

University of Wales Trinity Saint David

Wales Institute of Science & Art



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***Designing a Gravity Racer in Compliance with the
Rules and Regulations of the Richards Castle
Soap Box Derby***

Integrating Project ACHA4008

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1 Introduction

This report details the research and development of a gravity racer, being designed to comply with the “Richards Castle Soap Box Derby 2020” regulations. A gravity racer, or soapbox, is a vehicle intended to be powered exclusively by the force of gravity thus it has no motor. A variety of components and materials were researched to determine the impact that variables, such as material, had on the performance and suitability of the components. This information was used to select parts and materials to use in the design of the gravity racer, while adhering to a £900 budget set by the group.

The group was named ‘Zero Emissions’ and each member was assigned a role based on their strengths and weaknesses. The members and their roles were as follows:

- Carter-Davies, C. as Team Manager
- Delancy, J. as Materials Researcher
- Ferreira, J. as Chief Designer
- Williams, R. as Handling Engineer
- Woodhouse, E. as Wheel Specialist

2 Methodology

The group work was organised using a Gantt chart created using Microsoft Excel, it specified tasks, who was responsible for which task, and the timeframe to complete the task. Discussions during group meetings were recorded through meeting notes.

The group examined other gravity racers to gain inspiration and have a better understanding of the vehicle type. The research into different materials and component types was assessed to compare benefits and drawbacks, and the group selected the ones they deemed to be most suitable for use in the gravity racer.

3 Research

3.1 Course

The gravity racer was being designed for use at the Richard's Castle Soapbox Derby, therefore it was crucial to understand the course. The course has a length of 550 metres and a reduction in elevation of 50m, with a varying gradient throughout (Richards Castle Soap Box Derby, n.d.). A satellite view of the area is shown in Figure 1.



Figure 1 - Layout of the Richards Castle Soapbox Derby course. (Google Maps, 2020)

The course begins on a ramp above a road. The road is paved, with potholes and loose chippings in some places, the course runs along this road down to the finish. There are short sections where the driver is required to travel off the road, and over grass or dirt. (jono026, 2012)

3.2 Materials

We researched materials as we needed something to create the frame and body. The first material researched was seamless cold drawn steel tube. It has no seams, and its structural integrity is better maintained through the rolling process, thus cold drawn steel is typically 20% stronger than cheaper Hot Rolled Steel tube (Wasatch Steel, 2018). The price of one metre of 31.75mm x 2.03mm mild steel tube was £4.45 and the price of one metre of 31.75mm x 2.03mm Cold Drawn Steel tube was £12.00 (Metals4U, 2021).

For the bodywork we researched fibreglass. Raw fibreglass was found to be approximately £20 per square metre (MBFibreglass, 2021) with a finished 2mm sheet of fibreglass costing around £44.00 per square meter (East Coast Fibreglass, 2021). DEFI Fiberglass (2021) state that fibreglass is pound-for-pound as strong as steel, however fibreglass has a much higher strength-to-weight ratio than steel.

Another material researched for the bodywork was carbon fibre, which is very similar to fibreglass in that it is a composite, being made up out of lots of fibres that are held together by resin. Carbon fibre is lighter whilst also being stronger than fibreglass, however it is more expensive to produce and purchase than fibreglass. The price per square meter of a 2mm sheet of carbon fibre was £246.58 (Easy Composites, 2021).

3.3 Chassis & Bodywork

Inspiration for the design of the chassis came from the cross karts (Figure 2) used in the Formula X Autocross series that runs in the USA. This chassis style was chosen as the regulations state that:

“The roll bar should be at least 35mm above the driver’s helmet when the driver is seated normally in the vehicle, and a second roll bar should extend at least 25mm beyond the driver’s gloved hands when placed at 12 o’clock on the steering wheel. If you are in doubt as to what is ‘substantial’ please contact our scrutineer before or during construction so as to avoid disappointment on the day.”

(Richards Castle Soap Box Derby, n.d.)



Figure 2 - Formula X Cross Kart (Parry T., 2018)

3.4 Steering

A rack and pinion steering system was researched. This had a 320mm gear rack pinion length, a 380mm steering shaft, and 245mm tie rods. The cost of the entire assembly was £69.99 (Figure 3) (giddoo2020, 2021).



Figure 3 - Steering Assembly (giddoo2020, 2021)

3.5 Suspension

Due to the condition of the road surface, it was decided that suspension should be implemented for stability and handling purposes. The initial choice of suspension was a coil spring shock absorber (Figure 4), commonly used on a mountain bike for rear suspension. It had a length of 150mm and a maximum load of 340 kg, and a price per unit of £8.06 when purchasing 4. However, the only adjustable variable was preload (Quattro Sports & Leisure, n. d.)



Figure 4 - Coil Spring Shock Absorber (Quattro Sport & Leisure)

The second choice of suspension was a pneumatic shock absorber (Figure 5). This had lengths ranging from 165mm to 250mm and stroke lengths from 37.5mm to 75mm, and had adjustable rebound and compression. The price per unit was between €499 and €645 (SRAM, 2021), which is approximately £430 to £560. One issue with air shocks is that they rely on having many seals to function, these seals create heat through friction. The build-up of heat alters the behaviour of the shock over continuous use (Kidd, 2017)



Figure 5 - Pneumatic Shock Absorber (SRAM, 2021)

3.6 Wheels and Tyres

Wheels are one of the most important parts of the gravity racer. When going around sharp corners at high speeds, the wheels can experience great lateral forces which can buckle the wheel, causing the gravity racer to crash. The diameter of the wheel plays an important role in the wheel's strength. The larger in diameter the wheel is, typically the weaker it will also be if it is not also made thicker. Therefore, gravity racers traditionally have wheels smaller than 20 inches in diameter (ScottishCarties, 2013). This can be seen happening in Figure 6.



Figure 6 - Gravity racer's wheel buckling from lateral forces (ScottishCarties, 2013).

Lightweight wheels improve acceleration, allowing the gravity racer to reach its top speed sooner. (ScottishCarties, 2013). In their article, LiteLok (2020) explains that although smaller lighter wheels accelerate quicker, heavier wheels and wheels with a larger diameter will have a greater top speed due to their extra momentum.

As stated in an article by Arthur, D. (2015), the main advantage of carbon fibre wheels is that they are much more aerodynamically efficient than traditional aluminium rims. Although rolling resistance would contribute to loss of energy from the gravity racer, Schwalbe Tires states that air resistance has a squared relationship with increased velocity, meaning that as the speed of an object doubles, the air resistance gets quadrupled (Figure 7). This suggests that air resistance is one of the main reasons for energy loss at higher speeds, and therefore any aerodynamic improvement of the wheels would help increase the maximum speed of the gravity racer.

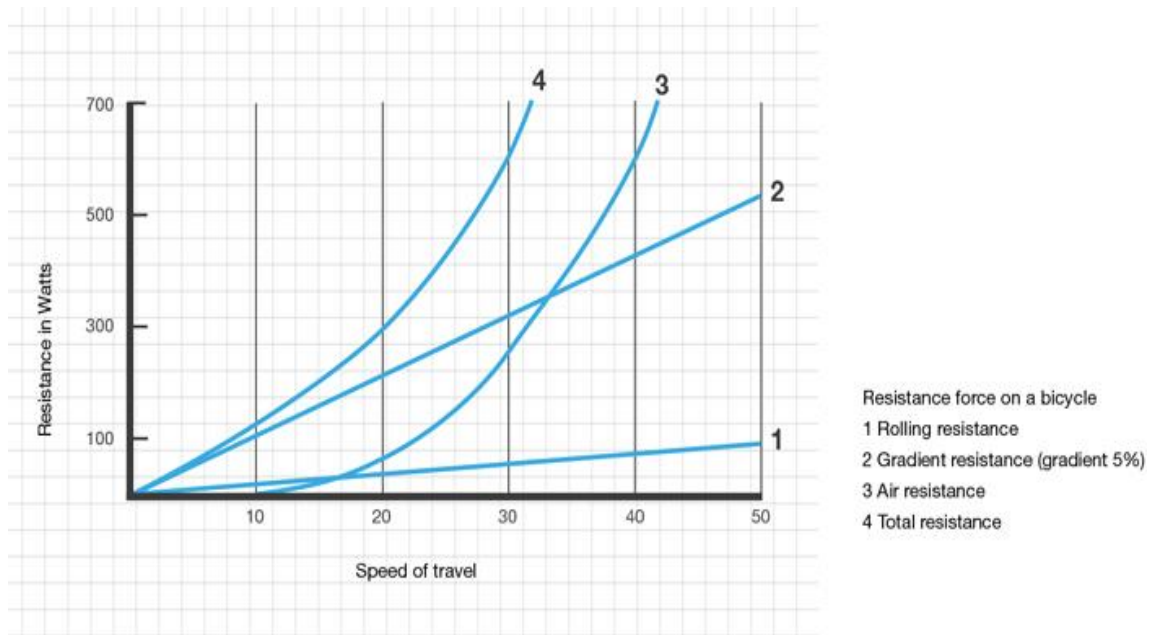


Figure 7 - Graph showing the resistance against a bicycle as velocity increases (Schwalbe Tires)

3.7 Brakes

The main brake types researched were disc brakes and rim brakes. Rim brakes are simple, cheap, and lightweight; however, they provide less brake force and are less effective when wet. Another issue with rim brakes is that they could limit wheel and tyre choice as they need to fit around the tyre (Brough, 2019).

Disc brakes were more expensive and heavier than rim brakes. Disc brakes are impacted less by wet conditions and apply more force, though applying more force could also be a downside as the wheels may lock up and cause loss of control. Disc brakes also allow for a greater variety of tyres to be used (Bracey, 2016).

4 Analysis

4.1 Materials

The material chosen to construct the frame was 31.75mm x 2.03mm Cold Drawn Steel tube. Cold Drawn Steel tube was chosen over the hot rolled steel as it was stronger, despite the additional cost, as the extra strength and rigidity would assist in both safety and performance. It was calculated that we need 35m of tubing to create the frame, bringing the cost of the frame to £420.

Fibreglass is the material chosen for the bodywork of the gravity racer. This is due to fibreglass being relatively cheap compared to carbon fibre. It is estimated that 3.1m² of material is required for the bodywork of the gravity race and for a sheet of carbon fibre that matches these dimensions of 2mm thickness it would cost £136.40. It was deemed to expensive to use carbon fibre for the bodywork

4.2 Body and Frame

At the beginning of the design phase, 3 sketches were elaborated to present to the rest of the team for approval.

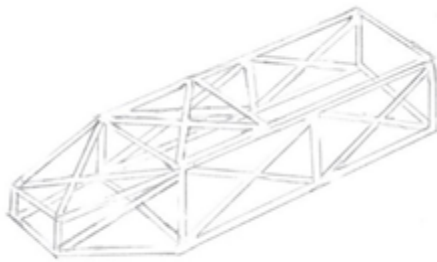


Figure 8 - Design Option 1

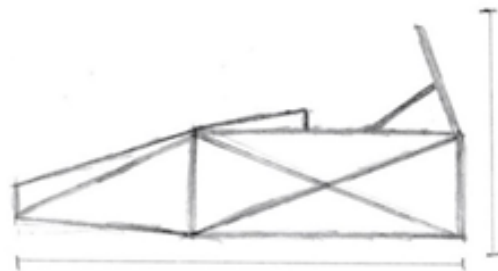


Figure 9 - Design Option 2

The first option, Figure 8, was ruled out due to the lack of roll over protection required for the event, so the choice was narrowed down to the second and third options. Due to the lack of reinforcements in the frame of option two, shown in Figure 9, it was decided that a material capable of withstanding the forces induced in a gravity racer would either need to be thick, and weigh beyond what was practical for transportation, or too expensive for the team's budget.

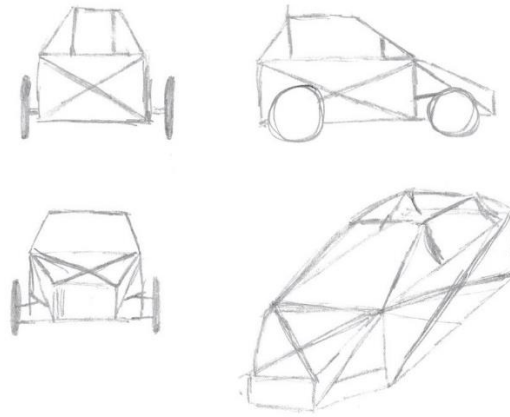


Figure 10 - Design Option 3

With the requirements, it was thought that the best course of action was to combine the head and hand protection into one, so the chassis was designed to have a full roll cage to comply with regulations and provide strength to the overall construction, as shown in Figure 10.

At the start this was drawn with the idea of a passenger compartment made from rectangular sections strengthen with cross bracing with the front end tapered to reduce frontal area to minimise drag from air resistance. From this, measurements were taken to ensure that drivers of any height fit and safely be able to get in and out. Height was decided to be 900mm, length 1600mm and width 800mm (Figure 11). This allows for the bottom of the frame to be 400mm high and the roll cage 500mm, this grants a taller opening for the occupant to exit quickly and safely from the vehicle, if needed.

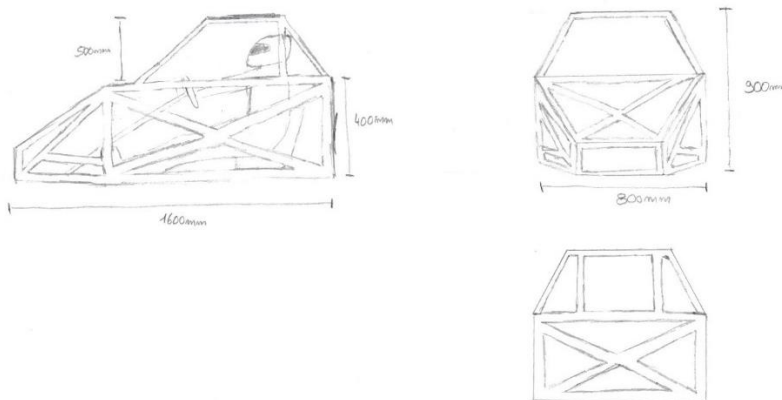


Figure 11 - Second Design Iteration

Shown in Figure 12, the third and last iteration of the design was made in CAD to give a better understanding of the information displayed in the design, as opposed to the hand drawings which can be misleading.

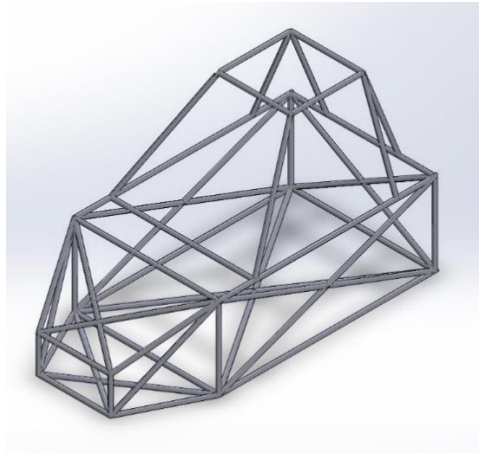


Figure 12 - The Final Design

As for bodywork, it was agreed that sheets would be made to be riveted to the frame itself and be painted and decorated. Inspiration for the livery came from the Lotus 97T used in the 1985 Grand-Prix as shown in Figure 13.



Figure 13 - Lotus 97T (Ultimatecarpage.com, 2015)

4.3 Suspension

The spring coil shock absorber was chosen over the pneumatic shock absorber due to multiple factors. The major factor being cost, the pneumatic shock absorbers were 50 times more expensive than the coil spring alternative. As we had a limited budget, we opted for the coil spring shock absorbers. These also had the benefit of being able to react to smaller forces more effectively and it did not come with the drawbacks of the pneumatic shock absorbers caused by the friction of its seals.

4.4 Steering

A steering wheel was chosen over handlebars as it was thought that the seating position and frame of the vehicle would make it awkward for the driver to use handlebars to steer effectively, which would be likely to hinder performance and could cause loss of control.

4.5 Wheels and Tyres

The wheels chosen for the project are Raleigh Trubuild 18x1.75 aluminium bicycle wheels. These wheels were chosen due to them being made of aluminium providing them with strength & lightness, being the correct diameter and being cheap at the same time, costing £48.38 for a set of 4 (Rutland Cycling, 2021) If there was no budget, a set of carbon fibre wheels could have been used, reducing weight and air resistance.

The tyre choice for the gravity racer is Schwalbe Kojak. They are lightweight slick road bike tyres which have been designed to provide very low rolling resistance to greater the acceleration and top speed of the gravity racer. (Schwalbe Tires, 2021). The Schwalbe Kojak tyres were found at a price of £28.99 per tyre, with a total cost of £115.96 for a set of 4.

4.6 Brakes

It was found that disc brakes were more suitable to the application than rim brakes as the gravity racer was likely to need brakes with more reliability and force. While rim brakes are simpler to attach to the wheel, there was concern that they would not apply enough braking force to slow the vehicle down effectively. Using disc brakes also bypasses the issue of rim brakes limiting tyre selection. Hydraulic disc brakes were found through Clarks (2015) at a price of £49.99 for a set of 2.

5 Evaluation

The group has worked well to research components and materials, and design the gravity racer. Every member was well suited to their role, however the tasks for each person could have been more specific. The project stayed on track following the Gantt chart (Figure 14), and meetings were held twice per week with only one occasion where a meeting was cancelled. The meeting minutes were detailed enough to understand the topic of the meeting, but in some cases the minutes were missing information about the topics discussed (Appendix 1).

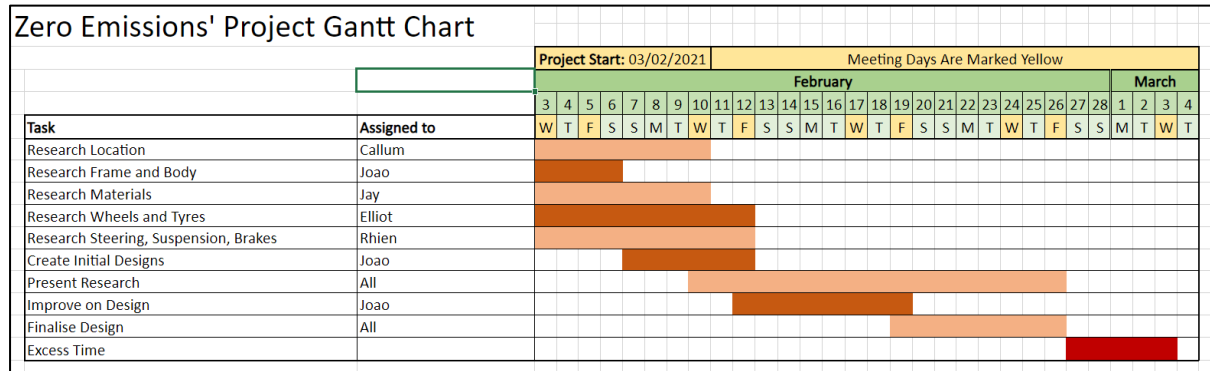


Figure 14 - The Gantt chart used to plan the project

The projected cost of the gravity racer at the end was predicted to be £872.96, which was £27.04 under the budget of £900 set by the group at the beginning.

6 Conclusions

In this project, roles were assigned to members through a discussion of their strengths and weaknesses. A Gantt chart was used to plan the project's schedule, and meetings were held twice per week to discuss progress and exchange ideas. The meetings were documented through the creation of minutes.

Materials and components were researched and assessed to select the most suitable choice, and a frame and body was designed with considerations towards them, as well as ensuring they follow the 'Richards Soap Box Derby' regulations, as well as adhering to the total budget of £900 agreed by the group.

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8 Appendices

Appendix 1 - Meeting Minutes From 3rd February to 24th February, 2021.

Soapbox Project Meeting Minutes

February 3, 2021

Meeting held via Microsoft Teams

Attendees: Callum Carter-Davies, Elliot Woodhouse, Jay Delancy,
Joao Paulo Mirra Ferreira, Rhien Joseph Williams

10:00am	Meeting begins
10:10am	The members introduce themselves, discussing their interests, experiences and the course they are on.
10:25am	The members discuss how they want the soapbox to look, Elliot submits pictures of other soapboxes and Joao submits a drawing of his design for the soapbox.
10:45am	Callum shares a link to the regulations found on the Richard's Castle soapbox derby website and the members discuss them and the effect they will have on the design. He suggests the group sets a budget for the design, the other members agree to set a budget of £900.
11:00am	Rhien suggests setting up future meetings on Wednesdays and Fridays at 10:00am. Everybody agrees.
11:20am	Meeting ended.

Soapbox Project Meeting Minutes

February 5, 2021

Meeting held via Microsoft Teams

Attendees: Callum Carter-Davies, Elliot Woodhouse, Jay Delancy,
Joao Paulo Mirra Ferreira, Rhien Joseph Williams

10:00am	Rhien begins the meeting
10:20am	The members discuss the roles and who would be most suitable.
10:45am	The roles are assigned to members by agreement, the roles assigned to each member are as follows: • Joao to designing the frame and body • Elliott to choosing wheels and tyres • Jay to choosing materials • Rhien to steering, suspension and brakes • Callum to managing time and writing
11:15am	Joao submits pictures of vehicles that are similar to the body he wants to design, suggesting Formula X Cross Karts. Everybody is in agreement.
11:30am	Jay suggests we exchange contact details to set up a group chat to talk about the project between meetings. Rhien suggests using Whatsapp. All the members exchange contact details and set up a Whatsapp group.
11:45am	The members agree to set up a meeting for next Wednesday at 10:00am. The meeting draws to a close.

Soapbox Project Meeting Minutes

February 10, 2021

Meeting held via Microsoft Teams

Attendees: Callum Carter-Davies, Elliot Woodhouse, Jay Delancy,
Joao Paulo Mirra Ferreira, Rhien Joseph Williams

- | | |
|---------|--|
| 10:00am | Rhien initiates the meeting |
| 10:10am | Joao submits his sketches of some designs for the frame of the soapbox, he has altered the design to be based more off the shape of a cross kart in formula x autocross. The members comment on the designs and check if they will meet regulations. |
| 10:30am | Elliot submits a picture of the wheels he has been researching and discusses the positives and negatives of different types. |
| 10:50am | Rhien discusses the brakes and steering assemblies he is researching. |
| 11:15am | Joao begins discussing his ideas for the bodywork, other members also contribute ideas for the style. The members agree to have custom bodywork rather than a replica of an existing vehicle. |
| 11:45am | Rhien and Joao discuss how the suspension components will mount to the chassis. Joao says he will design some mounts which would be built into the chassis. |
| 12:00pm | The meeting draws to a close. |

Soapbox Project Meeting Minutes

February 12, 2021

Meeting held via Microsoft Teams

Attendees: Callum Carter-Davies, Elliot Woodhouse, Jay Delancy,
Joao Paulo Mirra Ferreira, Rhien Joseph Williams

- | | |
|---------|--|
| 10:00am | Joao starts the meeting off by showing the members some improved sketches of the design of the frame and body, as well as different liveries that could be applied to the bodywork. He discusses reasons for certain design choices, for example, diagonal crossbars to increase rigidity. The other members examine them and determine they are suitable and ensure the designs meet the soapbox derby's regulations. |
| 10:20am | Jay says he will research the shape of the pipes and determine whether square or round would be better. |
| 10:40am | Elliot asks what methods would be used to cut the metal tubes used in the frames, and suggests using a hole saw to cut a curve in the end of some of the metal tubes so they will sit flush with the sides of other ones. |
| 11:00am | Rhien says he is considering using coil spring suspension and Joao suggests he could use a spring shock used on the rear of mountain bikes, with one on each corner. |
| 11:15am | The members of the group discuss the materials that could be used for the outer bodywork, suggesting fibreglass or carbon fibre. Jay suggests that the carbon fibre sheet could be too costly for the planned budget. |
| 11:30am | The meeting draws to a close. |

Soapbox Project Meeting Minutes

February 17, 2021

Meeting held via Microsoft Teams

Attendees: Callum Carter-Davies, Elliot Woodhouse, Joao Paulo Mirra Ferreira,
Rhien Joseph Williams

- | | |
|---------|---|
| 10:00am | Callum begins the meeting and show his research of the racecourse, showing the course length, corners, and change in elevation. |
| 10:15am | Joao says he has calculated the estimated length of the steel tubes required to be 32.5m |
| 10:35am | Elliot discusses the wheels he is planning on using, and says he is finding a good balance between weight, speed, acceleration, cost, and grip. |
| 10:50am | Rhien shows his research into brakes and is deciding between v-brakes and disc brakes. |
| 11:10am | Joao submits a CAD model of the frame to the group. |
| 11:15am | The meeting draws to a close. |

Soapbox Project Meeting Minutes

February 24, 2021

Meeting held via Microsoft Teams

Attendees: Callum Carter-Davies, Elliot Woodhouse, Jay Delancy,
Joao Paulo Mirra Ferreira, Rhien Joseph Williams

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| 10:05am | Joao starts the meeting off by uploading his work on the research and designs. Elliot also uploads his research and write-up. Other members of the group read through and confirm they are happy with it. |
| 10:20am | Joao says we need approximately 3.1 square meters of material to create the body work. |
| 10:40am | Jay and Rhien say they will have their reports written up for the next meeting. |
| 11:00am | Rhien says he will finish up his research into the steering mechanism. |
| 11:10am | Callum says he will begin putting together the report. |
| 11:30am | The meeting draws to a close. |