

University of Wales Trinity Saint David

Wales Institute of Science & Art



Soap-Box Racer Report

Engineering Projects (ACHA4034)

Group C

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1. Introduction

The aim of this project was to design a gravity-powered soapbox racer capable of competing at the Richard's Castle Soapbox Challenge. The course is stated to be 550 metres long with a total vertical drop of 50 metres and typically reaches speeds of 30–40 mph during a run (Richards Castle Soapbox, 2025). The design had to satisfy a set of requirements covering wheels, braking, and safety. Key constraints included a maximum length of 2,500 mm and a width of 1,500 mm; a minimum ground clearance of 50 mm; pneumatic tyres only; a braking system capable of holding the vehicle on a 1-in-8 gradient; and a substantial roll bar for four-wheeled designs. The total build budget was capped at £500. Given these constraints, the group's objectives were to produce a structurally sound design, competitive on the course, safe for the driver, and manufacturable within budget. Mass reduction and aerodynamic profile were identified early as the two performance variables most within our control, since the course itself is fixed.

2. Design

Research into the most successful designs from Red Bull and similar competitions (REF) a four-wheel layout, offering stability and ease of assembly. A simple elongated hexagonal chassis, with a wider wheelbase at the front. For the chassis, a welded mild steel tube frame was chosen. Research into the most successful designs from Red Bull and similar competitions (<https://www.youtube.com/watch?v=zYfXEPsay40>) made it clear that the most successful designs were all 4-wheeled, so this was the design the group settled on. Offering stability and ease of assembly led to a simple elongated hexagonal chassis with a wider wheelbase at the front.

For the frame, a welded mild steel tube assembly was chosen. Research into small vehicle chassis design revealed that mild structural steel is the most common choice for this type of application due to its weldability and low cost. (Abdullah et al., 2022)Mihalić et al., 2023). The chassis was designed with the driver's seat bolted directly to the chassis rails, satisfying the regulation requirement, with two main longitudinal members and three cross-members for rigidity. Then, using the front end of a bicycle mounted at the foremost cross piece, offered a simple, cheap solution to steering. Keeping the solid forks and headstock, welding at a suitable angle to the frame, bracing, and then replacing the original steering stem with an extended unit to attach the track rods. Using stub axles and track rods attached to the bottom end of the steering stem converts the bicycle's steering geometry. The handlebars also give the driver a natural bracing point, and the low-profile upright gave clearance for the driver's legs to easily extend past the assembly compared to a traditional kingpin steering rack. The price and availability, plus ease of connecting to pre-existing brake callipers, were the deciding factors in selecting this layout.

A braking lever is then mounted on the bars, cable-operated to a disc on the rear axle using a drift trike unit or similar, as if one wheel on an axle is braked, both must be braked under the regulations, so a single calliper acting on the rear axle satisfies this cleanly. Taking advantage of the maximum width allowed, despite the added chassis weight, offered improved stability and clearance between the frame and wheels when steering. The tyre option depends significantly on how many and how sharp the corners on the actual course are. Where the track sections are predominantly straight with shallow bends, narrow wheels are likely to outweigh the traction benefit of wider ones, as at gentler corner angles, the force required is low enough that a narrow tyre will cope. If the course has tighter turns, this shifts the decision towards wider tyres. Based on watching footage from previous Richard's Castle events ("Soap Box Derby | Richards Castle, Accessed 2026.)The course appears to be largely straight with a few shallow bends, which led the group to favour narrower bicycle wheels with the tyres inflated to the upper end of their rated pressure range to minimise rolling resistance.

Using pillow bearing blocks for the rear axle reduces friction and is an easy installation system with simple adjustability via spacers to raise and lower height relative to the chassis. The driver position had an obviously optimal solution. Having them seated upright, similar to a conventional kart, was rejected on aerodynamic grounds as an upright driver presents a much larger frontal area, which directly increases drag force. Placing the seat in a semi-reclined position, feet first, is consistent with competitive soapbox designs and brings the frontal area down considerably. Achieving this required a small trike-type seat and a back support mounted on the roll bar. This also minimises the roll bar materials, as it is required to extend 35mm above the driver's helmet height when seated. Using stiff cardboard to voids and negative space in the frame and exposed areas to somewhat limit drag and air distortion around the driver, and shaped ultimately for a proven air foil silhouette (He et al., 2019).

3. Engineering Calculations

To work out the slope angle from the available data, the following equations were used.

The average slope angle of the course can be estimated from the given data. With a course length of 550 m and a vertical drop of 50 m:

$$\sin \theta = \frac{50}{550} = 0.0909$$

$$\theta = \cos(0.0909) = 5.2^\circ$$

The regulations note that some sections are steeper than this, which would produce higher accelerations on those portions, but 5.2° is used here as a working assumption for analytical purposes.

Equation of Motion

Table 1: Equation of Motion Data

Parameter	Symbol	Value
Combined mass	M	120KG
Slope angle	θ	5.2°
Frontal area	A	0.6m ²
Drag coefficient	Cd	0.8
Rolling resistance coefficient	μR	0.004
Air density	ρ	1.225 kg/m ³

A soap box travelling down a slope is acted on by three main forces in the direction of travel: the gravitational component along the slope (F1), aerodynamic drag (F2), and rolling resistance (F3). Applying Newton's second law (Driscoll et al., 2016a):

$$ma = f1 - f2 - f3$$

Resolved as follows:

$$F1 = mgsin\theta$$

$$F2 = \frac{1}{2}\rho^2Cd A$$

$$F3 = mg\mu Rcos\theta$$

Rearranging gives the equation for motion:

$$a = g \sin \theta - \left(\frac{1}{2} m \right) \rho v^2 C_d A - g \mu R \cos \theta$$

Estimated values for driver and vehicle combined mass (M), frontal area (A), air density (p) and drag coefficient (Cd) were based on the design measurements and sketches, and further based on (Ackroyd, 2014; Driscoll et al., 2016b). The rolling resistance value of 0.004 is consistent with pneumatic tyres on a sealed road surface.

The regulations specify that the braking system must be able to hold the vehicle stationary on a 1 in 8 gradient.

Finding the angle:

$$\theta_{\text{Brake}} = \tan^{-1} \left(\frac{1}{8} \right) = 7.13^\circ$$

The component of weight acting along the slope, which the brakes must overcome, is:

$$F_{\text{Brake}} \geq m g \sin \theta_{\text{Brake}} = 120 \times 9.81 \times \sin(7.13^\circ)$$

$$F_{\text{Brake}} \geq 120 \times 9.81 \times 0.124 = 145.8 \text{ N}$$

The rear braking system selected should comfortably exceed this; a mechanical bicycle calliper can generate several hundred Newtons of clamping force.

Finding theoretical maximum speed:

$$v = \frac{\sqrt{2m (g \sin \theta - g \mu R \cos \theta)}}{(\rho C_d A)}$$

Substituting values from Table 1:

$$g \sin \theta = 9.81 \times 0.0909 = 0.892 \text{ m/s}^2$$

$$g \mu R \cos \theta = 9.82 \times 0.004 \times 0.9959 = 0.039 \text{ m/s}^2$$

$$v^2 = \frac{2 \times 120 \times (0.892 - 0.039)}{1.225 \times 0.8 \times 0.6}$$

$$v^2 = \frac{240 \times 0.853}{0.588} = 348.1$$

$$v = 18.7 \text{ ms} = 41.8 \text{ mph}$$

4. Materials.

Component	Price
Bicycle (including brake and steering system)	~£100 (eBay)
20" BMX wheels x 2	~£50
Rear axle with disc	£60 (eBay)
Stub axles and king pins x2	£30
Track rod and linkage x2	£16
Steel tube (size)	£26.99
Bolts/hardware	£30
Seat	£15
Welding consumables	£5
Pillar Bearings	£25
Entry Fee	£50
Total:	£407.99

Table 2: List of materials used and prices

5. Evaluation

The analytics predict a velocity of around 42 mph on the average course gradient, which is consistent with the quoted event speeds of 30–40 mph. (“Soap Box Derby | Richards Castle, Accessed 2026.) The model does have limitations; it assumes a constant average slope angle of 5.2° , whereas the actual course has steeper sections that would produce higher peak accelerations and speeds. Factors like aerodynamics and friction from components are also not accounted for. Driscoll et al. (2016) note that their own model overpredicted top speed by around 6% compared to a real-world world record attempt, which gives a reasonable indication of the error expected. The stability of the soapbox was also considered; a lower centre of gravity reduces rollover risk, which is why the semi-reclined driver position and low seat mounting were installed. Rajpal et al. (2014) note that a higher centre of mass and narrower wheelbase both increase rollover tendency; the design also uses the maximum allowable width to address this.

Without a physical test rig available, the assumptions and borrowed data values produce an acceptable accuracy for the design exercise. Ideally, a prototype would be built and iterated on as decisions were made regarding design and material choices.

6. References

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