enabled
Overall Size	294*210*111mm

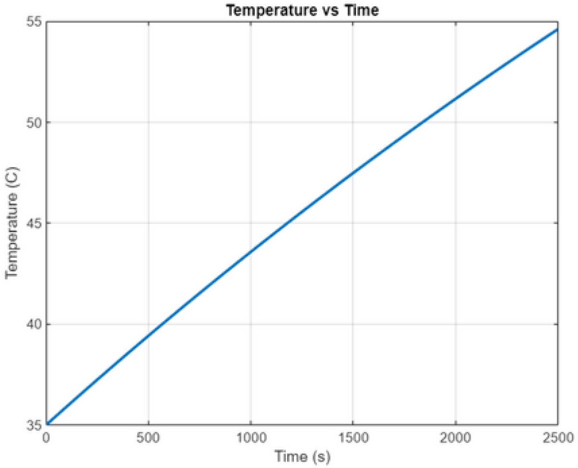
Elcon Charger

Thermal Management

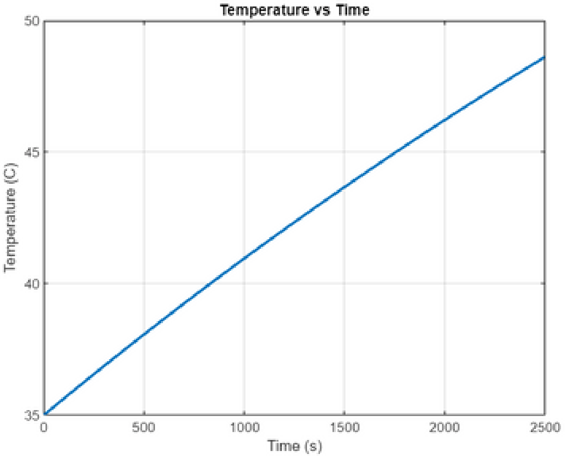
Cooling Method	Air cooling is used for ease of design and implementation.
Advantages of Air Cooling	Lighter system, reduces vehicle weight, requires less maintenance.
Thermal Exchange	Aluminium fins placed between the cells for thermal exchange.
Heat Transfer Mechanism	Heat is absorbed through contact with cells, transferred to sides of fins.
Cooling Mechanism	Air from fans passes over fins, transferring heat through convection.
Thermal Pads	Thermal pads used to ensure proper contact between cells and fins.



Thermal Management



3C



2.5C

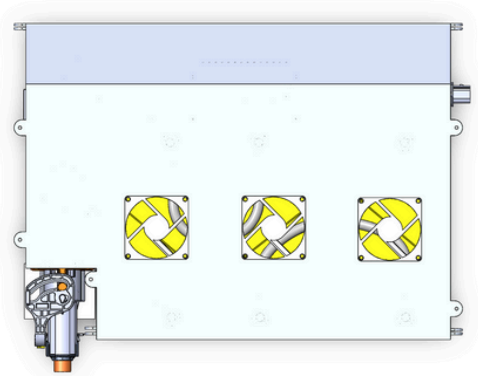
Analysis using ANSYS and MATLAB at 3C and 2.5C discharge currents over 2500 seconds, with natural convection showed temperatures consistently below 60°C.

However to maintain optimal temperatures, we decided to use active air cooling via fans of 9W rating.

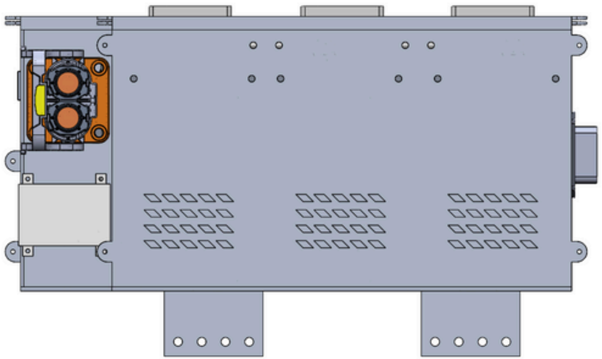
Thermal Management

Cooling Fan

Power of fans: **9 W**



Designed to allow air flow through the fins coming out of the segments

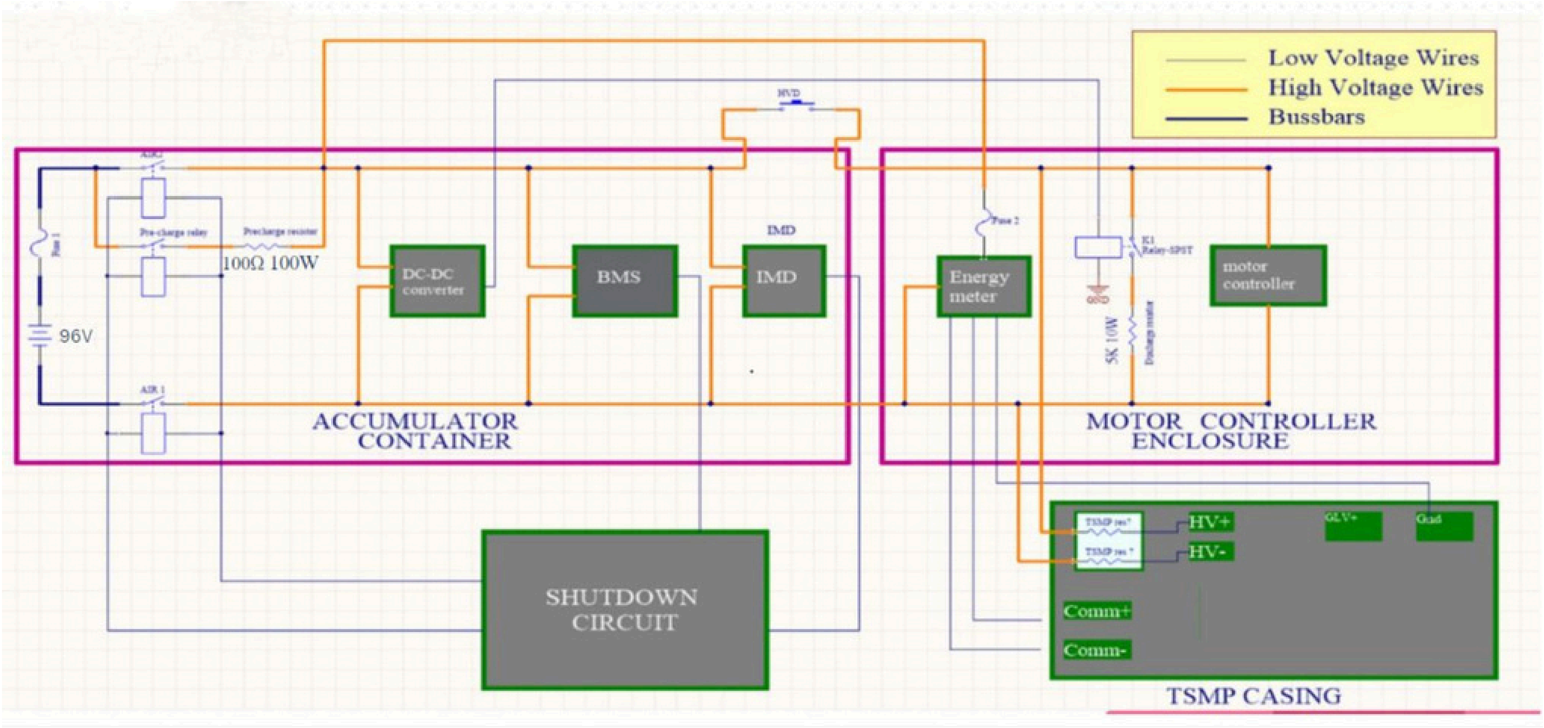


Slits are cut at the lower back end of the accumulator for airflow coming through the top of the lid and passing along the fins to the bottom

Fan Configuration

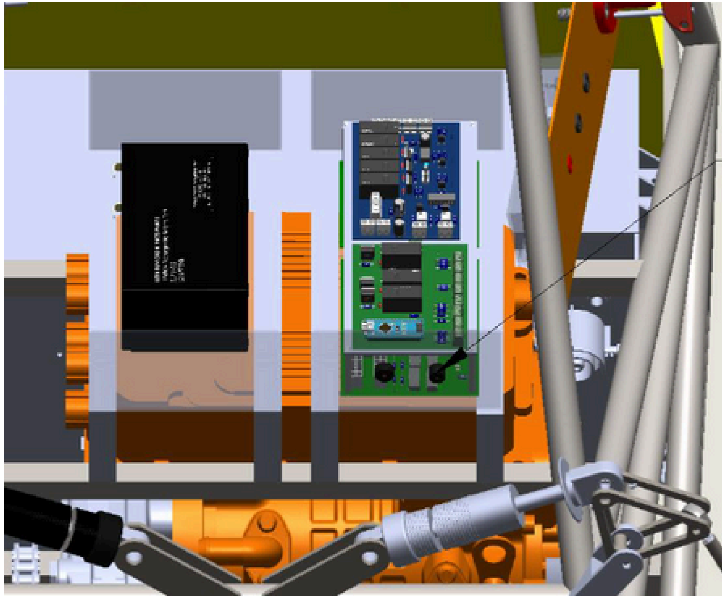
- Three fans are positioned at the inlet atop the accumulator.
- Air flows over the fins extruding from the stack, thus cooling the stack.
- Heat is then extracted through an outlet at the rear of the accumulator.

HV Wiring



Block Diagram

LOW VOLTAGE ELECTRONICS



Subsystem Vehicle Coherence

Vehicle Goals → **Constraints** → **Derived Subsystem Goals**

Vehicle Goals

1. **Dynamically Balanced Vehicle**
2. **Reliability and Efficiency**
3. **Acceleration and Speed**

Constraints

1. **Reuse Decisions** :
   a. Dampers, Master cylinders, Calipers
   b. Motor and differential
   c. Same cells and capacity
   d. BMS
2. **Availability of raw materials**
3. **Technical Limitations**
4. **Financial Constraints**

Chassis And Aerodynamics

- Compact packaging
- CG height reduction **50 mm**
- Minimizing manufacturing errors
- Reducing drag coefficient

Brakes And Wheel Assembly

- Factor of safety > **1.5**
- Unsprung mass reduction by **~ 4 Kg**
- Increasing peak deceleration to **1.6 g**
- Effective thermal management

BMS and Cooling

- Weight reduction by ~ **9 kg**
- Ease of maintenance
- Rapid troubleshooting
- Effective thermal management
- Optimal packaging of segments

Suspension And Steering

- Minimum turning radius< **3 m**
- Peak steering torque<**7.5 Nm**
- Optimal slip angles during turning
- Preventing bottoming out

Powertrain

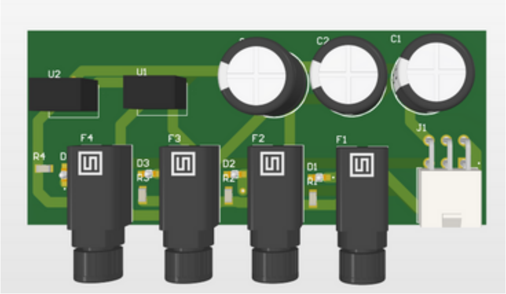
- **O**ptimal gear ratio selection for finishing endurance with 3.7kWh
- Acceleration time < **6 seconds**
- Weight reduction by ~ **2 Kgs**
- fatigue life > **10^6 cycles**

Electronics + DAQ

- Reliable PCB design and **signal integrity**
- Robust wiring and connections
- Reliable **data acquisition** and displaying relevant data

LV Power Management

LV Battery



DC converter with PCB mountings

LV SUPPLY :

- 12V 12Ah LFP Battery , Continues Current Rating : 12A
- Capacity of battery selected to last dynamic events.
- Measured range of continues LV current drawn by vehicle during dynamic testing = 2.5A - 3.75A
- Estimated runtime of battery on single charge 192-288 Minutes.
- Charging Duration = 120 Minutes
- High capacity eliminates need for separate DC-DC converter to share LV power load
- 12V to 5V and 12V to 24V PCB mount converters also used to power various sensors

Sensitive Component Protection and Fusing

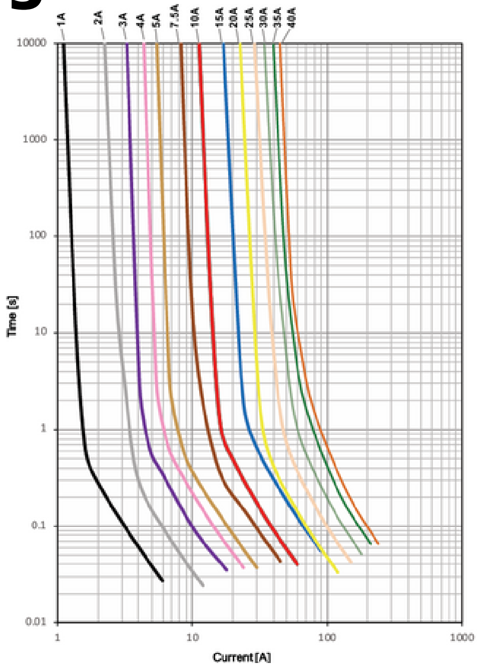
Blade fuses

Power to the LV system is distributed via a fuse box which protects the LFP battery and the individual circuits.

- **12A fuse protecting the LFP battery**
  Fuse chosen in accordance to the maximum discharge current limit of the LFP battery.

- **Shutdown circuit path**
  3A blade fuse protecting the AIR current path carrying 7.5A inrush for 25ms, 0.75A under nominal conditions. It is ensured that the I^2t requirement does not trip the fuse.

- **Critical sensitive components**
  Fuses are simillarly selected for the Motor Controller Unit, Orion BMS 2 and the IMD such that they comply with the time-current characteristics of the curve



Time-Current characteristic curve

LV Wiring and Connectors

Wire	Usage	Specificatoins
20 AWG	Transfer Signals between PCB’s	2A and 200°C
18 AWG	Wiring outside the enclosure, connecting sensors and buttons to the enclosures.	5A and 200°C
UL 94V-0 rated	Inside Accumulator	Flame retardant
Raychem DR-25 Heat Shrink	Used for securing connections	-75°C to 150°C

18 AWG Wires

Raychem DR-25 Heat Shrink

Raychem nylon conduit

LV Wiring and Connectors

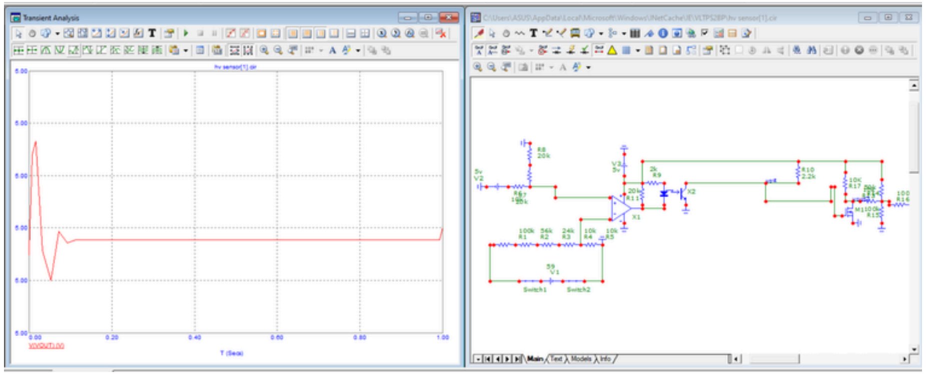
Connector	Usage	Specifications
Deutsch DTM04	Accumulator LV connector	IP68, 10A, UL94-V0
KK-type	Connect the PCB to the wires from the enclosure with the data from the sensors and switches. They have positive locking.	2.5A 30 to 22 AWG
Molex Micro-Fit	Used for Wire to Wire connections	10.5A, -40 to +105°C

Deutsch DTM04

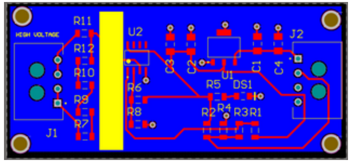
Molex Micro-Fit

KK Type

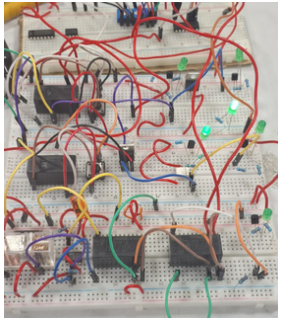
LV Circuit Design



MicroCap Simulations



PCB design



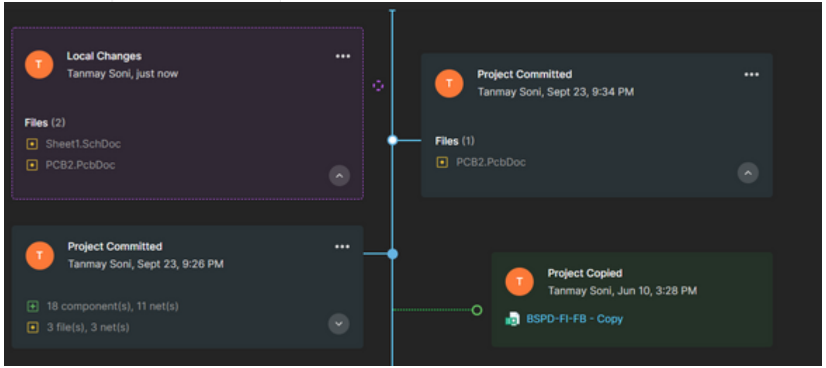
Breadboard testing

Circuit Simulation : Using MicroCap to conduct circuit simulations and develop preliminary circuit designs.

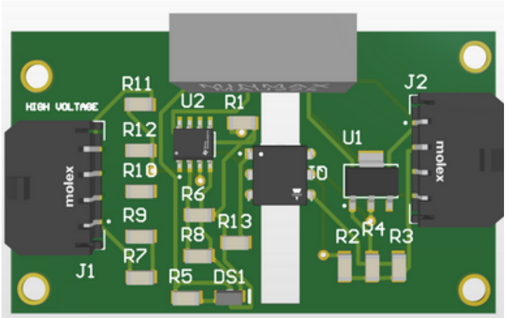
Circuit Validation : Using breadboards and electronic components to validate circuit simulations and create iterative design changes.

Circuit Prototyping : Using Altium Designer to design prototype PCBs for validated circuit designs.

LV Circuit Design



Altium Version Control



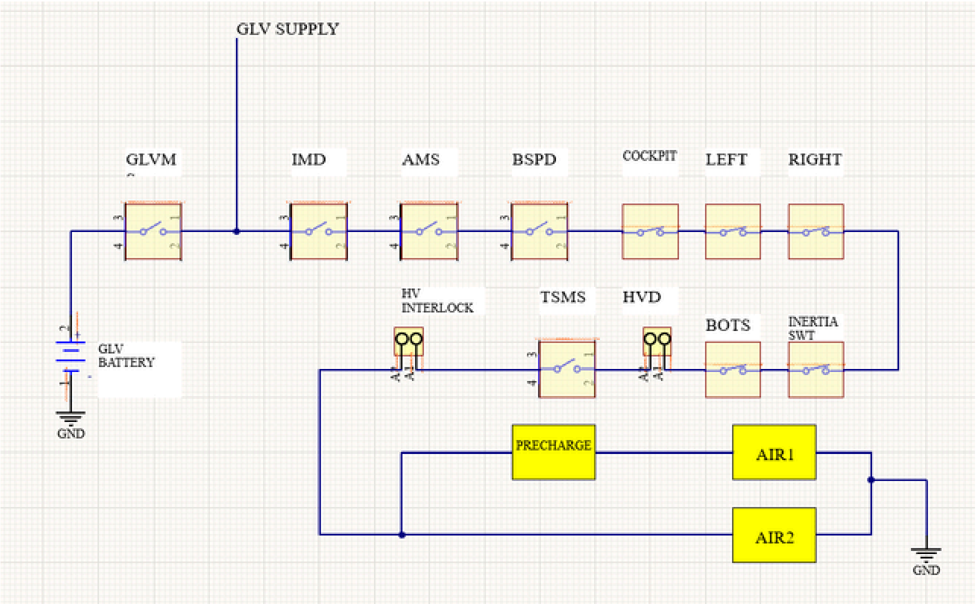
PCB with Component Placement

Hardware and Software Version Management : Using Altium Designer's Git version control to manage circuit iterations

GitHub Repositories for software development and version control

Component Selection and placements: Selection of ICs and connectors and electronic components with appropriate power ratings.

Shutdown Circuit



Block Diagram

- Integrated shutdown circuit with latches for ease of connection and diagnosis
- 8A PCB relays for IMD, AMS, BSPD powerstages
- Appropriated rated fuse (7.5A) used for shutdown circuit protection
- Flyback diodes for AIR coil, to reduce reverse inrush current during shutdown circuit opening

AIR(s)

Two LittleFuse DCNHR250QFA contactors are used as AIR which isolated both ends of battery when shutdown path is open. Auxiliary contacts for TSAL relay state detection
Its ratings are as follows:

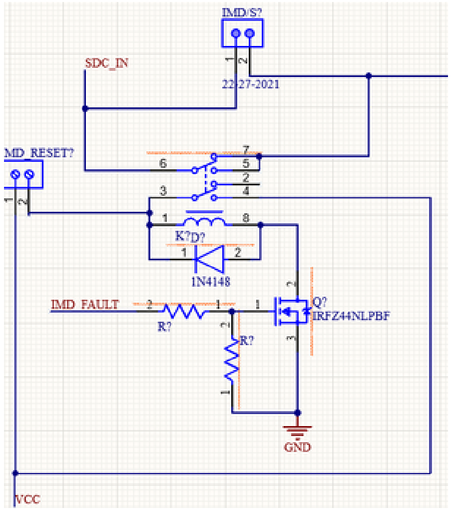
- Voltage Rating : 900 VDC
- Current Rating : 250 A

HVD

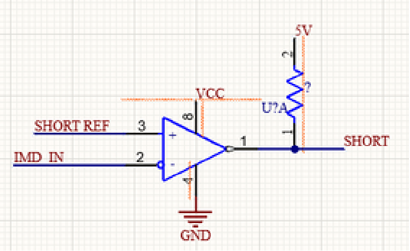
HVD AMPHENOL PCD MSDM4502 is used

- Current Rating : 250A
- Voltage Rating : 1000V HVD also consists two integrated internal HVIL
- HVD will be operated by rotating its lever and pulling it out which will also open the shutdown circuit.

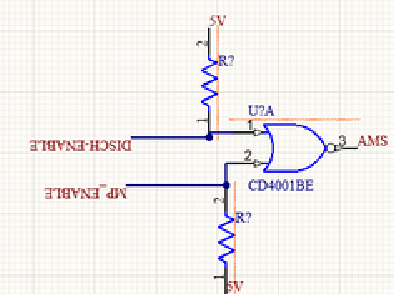
Reset Latching for IMD/BMS



IMD Latching Circuit Diagram



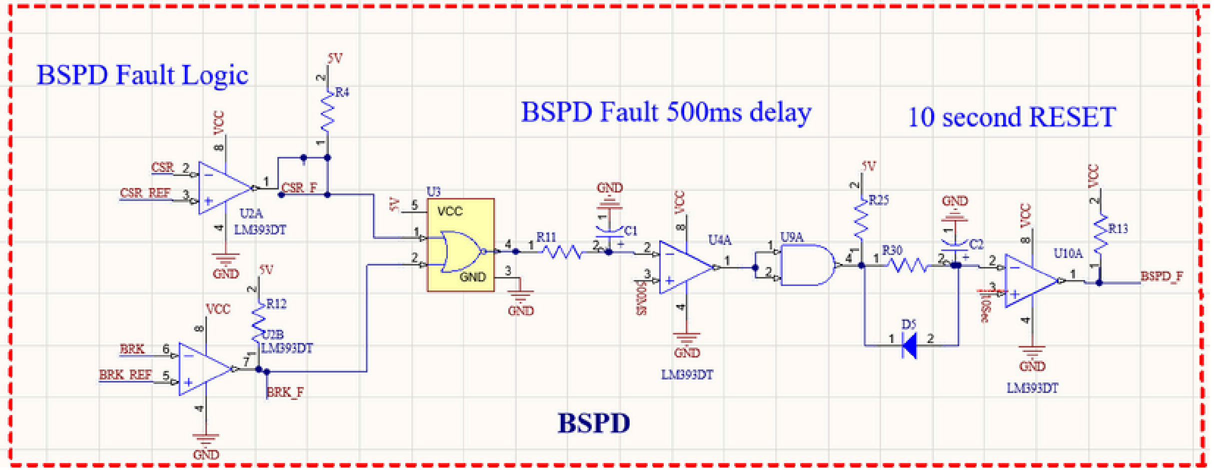
SCS checks

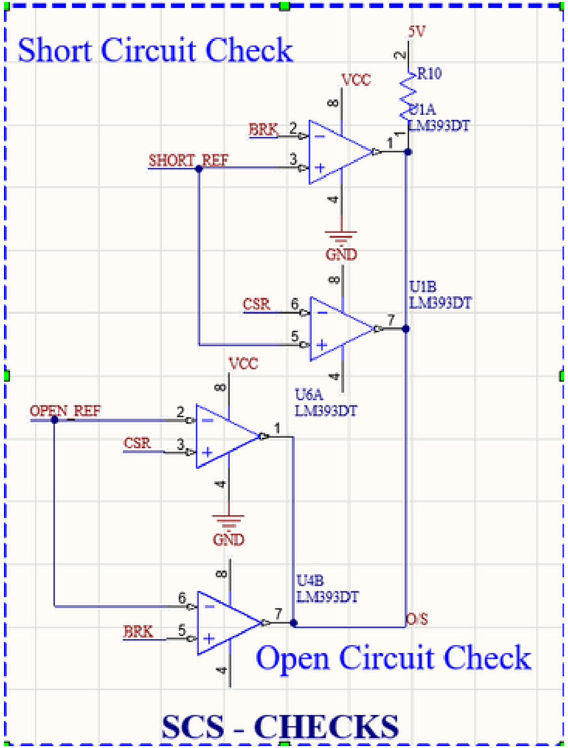


Redundant AMS signals

- Minimal component latching, single relay, MOSFET and push button based reset
- NMOSFET used for reliable and quick relay control during fault
- PUN and PDN for open circuit detection
- Comparator based short circuit SCS check implementation
- Redundant Signals for AMS for reliable fault detection

Brake System Plausibility Device



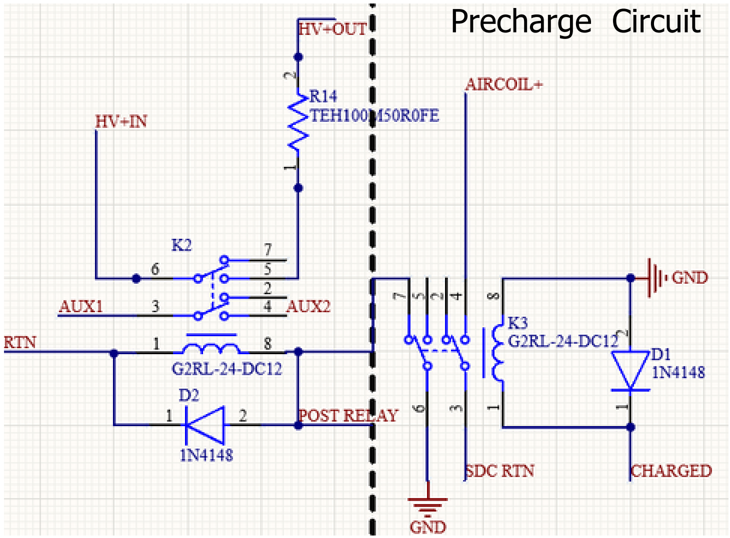


- Utilization of open drain comparators with common pull up network for AND logic in SCS check without AND gates
- Using RC networks for 500ms and 10sec reset delays instead of 555 timer.
- Using diodes for quick capacitor discharge during fault conditions in 10sec reset logic

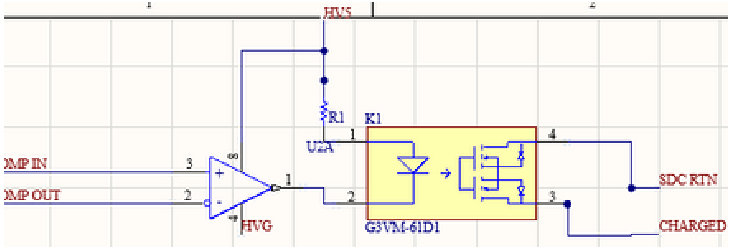
Precharge and Discharge

	Pre-charge Circuit	Discharge Circuit
Resistor	100Ω	100Ω
Maximum Voltage	96V	96V
Time:	3.2391s	0.507s
Peak Power: 92.16 W	92.16W	92.16W

- Voltage comparator to constantly monitor bus voltages for 95% precharge
- DPDT 8A Precharge/Discharge relay, double pole for mechanical state detection

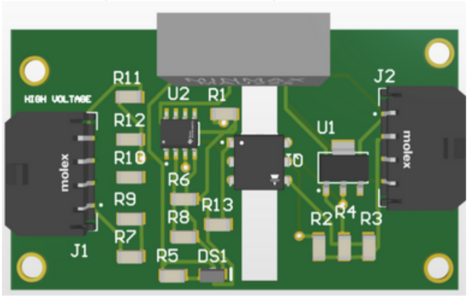


Precharge Circuit

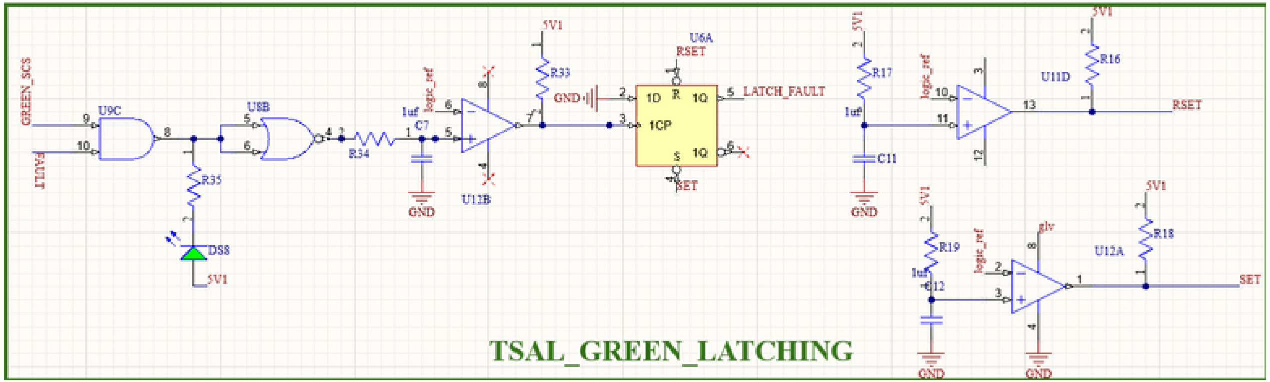


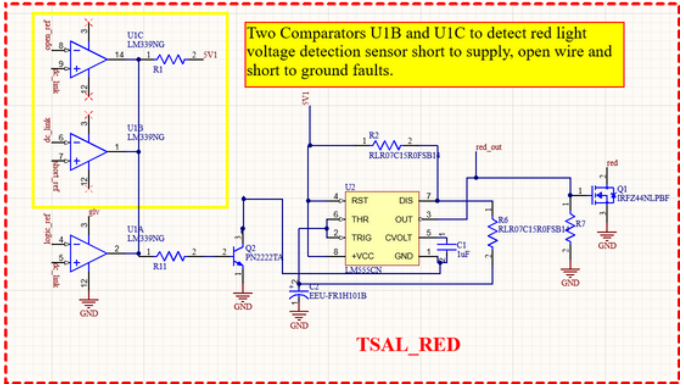
Discharge Circuit

Tractive System Active Light



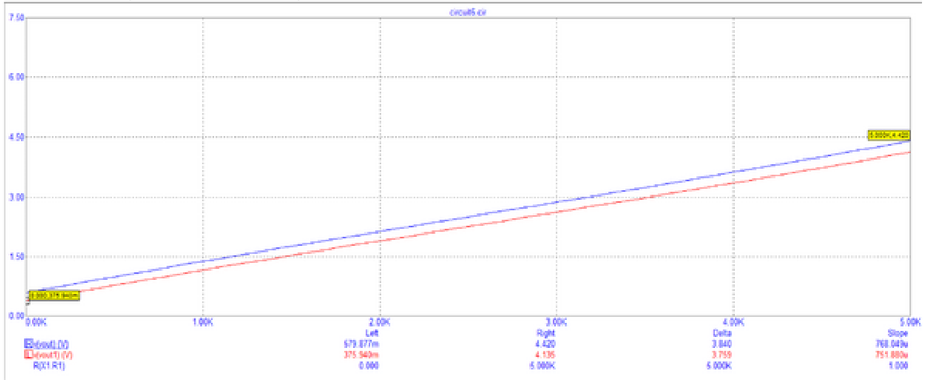
TSAL HV SENSOR





- Self developed High Voltage Sensor using comparators for TSAL red and green detection
- Used Automotive D latches for green light latching circuit
- Open drain voltage comparators for voltage sensor SCS checks for TSAL green and red circuits
- Fully independent TSAL green and red light circuits

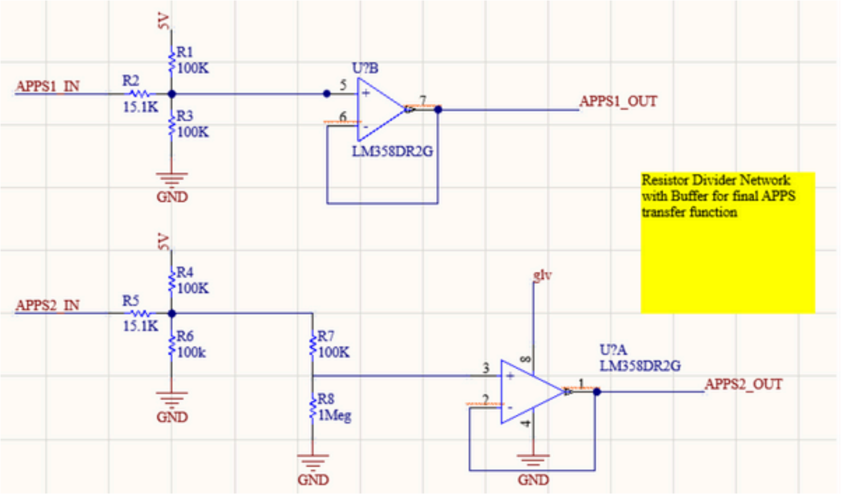
APPS - Acceleration Pedal Position Sensor



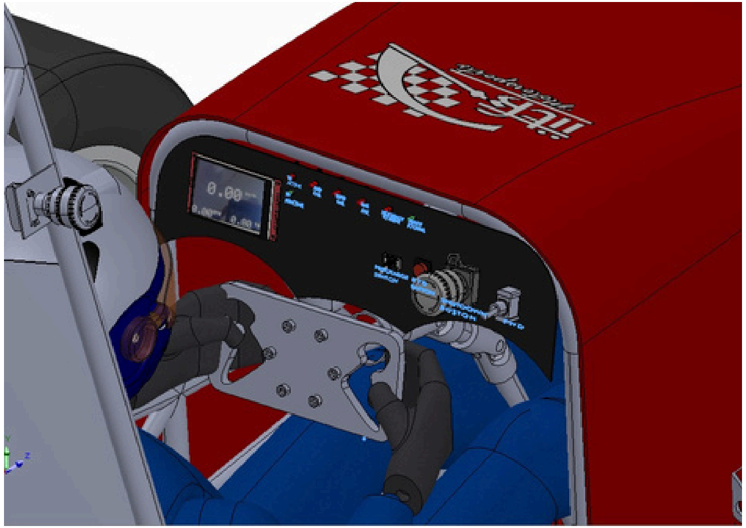
APPS Voltage Output Plot

- Resistive network for tunable APPS transfer function
- Independent non intersecting Transfer functions for different APPS
- Buffer Circuit for signal integrity

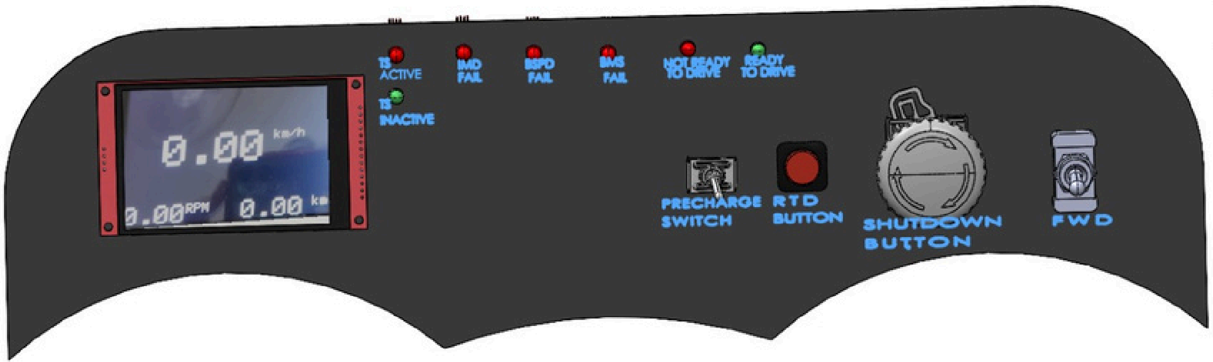
- Linear 5Kohm Potentiometer for APPS
- 50mm travel chosen for optimum pedal travel



DAQ + DRIVER INTERFACE



Driver Interface



ACTUATION

- Shutdown Button (NC)
- RTD Button (Momentary NO)
- Precharge Enable (Toggle NO)
- Forward Switch (NO)

INDICATORS

- AMS, BSPD, IMD Fault
- TS Active/Inactive
- RTD Enable/Disable

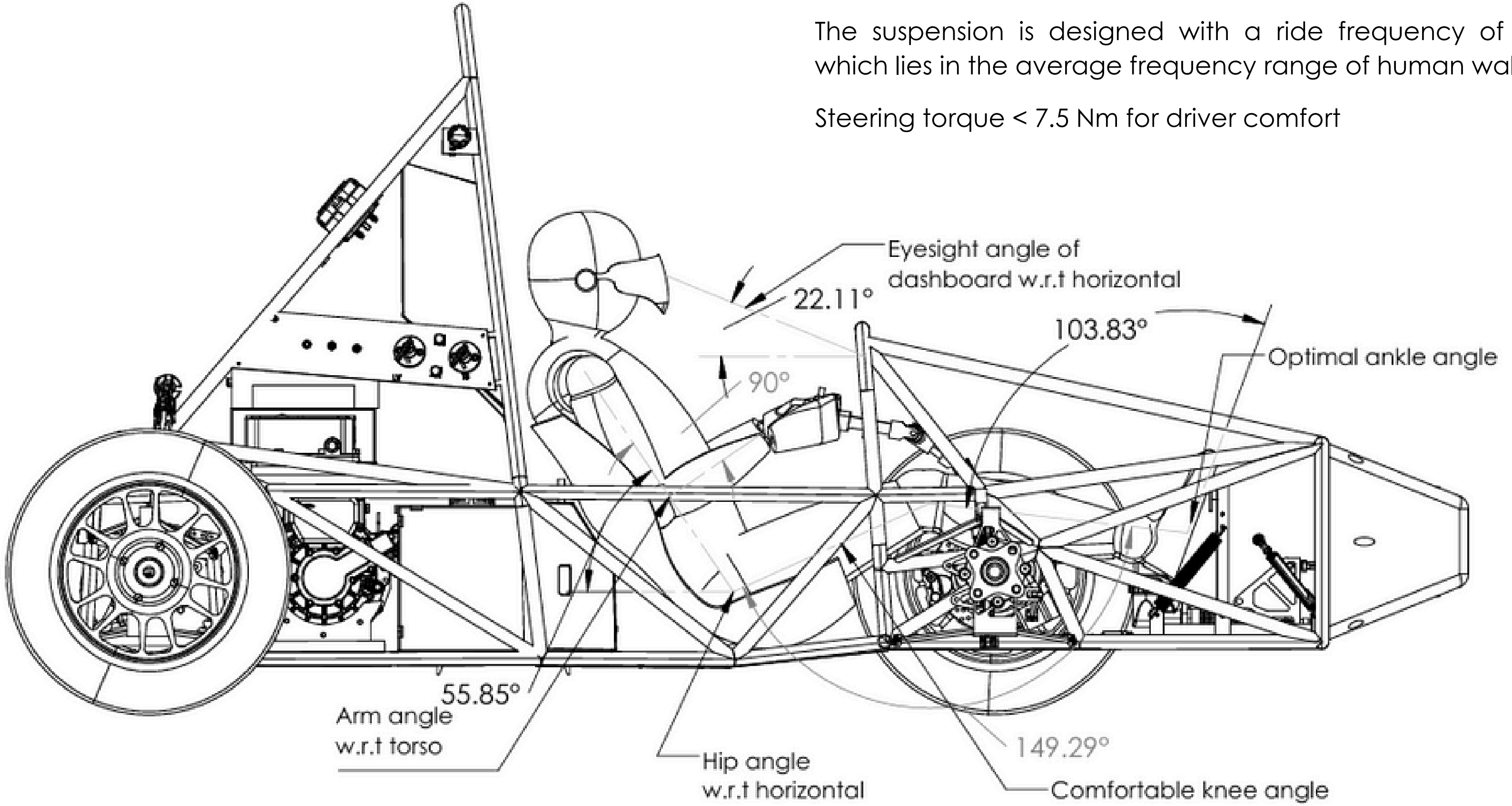
HUD

- Motor RPM
- Vehicle Speed
- Battery SOC

Driver Bio-Mechanics

The suspension is designed with a ride frequency of 1.9 Hz, which lies in the average frequency range of human walking.

Steering torque < 7.5 Nm for driver comfort



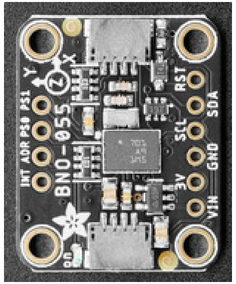
Data Acquisition

Motor Encoder

A device that measures the position, speed and direction of rotation of an electric motor's shaft.

Inertial Measurement Unit

1. Measuring orientation data for post analysis
2. 9-DOF IMU
3. Measure change in Caster- camber angles

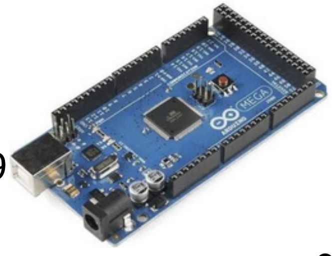


CAN Transceiver

Used to log live CAN data from the AMS

Micro-Controller Unit

1. Arduino Mega2560 is used as microcontroller unit.
2. Arduino is powered by 9 volt battery



Failure Modes and Effect Analysis

Subsystem	FMEA
Chassis and Aerodynamics	• Real-world crash scenarios simulated • FoS>1.5 and use of standard IA for safety
Suspension and Steering	• FoS > 1.5 for extreme bottoming out cases such as 1.5G braking + 1.5 Lateral Acceleration. • Swivel joint used in control arms in order to prevent breaking under shear load.
Brakes and Wheel Assembly	• Individual component analysis keeping FoS > 1.5 under extreme loads. • Proper alignment of wheel assembly and brake components to prevent failures in dynamic conditions.
Powertrain	• Material hardening on sprocket teeth to prevent wear and tear. • Sturdy scatter shield to prevent damage to nearby parts • Careful alignment of sprockets using spacers.
High Voltage	• Modular accumulator design for independent and convenient (dis)assembly/replacement of components. • Testing to examine the health and safety of cells.
Low Voltage and DAQ	• SCS checks for all critical signals like BSPD sensors, use of appropriate connectors and buffers for signal integrity • Use of rated ICs, MOSFETS, relays and appropriate rated fuse for sensitive component protection like AMS, IMD

Thank You!