

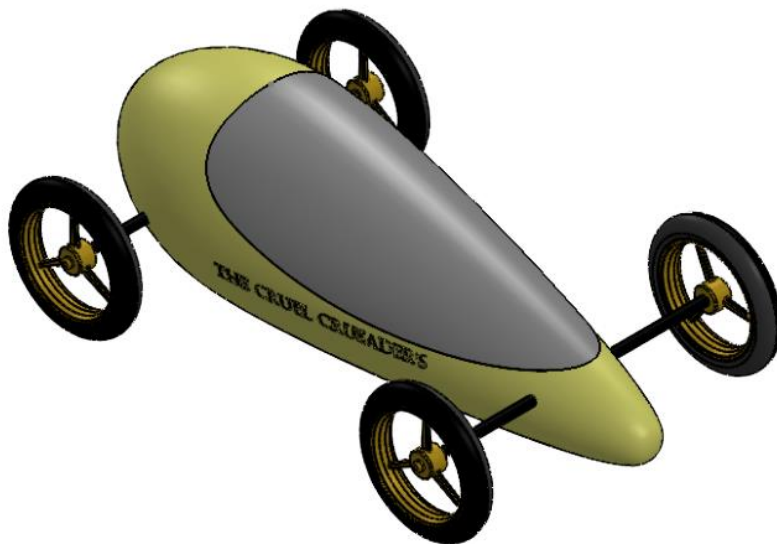
University of Wales Trinity Saint David

Wales Institute of Science & Art

Project Second Report

Design of a “Soap Box type of Car”

Integrating Project – ACHA4008



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1 Introduction

The second part of this project involves producing CAD drawings related to the soapbox design selected in the 1st report. It also presents the calculations of forces and other design calculations associated with the creation of the Soapbox.

2 Design calculations

Some design calculations that were requested to be included in the second report of this project were performed in the 1st report of this project. To comply with the requirements of the 2nd report, some of these calculations were included in this report as well.

2.1 Potential Energy and Kinetic Energy calculations

From the 1st part of this report, the total weight of the soapbox type of car was designed to be 233kg.

According to the law of conservation of energy, the potential energy of the soapbox type car (together with the driver) should be equal to the kinetic energy of the soapbox type car (including the driver) at the end of the race.

This relation is given in equation 1

$$P.E = K.E$$

$$mgh = \frac{1}{2} m V^2 \quad \text{Equation 1}$$

Solving equation 1 for V, the expected velocity of the soapbox car at the end of the race was calculated.

$$V = \sqrt{2gh} = \sqrt{2 \times 9.81 \times 50} = 31.32 \text{ m/s or } 112.75 \text{ km/hr} \quad \text{Equation 2}$$

This speed is too high if compared with the velocity achieved in the previous soapbox derby competitions. (*Soap Box Derby | Richards Castle | Fastest carts down the hill*, no date) This value is because the drag force, the friction between the wheels and the road, and the bearings' friction are not taken into account in this equation.

2.2 Calculations of forces and expected velocities during the race

To obtain more realistic results regarding the velocity of the soapbox car along the race track, the force due to the mass of the soapbox car, including the driver along the plane on the race track, was calculated. Also, the drag force on the soapbox car was considered. These calculations were performed in part one of the project and are presented again below:

Figure 1 shows the forces acting on the Soapbox when the soapbox car is on an inclined plane.

In part one of the project, the total weight of the soapbox car, including the driver, was estimated to be 233kg. Based on this value, the force F_w , which will accelerate the vehicle,

was 207N using equation 1. This force was calculated based on the race track's average gradient even though it varies.

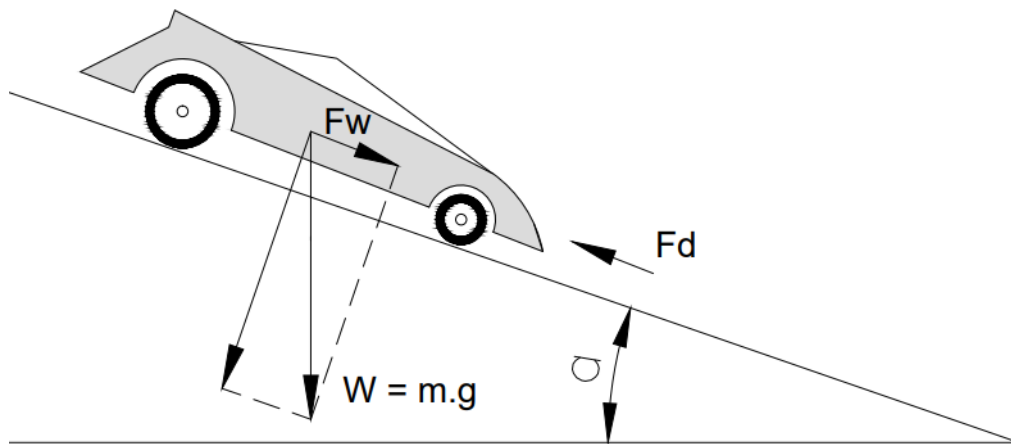


Figure 1 – Forces acting on an object on an inclined plane

$$F_w = mg \sin \alpha = 233\text{kg} * 9.81\text{m/s}^2 * \sin 5.19^\circ = 207\text{N} \quad \text{Equation 3}$$

As the soapbox car will accelerate as it goes downhill, this will activate the drag force given by equation 2.

$$F_d = C_d \frac{1}{2} \rho V^2 A \quad \text{Equation 4}$$

The soapbox car will continue to accelerate until the force (F_w), which activates the soapbox car's movement, becomes equal with the drag force (F_d). Considering the factors that affect the drag force to achieve higher speeds, the drag coefficient and the soapbox car's frontal area have to be minimized.

Using the information about the soapbox car winner in the 2019 Richards Castle Soapbox car derby (*Soap Box Derby | Richards Castle | Enter your cart and race*, no date), stated in part one of this project, a spreadsheet was prepared using engineering fundamentals. (Abi Summerfield, 2021) Based on the mathematical model built in Excel Spreadsheet, the drag coefficient of this soapbox car was determined using the trial and error method. This approach was necessary to add a reasonable value to the coefficient of drag of the soapbox car designed under this project. Having a fair value for the drag coefficient and using the necessary values for the soapbox car, which is design under this project, then the soapbox car's timing was determined. The following table shows the values which were used in the calculations.

These values were used in calculating the acceleration, the speed, and the distance covered by the soapbox car at 0.5sec intervals using equations 5, 6, and 7.

Table 1– Design Parameters

Parameter	2019 Winner – Soapbox car	Project Soapbox car
Weight of soapbox car	163 kg	163kg
Mass of driver (s=assumed)	70kg	70kg
Height of soapbox car	1.4m	0.8m
Width of the soapbox car	0.7m	0.8m
Height of tyres	0.6m	0.6
Width of tyres	0.07m	0.07m
Coefficient of drag (estimated)	0.49 (Calculated)	0.49
Timing	44.003sec	41 secs (calculated)

$$dS = udt + \frac{adt^2}{2} \quad \text{Equation 5}$$

$$u = \alpha dt + u_o \quad \text{Equation 6}$$

$$\alpha = \frac{F_w - F_d}{m} \quad \text{Equation 7}$$

NOTE: In calculating ds, in equation 5, the average speed between the time intervals was used, and the acceleration in the previous time interval was used. This approach will cause some errors in the calculations, but these errors can be minimized if the calculations are made in smaller time intervals.

Figure 6 shows the distance travelled by the soapbox car to time. The graph shown in Figure 6 shows that the soapbox car can reach the finish line in 41 seconds.

As it can be seen from Figure 6, due to the fact the frontal area was reduced, this resulted in having a faster soapbox car than the year 2019 soapbox car winner. It was assumed that the soapbox car weight and the drag coefficient would be 233kg and 0,49, respectively. It is believed that the soapbox car that was considered in this project has a better drag coefficient, and the fact that additional fixed weights can be added to the soapbox car, it is believed that the soapbox car can perform better. It has to be noted that some assumptions were made in producing these results. One hypothesis is that the driver will not apply the brakes. Some inaccuracies in the assumed values and calculated values might cause some deviations from the racing results. That is why before the competition, it is required to carry out test runs.

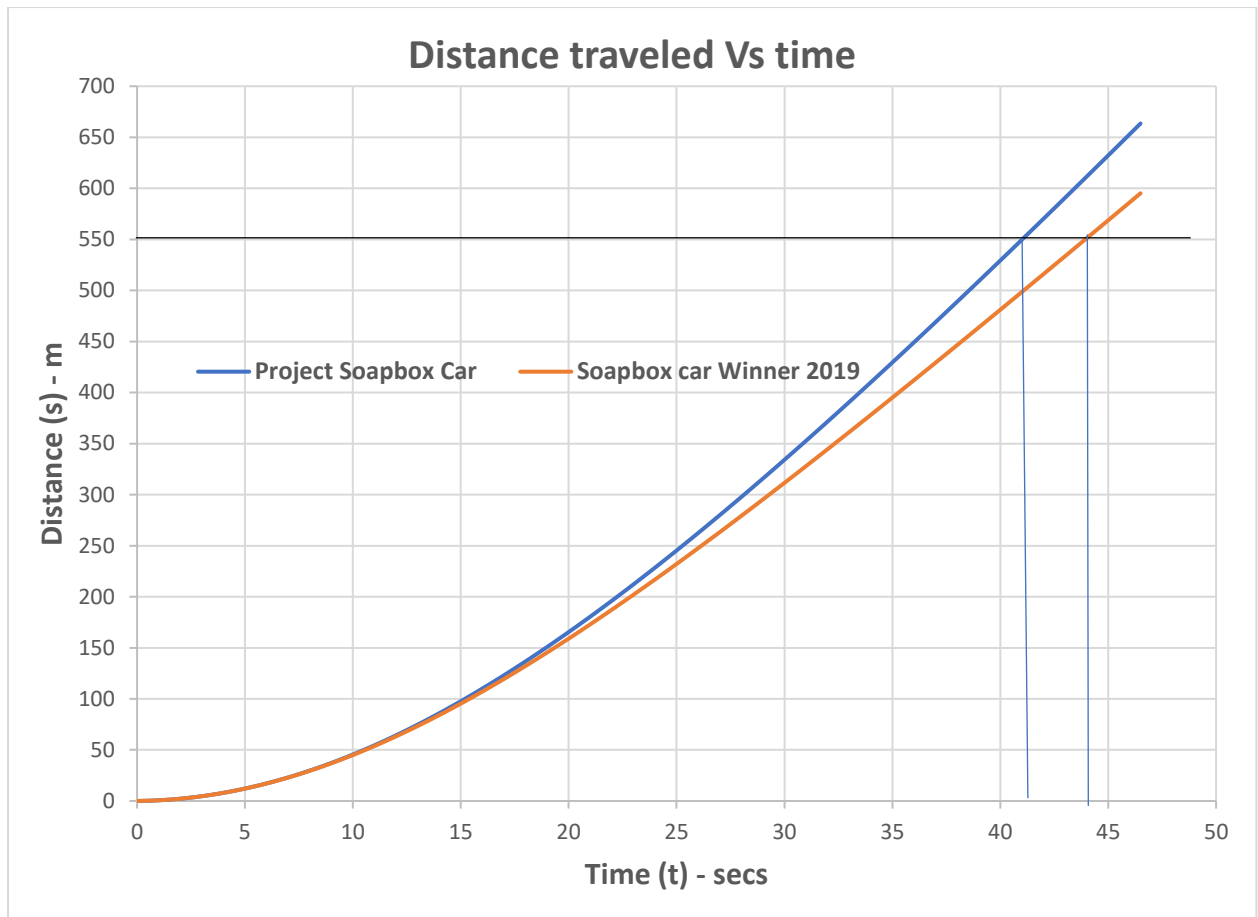


Figure 2– Distance Vs. time - Comparison between Project soapbox car and 2019 winner Soapbox Car

The maximum speed that is expected this soapbox car will reach is approx. 78.6km/hr when F_d reaches F_w . As shown in Figure 7, this will not occur before the end of the race, and the top speed that this Soapbox will reach during the race is 73km/hr if no brakes are applied and if the wind speed is zero.



Figure 3 – Distance travelled / speed Vs. Time

2.3 Forces acting on the tires

When the soapbox type of car is at equilibrium, the forces on wheels can be calculated by dividing the total weight of the soapbox car, including the driver's weight, by four.

Considering that the total weight of the soapbox type of car, including the driver, was calculated to be 233kg (from part 1 of this project), the force on each tire was calculated to be 571N.

$$F_{\text{tyre}} = 233 \times 9.81 / 4 = 571 \text{ N}$$

Also, apart from this vertical force exerted on the tires, a horizontal force due to the drag force is exerted on the tires during the race. The drag force takes its maximum value when the soapbox car reaches its top speed. At Maximum speed, the drag force is equal with F_w . F_w was calculated before and is equal to 207N. Therefore, on each type, 51.75N is exerted as well.

Another force exerted on the tires is the force during braking at the end of the race. This force was calculated in part one of this project, considering that this Soapbox will reach a 73km/hr speed during the race and assuming that it has to stop in 5 seconds. This force was calculated using the equation below:

$$F_b = \frac{dv}{dt}m = \frac{73 \cdot 1000 / 3600}{5} \cdot 233 = 945N$$

Equation 6

All forces on wheels which were previously calculated are the expected forces. During the brakes' selection and during the design of the axles and the framing of the soapbox car, these forces have to be multiplied by a reasonable safety factor.

The tires' inflation, the type of the tires, and the wheel bearings create frictional forces, which cannot be evaluated at this stage of the design that is why there were not presented in this report.

3 CAD Design Drawings

After completing the design calculations and the draft sketch of the selected soapbox car design, CAD drawings were produced using "Solid Works."

The Soapbox car was drawn into three parts: The body of the Soapbox car, the windscreen, and the wheel. Then these parts were assembled using the assembly feature in "Solid Works." The drawings of these parts are shown in the figures below.

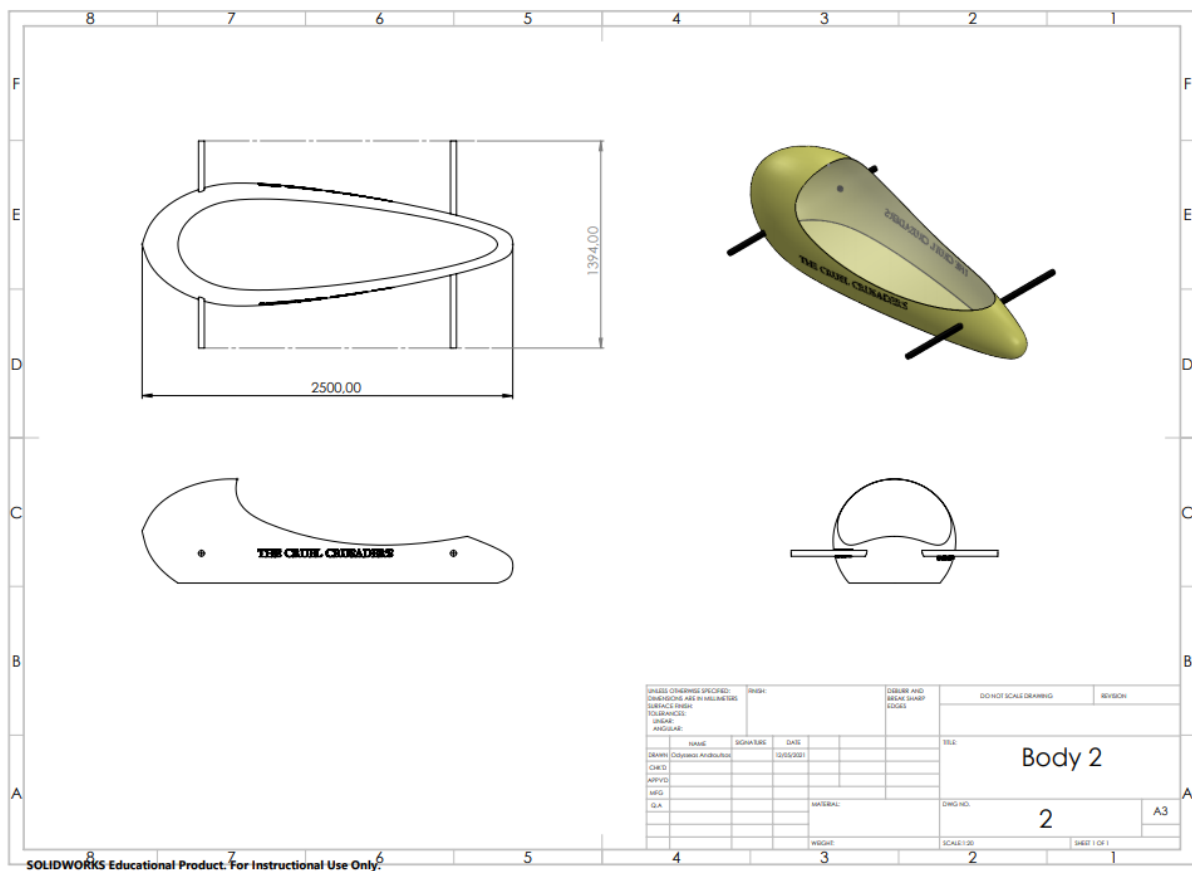


Figure 3– Soapbox car body and axles – Part 1

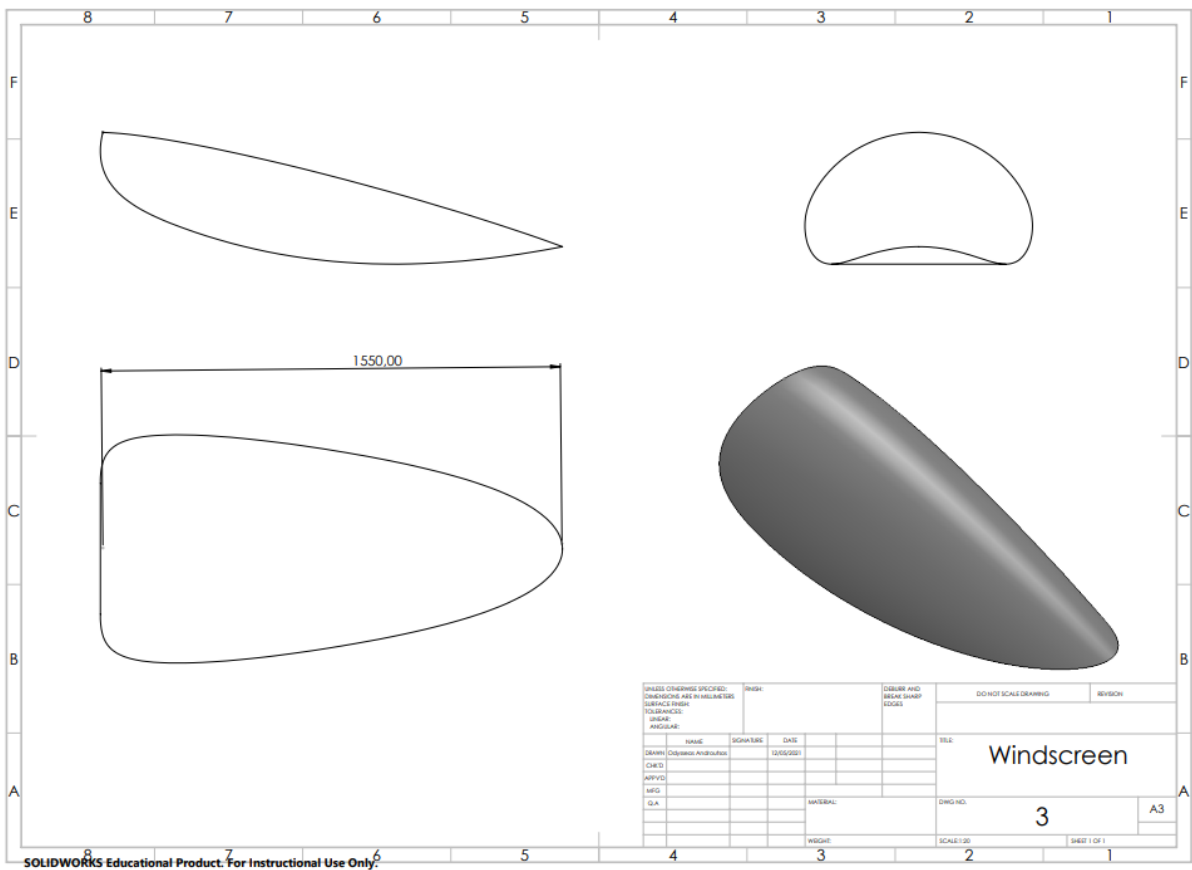
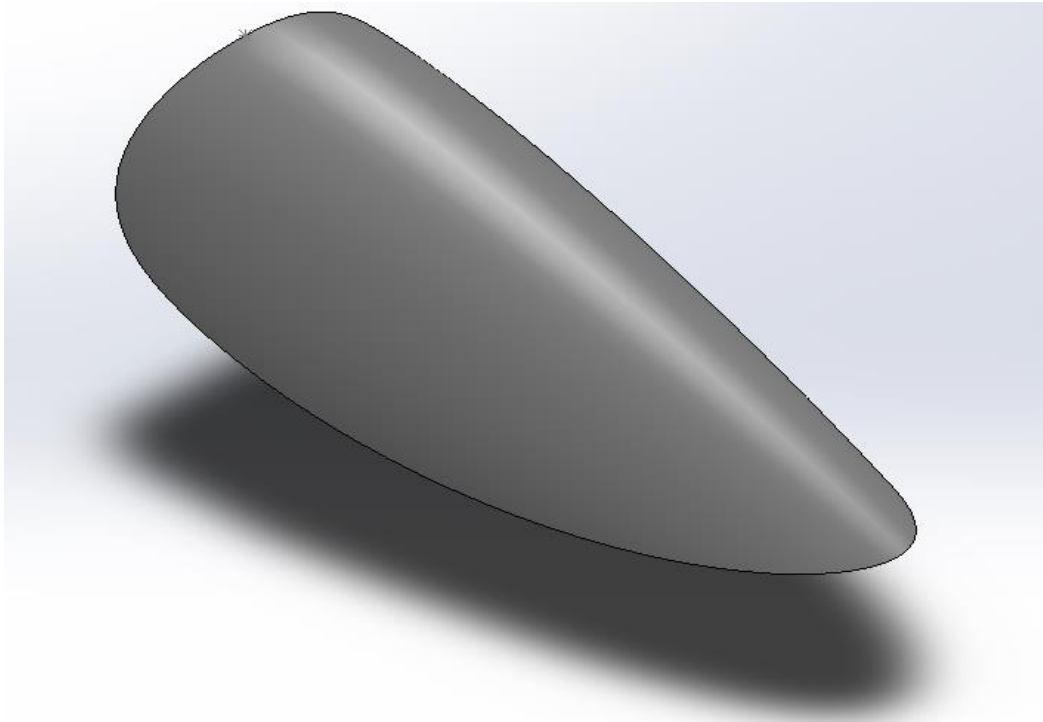


Figure 4 – Soapbox car - Windscreen - Part 2

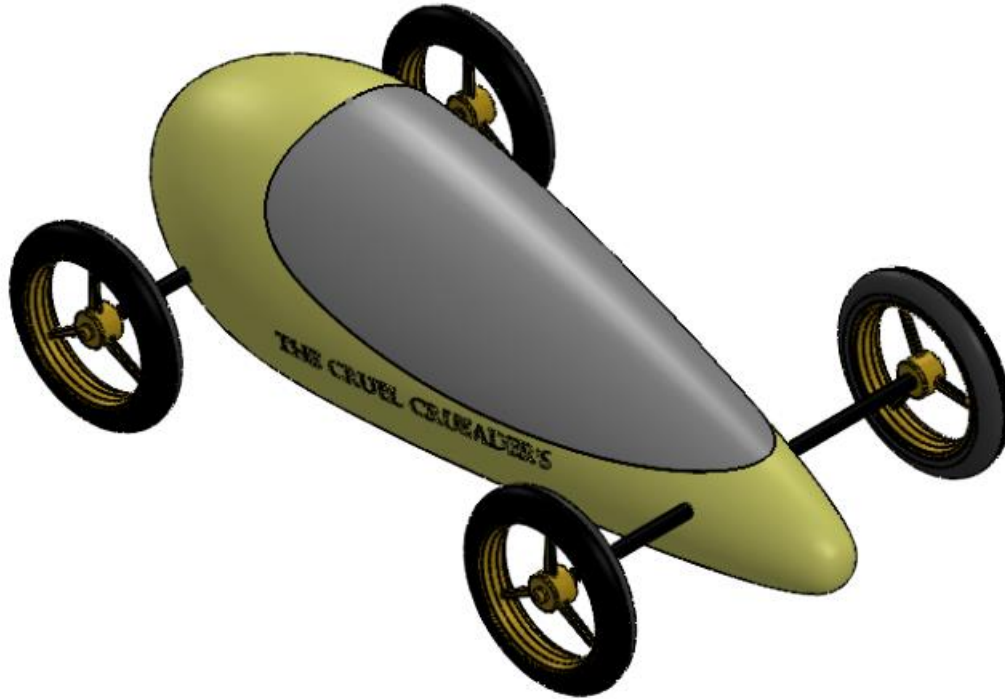


Figure 6 – Soapbox car - Assembly

After completing the assembly, a CAD drawing was produced and placed on an A3 sheet. This drawing is shown in the figure below.

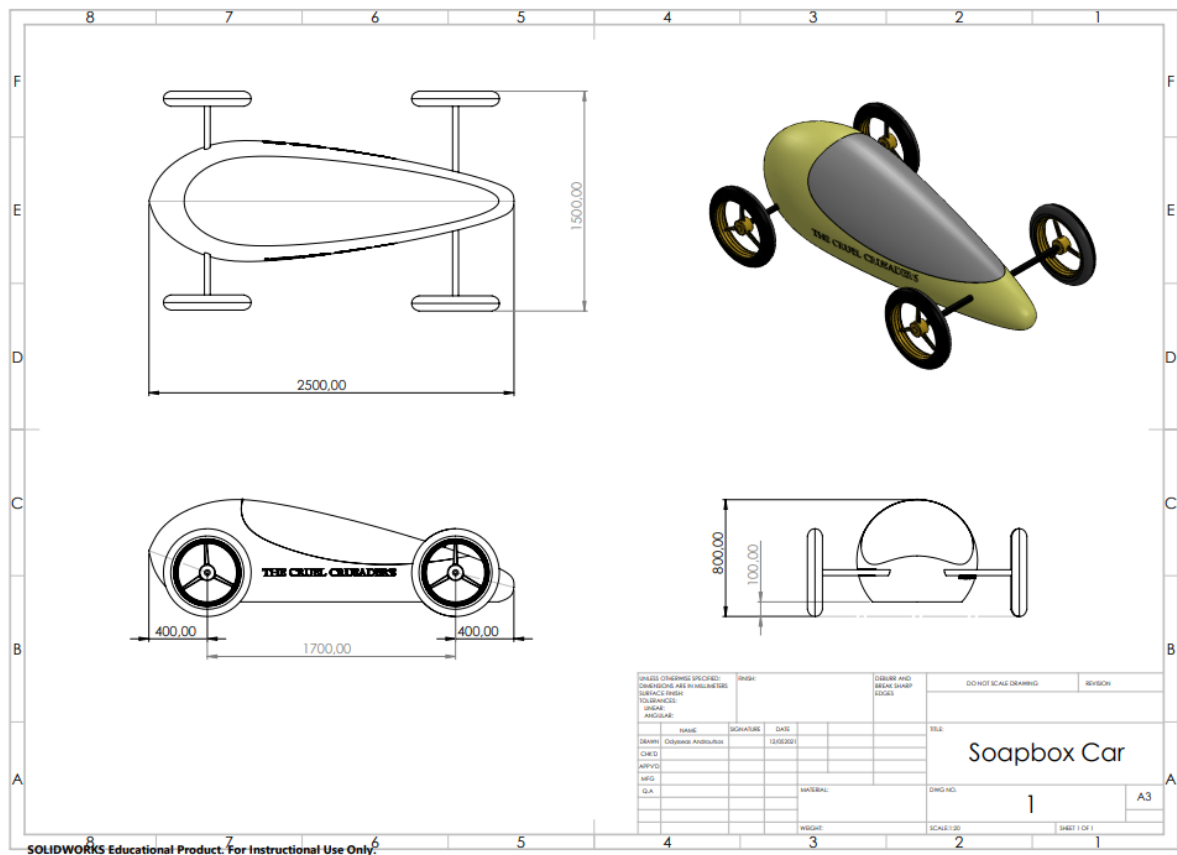


Figure 7 – Soapbox type car – CAD Drawing

4 Design evaluation

The design of the Soapbox was made to comply with Soapbox Derby completion regulations using basic engineering fundamentals. It is believed that the design achieved the objectives set at the beginning of the project. In completing the design, some assumptions were made. The drag coefficient was set at 0.49. The friction of the tire and the friction of the bearings were not considered in the design. Also, in the preparation of the CAD drawings, attention was given to the shape of the soapbox car and not to the connectivity of the various materials used for the construction of the soapbox car. These omissions sometimes look minor but are essential, especially in racing. Due to restriction on the length of this report, sensitivity analysis on the factors affecting performance /speed of the soapbox car was not performed.

The members of the design team of this project worked together to complete this project on time. There were some issues regarding the RAM required on the computer that the CAD drawings were prepared. This issue was identified early and got resolved. The Covid 19 restrictions did not allow the team members to meet personally and know each other better, but this was not an obstacle in fulfilling the project's requirements.

5 Conclusions

This project helped the team members understand the engineering fundamentals and their importance in using them in the design. Based on the current knowledge obtained during this academic year, the design of the soapbox car was produced according to the design requirements. Using the equations of motion and engineering fundamentals, a velocity time graph was created for the designed soapbox car to help predict the soapbox car's timing during the race. The assumptions and the omission made during the design of this project have to be checked by computer simulations, wind tunnel tests, and finally, test drives.

5 Acknowledgements

We want to express our sincere appreciation to our professors, Andrew Noble, Abi Summerfield, and Richard Sutton, for all they have taught us during this academic year and which were very helpful in completing this project.

6 References

Abi Summerfield (2021) *Engineering Science*.

Soap Box Derby | Richards Castle | Enter your cart and race (no date). Available at: <https://www.richardscastlesoapbox.co.uk/race> (Accessed: 24 February 2021).

Soap Box Derby | Richards Castle | Fastest carts down the hill (no date). Available at: <https://www.richardscastlesoapbox.co.uk/competitors> (Accessed: 24 February 2021).