

Electric Motor Implementation in a Formula 750 Vehicle

FINAL GROUP REPORT

PIERLUIGI BONAGURA (2005700), MICHAEL CURTIS (1902276), CHRIS
BELL (2003884), JOSEPH BELCHER (1803210), ROMYLOS FRANGOS
(1802755), ALEXANDER BENNETT (2004205)

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Abstract

Purpose: The purpose of this report is to convert the Formula 750 into an Electric vehicle

Methods: Firstly, each member of the group has been assigned specific tasks, further, a Gantt chart and meeting minutes have been created to secure those milestones and goals are met.

Results: every member has achieved specific findings such as: Duty cycles, temperature requirement, final drive ratio, harness, regulations, different types of battery, and stress calculations. Furthermore, the electrical harness system has been created and the final radiator size has been calculated to achieve the best cooling system for the vehicle. Then the final assembly and Optimum lap test has been the final section.

Conclusion: To conclude, the first Duty cycle in the Donnington Park circuit has shown that the forces acting on the vehicle, energy required to accelerate and decelerate. The other duty cycle has been important to find the best final ratio of the formula 750. The stress analysis calculations have been fundamental for the final assembly, and the Optimum lap which illustrates the max speed of the vehicle into a different circuit, emphasizes the power of the electric vehicle.

1 Introduction

This group project aims to convert an Internal Combustion Engine (ICE) into an electric vehicle (EV).

The Internal combustion engine has become one of the most powerful resources on personal transport (Gibson, 2020). On the other hand, the UK Government according to the prime minister, is aiming to ban the sales of new cars petrol, and diesel by 2035 to 2040 (Dron, 2022).

Unfortunately, there is no clear evidence that batteries have an acceptable combination of power, efficiency, and life cycle due to the toxic material and being hard to recycle. In Appendix 2, a table with different types of batteries can be found (Stone & Ball, 2004).

Appendix 1 illustrates the overall Group Gantt Chart, with the specific task and time required for each member of the Group.

For the first section of this report, the group has been divided into each specific task. Subsequently, each individual member has done individual research on the Formula 750. Finally, a brief conclusion of the main findings, stress analysis calculations and further steps will be explained.

2 Project organisation

2.1 Role and Task Allocation

After various meetings with other members of the group and with the tutor, it has been agreed that each individual should have a specific role as evidenced in Table 1.

Name	Role(s)
Pierluigi Bonagura	EV Group Leader
Michael Curtis	Battery / Project Lead
Chris Bell	Drivetrain
Romylos Frangos	Electrical Powertrain (Motor and motor controller)
Joseph Belcher	Thermodynamics
Alex Bennett	Harness

Table 1 - A list of each member and their respective roles

3 Contributions and work completed by individuals

3.1 Pierluigi Bonagura 2005700

3.1.1 Work content

The role assigned to Pierluigi Bonagura was the group project manager for the Ev Group project.

In the view of Katz and Kahn cited in Jha (2005), the role of a project manager is fundamental and needs to have specific requirements such as (Jha, 2005):

- Technical skills
- Human relationship abilities
- Visionary skills

Any project has a specific ambition, begins at any time, and ends when all the tasks have been met with the help of material resources and manpower (Punmia & Khandelwal, 2002)

As a group leader, he has been involved in organising meetings each week, managing risk assessment, looking at the manual of the Controller, data analysis, potential buckling calculations and final Assembly.

3.1.2 Management

As a group project manager, three main phases have been analysed such as (Punmia & Khandelwal, 2002):

- Organise a Project
- Schedule a Project
- Control the Project

For the group project, a personal Gant Chart has been created, as illustrated in Appendix 3.1, with the entire hours and the main tasks completed for the Group project, which have been important for the efficiency of the overall project.

Although organising meetings and conducting research have been the most relevant parts, other tasks which have taken fewer hours, have also been crucial for the time management of the group project.

As the Brexit has risen a concern for the potential delay and price increase, especially for the Automotive sector (Leeson, 2019), the table, in Appendix 2, illustrates the overall materials which have been selected and those that have been purchased. Also, the table shows the Battery

Nissan Leaf which has been selected previously and then replaced with a Range Rover Sports Ev/Hybrid high Voltage JPLA10B759AP. The Range Rover Battery is less expensive than a Battery Nissan, which will benefit the entire group project.

3.1.3 Risk assessment

In any group project, it is important to consider the risk assessment of it. In the view of Mark (2004) cited Morote and Ruz-Vila, the definition of risk is a combination of complications and problems which have risen the concern of the final achievement and the project aim.

Therefore, to mitigate and prevent this risk following judgment needs to be considered (Morote & Ruz-Vila, 2011):

- Risk of identification, which prevents a risk of future events which could appear or not appear.
- Risk assessment, that is the risk of a dubious event that can affect the ambitions of the overall group project
- Risk monitored and analysed, this is the stage where the project needs to be tracked and identify the risk and mitigate through the time.

3.1.4 Motor control Sevcon

The Gen 4 size 10 has been selected for Formula 750. The controller's main scope is to manage the power of a 3 phase AC induction in the electric vehicle. In addition, the function of the controller is to regenerate power as the vehicle is slowing down, which can convert the kinetic energy into electrical energy, which is recovered into a battery. Table 2 illustrates the range of temperature in which the controller is operating. Also, the main ability of the controller is to monitor and control specific components such as (Sevcon, 2020):

- Voltage battery
- Capacitor voltage
- Motor Emrax 268 current
- Motor Emrax speed
- Controller temperature

Table 2. Maximum and Minimum operating point of the Gen4size10

Operating temperature	-40° C to +25°C (no current) +25°C +80°C (no current derating, but reduced time at rated operating point) When operated with a liquid-cooled in the radiator, the maximum coolant inlet temperature shall be 40°C and the maximum coolant temperature rise shall be 25°C.
Non-operation-temperature	-40°C to +85°C (The controller can be stored up to 12 months)
Shock and vibration: Bump	40 g peak, 6 ms, 1000 bumps in direction rate of 1 to 3 Hz.
Weight (excluding cable and no coolant)	10.7 kg

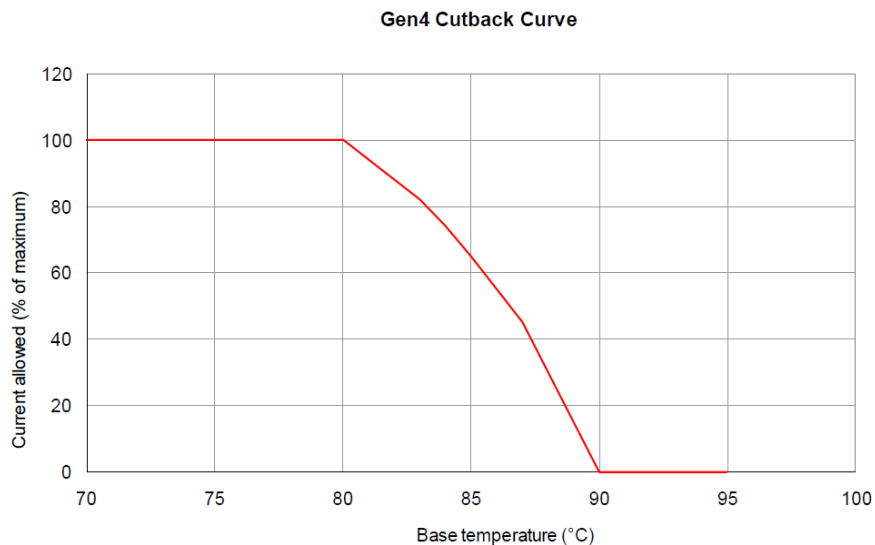


Figure 1. Current allowed against Temperature (Sevcon,2020,p.54)

Furthermore, as illustrated in the graph in Figure 1, the controller is aiming to support the excessive current, as the temperature increases above 80 degrees, the current allowed from the controller will decrease until the temperature reaches 90 degrees where the controller switch off for safety reasons (Sevcon, 2020). Therefore, the optimal temperature is between 70° and 80°.

3.1.5 Data analysis

The real data from Donnington Qualification were collected, analysed and used for the Formula 750 as illustrated in Figure 2.



Figure 2. Formula students 750

Table 3. Technical Vehicle characteristics

Frontal Area	Gravity	Rolling resistance	Coefficient of drag	Mass	Air Density	Conversion	Losses
m ²	m/s ²	Newtons	Newtons	Kg	kg/m ³	w to kw	Percentage
0.917	9.81	0.012	0.63	480	1.225	1000	10

On the other hand, Table 3 illustrates the vehicle specifications from Formula 750 which has been given by the Aerodynamic group and Chassis Group.

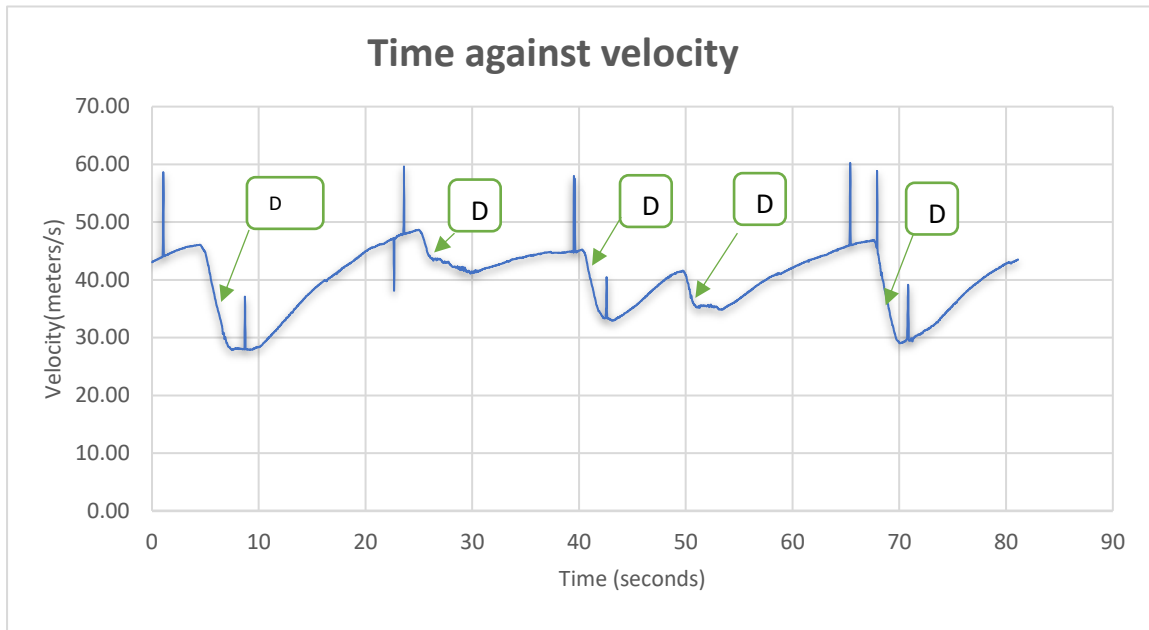


Figure 3. Time against speed of the Formula 750 in Donnington

Figure 3 illustrates the entire duty cycle of the vehicle in the Donnington. As electric vehicles can store electric energy, the Formula 750 will be able to store some energy in the Battery during the deceleration labelled with “D” (Ehsani, et al., 2018).

Other forces acting on the vehicle have been investigated, producing the drag force.

The rolling resistance has an imperial impact especially at a high speed, further, Equation 1 illustrates the formula used from which the graph, in Figure 4, has been plotted. (Schuetz, 2016)

.

Equation 1

$$\textbf{Rolling Resistance} = m * g * C_{rr}$$

Where m (total mass of the Formula 750)

G (gravity acting on the vehicle)

C_{rr} (Coefficient of rolling resistance)

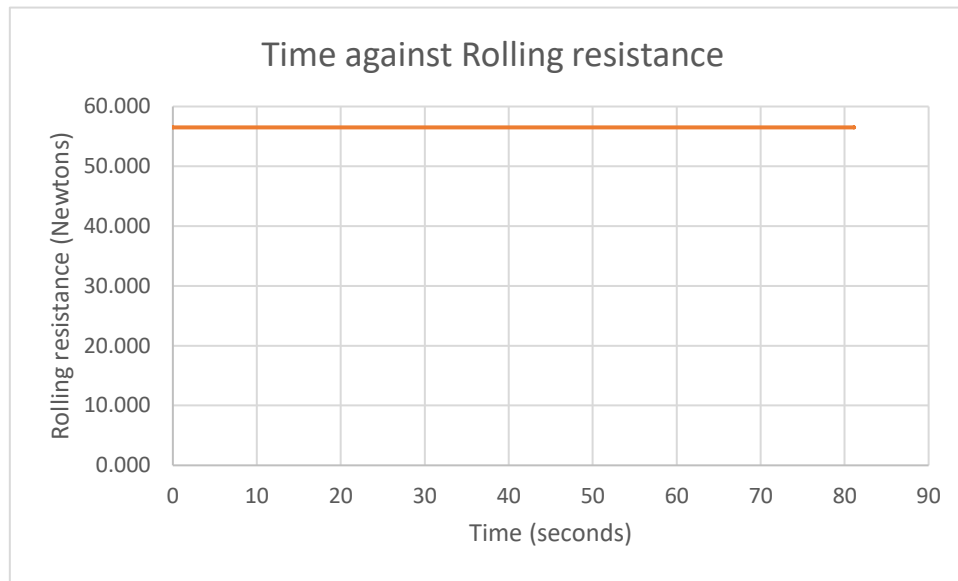


Figure 4. Rolling resistance acting on the vehicle

Whereas Equation 2 illustrates the Aerodynamics force's importance, the value has been taken from Table 3 above (Schuetz, 2016).

Equation 2

$$\mathbf{Aero} = \frac{1}{2} * p * V^2 \Delta * A * C_D$$

Where p (the air density)

V (is the velocity of the Formula 750)

A (This is the frontal area of the vehicle)

CD (This is the Coefficient of drag of the vehicle)

From Table 3 and Equation 2 the aerodynamic force against time has been plotted.

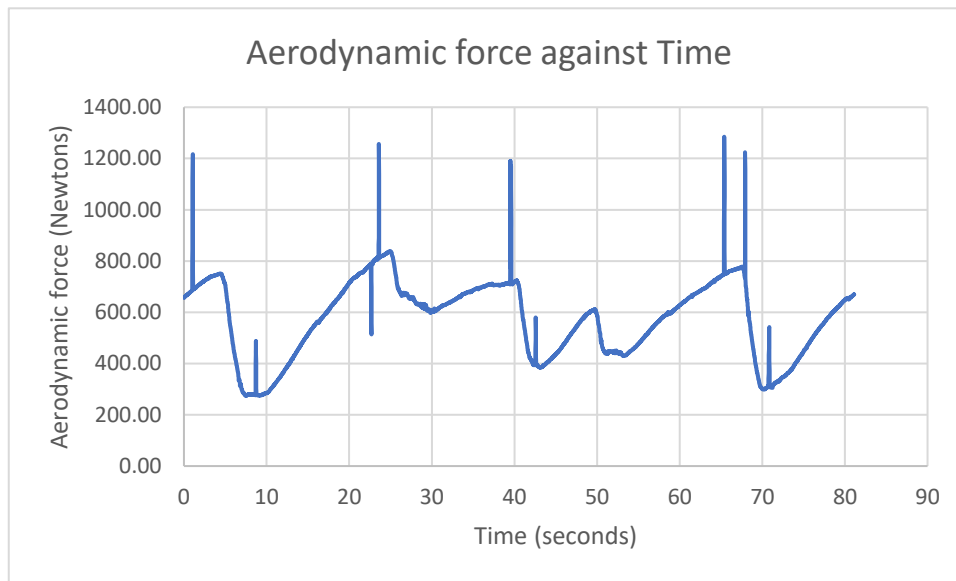


Figure 5. Aerodynamic force against time

In addition, once the collected data were found, the drag of the Formula 750 has been found, as illustrated in Figure 5.

As shown in the graph in Figure 5 the drag depends on the frontal area and the drag coefficient. Therefore, the Aerodynamic drag is a force which is generated partly from friction which flows over the surface (Barnard & Harry, 2001).

Following, the acceleration force of the vehicle has been calculated. According to Newton's second law, the acceleration force is:

Equation 3

$$F = M * A$$

Where

M = Mass of the 750 A=acceleration

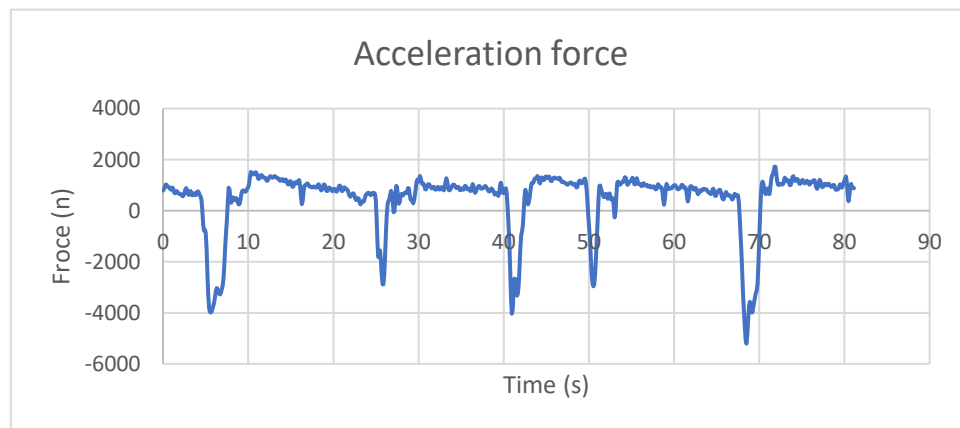


Figure 6. Acceleration force against time

Figure 6 evidence that the force acting on its vehicle is equal to its acceleration and the entire mass of the vehicle (Dynamics, 2011).

Therefore,

Equation 4

$$\text{Total resistive force} = \text{Acceleration force} + \text{Drag Forces}$$

Acceleration force has been found from Equation 3

Drag Forces has been calculated from Equation 1 and 2

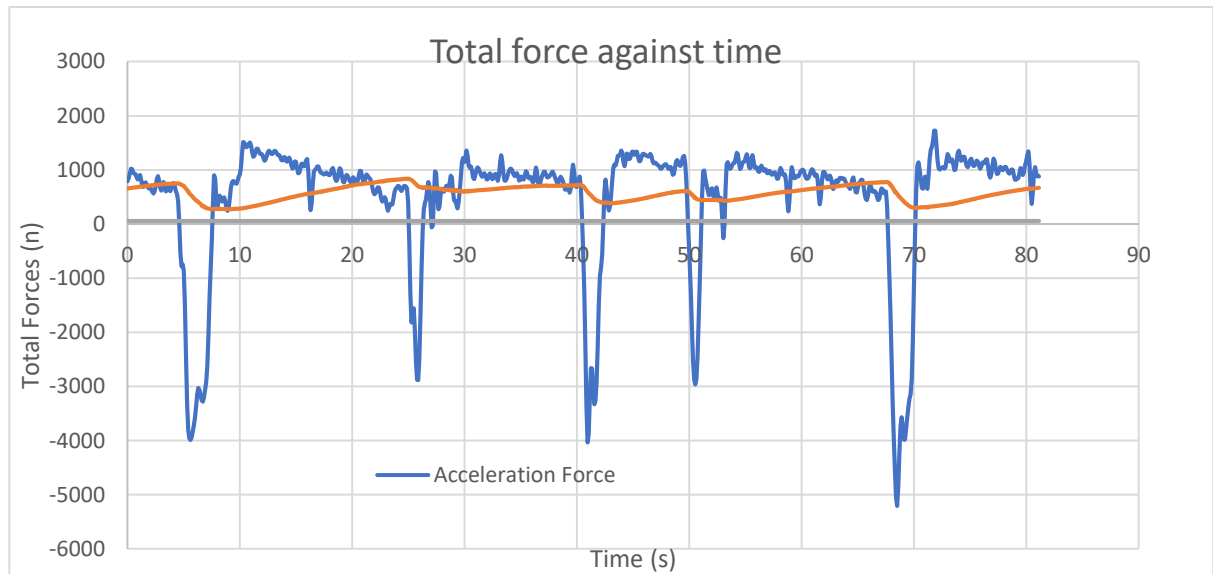


Figure 7. Total force acting on the formula 750 during the duty cycle

Figure 7 illustrates the importance of all the 3 main forces acting on the vehicle which will impact on the energy consumption on the vehicle (Ehsani, et al., 2018).

The important aspect is that electric vehicles are able to recover energy as the vehicle is decelerating (Xiong, et al., 2018).

In addition, from the total forces, the Power required have been calculated as (Barnard & Harry, 2001):

Equation 5

$$P = F * V$$

F total Force calculated from Equation 4

V is the speed of from the Donnington qualification lap

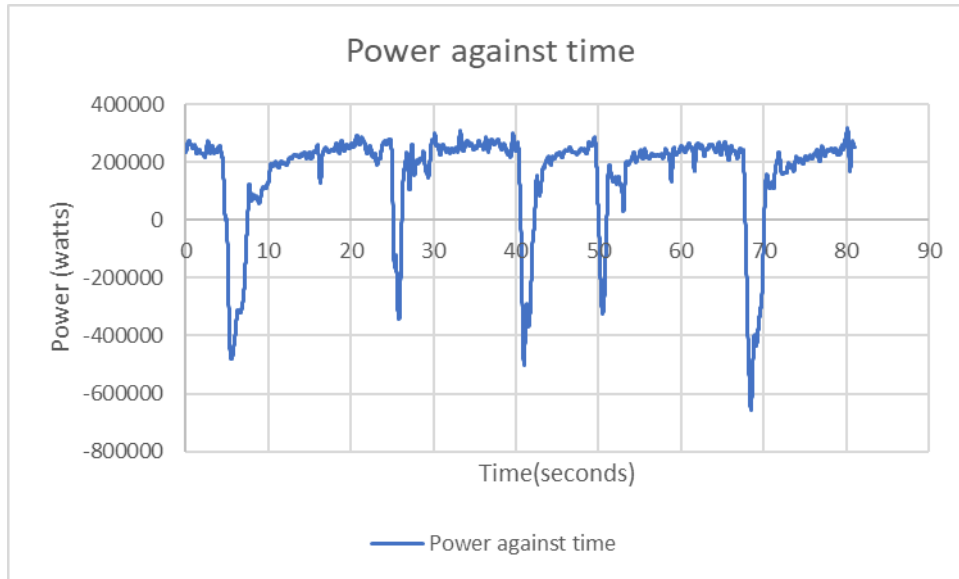


Figure 8. Energy utilized during the duty cycle

From equation 5, Figure 8 shows the power required against time. The time distribution is favourable for the overall power train design, which can explain a better efficiency region of the power train which is designed for the best operation time area (Ehsani, Gao, Longo, & Ebrahimi, 2018)

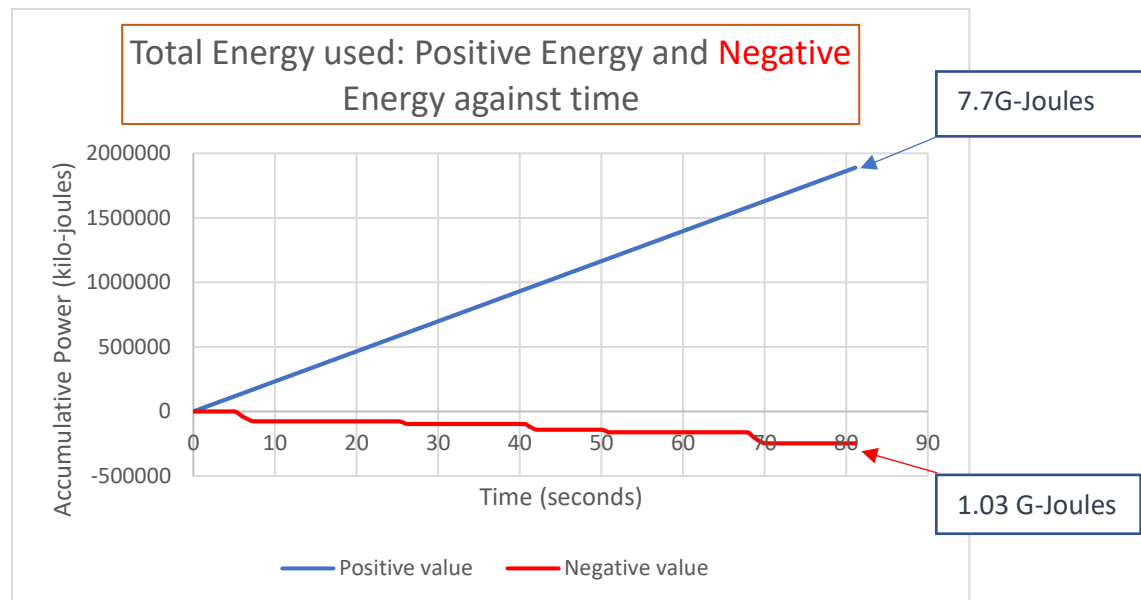


Figure 9. Accumulative tractive Energy

As energy in the battery is limited during the traction system, it has a crucial importance, especially in a Motorsport application (Ding, et al., 2017). Figure 9 illustrates a positive kilojoule, which is the energy that will be lost and cannot be recovered which is a total of 7.67 Gigajoules, whereas the negative energy in red is the energy that can be recovered through the battery and the cumulative energy recovered is about 1.03 gigajoules. Therefore, some wasteful energy through the braking can be stored and utilized as extra power while the vehicle is accelerating at the same time able to reduce the energy consumption.

Other data have been investigated to find the overall efficiency of the Formula 750 using the Optimum lap software. Table 4 below illustrates a table of general data which has been given from the Aerodynamic group and Chassis group.

Table 4. General Data of the Formula 750

General Data			
Mass		Vehicle	
480	kg	Formula 750	
Aero Data			
Drag Coefficient		Downforce Coefficient	Units
0.6	N	3	N
Frontal Area		Air Density	Units
0.917	m^2	1.2	kg/m^3
Tyre data			
Tyre radius		Rolling resistance	Units
0.26	m	0.013	N
Longitudinal Force		Lateral Friction	Units
1.7	N	1.7	N

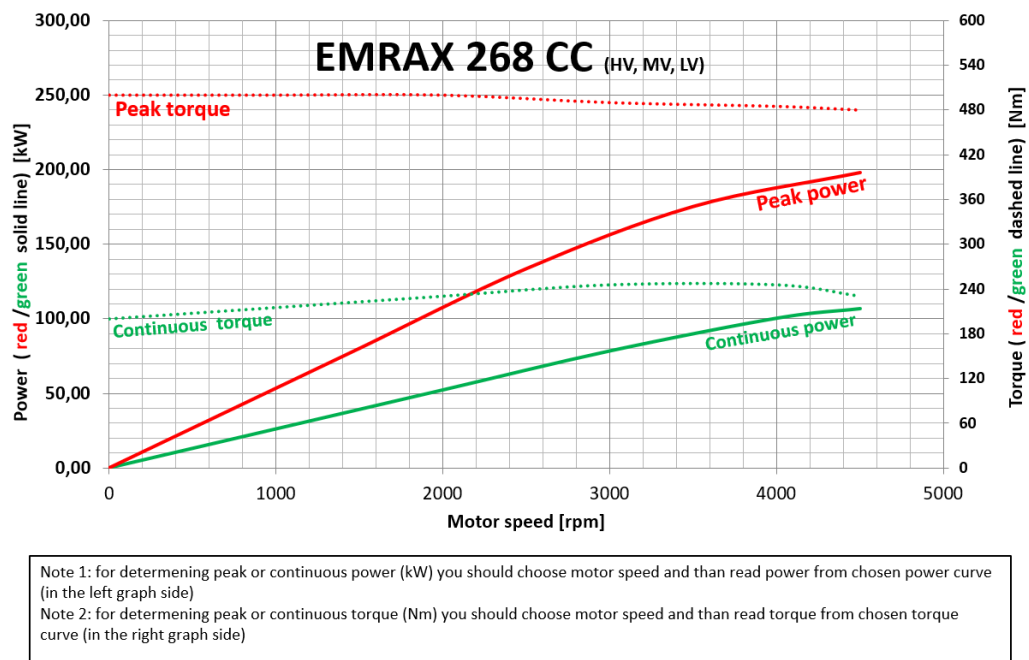


Figure 10. Emrax 268 graph with Continuous Torque and power required(Emrax, p.22,2020)

After that the torque was collected from Figure 10, the specific torque required for each rpm has been Moreover, other specific data have been collected from a different group as illustrated the Table 3.

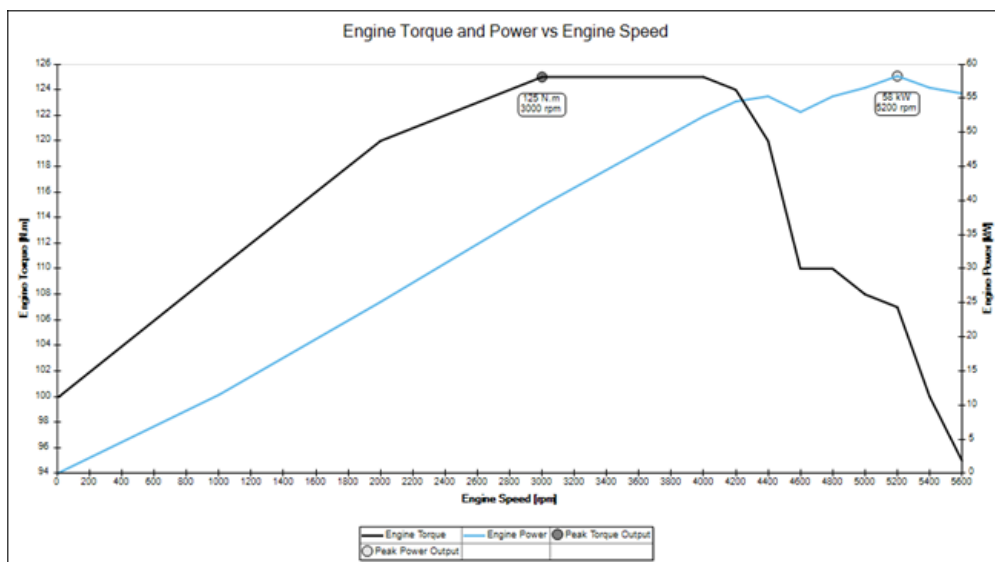


Figure 11. Torque required of the Emrax 268

Also, the first graph which has been created from the Table 3 and Figure 10 is the Torque request of the vehicle as illustrated in Figure 11.

Also, the graph illustrates as the Emrax motor 260 will require 220 Nm at the same time a 115 kw of power is required from the battery which will be sent by the controller Sévon.

In addition, once all the data were collected a simulation in Optimum Lap has been carried through a different circuit called the “Road America” circuit.



Figure 12. Data from an Optimum lap of a Road America Circuit

Finally, the graph in Figure 12 illustrates that the vehicle is able to maintain a constant speed through its circuit.

3.1.6 Weight Distribution and regulations

Another crucial aspect that has been considered is the weight distribution of the Formula 750 and its regulations.

Table 5. Regulations of Powertrain Group (Formula750,2022)(Imeche,2020)

Transmission and Drive	Coolant Fluid and System Sealing	Further regulations
•Any transmission can be used •The master switches needs to be relevant for the safety of the driver	•Only water or oil can be adopted for a coolant •Any lubrication needs to be closed to prevent leakage.	•Minimum weight of 480 kg with the driver. • The battery needs to be able to have a repetitive starts

As illustrated in Table 6, following the regulations from the Formula 750, it has been quite challenging for the EV group to find the right place where to locate each component (Formula750, 2022) (Imeche, 2020). Therefore, since there were no clear regulations on Electric vehicles, the best solution was to consider the manual of each component and at the same time take into consideration the weight distribution of the vehicle.

3.1.7 Modelling and Euler's Buckling

The Controller has been modelled in Solidworks and added through the final Assembly.

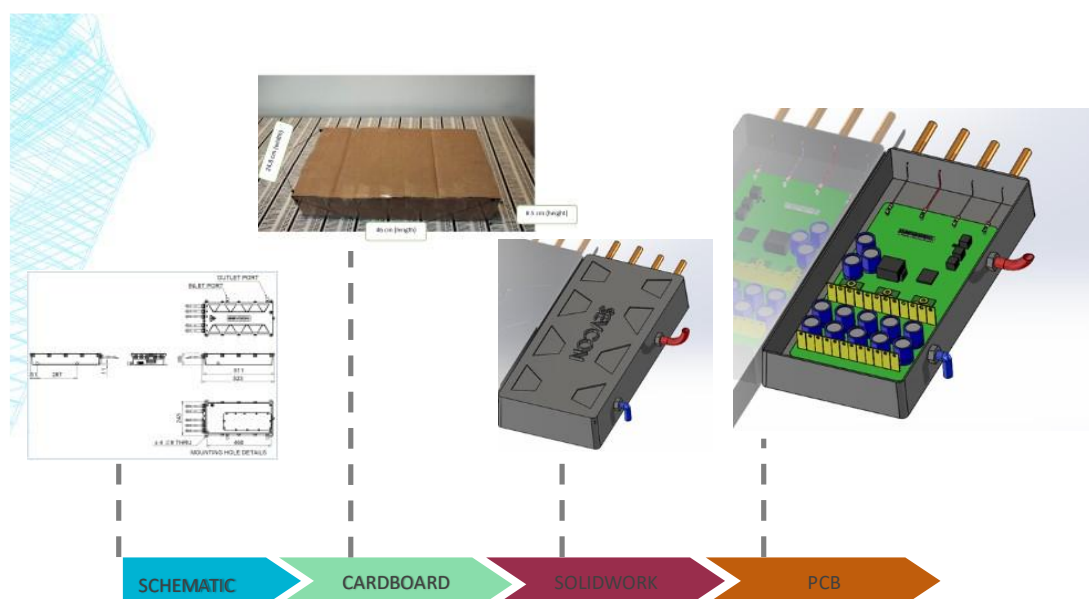


Figure 13. Steps to the final Design model of the controller Sevcon Gen 4 size 10 (Sevcon,2020,p.20)

As illustrated in Figure 13, the dimensions have been collected from the Sevcom manual, then a Cardboard has been modelled to have an original overview of the model, then the final Solidwork model has been designed through Solidworks with the PCB of the controller.

On the other hand, the Euler's was discovered in 1759 by Leonard Euler, which has been used for project design (Rosato & Rosato, 2003).

Any component which is located in a car can be subject to torsion or buckling (Brown, et al., 2001). In the view of Euler "the stress in the column due to direct loads is small compared to the stress due to buckling failure" (Buckling, 2020). As for the controller will be in the car and installed with bolts on one side, the concern on buckling failure has risen due to the excessive weight of the battery, so a critical buckling load has been calculated.

The critical buckling load has been calculated as follow:

Equation 6

$$F_{Cr} = \frac{n\pi^2 EI}{L^2}$$

From Equation 6 Table 7 illustrates the main equation which has been done to calculate the critical buckling load.

Table 6. Data for the Euler's critical load

Value	Description	Total-Units
E	Modulus of Elasticity for aluminium	69 Gpa
n	both ends pinned	1
I	The second moment of Area	$1.27 \cdot 10^{-6} \text{ m}^4$
A	The total area of the Controller	$(0.85 \cdot 0.248)$ $= 21.08 \cdot 10^{-3} \text{ m}^2$
L	length of the controller	0.523 m
b	length	0.248 m

h	width	0.085 m
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The second moment of the area has been calculated as (ToolBox, 2012):

Equation 7

$$I_{xx} = \frac{b * h^3}{12}$$

Therefore, from Equation 7 and Table 7,

$$I_{xx} = \frac{0.248 * 0.085^3}{12} = 1.27 * 10^{-6} m^4$$

In addition, the critical load buckling from the equation 6:

$$F_{CR} = \frac{1 * \pi^2 * 69 * 10^9 * 1.27 * 10^{-6}}{0.523^2} = 3.16 \text{ Mega Newtons}$$

The slenderness ratio can be definite as the ratio of the radius of gyration “K” and the length.

The radius of Gyration is calculated as (Rosato & Rosato, 2003):

Equation 8

$$SR = K = \sqrt{\frac{I}{A}} = \sqrt{\frac{0.523}{21.08 * 10^{-3}}} = 93.17 \text{ mm}$$

Also, the Slenderness ratio has been calculated as:

$$SR = \frac{L}{K} = \frac{523 \text{ mm}}{93.17 \text{ mm}} = 5.61$$

As most of the failure during the Design process occurs when the Slenderness ratio exceeds 100 (Rosato & Rosato, 2003), however, as illustrated the Equation 8, the Slenderness ratio is 5.61 which is a good number that evidence that the buckling failure does not occur. In addition, if an extra load is applied to the controller, then the formula needs to be updated.

Also, the Test has been tested in Solidworks as illustrated in Figure 14, the controller has been compressed by 3.16 Mega Newtons.

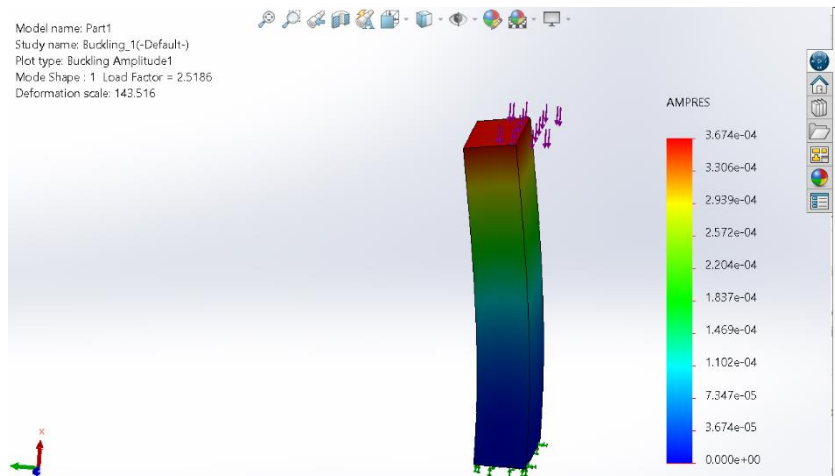


Figure 14. Buckling simulation in Solidworks

3.1.8 Validation and testing

The first analysis has been evaluated through the Donnington lap. Figures 4,5,6,7 illustrate the total tractive force as the vehicle is accelerating. Subsequently, the Power required for the vehicle has been illustrated, further, Figure 9 illustrates the red accumulative negative value of 1.03 Giga-joule, although they are not much energy that can be used but it can be an exceptional booster as the vehicle is accelerating. In addition, another test through Optimum lap illustrates the incredible constant speed of the Formula 750 as illustrated in Figure 12 over the Road America circuit.

The potential Euler's buckling calculations for the controller illustrated in Equation 6, gives the same result of the testing in Solidworks. Therefore, a force over 3.15 Mega Newtons could cause a buckling failure over the component and at the same time a damage of the controller Sevcon Gen 4 size 10.

Therefore, Figure 15 illustrates the final Assembly of the vehicle. Moreover, the final assembly evidence there is not much weight on the controller for two reasons to reduce the force acting on the controller and do not have many hot components around of the controller that could cause the overheat of the Sevcon. Further, the brackets have been designed to secure that the motor Emrax is held in place on the chassis.

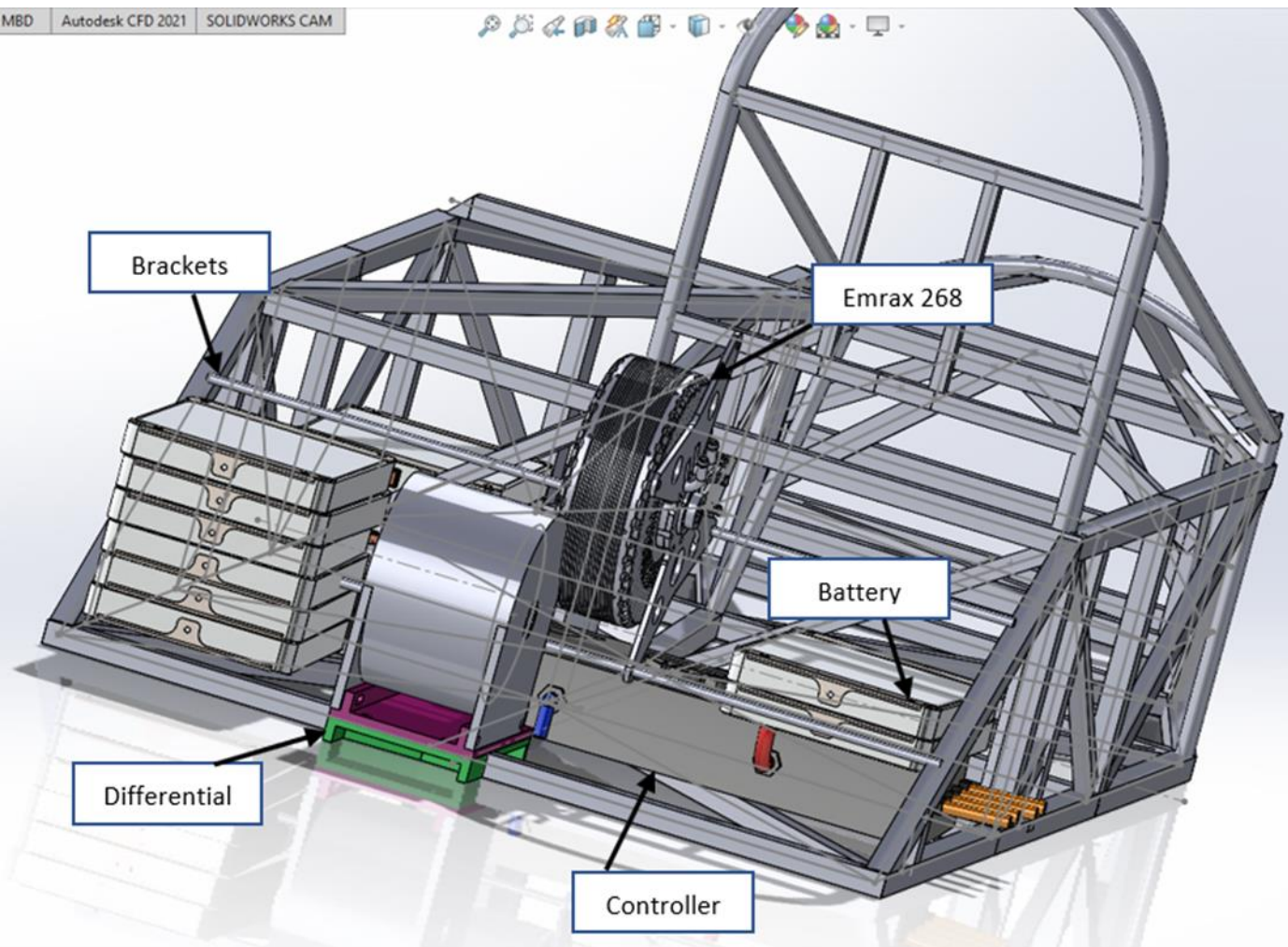


Figure 15. Final Assembly Ev powertrain

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3.1.10 Appendix

Appendix 3.1

Table 7. Bonagura Pierluigi Gantt Chart

Student number and role	Task	Task Description	Hours required	Start Date	End date
Pierluigi Bonagura_2005700_(Group Leader)	Organise meeting	Meetings have been scheduled each week with the tutor and other members of the group	40	18/10/2021	28/03/2022
	Online meeting	Online meetings have been organised each month to keep the progress of the project	6	18/10/2021	28/03/2022
	Research	I have been focused on the team group project finding solutions and doing my own research. Also, I have approximately spent 5 hours each week to secure the efficiency of the group project	100	18/10/2021	28/03/2022
	Legislations	For any changes or components purchased, the relevant 750 regulation was considered.	10	18/10/2021	28/03/2022
	Finance	The cost for the materials was forecasted. It has been one of the challenging tasks due to the pandemic and other political issues such as Brexit.	15	01/11/2021	01/12/2021
	Record	As part of the group leader, it is important to take as many notes as possible and assign each task to every	10	18/10/2021	01/11/2021
	Communication	It is another crucial step where the group leader needs to be ready to help other	5	18/10/2021	29/03/2022
	Preparation	Be prepared for the Interim Viva, Final Viva Presentation and Final writing report	20	18/10/2021	31/03/2022
	Prevention	Sometimes predict what can go wrong can be beneficial for the overall project	5	01/11/2021	28/03/2022
	Modelling	Modeling something in Solidworks it can make a group project running much more accurate	20	07/01/2022	28/03/2022
Total hours			231		

3.2 Michael Curtis

3.2.1 Research carried out

To begin the research phase for the battery a few electric racing series were looked at to gather an understand of the requirements and specifications of each. Initially the Formula E series was looked at which was supplied by McLaren Applied Technologies from 2018 to 2020 for the Gen2 Formula E car as well as supplying the E-Motor and Motor Control Unit from the start of the series. These battery packs were able to store 54 kWh of usable energy and output 200kW for the race and 250kW for qualifying. (McLaren Applied Tech, 2016) The requirements for the batteries can be seen below:

4.1	Main information	
	Maximum voltage at anytime:	1000 V
	Minimum voltage at anytime:	450 V
	Maximum cell weight:	250 kg
	Maximum battery pack weight:	330 kg
	Maximum battery pack volume:	320 litres
	Season mileage:	6000 km
	Battery life:	1 season
	Cycles:	150

Figure 1 - Battery pack requirements from the FIA (FIA, 2016)

Using these specifications, we were able to get an idea of what the requirements of our battery pack would need to be able to do, mainly the estimated milage along with the battery life which would also aim to be for at least 1 season if not more if possible. It was also useful to look at the cycles of the battery as this means if we were to use a regular vehicle battery, we could ask more from it due to the fewer cycles compared to a road car which has about 500 cycles before performance loss starts to occur. (EDF Energy, 2021)

As well as Formula E, another electric vehicle project was looked at from Play and Drive. It was an electric car based on the Formula 4 GEN1 chassis by Mygale. It was aiming for a similar specification as us just with a different chassis with some higher top power requirements and used a similar higher qualification power like the Formula E car. Below are the specifications provided by the co-founder of Play and Drive for the F4E GEN1 Proto and after contacting the co-founder we learnt that the batteries were 21700 cylindrical cells giving a high reliability along with impact resistance and high working temperature. (Meura, 2021)

- Total Car Weight: 684Kg (without driver)
- Battery Capacity: 36.0kW.h (High Power)
- Battery Weight: 217Kg (Cooling System included)
- 750V Electric Propulsion System
- Race-Mode Power: 120kW (163HP) (15min races FIA tracks)
- QL-Mode Power: 140kW (190HP) (2 laps chrono FIA tracks)

Figure 2 - Specifications of the F4e GEN1 Proto

During the research phase of the project, many batteries were considered for the project and have been laid out in the following table with the specifications for each battery pack. Some would need to be in multiples to be viable for the project and others don't have complete data due to the lack of information from suppliers or are awaiting responses.

Battery Pack	Modules	Capacity (kWh)	Nominal Voltage (V)	Weight (kg)	Ampere Hours (Ah)	Mod. Dimensions (mm)	Mod. Volume (mm ³)	Pack Volume (mm ³)	Cooling Type	Lead Time (Days)
Nissan Leaf	24	40	349	208	112	319x222x68	4815624	115574976	Passive	45
VW e-Golf	22	35	323	242	108	335x150x105	5276250	116077500	Air	30
JLR Range Rover PHEV	9	15	453	145	298				Liquid	
BMW i3	8	40	352	352	120	410x300x150	18450000	147600000	Liquid	20

Table 1 - Battery Pack comparison table

For the Nissan Leaf battery pack, the data was collected from Second Life EV Batteries who were selling the battery pack, along with a test on each of the batteries in the pack giving a good idea of the actual capacity – something not provided by the other providers of the batteries. They also give one of the best power to weight ratio of the batteries with data available and are passively cooled which means no air needs to be supplied to them at all but this can have some drawbacks in hotter climates and prolonged race sessions. (Ruffo, 2021)

For the BMW i3 batteries, these were chosen for comparison due to them also being available from Second Life EV Batteries and had similar specifications to those of what we needed. These would be a great selection however due to the weight of these batteries compared to the Nissan leaf and the liquid cooling as well as weight would be much higher than even the JLR Battery packs.

For the VW E-Golf batteries, they were selected for the slightly squarer size of the overall modules, along with them being the initial battery chosen. They also allowed for a larger comparison between different batteries to see what was available to us. They ended up being not chosen due to the lower capacity and voltage compared to the Nissan Leaf batteries along with the higher weight and volume comparatively.

For the JLR Range Rover PHEV battery pack, it was chosen due to the lower module count allowing for more power and voltage per battery and the support available due to the battery being handles by a local supplier. However, these batteries have been lacking information on

the individual modules but even considering this these batteries would be ideal due to the quantity available to the supplier. This allows for plenty to be supplied for the racing series. Along with this, a follow up has been sent to the supplier and are awaiting response. The following questions have quoted directly from the email sent to the supplier of those batteries from us.

- Does it have any cooling system?
- Do you have the dimensions of the individual modules?
- Does each module have its own insulation?
- We'd like to have two separate boxes, one alongside the driver and another in the rear (with ideally 80-100kg alongside the driver and the rest in the rear), would it be possible do this with your BMS?
- What is the maximum recharge rate of the batteries?

We were provided lap data by some of the existing teams within the Formula 750 series which has been useful for all the groups but for us, as we were able to use this data to gather an idea of what the estimated lap time was. Using the knowledge of a 20–25-minute race time for a standard race and 45-50 for an endurance race calculations can be completed for the estimation of battery usage.

Another consideration would be the amount of power available on track in the pit lane if there were to be multiple races in one day or if they needed to be recharged for multiple sessions such as practice. This would need an implementation of improved charging facilities at each track or be recharged before arriving at the circuit, another consideration when selecting a pack that has a slightly lower capacity. The recharge rate can also be artificially limited to help reduce the strain of power at each track but at the cost of taking longer to recharge.

3.2.2 Designs carried out

Initially, the battery modelled was the *VW e-Golf* battery that was first selected, and only some simple test designs that were not saved were used for this battery. After moving to the *Nissan Leaf* battery, CAD models were sourced for the understanding of the placement of the battery. The original design can be seen below, showing the first pass of the placement of the batteries.

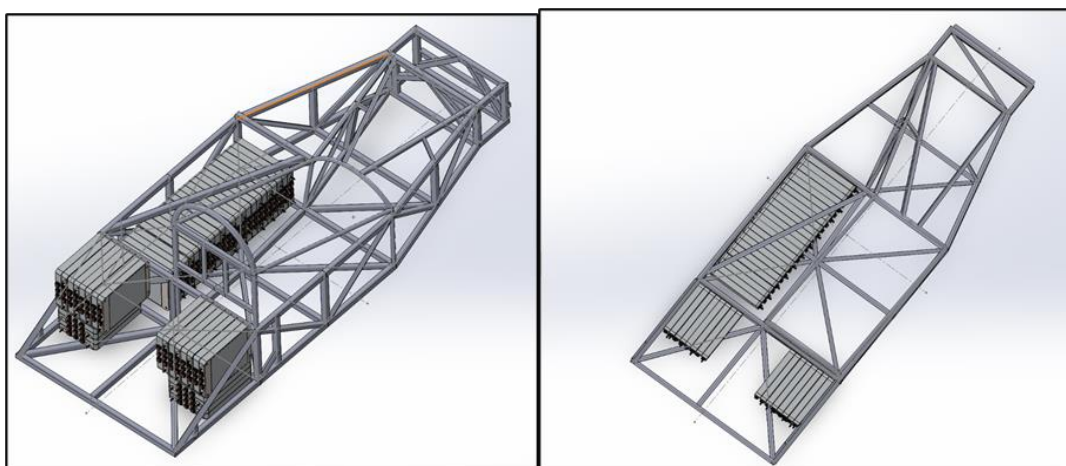


Figure 3 – Version 1 of the battery placement, side angle view (left) and top-down view (right).

This initial design used the space at the rear to attempt to fit the remaining batteries that wouldn't fit alongside the driver. This caused a weight imbalance due to the large number of

modules alongside the driver as well as not fully utilising space in the rear of the vehicle. This does have the advantage of bringing the centre of mass down a bit, but it is offset a bit by the higher placement of some of the rear batteries. This led to a redesign of where the battery placement should be which can be seen below.

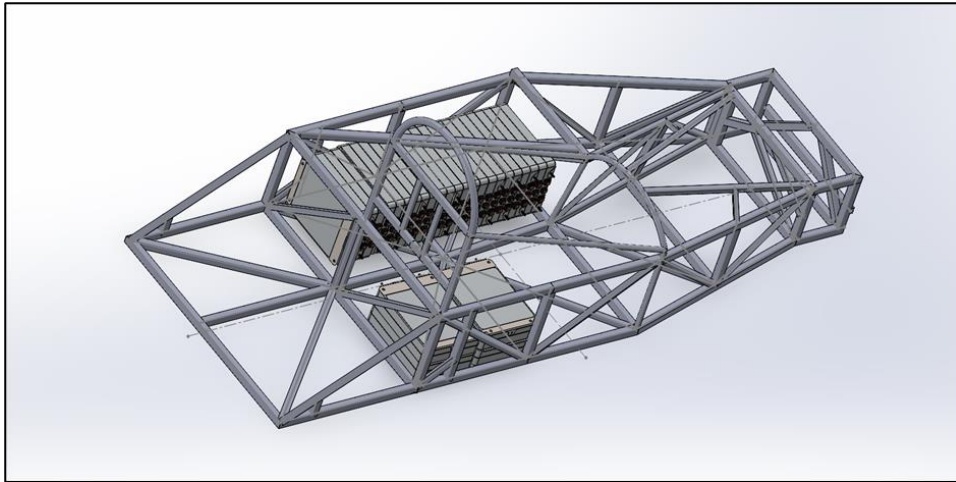


Figure 4 - Top-down view of version 2 of the battery placement.

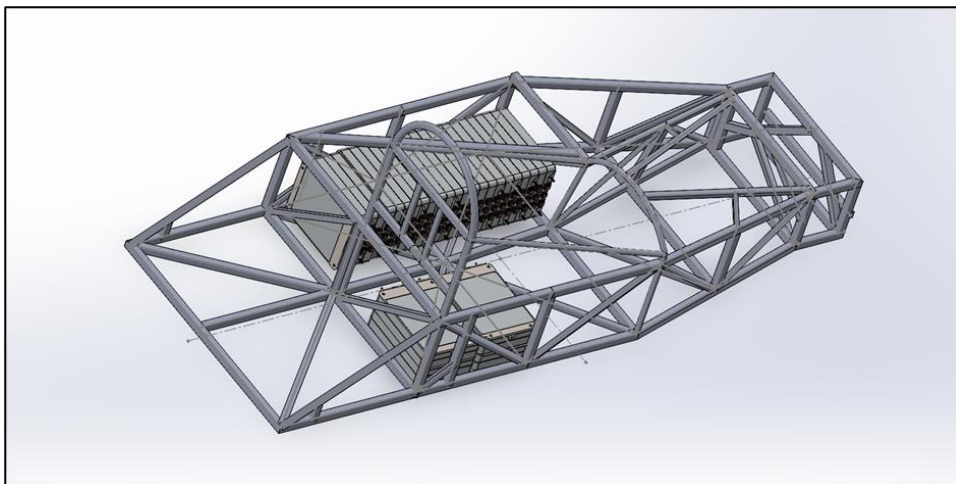


Figure 5 - Side in angled view of version 2 of the battery placement.

This secondary design used the space underneath the driver however this design was struck off quite quickly due to the fact the driver will not fit if the driver was to be raised by any amount. This was discovered after liaising with the chassis and aerodynamic groups. However, even with that design being possible the rest of the batteries are placed alongside the driver leading to a weight imbalance due to an estimated driver weight of 80-90kg.

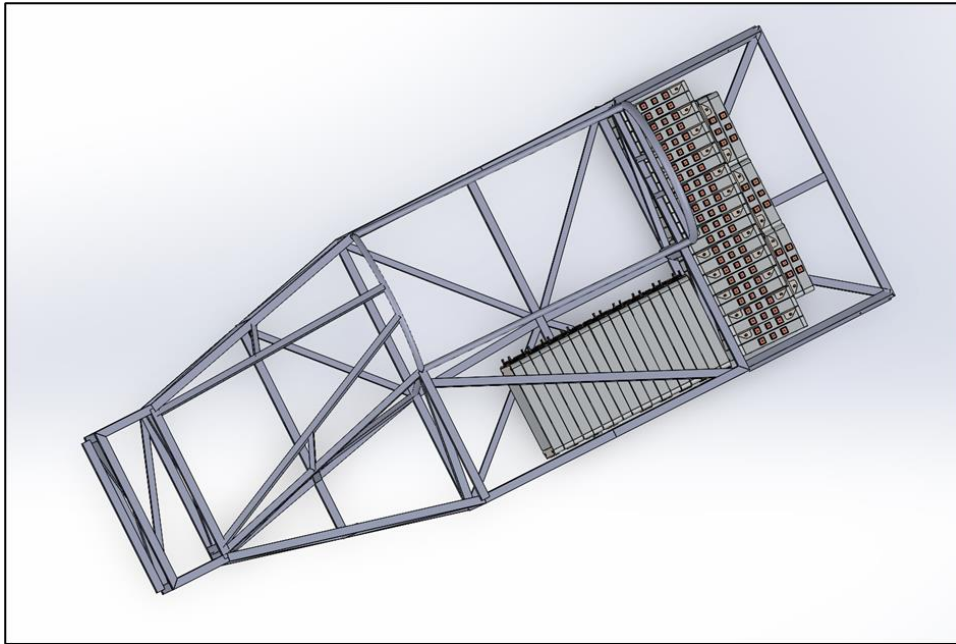


Figure 6 - Top-down view of version 3 of the battery placement.

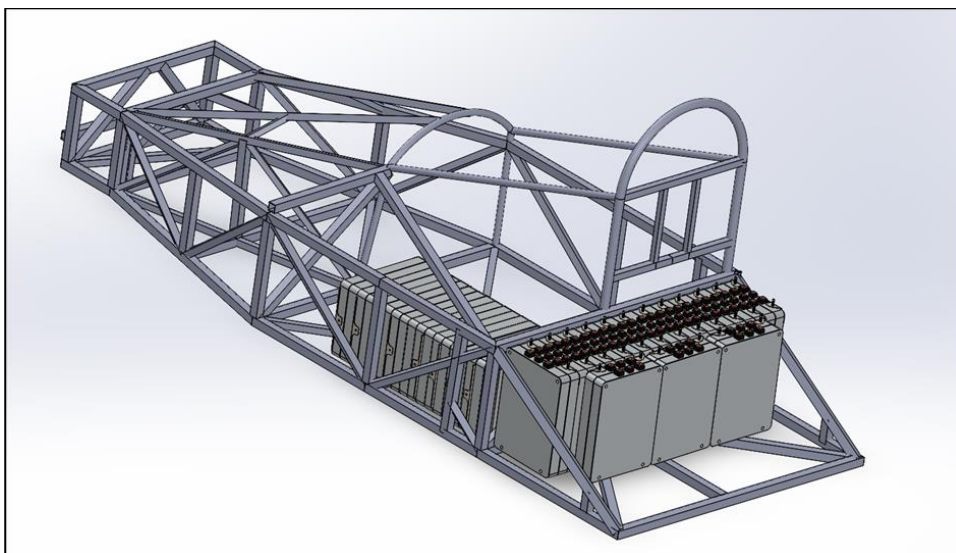


Figure 7 - Side on angled view of version 3 of the battery placement.

In this third design, the best parts of designs one and two were used to make an even weight distribution alongside the driver with the rest at the rear of the vehicle. This utilises the space where a typical ICE engine would be with added advantage of utilising space which an ICE couldn't use the space alongside the driver. This helps with the weight distribution and centre of mass of the vehicle by utilising the right-hand sided placement of the driver.

3.2.3 Development carried out

Initially, the battery selected was the VW e-Golf since it met the requirements of our power needs however due to the weight of the pack a more in-depth analysis was required. More research was carried out and a comparison table of each battery type researched was created, but at the time of creation no information was available on the JLR PHEV battery due to waiting on information from the supplier.

Battery Pack	Modules	Capacity (kWh)	Nominal Voltage (V)	Weight (kg)	Ampere Hours (Ah)	Mod. Dimensions (mm)	Mod. Volume (mm ³)	Pack Volume (mm ³)	Cooling Type	Lead Time (Days)
Nissan Leaf	24	40	349	208	112	319x222x68	4815624	115574976	Air	45
VW e-Golf	22	35	323	242	108	335x150x105	5276250	116077500	Air	30
JLR Range Rover PHEV	9	15	453	145	298				Liquid	
BMW i3	8	40	352	352	120	410x300x150	18450000	147600000	Liquid	20

Table 2 - Battery Pack comparison table

The table utilises the functions of excel to help get an idea of the dimensions and volume of each battery pack to get an idea of the space requirements with and without the casing. Due to the space available, a self-made and designed casing is required to be able to fit the modules into the chassis. This means that the pack volume can be discounted, and each module dimensions and volume can be compared. There are several important differences between the VW and the Nissan which can be seen mainly in the rough module volume calculations which gives approximately 4815 cm³ of the Nissan compared to the 5276 cm³ of the VW. This along with the lower weight and higher power capacity made it a clear contender for the battery with the BMW discounted early on due to the high weight.

After continuing development on the Nissan modules, the specifications on the JLR battery arrived and after deliberating on the change late into the process the decision was made to switch to the JLR batteries. This was due to the lower overall cost of the JLR battery packs along with the fact that the supplier was able to provide a BMS whereas the other batteries would require a custom made one. The supplier was able to make and pre-program for our needs with the modules they supply rather than sourcing our own, which was becoming an issue with the Nissan Leaf batteries. The main downside of the JLR batteries is the slightly higher weight of the overall pack and the slightly lower capacity but once the individual module weights come back a full analysis should be available. Even without that knowledge, the JLR Range Rover PHEV batteries seem the best choice for our needs with the low cost, readily available support, and the quantity of packs available for the Formula 750 series.

3.2.4 Analysis carried out

In the end, the battery pack selected was the Jaguar Land Rover PHEV Battery Pack due to the availability of packs from the supplier as well as the repackaging with a battery management system (BMS) they offered to us. This would also reduce cost and time for finding and installing a BMS that works with the battery pack chosen and allows for it all to be repaired in house and have less people to maintain and understand the already complex systems of the battery pack.

Item	Estimated Indv. Cost	Quantity	Total Cost
JLR PHEV Battery Pack	£2,500.00	2	£5,000.00
Aluminium (for Protective Box)	£100.00	1	£100.00
Rubber Insulation (for Protective Box)	£50.00	1	£50.00

Battery Management System	£300.00	1	£300.00
Overall Cost			£5,450.00

Figure 8 - Table showing the bill of materials

You can see the estimated cost of the JLR PHEV pack, which is taken from prices found on eBay, and is likely to be an overestimation of the actual price from the supplier. Along with the aluminium and rubber insulation they are also estimated due to the unknown full dimensions of the repackaged set of two battery packs.

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3.3 Chris Bell

Introduction

The responsibility that was undertaken of the drivetrain section of the of the electric vehicle project. Some of the areas under that responsibility include the selection of drive ratio, selection of differential (diff), method of drive and the design of brackets for the differential.

Duty Cycle

The first task that needed to be undertaken was to determine the duty cycle of the current ICE powered formula 750 car. This is important because it will show what the current top speed is, the average speed and the minimum speed.

The data that was provided was taken from the current formula 750 car which utilises a Fiat Fire Internal Combustion Engine. The data was taken from the car around two different circuits in qualifying and from two different weather conditions. The first set of data was taken from Donnington Park National Circuit in the dry, the second set of data was taken from Anglesey Circuit in the wet.

The three key data points to get were top speed, slowest speed, and the average speed. The top speed is important to get because it gives a target speed for the EV car and with this the final drive ratio can be worked out. The slowest speed is important because once the final drive ratio is worked out it will show what the corresponding motor speed is, and this will show whether the motor will bog. The average speed is important because this shows what speed the car spends most of the lap at. This can then be tailored so that the motor can be run at the most efficient RPM.

The values from the data for Donnington is that the top speed was 175km/h, the slowest speed was 100km/h, and the average speed was 143km/h. The top speed from Anglesey was 171km/h, the slowest speed of 40km/h and an average speed of 107km/h.

Gear Ratio

Because electric motors have a different torque characteristic compared to internal combustion engines it means that the car can be run using only one gear and won't need a gearbox. This is

because electric motors have a flat torque curve meaning that they provide maximum torque from 0 RPM all the way to maximum RPM. This means that there will be less weight for the EV proposal because a gearbox weighs about 50kg. Because of the weight of the batteries keeping weight to a minimum is important.

As a result, the proposal will only feature a final drive ratio. Because the car will only feature one gear it means that it will have to be designed for all speed. As a result of this the ratio will have to be able to reach the top speed and to also allow the car to be driven through the paddock.

To work out the drive ratio Equation 1 was used. The ratio was worked out in excel (as shown in figure 21) as this allowed for changes to be made in the future to the final drive ratio if the details about the car change. The information required to work out the drive ratio include, motor rpm, vehicle speed and the wheel radius.

The motor speed can be taken from the Emrax manual, (Emrax, 2017), this shows that the top motor speed is 4500RPM. The vehicle speed can be taken from above which gave a target top speed of 175km/h. It was decided that the top speed put in should be 180km/h because this will mean that the motor will not be at max rpm when the vehicle is at max speed. This will allow for less wear on the motor due to the reduced motor speed. The final value of the wheel radius was taken using a digital height gauge and measured from the floor to the top of the wheel giving the diameter. The wheel diameter was read as 520mm meaning the radius was 260mm.

Using Equation 1 it was determined that the final drive ratio should be 2.5:1. This ratio means that when the car is at the slowest speed the motor will be turning at 1000RPM. This means that it should not be bogging in the slower speed corners due to the torque that the motor can provide at low RPM's.

It is also possible to see the motor speeds at each of the average vehicle speeds and then see where it lies on the efficiency map. From this it is shown that the average speed at Donnington was 143km/h and so the corresponding motor speed was 3647RPM and the 107km/h at Anglesey resulted in a motor speed of 2729RPM. From the efficiency map in the Emrax manual (Emrax, 2020) it shows that the motor will be running between 95% and 93% at these speeds. The same manual shows that the peak continuous torque occurs between 3000RPM and 4000RPM meaning that the motor will be running at peak torque for most of the lap.

Drive Method

There will need to be a way for the motor to transfer the torque to the wheels and to change the drive ratio. The two options that were explored was either chain or belt drive. This is because it allows for better placement of the motor. It was decided that the belt drive was the better solution due to the mess created by chain drive.

Because chains must be correctly lubricated for them to work efficiently it means that they throw oil around which will create a mess in the bodywork. Belt drives do not require lubrication and therefore will not throw oil meaning that it is the cleaner option.

The final drive ratio can also be implemented here because you can use the ratio from the drive sprocket and the driven sprocket. In this case the car will use a 12-tooth drive sprocket and 30-tooth driven sprocket.

The sprockets that will be used are the Gates POWERGRIP® GT®2 SPROCKETS which use a 5mm pitch belt, are the P12-5MGT-09AL and P30-5MGT-09AL (Gates, 2014). The minimum number of teeth is 12 which is why this number of teeth was chosen. The belt is a PCC 5MGT 625 9 (Gates, 2022) which means that it is 625mm in length.

This was decided because using the tension calculator from gates, (Gates, 2020), it will show the centre distances between sprockets. The minimum distance between sprockets must be 258mm because the radius of the motor is 138mm and the radius of the diff housing is 110mm. 10mm was added as a clearance distance. The centre distance quoted for the 625mm was 260mm.

Using this tension calculator from gates it will also show what the static tension on each strand will need to be from 2697 to 2966 lbs. To convert this into Newtons then it must be multiplied by 4.4482, (ConvertUnits, 2022), this will mean there it will require a tension between 11.996KN and 13.193KN.

Differential

There will need to be a way to split the torque between then wheels and to do this the car will use a differential. Because the car will be using a belt drive the first solutions that were looked at were Quaife and Drexler chain drive diff. This was because both diffs are purpose made for chain drive vehicles.

However, the Drexler diff was decided to not be used because of the torque requirements from the formula 750. The Drexler diff was designed for the formula student and as such had a maximum

torque value of 1200Nm (Drexler, 2014). The maximum torque that was decided for the formula 750 was 1989Nm as worked out using equation 2.

The values need to work this out was a wheel radius which as determined earlier to be 0.26m, a friction coefficient from the tyre which was 1.3 and a weight. The weight was taken to be the 600kg because the minimum weight for formula 750 (750 FORMULA CHAMPIONSHIP, 2022) is 480kg and with the inclusion of batteries it means that the EV proposal will be heavier.

The Quaife diff was not to be used for two reasons. The first was the lack of data being provided by Quaife on the maximum torque for the diff and the second was due to regulations. Section 5.9 paragraph 5 of the 2022 formula 750 regulations states that “locked or limited slip differentials are all prohibited”. Because the Quaife is a helical LSD (Quaife, 2020) this means that it is not able to be used in the championship.

The option that was decided upon to be used was to use a standard road car diff and then mount the sprocket onto that and use it in the same way as the Quaife diff. A ford focus differential was used and using some calculations it was shown to have a maximum torque of 2093Nm. This gave enough strength for it to be used on the EV proposal.

The way this value was calculated was taking the coefficient of friction for the tyres to be 0.8, (Zhao, 2017), the weight to be 1750kg (Pawel Zal, 2017) and the radius of the wheel to be 254mm. This was done by taking the tyre spec of the same car and then calculating it. The tyre spec for this car was 195/65 R16, (Wheel-Size.com, 2022), and when this is calculated it will give the value of 254mm.

Driveshafts

The driveshafts that were considered was at first the driveshafts used that can be bought from Drexler and Quaife for each of their respective diffs. However due to a reconsideration of what diff will be used it was decided to use the driveshafts from the standard ford focus. This is also a cheaper solution which is one of the aims of the series, which is to provide cheap racing.

The driveshafts can then be made to size for the placement of the diff. this can be done by using the process of sleeving. What this comprises of is cutting the driveshaft in half and then placing a smaller tube inside of the driveshaft and then sliding the two halves of the shafts so that you get the desired length before welding the small tube to the driveshaft. The lengths required for the driveshafts are 560mm for the left driveshaft and 650mm for the right driveshaft.

Housing Design

The housing is an important part of the design because it will be holding the diff and shielding the bodywork of the car from debris that may be thrown from the diff or belt. As worked out earlier the housing will have to hold up to 2000Nm. Another part of the design is the tension on the belt will need to be adjusted so there will need to be a way to move the motor of the diff so that the required tension is applied.

The starting design was based of the Mk 3 focus differential that Quaife manufacture, (Quaife, 2020) as this will have the same size standard differential. A model in Solidworks was made to these measurements as shown in figures 3 and 4. Then a made a sprocket that could fit onto the diff to show how the drive would be converted (Figure 7).

The next part of the design process was to design the housing to hold the diff and to stop the spray from the belt drive. As such the design enclosed the diff with two cut-outs for the belt to grip on the sprocket. There are holes in the side to allow the diff to sit in and be held as shown in figures 5 and 6.

Because the car is belt driven there will need to be a way to tension the belt and this will be done by making a plate that the housing can slide on. The plate that the housing sits on has two rails that the housing can bolt onto. The holes for the bolts are 30mm long which will allow for it to be long enough to adjust the tension (figures 8 and 9). The plate is then mounted onto brackets that will be welded onto the chassis as shown in figures 10, 11 and 12. The brackets are design so that they will allow for as much contact with the chassis for added strength.

The decision of the placement for the differential was made with discussion with the Chassis Group and the placement of the rear suspension. The Chassis Groups specified that the diff should be in the same Z-axis in the car as the ICE group however didn't mind where the placement is in X-axis.

Because of this the housing the housing was placed in the same Z-axis as the ICE output however the differential was moved into the centre of the chassis to allow for brackets to be designed. It will also mean that the weight distribution will be more in the centre reducing the roll of the car.

Using the simulation function in solidworks a static study was ran on the housing, plate and brackets. The material used for this 1060 Alloy Aluminium. This is because the material that the housing will be made out of when complete is Aluminium because Aluminium is lighter weight than steel without compromising strength. The aluminium chosen had a Young Modulus 69GPa, a tensile strength of 68.93 MPa and a yield strength of 27.57 MPa

Because the brackets will be welded to the chassis, they had a fixed geometry so that they wouldn't move. The plate was bolted onto the brackets using the bolt connections in the connections tab. The housing was bolted to the plate. A bearing load of 2000 Nm was applied which was taken from the grip torque as worked out earlier.

The results (Figures 16, 17 & 18) show that the components will withstand the bearing load of 2000N. this is because as the scale shows most of the components are in dark blue indicating it is in between 616.7Pa and 2.275MPa. The max stress that solidworks calculated was 22.75MPa meaning that all of the components will be within the yield strength of 27.57MPa and so the components wont fail.

To validate this study another study was run using a 200mm rod of diameter 20mm with a Youngs modulus of 69GPa which is the same as the housing. That study outputted a displacement of 1.839×10^{-3} mm. To ensure that figure lines up with real world values a calculated displacement was ran giving a value of 1.840×10^{-3} mm.

The steps to achieve this was to calculate the area of the face for the rod which was 3.142×10^{-4} m. next step is to work out the stress which can be done using equation 4 which results in 0.6365 MPa which is the same as the solidworks value. After this the strain will need to be calculated using equation 5 which gives a value of 9.202×10^{-6} . The last step to work out the displacement is done by using equation 6 which gives a value of 1.840×10^{-3} mm which is also the same as the solidworks model. Because of this parity it shows that the results gained from the simulation can be trusted.

Equations

$$DR = \frac{RPM}{\left(\frac{V \times \frac{10}{36}}{\pi \times \left(\frac{D}{1000} \right) \times 60} \right)}$$

Equation 1

$$GR = (W \times g) \times \mu \times r$$

Equation 2

$$A = \frac{\pi \times D^2}{4}$$

Equation 3

$$\sigma = \frac{F}{A}$$

Equation 4

$$E = \frac{\sigma}{\varepsilon}$$

Equation 5

$$\varepsilon = \frac{\Delta L}{L}$$

Equation 6

DR = Drive ratio

W = vehicle weight (kg)

V = Velocity (km/h)

g = gravity (9.81m/s²)

D = Diameter (m)

μ = tyre friction coefficient

GR = Gear ratio

r = wheel radius (m)

A = area (m)

σ = stress (Pa)

F = Force (N)

E = Youngs Modulus (Pa)

ε = strain

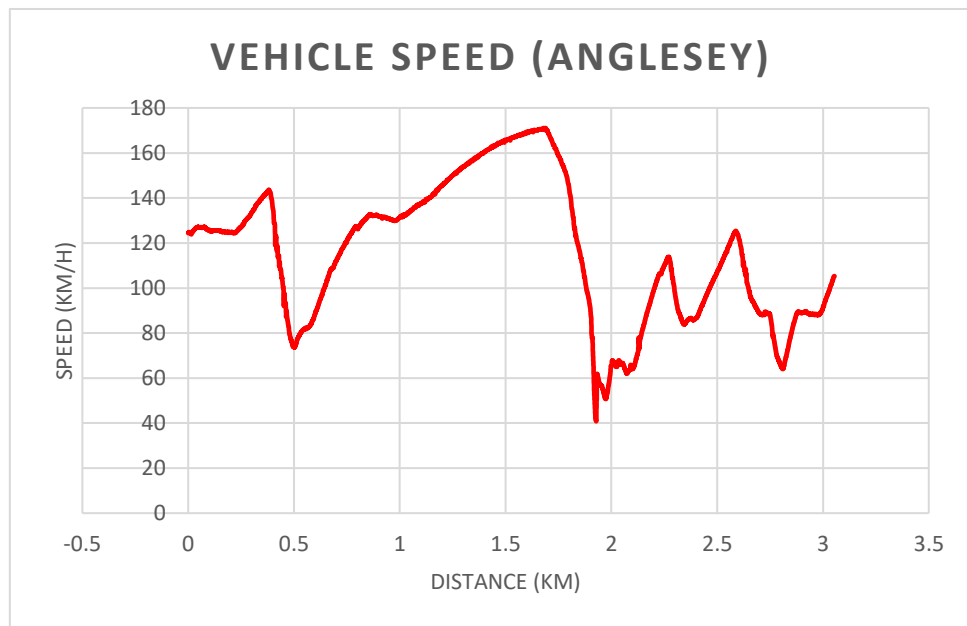
ΔL = change in length (m)

L = Length

Figures

Graphs

Figure



1*

showing the current Formula 750 lap data of vehicle speed against distance around the Anglesey Circuit in wet conditions during Qualifying.

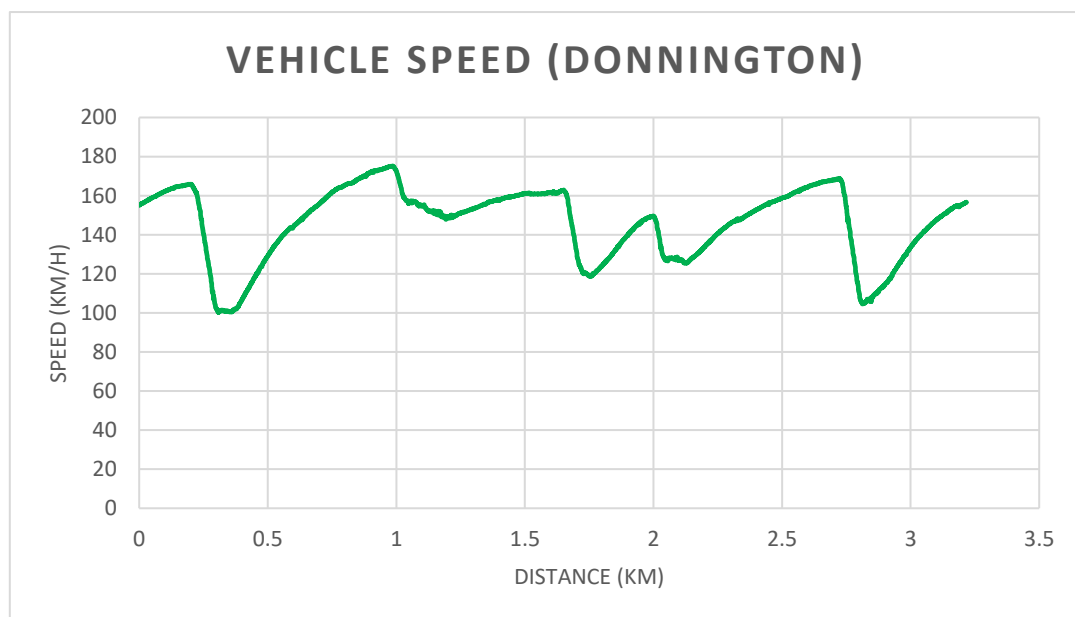


Figure 2* showing the current Formula 750 lap data of speed against distance from Donnington Circuit in dry conditions during Qualifying.

* The data provided for these graphs had some errors imbedded in it. As a result of this I have removed these errors and so the graphs above may not be accurate due to these inaccuracies.

Solidworks Models

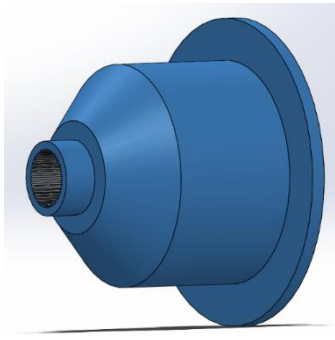


Figure 3 Showing the solidworks differential

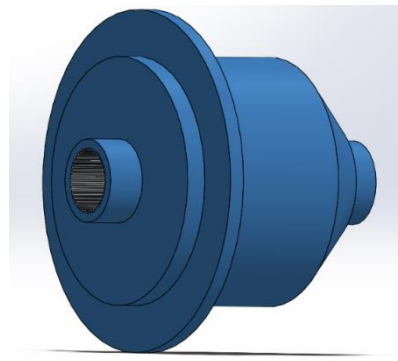


Figure 4 showing the solidworks differential

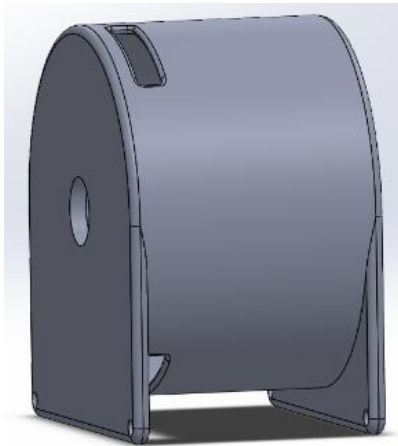


Figure 5 showing the housing for the differential made in solidworks

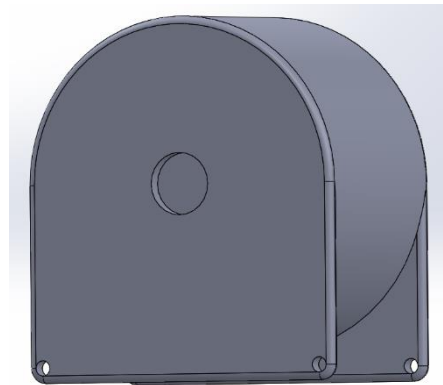


Figure 6 showing the housing for the differential made in solidworks

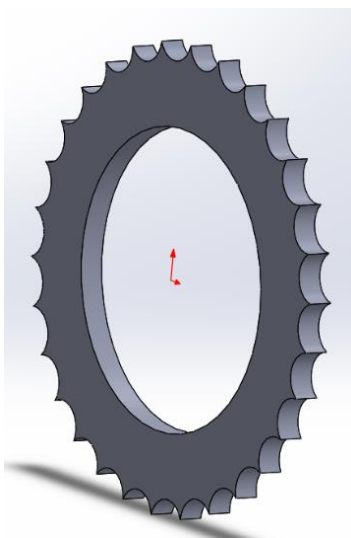


Figure 7 showing the sprocket for the differential made in solidworks

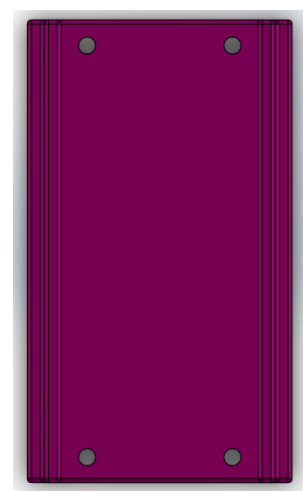


Figure 8 showing the plate for the housing to sit on made in solidworks

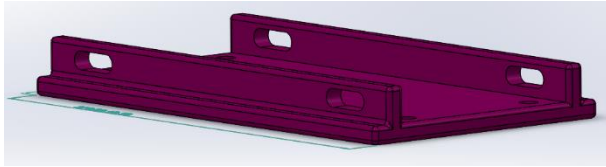


Figure 9 showing the plate for the housing to sit on made in solidworks

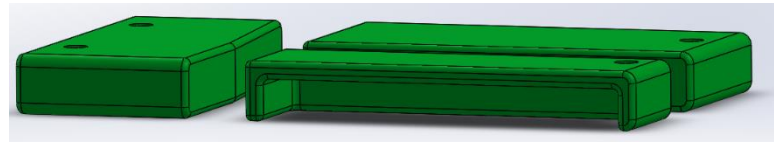


Figure 10 showing the bracket to attach the plate to the chassis made in solidworks

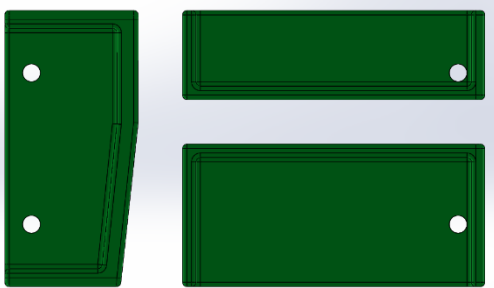


Figure 11 showing the bracket to attach the plate to the chassis made in solidworks

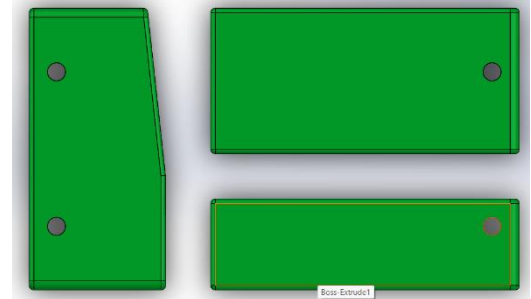


Figure 12 showing the bracket to attach the plate to the chassis made in solidworks

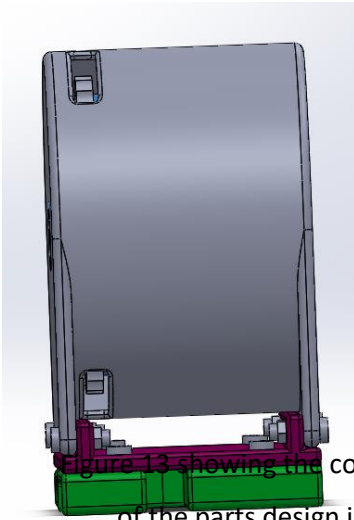


Figure 13 showing the complete assembly of the parts design in solidworks

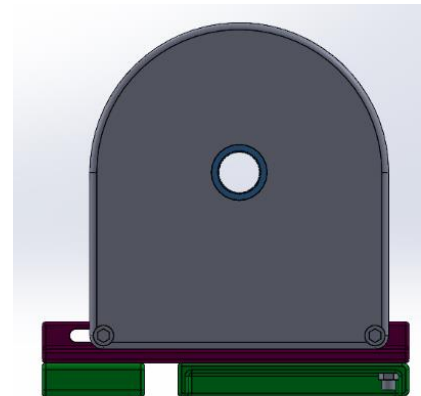


Figure 14 showing the complete assembly of the parts design in solidworks

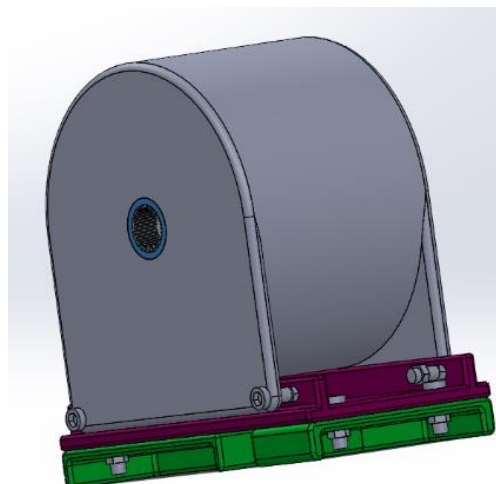


Figure 15 showing the complete assembly of the parts design in solidworks

Stress Analysis

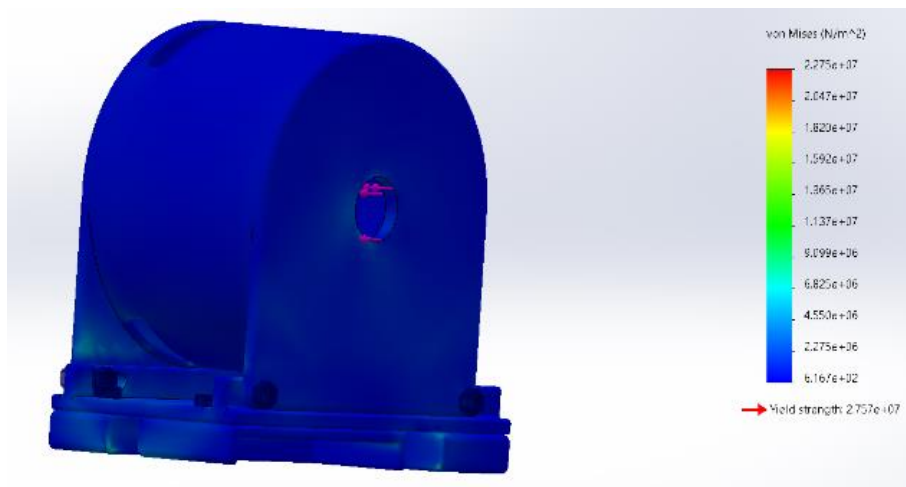


Figure 16 showing the housing, brackets, and plate stress analysis results in solidworks

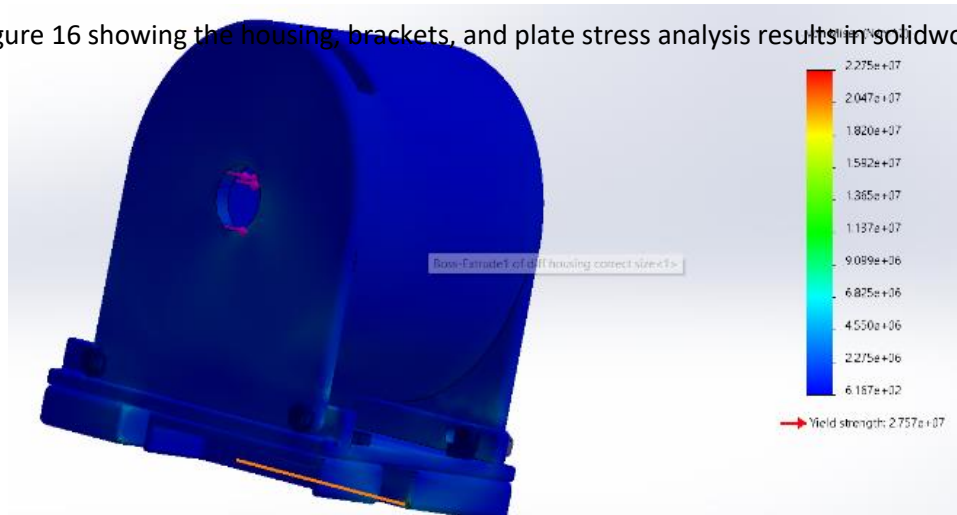


Figure 17 showing the housing, brackets, and plate stress analysis results in solidworks

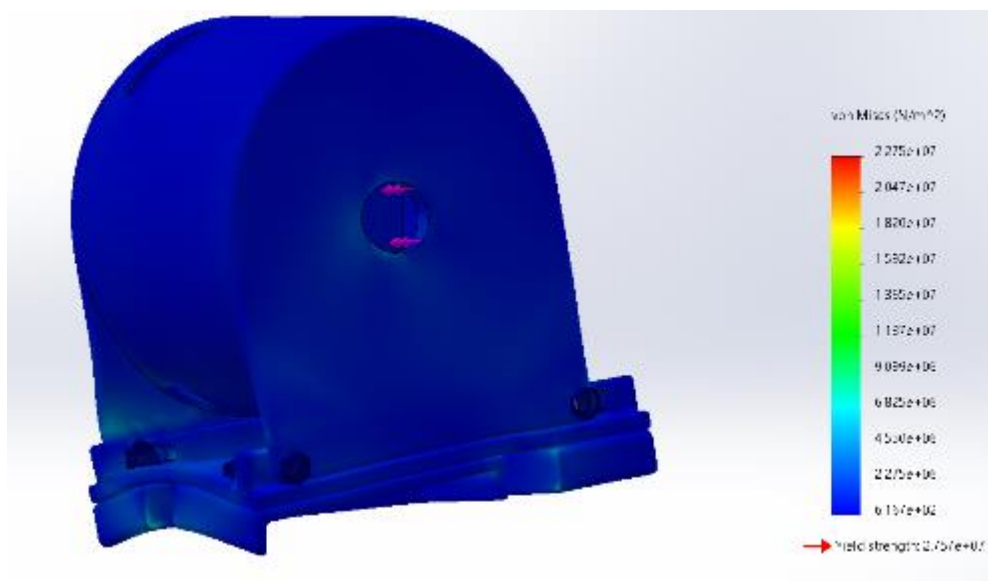


Figure 18 showing the deformed result from the stress analysis performed on the brackets, plate, and housing in solidworks

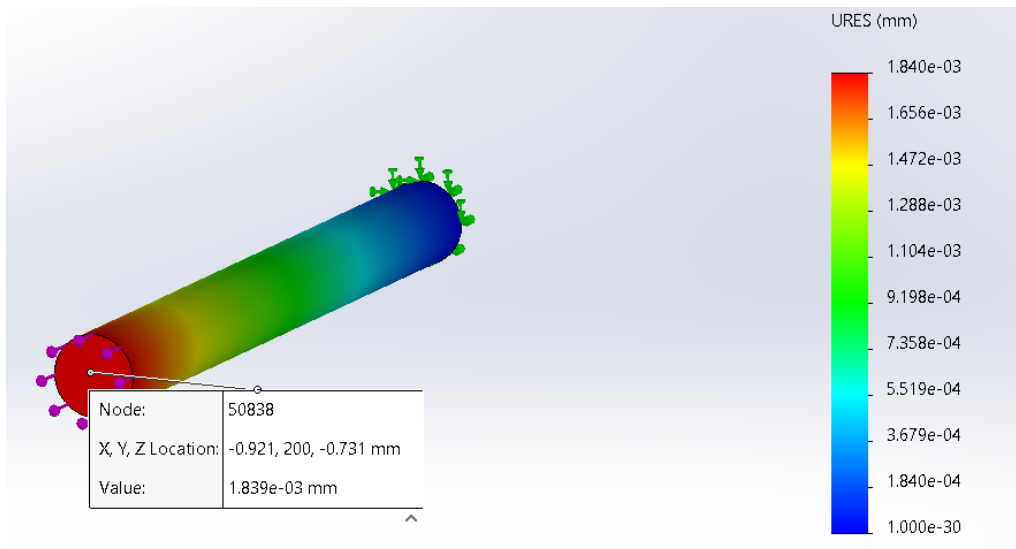


Figure 19 showing the validation rod in solidworks which is showing a displacement of $1.839 \times 10^{-3} \text{ mm}$

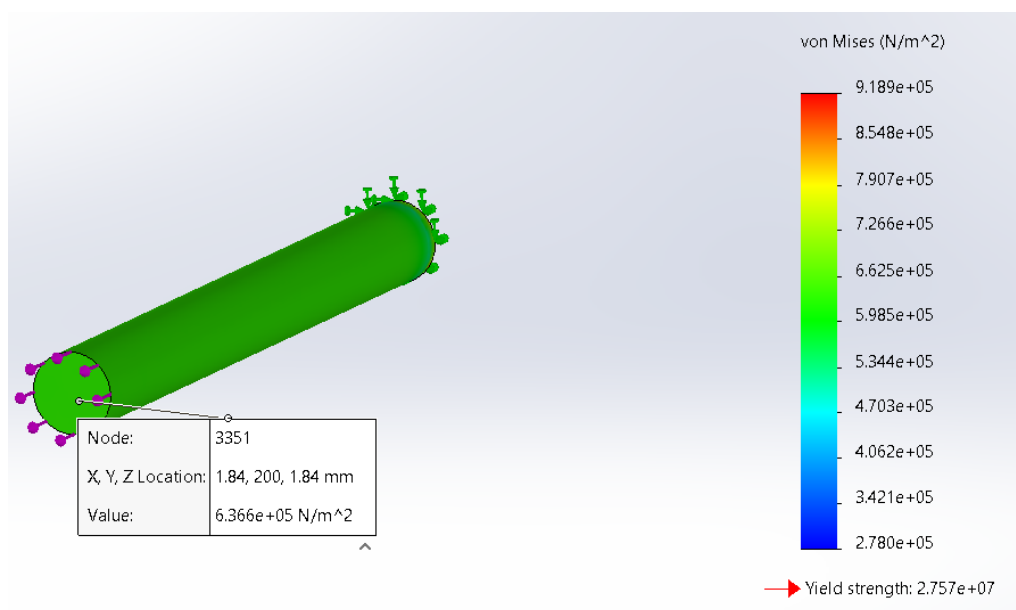


Figure 20 showing the validation rod in solidworks which is showing a stress of 0.6366 MPa

Other Figure

Figure 21 showing the calculator made in excel to calculate the drive ratio and the corresponding speeds

Radius (mm)	260	Diameter (mm)	520	Radius (mm)	260	Diameter (mm)	520
Speed (km/h)	180	Speed (km/h)	180	Speed (km/h)	180.00	Speed (km/h)	180.00
RPM	4500	RPM	4500	RPM	4500	RPM	4500
Drive Ratio	2.50	Drive Ratio	2.50	Drive Ratio	2.5	Drive Ratio	2.5
Radius (mm)	260	Diameter (mm)	520	Radius (mm)	260.00	Diameter (mm)	520.00
Speed (km/h)	143	Speed (km/h)	107	Speed (km/h)	180	Speed (km/h)	180
RPM	3647	RPM	2729	RPM	4500	RPM	4500
Drive Ratio	2.5	Drive Ratio	2.5	Drive Ratio	2.5	Drive Ratio	2.5

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3.4 Romylos Frangos

3.4.1 Team role.

Team Role: Electric Powertrain Selection

Due to the fact that this is a group project, the overall workload had to be split evenly amongst each and every member. Thus after our initial meeting it was clear to each group member what was expected of them and which their role was. I was assigned with the task to select an appropriate electrical powertrain for the Formula 750, and to determine the position and the manner in which it will be placed onto the chassis.

3.4.2 Research/Literature review

Electric motors have been in action for quite some years now, in fact Formula E (Electric) made its debut in the 2014 ePrix (Electric Prix), Beijing, **China (FIA, 2014)** and since then the motorsport has been growing rapidly due to its popularity. Formula 750 is the oldest continually running race series in the world (even older than F1), meaning that even at limited budgets and lower costs a race even can still attract loyal spectators of the sport.

(750Motorclub)

These electric motors are manufactured by the company EMRAX, having its headquarters in Slovenia. Emrax manufactures several electric motors. **(EMRAX)**.

This means our group had the option to select the motor which best satisfies our interests and needs, based on official Formula 750 racing rules and regulations. Therefore, we chose the EMRAX Medium size motor 268 as it is the only one which meets and fulfils the needed criteria.

The criteria taken into consideration when comparing the available motors were cost, weight, power (kw), performance and adherence to the official Formula 750 rules and regulations. (EMRAX, EMRAX 268 Technical Data Table). We elaborate on motor comparison and selection in the following paragraphs.

Figure 1 below displays the technical data of three EMRAX 268 motors with their main difference being voltage usage. I presented these three options to my colleagues/rest group members and discussed with them the reasons why the Medium Voltage one is the optimal

choice. The Medium motor was chosen, for it can have up to 107kw of continuous motor power (from 2000-4000rpm) rather than the High Voltage one, which offers only 86kw of continuous power.

In addition to that, all three motors weigh the same and support the same cooling methods (air cooled, liquid cooled, combined cooled) thus “eliminating” these criteria (weight, cooling method) from the equation.



Manual for EMRAX Motors / Generators | Version 5.4 | 5th of March 2020

EMRAX 268 Technical Data Table

Type	EMRAX 268 High Voltage			EMRAX 268 Medium Voltage			EMRAX 268 Low Voltage*								
Technical data	AC	LC	CC	AC	LC	CC	AC	LC	CC						
Air cooled = AC Liquid cooled = LC Combined cooled = Air + Liquid cooled = CC															
Ingress protection	IP21	IP65	IP21	IP21	IP65	IP21	IP21	IP65	IP21						
Cooling medium specification (Air Flow = AF; Inlet Water/glycol Flow = WF; Ambient Air = AA) If inlet WF temperature and/or AA temperature are lower, then continuous power is higher.	AF=20m³/h; AA=25°C	WF=8l/min n at 50°C; AA=25°C	WF=8l/min n at 50°C; AA=25°C	AF=20m³/h; AA=25°C	WF=8l/min n at 50°C; AA=25°C	WF=8l/min n at 50°C; AA=25°C	AF=20m³/h; AA=25°C	WF=8l/min n at 50°C; AA=25°C	WF=8l/min n at 50°C; AA=25°C						
Weight [kg]	20,0	20,5	20,3	20,0	20,5	20,3	20,0	20,5	20,3						
Diameter ø / width [mm]	268 / 91														
Maximal battery voltage [Vdc] and max load RPM	800 Vdc (3600 RPM)			650 Vdc (4500 RPM)			250 Vdc (4500 RPM)								
Peak motor power at max load RPM (few min at cold start / few seconds at hot start) [kW]	160			200			200								
Continuous motor power (at 2000-4000 RPM) depends on the motor RPM [kW]	67	73	86	86	91	107	86	91	107						
Maximal rotation speed [RPM]	4500 (5500 for a few seconds with magnetic field weakening)														
Maximal motor current (for 2 min if it is cooled as described in Manual) [Arms]	250			400			1000								
Continuous motor current [Arms]	125			190			500								
Maximal motor torque (for a few seconds) [Nm]	530														
Continuous motor torque [Nm]	200	213	250	200	213	250	200	213	250						
Torque / motor current [Nm/1Aph rms]	1,90			1,30			0,46								
Maximal temperature of the copper windings in the stator and max. temperature of the magnets [°C]	120														
Motor efficiency [%]	92-98 %														
Internal phase resistance at 25 °C [mΩ]	22,9			30,5			1,8								
Input phase wire cross-section [mm²]	11,4			17			42,5								
Wire connection	star														
Induction in Ld/Lq [μH] of 1 phase	292/273			126/118			17/15,9								
Controller / motor signal	sine wave														
AC voltage between two phases [Vrms/18PM]	0,126			0,0825			0,0304								
Specific idle speed (no load) [RPM/Vdc]	5,4			8,2			22,0								
Specific load speed (max load) [RPM/Vdc]	4,5			7			18								
Magnetic field weakening (for higher RPM at the same power and lower torque) [%]	up to 100														
Magnetic flux – axial [Vs]	0,1014			0,0664			0,0246								
Temperature sensor on the stator windings	Mty 81/210														
Number of pole pairs	10														
Rotor inertia LC motor [kg*m²]	0,0922														
Bearings (front/back) – FAG	7206-3207 (for axial-radial forces; for pull-push mode, at 25°)														

*EMRAX 268 low voltage version always has 2 sequences of phase connectors (2xUVW).

Figure 1

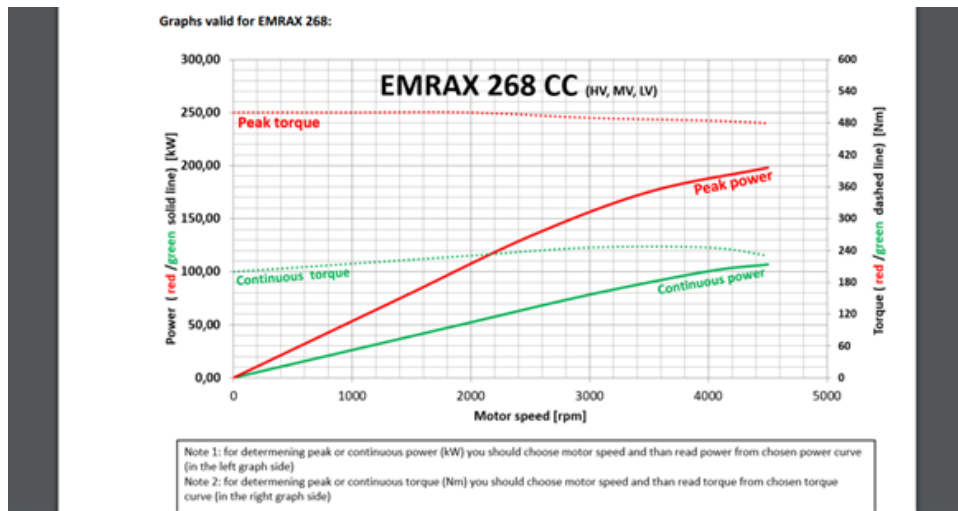


Figure 2

Figure 2 above, shows us the Power (kw) and Torque (Nm) on the y-axis compared against Motors speed (rpm) on the x-axis. We can see that throughout the range of the rpm during acceleration, torque starts from 180Nm and goes only up to 240Nm of torque, that means that the torque is there from the moment the driver presses the pedal which means having instant torque that keeps rising through the acceleration of the vehicle.

Furthermore, at peak power 200kw the torque is 400Nm at 4500rpm, and for a few seconds when the controller has saved up enough energy the motors peak power can reach 250kw and 500Nm of Torque.

According to Formula 750 official rules and regulations we have the following restrictions:

- Minimum weight of the vehicle including the driver is 480kg
- Maximum brake horsepower of the vehicle 100bhp
- No use of any electronic traction control system
- Automatic transmissions are prohibited

Considering what it is mentioned in the above paragraph a decision was made for the best performing motor within our budget limits. Namely the Emrax 268 medium size electric motor has the following characteristics:

- Weight: 20.3 kg
- Power: 200kw (which translates 268bhp)
- Electronic traction control system is included by the manufacturer but will be disabled before the race and will remain disabled throughout the whole duration of the race, via the use of motor controller.
- Manual transmission (including Reverse gear)
- 250Nm of Torque (500Nm for a few seconds)

- Combines cooled (both liquid and air)
- Maximum battery voltage 650Vdc
- Maximum rpm of 4500

We can observe that our selected motor meets the criteria for weight and performance but exceeds the maximum allowed 100bhp as stated by the official rules and regulations. To avoid any sanctions and/or misunderstandings a motor controller will be used to reduce the power to 100bhp, thus making our selection eligible and enabling us to compete in the race. **(Sevcon, en 4 Applications Reference Manual)**. This explains why we did not choose a cheaper or a smaller alternative motor.

An electric motor generates force in the form of Torque by converting electrical energy to mechanical energy which is applied to the motors shaft. This specific electric motor (Emrax 268 medium voltage) is a brushless motor, an alternative was a brushed motor. The main difference between the two is that brushed motors are mechanically driven rather than the brushless ones which are electrically driven. **(Millett, 2022)** Furthermore, brushless motors also known as “pancake” generators which the rotor is a flat disk of magnets which rotates on a shaft above a flat ring of stationary wrapped coils. (see figure 3) **(Printed Motor Works, 2022)**.

This type of electric motors (brushless) have no friction which means less heating and better performance, thus having very high numbers of torque.

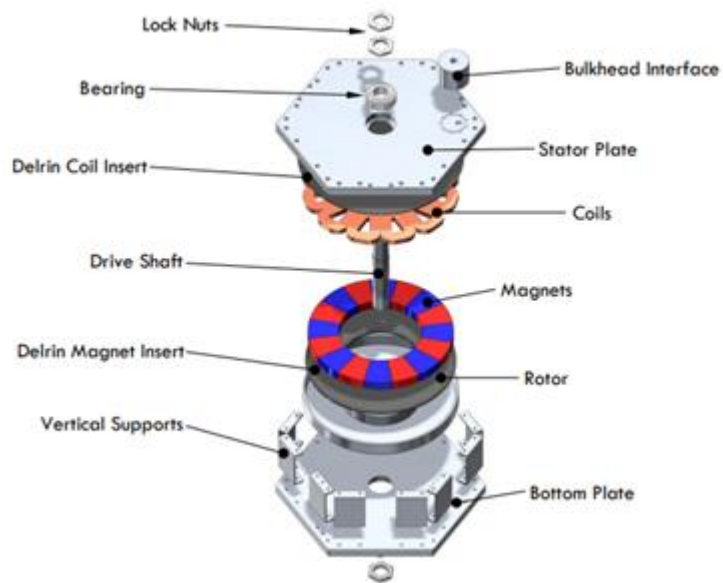
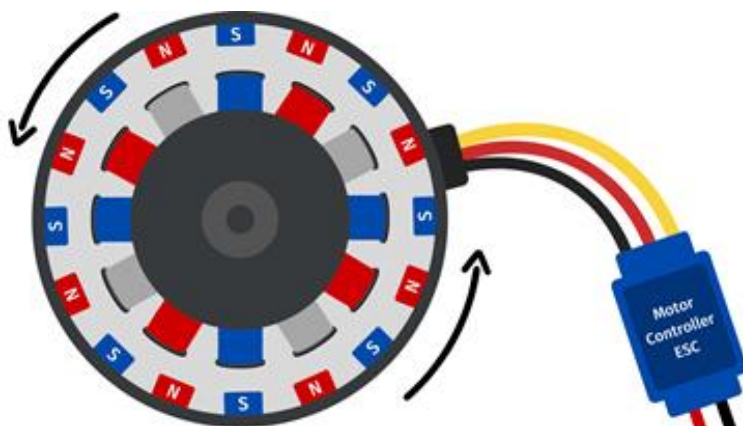


Figure 3

Figure 4



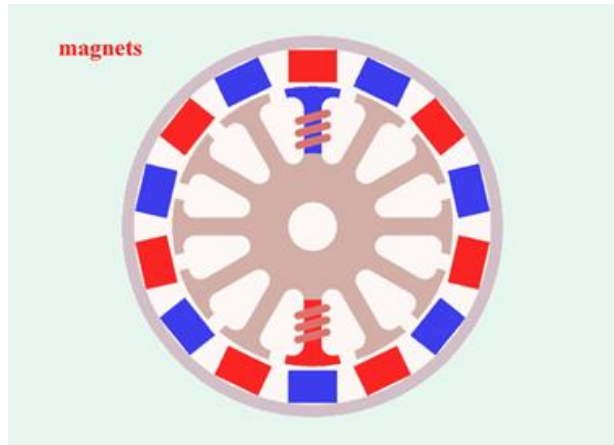


Figure 5

By using the Gen 4 size 10 controller we are able to tune down the motor to have the exact horsepower as stated by the regulations of the 750 Formula. The controller is from the company named SEVCON.

The motor controller can store power while the car is slowing down, which then it can use in the accelerating part. Further, the controller uses a 3 phase AC induction to control the power supply around the car (Sevcon, en 4 Applications Reference Manual). On top of that 3 phase induction motors are widely used mainly because they do not require a starting device (reference of the argument said, not required a started).

Characteristics of the motor controller (Gen 4 size 10):

- It can provide up to 300kw of power
- Weights 10.9kg
- Best operates between the temperatures of 25-85 degrees
- Uses an integrated logic circuit

Figure 6 and figure 7 shows the weight distribution of the car, using the weight distribution calculator. **(Racingaspirations, n.d.)**

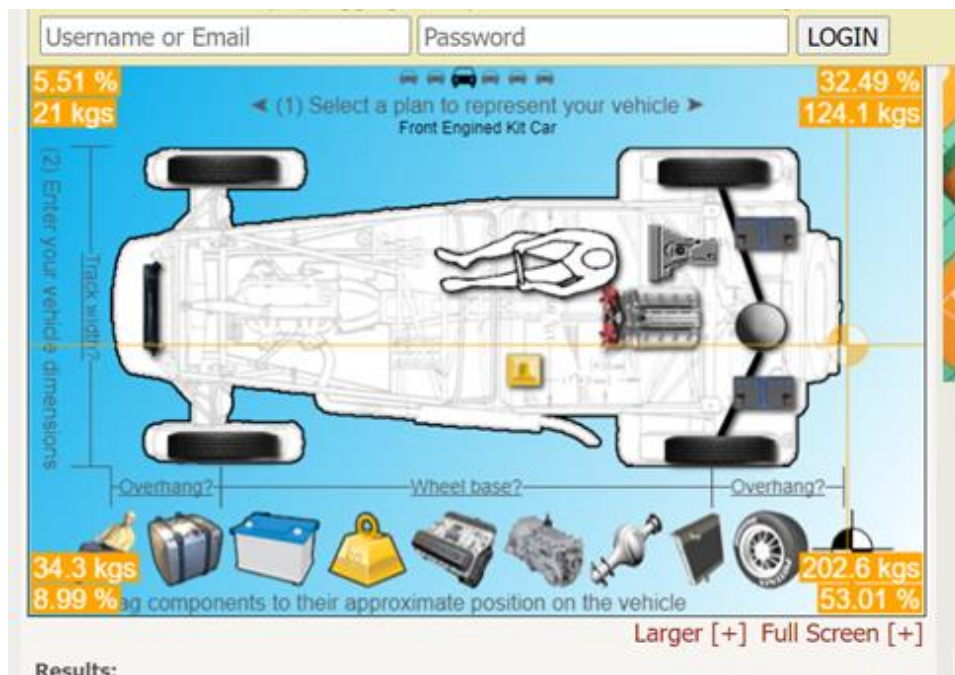
Figure 6

Results:

Corner Weights		Front to Back		Side to Side		Total
Front Right	21 kgs	Front	55.3 kgs	Right	145.1 kgs	382 kgs
Front Left	34.3 kgs			Left	236.9 kgs	
Rear Right	124.1 kgs	Rear	326.7 kgs	Right	145.1 kgs	
Rear Left	202.6 kgs			Left	236.9 kgs	

If you want to use this calculator [ad free](#), enable unlimited private models and work

Figure 7



In figure 6 we can see that the total weight of the car comes to 382kg this means that we need another 98kg to reach the minimum weight of the vehicle. In order to achieve that we will place a ballast in the passenger side for additional weight, extra to the driver weight. That is because the official rules and regulations of the 750 formula enable us to place extra weight (other than the combined weight of the vehicle and the person driving it) for weight distribution and for reaching the minimum allowed weight of 480kg. Figure 7 shows a general weight distribution of parts on the vehicle.

3.4.3 Work progress

Having purchased the motor and the motor controller the need to progress to the next step was evident. The next step consisted of finding out how and where to place them on the available chassis.

Dimensions of both motor and motor controller enabled us to figure the solution to our above query. One can observing figure 7 below and identify that the motor and the controller can in fact be place both in the passenger side of the chassis or even behind the actual driver.

However, race regulations state that only fire extinguisher and any ballast required to comply with the minimum weight regulation could be placed there. (https://www.750mc.co.uk/ugc-1/1/1/0/2022_final_regs_-_750_formula.pdf page 4 of 7).

Moving on to second option, placing them behind the driver seat. Based on this suggestion a discussion was made with my group colleagues; so as to ensure that the placing motor and motor controller in the space behind the driver seat would not interfere with any of their work.

Figure 8



Measurements of the space behind the driver:

Length: 76cm (C=46cm M=26.8cm)

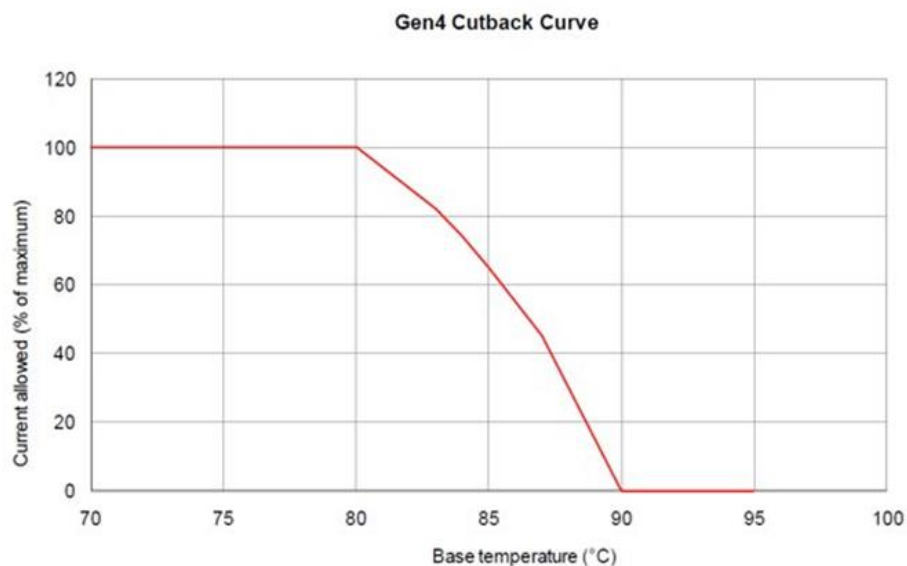
Width: 64cm (C=24.8cm M=13.6cm)

Unfortunately, due to extenuating circumstances out of our control; only the motor has arrived since placing the order and purchasing it. The motor controller purchased for the scope and purposes of this part of the group project has yet to arrive of the time writing and submitting this report (1st of April 2022).

Therefore, resulting in our group not being able to assemble the car due to not having all the required parts to do so. Even though most, if not all the research, background work and organization, were carried out to a satisfactory standard.

But that did not stop us from calculating and figuring out all the theoretical work, even thinking of future problems that might occur like the motor or the batteries overheating. If that ever happens we proposed that the motor or the batteries should be placed inside a specific case built for them in order to protect them from overheating and other external dangers. (**EMRAX, EMRAX 268**), (**Sevcon, Gen 4 Applications Reference Manual**). But Sevcon has already think ahead of us as it has programmed the controller to cut back power as the temperature increases more than 80 degrees. The current will continue to decrease until the temperature of the controller goes 90 degrees after that the controller automatically switches off. (**Sevcon, Gen 4 Applications Reference Manual**)

Figure 9



3.4.4 Designs carried out (as applicable).

Cardboard designs were made as examples for the area and volume to be occupied by the motor and the motor controller, as to have a realistic example of how it will fit in the vehicle. Insert pictures here

In addition to the physical cardboard design, a 3D Cad design was made as well for us have a better and more hands-on approach, rather than just browsing blueprints on a computer monitor.

Figure 10

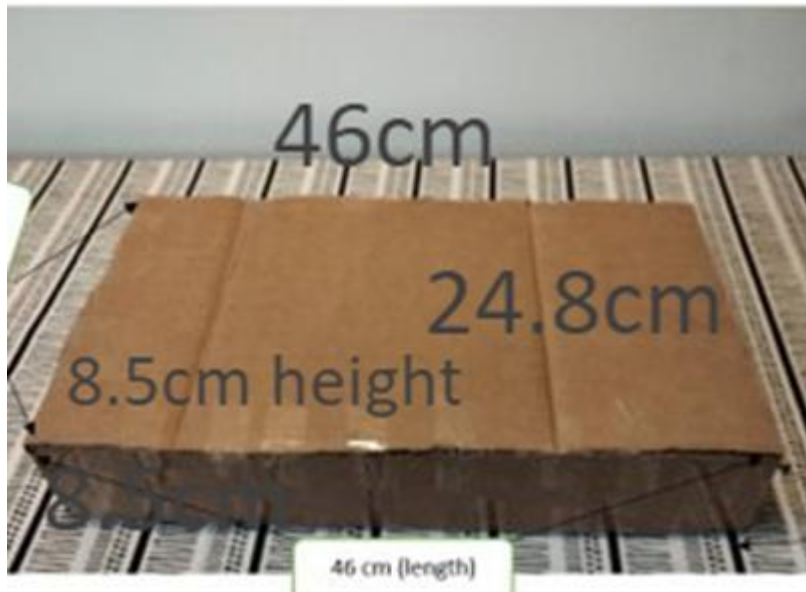
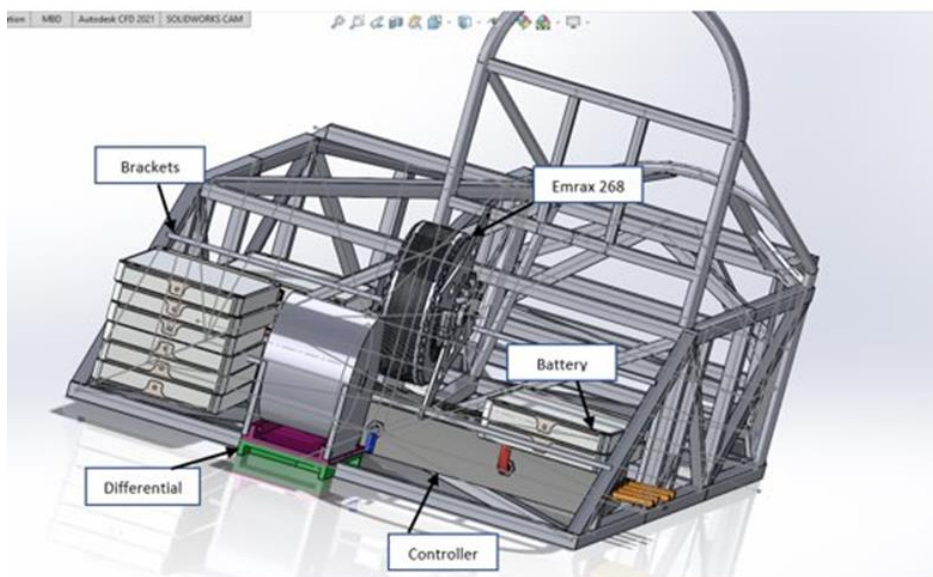


Figure 11



Figure 12



3.4.5 Development

While we were waiting for the motor and the controller to come, in the meantime we address other priorities that needed to be looked at and resolved.

At the same time the radiator size had to be found in order to make a template again for a more realistic example of how the parts will look like. Although the radiator was a specific area information from all the team members where needed such as temperature of the components, how many litres per min the water pumps need to pump the controller and the motor.

After a few months the motor arrived so our group was able to inspect it and make sure that nothing was missing from the package. In those few months the group made a lot of progress by deciding where to put all the components making sure that everything is measured and weighted perfectly.

Some of the actions that the group had to take was make frequent meetings with our team advisor and our team members in order to keep everyone update of how the project is progressing and what problems we ran into. Furthermore the group was keeping notes of the other teams progress and listening what their decisions was in order to know how the other teams are doing and what information can our group provide them with.

3.4.7 Build carried out

Figure 13



Figure 14



Figure 15 Mounting hole of the electric motor



3.4.8 Conclusion.

As it mentioned above in section 3.4.3 “Work done”; due to unforeseen events we were unfortunate enough to miss out on having a motor controller, which is essential in assembling and building the car for this group project.

Nevertheless, this does not take away all the hard work produced by our group. We strongly believe that the research, background work, organization, mental and physical preparation were carried out to a satisfactory standard.

I have gained valuable insights on how to participate in a group actively and purposefully; both in the technical and the human aspect.

The amount and quality of research, literature review, measurements, calculations and comparisons in this part of the project have helped me broaden my understanding on electric motors and the racing sport world in general.

I have realised how important it to be able to rely on and trust others. Take into consideration of my colleagues' work ethic and rationale in decision making.

3.4.9 References.

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3.5 Joseph Belcher

3.5.1. Team Role: Thermodynamics & Cooling

Within the Formula 750 EV Powertrain project my role was thermodynamics & cooling. This meant my job was to study the thermal properties of the necessary components and to design a system to keep these components in their specified temperature ranges. This is important as components such as the motor or motor controller will shut down if they reach temperatures over 90°C rendering the car useless in a race situation. Thus, the system must be as effective as possible, in efficiency as well as size and simplicity due to the purpose of the vehicle.

3.5.2 Developments Since Interim Viva

Following on from the interim Viva Report certain aspects of the project changed. The main change being the battery selection, this change was due to the intended Jaguar Land rover pack information we had requested not being supplied to us. Combatting this inconvenience, we reverted to our original selection of the Nissan Leaf battery packs. This affected my area of work as the Jaguar Land Rover packs are liquid cooled meaning they were a large part of the thermodynamic process both supplying energy to components as well as regenerative braking sending power back into them. However, the Nissan Leaf batteries are air cooled meaning they require no liquid cooling assistance to function. Therefore, the job of cooling the pack fell into the hands of the aerodynamic team who had to figure out ways to provide them with sufficient air whilst not affecting the drag and other aero aspects of the vehicle.

This change was not all negative however as it decreased the net weight of my cooling system due to the fact the cooling plate that sits below the battery pack was no longer needed. Not only did this decrease the weight but it meant we needed less coolant to fill the system and with each litre of water ethylene glycol weighing just over 1kg this shredded even more weight, improving the power to weight ratio as well as the weight distribution of the vehicle.

As always where there is an advantage there is normally a disadvantage. The disadvantage to this change was that our previous calculations of the original cooling system were now invalid and needed to be re-done. The original calculations including the battery pack cooling gave us a radiator surface area of 1.62m², without the battery pack included in the system we gained a new surface area of 1.37m² (decrease of 0.25m²).

Temp In	Temp Out
90°C	60°C

$$A = \frac{Q}{U\Delta T_{lm}}$$

$$Q = 0.096 \text{ Kg/s} \times 75 \times 5 = 36\text{J/s}$$

$$\Delta T_{lm} = \frac{90 - 85}{\ln(90/85)} = 87.48^\circ\text{C}$$

$$U = 300 \text{ W/(m}^2\text{x}^\circ\text{C)}$$

$$A = \frac{36,000}{300 \times 87.48} = 1.37\text{m}^2$$

A = Area
Q = Heat Transfer Rate
U = Overall Heat Transfer
 ΔT_{lm} = Log Mean Temperature

(Figure 1, Revised radiator calculations)

Another development since the Interim Viva was the placement of the radiator. Due to the aerodynamics team finalising their choice of aerodynamic packages for the car it became evident that they wanted the radiator to be situated at the nose of the vehicle. At this position the radiator will be supplied with ample amounts of fresh air via the nose duct of the body. With this decision finalised I could begin to work on designs of the radiator.

3.5.3 Research

Following on from the Interim Viva I had to finalise decisions on what would be included within the system building up to the vehicles final assembly plan. To assist these decisions, I conducted research into the various areas to support my choices, helping make the best system possible.

In order to produce the best cooling system possible, I started my further research by looking at the components in which I would be cooling. This consisted of the Emrax Gen 4 Size 10 motor and the Sevcon Gen 5 Size 9 Motor Controller. The Emrax motor we will be using has very high efficiency ranging from 93%-96% (Emrax, 2022), meaning from the 110kw we will be producing we will be losing around 7.7kw of energy in mainly heat. The Sevcon motor controllers' efficiencies range from 95%-98% (Borgwerner, 2022), this leaves us with a maximum loss of 5.5kw meaning the overall loss from both systems combined is 13.2kw. This 13.2kw is what I will cooling from the systems to keep them in their specified temperature ranges of +25°C to +50°C (Emrax motor) & -25°C to +80°C (Sevcon motor controller).

The next component in the system I needed to research was the heat exchanging unit itself (Radiator), Inadequate levels of heat dissipation could lead to engine overheating and subsequent breakdown (Lavery, 2014). To avoid this, I researched to find what aspects I would need to focus on in order to produce an effective motorsport orientated radiator. Motorsport's radiators must be built to endure significant forces and loads while still being as light as possible in order to keep the car's overall weight low (Lavery, 2014). To achieve this goal, I looked at various materials being used in modern motor vehicle radiators to compare their advantages and disadvantages to help me decide on the material that our Formula 750 radiator will be constructed from. Following on from this research the majority in modern motorsport believe that aluminium is the best option due to its great thermal conductivity which is 205 W/mK (Thermal Conductivity, 2022) and its low specific weight of 2.8 g/cm³ (Roberts, 2022), which is why it will be the material our Radiator is made from. Other aspects of my research featured the affects of different sizes and shapes of radiator. the research in this area was less specific since the size of the radiator depends on the amount of heat you are trying to dissipate from the system and the shape is mainly focused on its location. However, via various studies its shown that a radiator with a larger surface area and thinner core exchanges heat better than one with a smaller surface area and thicker core. This is since the fresh air being fed to the radiator increases in temperature as it passes through it, therefore the thinner core allows the air to exit sooner than the thicker core which due to its increased depth allows for the air to increase dramatically in temperature before it has exited the radiator (Lavery, 2014). Due to these findings, I decided that when I design the radiator I will use as much of the available space as possible to create the largest surface area and thinnest core possible.

With the material and other aspects decided I needed to find an appropriate company who would be able to produce a high-quality product specific to our needs. After communicating with a few companies via phone calls and emails I ended up choosing a company under the name of Coolex to build the radiator. Coolex is one of the few remaining specialist motor cooling companies in the country offering bespoke made cooling products (Coolex, 2022). After speaking to the owner of the company Steve Parker I was informed that Coolex had previously worked with other university's such as oxford, Birmingham and Manchester on similar projects and that he was more than happy to not only support the manufacture of the radiator but to sponsor the vehicle as well. This means we will have his full support and advice as well as the opportunity to build a relationship with a recognized company for the future.

Coolant is obviously a huge part of the system for obvious reasons, the selected liquid will be essential in conducting the heat from the components then travelling to the radiator where it is cooled once again to repeat the cycle. Choosing the right coolant is therefore crucial to try and produce the most efficient system. There are many types of coolant that have been used and tested for EV powertrains since their introduction. The main types are water ethylene glycol (1:1), silicones and nanofluids (Miller, 2021). However, it seems many of the EV manufacturers as well as EV race teams favour water ethylene glycol mixed at a ratio of 1:1. Below is a table displaying the performances and estimated cost per litre of the

most popular coolants used in EV's. As can be seen water ethylene glycol has a relative heat transfer rate of 0.62 and cost an estimated £1.50 per litre. This makes it a great option as it is effective in transferring heat and cost effective too. You may ask why not use water as it has a higher relative heat transfer and is a fraction of the price. However, water boils at 100°C which is an issue since our coolant reaching a calculated 90°C leaves us with very small room for error. If the systems temperature peaks slightly the water could boil rendering the system extremely ineffective. As previously mentioned, if certain components pass their maximum operating temperature they will shut down, which is a disastrous in a race event. To combat this the ethylene in the mixture increases the boiling point from 100°C for pure water to 108.8°C (*chemical-supermarket.com*, 2022). Therefore, making our coolant system a safer and more full proof system which is why we will be using it in our Formula 750 vehicle. I checked EV race regulations to ensure this was possible and found it is indeed allowed.

Coolant	Relative Heat Transfer Rate	Electrically conductive	Cost (£/litre)
Water	1.00	Yes	0.001
EG/water 50:50 v/v	0.62	Yes	1.5
Aromatics (DEB)	0.23	No	45
Aliphatics (PAO)	0.23	No	2.74
Silicones (Syltherm XLT)	0.18	No	15.29
Fluorocarbons (FC-770)	0.11	No	366
Liquid metals (Ga-In-Sn)	65.17	Yes	5732
Nanofluid - EG/Water+5%CuO	0.75	Yes	unknown

(Figure 2, Alternative Coolant Performances)

Header tanks are included in most vehicle coolant systems, its job is to allow the cooling system to expand under heat and any overflow and excess coolant to safely circulate (*Merlin Motorsports*, 2022). They are also placed at the highest point in the system to allow air to rise and escape the system to stop air pockets circulating.

I also needed to select a water pump for the coolant system. A water pump ensures the coolant keeps moving through the hoses and radiator to maintains an optimum operating temperature (*Haynes*, 2022). Via research of the Emrax motor & Sevcon controller I found they both require a flow rate of 10 l/min (*Emrax*, 2022) (*Borgwerner*, 2022) of water ethylene glycol meaning I will need to find a pump capable of supplying them both with this.

Finally, I had to research and select a suitable hose to connect the system together. These hoses will be responsible for transporting the coolant pumped around the system to and from each component. The most common material in coolant hoses for the vehicle industry is a reinforced synthetic rubber, the same synthetic rubber used in other components such as belts (auxiliary and timing). They are designed to withstand heat, vibration, pressure, and cooling system chemicals (*Mechanic*, 2022). They have been trailed, tested, and developed over the years to

an extremely high standard which is why I will be using the same material hoses in my cooling system. It is also a requirement mentioned in the Formula 750 regulations to use listed materials which our chosen material is.

3.5.4 Products Chosen

- **Radiator: Coolex Custom Radiator**

- Custom made to fit our requests & requirements.
- High quality.
- High efficiency.
- Experienced in EV heat exchanger packages (Worked with vintage voltage).
- Recognized manufacturer of bespoke radiators.

- **Coolant: Water Ethylene Glycol (1:1)**

- Temperature range of -36.6°C to +108.8°C.
- Common in EV race Vehicles meaning it is a proven choice.
- High heat transfer.
- Low cost.
- Meets EV race Regulation requirements.

- **Header Tank: 1L Mishimoto Motorsport Header Tank**

- Lightweight.
- TIG welded for maximum durability.
- Developed in motorsport.

- **Water Pump: Davies Craig EWP80 Pump & Controller Combo**

- Small & lightweight design.
- Adjustable flow rates via the controller.
- Many high-quality features to be accessed via the controller such as data logging, programming & features like shut down cooling allowing you to customize the unit to your required needs.

- **Coolant pipe: Reinforced Synthetic Rubber Hose**

- Trailed and tested in the vehicle industry over many years.
- Used in many motorsport applications.
- Withstands heat, pressure, and vibrations.
- Relatively cost effective.
- Meets race regulations.

- **Accessories**

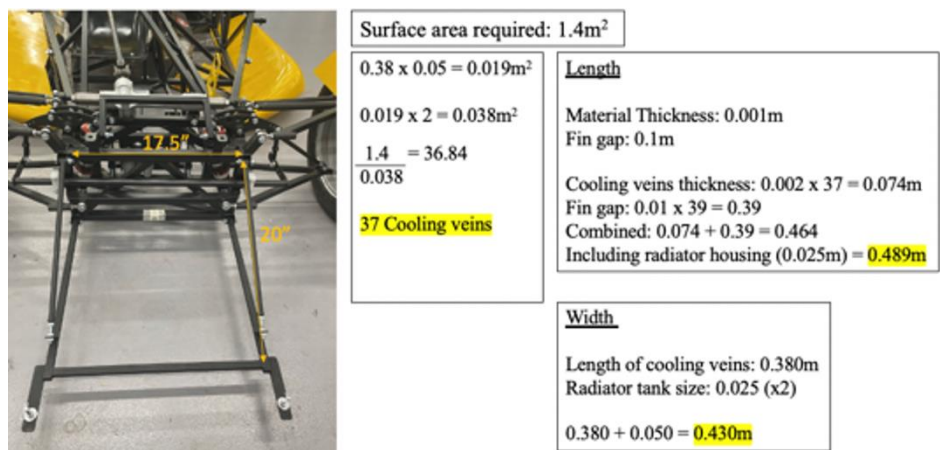
- Suitable sized jubilee clips will be used to attach the pipe at joins in the system as well as individual components. These were chosen due to their common use for this exact application.
- Ties will be used to secure the hose to the chassis of the car holding it in place during the event.
- Fittings can be used to maximize flow in the system for bends and other aspects stopping the coolant hose from flexing or crimping under pressure.

3.5.5 Desing

First, I had to analyse the space the radiator would be situated and create a template. To start this process, I studied the nose of the car and took dimensions. This allowed me to understand the maximum values the radiator could be to make the most of the space. As previously mentioned in research my aim was to use as much of the available space to create the largest surface area possible along with the thinnest core possible. I took the overall heat transfer area required of 1.37m^2 and rounded it up to 1.4m^2 to allow us some further safety and reliability within the system. I then looked at the space the radiator and chose the maximum length each vein could be whilst allow an inch (25.4mm) either side for the radiator's intake and outlet tanks, this left me with a value of 380mm. I then multiplied this 380mm by the thickness of the core (25.4mm) to gain the surface area. Each vein will consist of two off the plates allowing water to flow in-between them meaning this surface area was multiplied by 2 to give me the final surface area of 0.038m^2 per vein.

Next, I took this surface area and divided it by the required 1.4m^2 to give me the number of veins I would need in total to meet this calculated amount. $1.4 / 0.038 = 36.84$, rounding this number up to 37 was necessary as it is not possible to have .8 of a vein and rounding down to

36 meant the specified area needed would not have been met. Once I had calculated the veins, measurements from a variety of radiators in the university workshop were taken to find the average space left in-between veins for the cooling fins. The findings resulted in an average 1cm (10mm) space in-between each vein. Next, I calculated the number of spaces needed by the thickness of the fins allowing for an inch tolerance due to the radiator housing. This gave me a radiator with the dimensions of 15.95” wide, 19.25” in length and 1” thick.



(Figure 3, Radiator sizing calculations)

Now that I had the size of the radiator it was time to make a template to ensure it would fit the selected location as planned. I used single ply cardboard to construct the template of the radiator which can be seen in place below in figure 4 & 5.

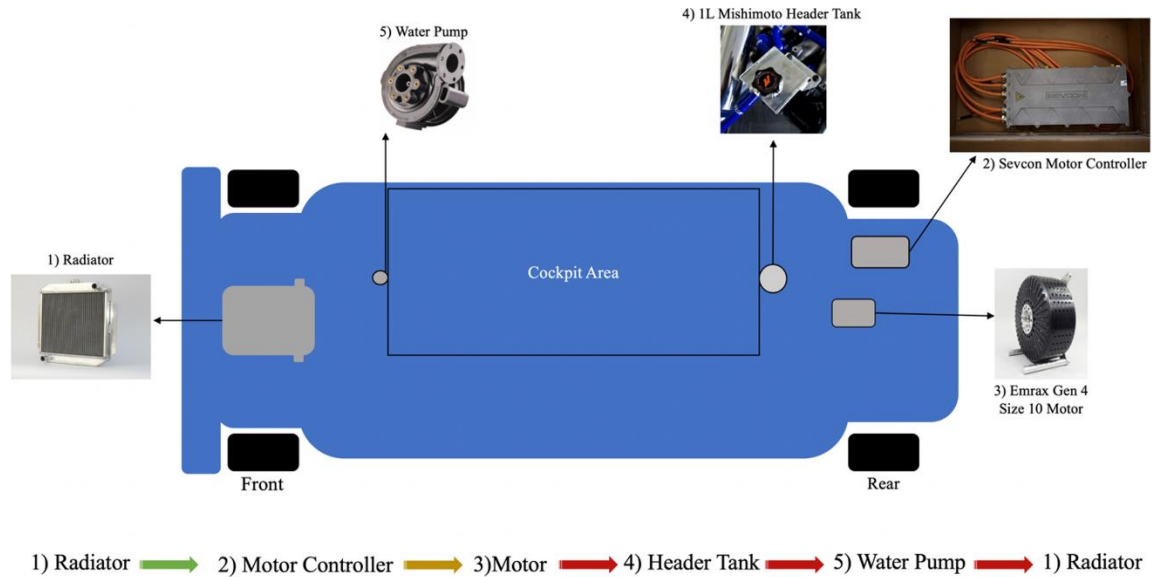


(Figure 4, Radiator Template in Selected Location)



(Figure 5, Radiator Template in Selected Location)

3.5.6 Assembly Plan



(Figure 6, Coolant System Assembly Plan)

The above figure (6) displays the assembly plan of the coolant system along with its cycle. Starting at the radiator the water ethylene glycol will travel to the motor controller where it will reach an estimated 70°C at operating temp, from here it will travel to the motor reaching around 85°C. The reason it travels in this order is due to the fact the motor has a higher temperature range than the Sevcon controller. From the motor the coolant will enter the Mishimoto header tank located at the highest point of the system on the rear of the drivers roll hoop. Exiting the header tank, it will then travel to the EWP80 water pump which will have been set to the 10 l/min specified flow rate of the motor and motor controller. From here the coolant is pumped back into the radiator at 90°C to exit and start the cycle again at 60°C. this system as previously mentioned will be connected using reinforced synthetic rubber hose, jubilee clips at joins and component inlet and outlet points and finally will use ties to secure the hose as it travels through the vehicles chassis.

3.5.7 Bill of Materials

Item	Cost (£)
Radiator	£600-£800
Coolant	£1.50 per litre
Header Tank	£162
Water Pump	£350
Coolant pipe	£150
Accessories (clips & fittings)	£200
Estimated Total	£1,700

3.5.8 Analysis

Concluding this report, this was a successful project. This is because a sufficient and effective coolant system has been designed for a Formula 750 EV. Firstly, I met my goals in terms of researching material and finding aspects of focus to produce an effective motorsport orientated radiator. For this my goals were to use as much of the surface area available in the selected location while keeping the core of the radiator as thin as possible. As can be seen in figure 4 & 5 in the design section of this report, the radiator template fits neatly in the nose of the vehicle taking up nearly all of the space available with a thin core measuring at just 1". However, I feel I could have further developed the system by building the radiator and other components in a CAD/simulation program such as Solidworks or Ansys design Modeler. This would allow me to construct the components into a functioning system all while measuring their thermodynamic efficiencies and properties. This would highlight any weaknesses if any in the system which could avoid expensive mistakes before purchasing the necessary components being used in the vehicle's final assembly.

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3.6 Alex Bennett

Team Role: Electrical System Harness

My role was to produce the electrical harness system which connects the main high voltage system (motor, controller and battery) and low voltage systems (throttle pedal, emergency switch and emergency fuses) together.

Research

It was crucial when starting this project to fully understand what a harness does in a normal ICE vehicle and then apply that to what it does in an electric vehicle to know where to start. This meant

there needed to be an understanding of what the machinery inside does. It was defined as a system of wires, connectors, terminals and components ordered together within the vehicle, which in turn pass on information to power the vehicle effectively within the system of Motor, controller and battery (sewsus, 2022). The high voltage system and components are more expensive and more difficult to source so maintaining these systems is vital.

This harness can be compared with ICE harness which has a low voltage arrangement up 12 volts. This normally only powers the lights, car's ecu and in car entertainment. Where the Electric vehicle differs is when there is both a high and low voltage system. The high voltage setup is the main propulsion system of Battery, Controller and Motor. The low voltage setup is some of safety aspect devices such as status light and dash display (Rowland, 2021).

Reasons for these components

In the electrical harness system, it is important that all the components and equipment are within the guidelines of both the series regulations and the UK governing motorsport body (Motorsport UK Yearbook 2021). The components here are low voltage and control all the items which help move the vehicle around more easily than without them (Motorsport UK, 2021).

Malfunction Display screen: this device shows important information regarding the battery status, temperature, speed, and speed of the motors, which is useful as a driver interface considering the difference in sensory elements being an electric vehicle (displaytechnology, 2021). Motorsport UK Yearbook 2021 states that this part is linked to the battery management system (BMS), this section informs the driver about the battery, motor, and temperatures when racing (Motorsport UK, 2021).

Accelerator pedal potentiometer: this mechanism's job to change physical input of the driver's foot into an electrical message which inform the controller to instruct the motor to speed up (Li, 2020). The potentiometer has an unlimited number of positions which means the increase in torque is linear. The throttle inputs must be linear and controllable so that the driver can handle the vehicle safely. Motorsport UK Yearbook 2021 (reg 5.30.18.) states there must be a throttle failsafe system which prevents both pedals being pressed at the same time by cutting the power to the motor (Motorsport UK, 2021).

Emergency crash switch: this mechanism is there to isolate the high voltage and low voltage systems in the event of an emergency (RS components, 2022). This component disconnects all the power to the vehicle. So, when an incident occurs the vehicle is safe to be touched by marshals or team members. This device must be easy to find and be visible. Motorsport UK Yearbook 2021 5.30.6-8., states that the vehicle must have two of these switches fitted to the system. With one within the

cockpit and one fitted to the roll hoop section, it must cut off to the general circuit breaker and must be marked accordingly (Motorsport UK, 2021).

Electrical connectors: these components connect high voltage components and cables together, such as the motor and battery. These are the main point of contact between each component and each cable (dalroad, 2018). The other connectors connect between the low voltage systems.

Motorsport UK Yearbook 2021 (5.29.16., 5.29.17.) States that connectors must be locked when in use and must indicate if they are not properly locked and not be live after four seconds (Motorsport UK, 2021).

Battery charger: This machine is a charger which increases the rate of charge to be put into the battery when charging (Lewis, 2022). The charger must be compatible with the battery plug and the voltage that is being put in. Motorsport UK Yearbook 2021 (reg 5.31.1.) states that this vehicle should be able to use public charging systems such as CHAdeMO and combined charging system (CCS) via one single external port. It also states that stopping and starting the charge cycle should be the same as charging a normal electric vehicle (Motorsport UK, 2021).

High voltage cabling: these are the orange cables which connect the high voltage lines between battery, motor, and controller (Wöhrl, et al., 2021). Motorsport UK Yearbook 2021 (reg 5.29.13-15.) states that all high voltage cabling must be continuous between connectors and terminals (Motorsport UK, 2021). If the system requires cable joins to operate it must have terminals bolted together with glands (Motorsport UK, 2021). The ingress protection must be at least IP65, and covers must be fastened together (Motorsport UK, 2021). Terminals must be crimped, or laser welded to be certified. Soldering is prohibited (Motorsport UK, 2021).

Pipe sheathing: this is a further protective covering for the high voltage cable also in orange. This extra layer protects the cable further from possible problems such as rubbing or wearing against edges (RaffenDayEV, 2022). In regulation 5.29.12 of the Motorsport UK Yearbook 2021 it states there must be orange conduit covering to shield the cables sufficiently to keep the wiring safe (Motorsport UK, 2021).

Low voltage connectors: These connect to the low voltage components safely; it is still important that these connections do not pose problems to the rest of the system (dalroad, 2018). Without these the vehicle would not run properly causing problems. Motorsport UK Yearbook 2021 (5.29.16., 5.29.17.) states that all connectors must be locked when in used and indicate if they are broken or not be live after for seconds (Motorsport UK, 2021).

Status light: this system shows the vehicle is safe to touch and this especially important in the event of a crash and shows the marshals and spectators if the system is safe or not (wrc, 2022).

Motorsport UK Yearbook 2021 (5.30.16.-2.) state that vehicles with a high voltage system must have an indicator status light of red or green and must be required to work even after the vehicle has crashed, broken or is not powered on (Motorsport UK, 2021).

Forward reverse switch/ indicator light: The switch provides a choice of moving forward or backwards and the light indicates to show the vehicle that it is ready to move to marshals, team members and (Mike, 2022). Motorsport UK Yearbook 2021 (Reg 5.30.17., 5.30.17.1-6.) states that the vehicle must have a ready to move light indicated white in colour when in forward with the throttle pressed. It must be positioned on the roll hoop which must be visible to drivers and others and must flash for different lengths of times when charging to show the system is receiving power and has not exceeded the voltage of the system (Motorsport UK, 2021). 5.11.2 states that all competitive cars must have reverse gear to move out of difficult situations (Motorsport UK, 2021).

12-volt battery: this device is needed to run the low voltage components as the main battery is too powerful (Battery World Varta-Automotive, 2021). Motorsport UK Yearbook 2021 (reg 5.29.26., 5.29.27.) states there must be a dc-to-dc converter (low voltage system) to charge the auxiliary 12-volt battery system. This system must never be used to charge the high voltage system (Motorsport UK, 2021).

Potential hazards/problems

The potential hazards within this project are important to understand as they have serious consequences when comparing a danger to life situation. It is crucial that the risks here are understood when it comes to working on these vehicles. Therefore, if connectors or cabling classified to carry particular loads of current and voltage are damaged or exceeded it can cause a multitude of problems within the system. For instance, it could to short circuit of the system, this would damage the components by melting or by fire. Furthermore, it is imperative that the cables are setup correctly so that in no way are they rubbing against the system's main components (Health and Safety Executive, 2022).

When work is carried out on the electric formula 750 the system must be isolated and disconnected for work to start. The system runs 350 volts it could fatally shock a person if not isolated (Health and Safety Executive, 2022). Though the system is disconnected there will still have remaining residual voltages (Health and Safety Executive, 2022).

Designs



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Drawing 2: Functional switching diagram example



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Development

Below is the bill of materials which reflects the pricing of electrical harness components. It gives a price to the drawing's concept' details and source of where to find each item. The table also list suppliers in this table case it mostly Electric Motorsport and RS components with a couple of exceptions. This is believed because of electric vehicles are still in their relative infancy when it comes to cheaper motorsports relatively speaking compared to price of ICE components.

The cost added comes to 2110k in relatively cheaper end components due to a larger availability of machines. Overall, the price of electric Formula 750 is likely to be at least five times the price of the current ICE vehicles on the grid. It means the current crop of racer would be likely to be priced out.

Further development could lead to changes which affect the design as well as the components required to build this or another version of the harness system. This could also the price of the build either negatively or positively in regards which components would be needed.

Materials	Description	Suppliers	Price £	Link
Display screen	Screen shows important information	Electric Motorsport	131.65	https://www.electricmotorsport.com/ev-parts/instrumentation/can-programmable/sevcon-smartview-604-60016-display.html
Malfunction indicator	Shows problems	Electric Motorsport	130.12	https://www.electricmotorsport.com/ev-parts/instrumentation/multifunction-meters/cycle-analyst-hc-high-current-10v-650v-w-remote-shunt.html
Throttle potentiometer	Accelerator control	Electric Motorsport	125	https://www.electricmotorsport.com/ev-parts/throttles/foot-pedal/foot-pedal-throttle-0-5k-ohm-curtis-fp-6-style.html
Crash switch Emergency switch system	Cut out for emergencies	Electric Motorsport	37.50	https://www.electricmotorsport.com/ev-parts/contactors-relays/emergency-disconnect/resettable-inertia-switch-crash-sensor.html
Electrical connectors	Low voltage connectors	RS components	180.72	https://uk.rs-online.com/web/p/electric-vehicle-connectors/1235223
Battery charger	To charge between races	Electric Motorsport	119.40	https://www.electricmotorsport.com/ev-parts/chargers/lithium/gbs-3-2v-15a-lithium-single-cell-charger.html
High voltage cables	Price by length (foot)	Electric Motorsport	6.46	https://www.electricmotorsport.com/ev-parts/wire/welding-cable/orange-welding-cable-2-0-awg.html
Conduit cables	Price to measure	raffendayev	1.52	https://www.raffendayev.com/conduit/harnessflex-20mm-solid-conduit-orange

High voltage fuses	Fuses to cut out if required	Electric Motorsport	50.52	https://www.electricmotorsport.com/ev-parts/fuses-holders/high-voltage-fuses/mersen-ferraz-shawmut-a30qs800-4-800-amp-fuse.html
High voltage connectors	High voltage connections on main components	RS components Electric Motorsport	15.31 201.44 237.28 204.15 180.72	https://www.electricmotorsport.com/ev-parts/wire/connectors/50-a-power-connector-152.html https://uk.rs-online.com/web/p/electric-vehicle-connectors/1235220 https://uk.rs-online.com/web/p/electric-vehicle-connectors/1741977 https://uk.rs-online.com/web/p/electric-vehicle-connectors/1235221 https://uk.rs-online.com/web/p/electric-vehicle-connectors/1235223
Status lights	Safe to touch light	RS components	0.637 13.27 2.659 13.72	https://uk.rs-online.com/web/p/pcb-led-indicators/6164172 https://uk.rs-online.com/web/p/panel-mount-led-indicators/2208945 https://uk.rs-online.com/web/p/pcb-led-indicators/1711323 https://uk.rs-online.com/web/p/panel-mount-led-indicators/2208944
12-volt auxiliary battery	Run low powered equipment	Electric Motorsport	457.32	https://www.electricmotorsport.com/batteries/lithium/4-cell-12v-packs/alithium-12-8v-100ah-4-cell-high-energy-density-lithium-battery-module.html

Table 8-Bill of materials

Analysis

From the perspective of the harness, it difficult to describe which areas have been done correctly, nevertheless the research into the system was conclusive in what it told us about the harness system. The design gave an impression of what it would look like given there was more time. The bill of materials gave us the components given in the drawing and price of what this section would cost. Furthermore, in the harness perspective it has directed research and development into new areas including high voltage circuits and components.

Presuming the project were to continue into the build stage, the next stage would be to work out the length of the harness between the battery, motor, and controller and the fitment of the required componentry going between these sections. These being connectors, fuses, terminals, conduits,

cabling and switches in order to build up our own harness. The length and fitment of the harness depends on where the main components go including the radiator and differential, so that none of the wires can rub against items and break or short circuit the vehicle. Only once the high voltage harness system is in place the low voltage system can be linked together in line with the regulations. It could be possible to simulate the harness so there is a more visual perspective of the system placing (Hermansson, et al., 2013).

If this project were to go further into a build, testing, and development stage there might have been likeliness for change in composition of components, design development from the drawings, and changes in the physical items when the vehicle was tested. It could be plausible that the project cost could increase just based on the probability it may have to be re-engineered (Rajesh, 2021).

Further analysis of my role in the group has at times led me out comfort zone in more ways than one. For example, working on CAD programs still being a weakness and learning enough to use Solidworks electrical to get visualisation of the harness. To show what work I had done developing the harness system for the vehicle.

The time factor has led to us not making the vehicle at the end of the year. This has been down to the lead time of months of the motor and controller. This from build, testing, shipping and delivery took 4 months to arrive.

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Appendix: Meeting minutes and other supporting information.

Table 9+3 HV battery safe light, Moving off indicator

Table 3:
HV RESS Status indicator states

Light Status	RESS Status
Green	Safe
Red	Danger (Isolation fault)

Table 4:
Ready-to-move indicator states

Light Status	Vehicle Status
Off	HV system de-energised
White always on	HV system energised – vehicle ready to move
White flashing	Charging

Drawing 3:
Fire Extinguisher Warning Symbol



Drawing 4:
Marshal Neutral Switch
Warning Symbol



Drawing 5:
High Voltage Warning Symbol



Figure 19+5+6 safety indicators

4 Achievement and progress relative to initial project plan and timing chart

From the Overall Group Gantt Chart, in Appendix 1, the weekly meetings, research, Data acquisition, regulations and communications with other groups have been successfully achieved, but personal Group meetings should have been done more regularly to avoid any complications and have a quick update on the overall ongoing.

Moreover, Appendix 3 illustrates the minutes of the main meetings. Thanks to this chart the main data highlighted in red were successfully met.

5 Review of successes and failures of the project

To conclude, the aim of the Group Project has been achieved, and from accurate research, value has been identified.

From the Overall group project Gantt Chart in Appendix 1, the main task highlighted in red have been successfully met, on the other hand, the group should have spent more time on assembly each component and have more meetings to discuss each other.

In section 3.1 has been important to understand the main forces that the vehicle cannot escape from, such as the drag forces and the final accumulative graph evidence that 1.03Giga-Joules can be an important booster that can be utilized when the vehicle is accelerating. Then the optimum lap test shows the continuous torque of the Motor Emrax 268 in a different circuit. Further, the critical bucking load evidence that an excessive load could cause a buckling on the main controller. For this reason, from the previous calculations, the final assembly evidence that there is not much load applied on the controller.

As evidenced the second duty cycles have been fundamental to understand the top, lowest and average speed which was able to find the final drive speed.

The radiator size has been 1.22m^2 , from the calculations illustrated that will be the best size to have an appropriate colling system through the vehicle.

Finally, the next step will be complete this proposal is to start the purchasing of the differential, driveshafts, sprockets and belts. After this the next step would be to start manufacturing the housing and the brackets using the milling machine. Once these steps are complete then the building of the drivetrain can commence with the welding of the brackets onto the chassis and then connecting the rest of the components together with help of the technician.

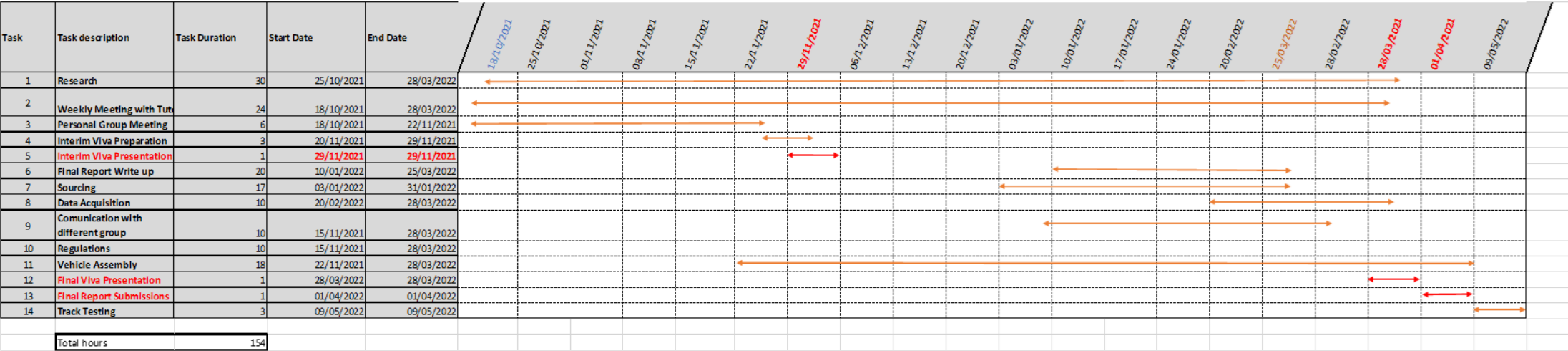
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7 Appendix: Meeting minutes and other supporting information.

7.1 Appendix 1

Table 10. Overall group project Gantt chart



7.2 Appendix 2

Table 11. Different types of batteries

Different types of batteries with specific Energy storage and specific power				
Battery type	Specific Energy storage Wh/kg	Definitive Power (Every 30 seconds at 80 % Capacity), W/kg	Average cost £/ kWh	Cycle life (Charges and Discharges to 80% of Capacity)
Lead-acid	35 (55) [171]	200 (450)	125 (75)	450 (2000)
Nickel-cadmium (NiCd)	40 (57) [217]	175 (220)	600 (110)	1250 (1650)
Nickel-metal hydride (NiMH)	70 (120)	150 (220)	540 (115)	1500 (2200)
Lithium-ion	120 (200)	300 (350)	600 (200+)	1200 (3500)

7.3 Appendix 3

Meeting Time and Date	18/10/2021 1pm
Agenda	Group split into specific area: Aerodynamic, Suspension, Powertrain, Simulation and (ICE) Engine group Meet with the tutor Understanding the scope of the Group project Milestone to assign next week Goal and activity to meet
Decision	Powertrain group
Meeting Time and Date	23/10/2021 1pm
Agenda	Meeting online on Teams Getting Know each other better Start research on the Powertrain area
Decision	Have an overview of 6 member of the group
Meeting Time and Date	3/11/2021 11am
Agenda	Assigned different specific task to each member of the group.
Decision	That is a fundamental date, so each member of the group knows the specific tasks to consider and milestones to achieve

Meeting Time and Date	26/11/2021 10 am
Agenda	A meeting of two hours to clarify who is doing a specific task Size radiator Battery "Nissan or Other types"
Decision	The group was ready for the first presentation of the Interim Viva Presentation
Meeting Time and Date	5/01/2022 6 pm
Agenda	Quick catch-up Update progress Start final assembly
Decision	Every member needs to start to think about the Assembly components
Meeting Time and date	24/03/2022 3 pm
Agenda	Final task to complete Writing report nearly completed Presentation Final Assembly Ready for the Final Viva Presentation and Final report Submission
Decision	Presentation ready by the 26/03/2022 Write report by the 25/03/2022

Figure 20. Meeting minutes