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P3 6 Carnage a Trois: Did the Pluriel Reach France?

D. Tyminski, B. Hunt, C. Raitt

Department of Physics and Astronomy, University of Leicester, Leicester, LE1 7RH

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Abstract

This paper looks into *The Grand Tour* special episode *Carnage a Trois*, to see if the trebuchet used by the hosts was sufficient to send the *Citroen C3 Pluriel* to France. The range of the trebuchet used is found, considering drag and non-drag conditions, to be 429 m − 492 m, meaning the *C3 Pluriel* did not reach France in the episode. A 6.14×10^{23} kg counterweight is found to be sufficient to complete the Dover to Calais distance considering drag, but resulting in a release velocity of $985c$, proving the unfeasibility of using such an unaerodynamic projectile to reach France.

Introduction & Trebuchet Information

In the special episode of *The Grand Tour: Carnage a Trois*, Clarkson, Hammond and May investigate the culture of French motoring. They find interesting cars, but conclude that they all truly hate one car this automotive industry produced: the *Citroen C3 Pluriel*. They wanted to return the car to its manufacturer, meaning return it to France. In the episode, the trio are shown to have used a trebuchet to perform the act. The *C3 Pluriel* is flung using the "*Enormous Catapult Machine*" from Dover to Calais and it is hinted that it hit a house in France of a man called *Louis*. This paper investigates the plausibility of using a trebuchet as a means of transporting vehicles needing developments in an airborne fashion over long distances, ie, could the *C3 Pluriel* actually reach France?

The trebuchet used is over 60 ft tall (18.3 m) and had a counterweight of 32 tonnes [1]. Inspecting the trebuchet visually, we estimate that the arm when extended directly vertical into its launch position, is approximately half the catapult's total height and that the downwards vertical path of the counterweight is around 12 m. We approximated the length of the sling to be equal to the length of the arm [2] [3], making the sling to be around 9.15 m in length making the launch height of the vehicle 27.5 m. We assume the angle of release is at the optimum 45°[4]. We take the efficiency at which potential energy is transferred to the kinetic energy of the projectile to be 70 % [5].

How far did the *C3 Pluriel* actually go?

We considered a non drag condition as the upper bound for the range of the *C3 Pluriel*. Potential energy from the counterweight is transferred to the kinetic energy of the projectile in the following expression:

$$\eta m_w g h_{drop} = \frac{1}{2} m_{C3} v_0^2, \tag{1}$$

where η is the efficiency, m_w is the counterweight mass, h_{drop} is the vertical change in height of the counterweight, m_{C3} is the mass of the *C3 Pluriel* (1158 kg [6]), and v_0 is the release velocity. This gets you $v_{0,nodrag} = 67.5$ ms^{-1}. Range, R, is the product of the horizontal component of velocity and the time of flight, t_f, as seen below:

$$R = v_0 cos\theta t_f, \quad (2)$$

where θ is the angle to the horizontal made by the projectile upon release. Projectile time of flight can be expressed as [7]:

$$t_f = \frac{v_0 sin\theta + \sqrt{(v_0 sin\theta)^2 + 2gh_0}}{g}, \quad (3)$$

where h_0 is the launch height of the projectile. Using the previously calculated v_0 value, we use equation (3) and then (2) to find the upper bound range resulting in $R_{nodrag} = 492$ m. To find the lower bound of the range of this trebuchet we look at how drag effects the journey of the projectile. We use python code to determine through an iterative process the effect drag has on the range of the *C3 Pluriel*. This process is too long to document in the paper, therefore the corresponding GitHub links are provided for the code used with explanations alongside the code for the steps taken. Both codes we use account for drag in the x and y directions. Plots are provided in GitHub to show the path taken by the projectile in the scenario considering the real trebuchet used in the episode. We consider drag acting on the car to find the lower bound of the range. The force due to drag can be expressed as [8]:

$$F_d = \frac{1}{2}\rho v_0^2 C_d A, \quad (4)$$

where ρ is the air density (1.225 $\mathrm{kgm^{-3}}$ [9]), C_d is the drag coefficient, A is the frontal area of the *C3 Pluriel* where the car's $C_d A = 0.762\ \mathrm{m}^2$ [10].

We model this scenario using Code 1 [11] [12]. To make the code work, we use some of the aforementioned equations as well as some of the equations listed in Table 1, and make the following assumptions to keep consistent conditions: projectile is a point mass, has no rotation, no lift and there is no wind, ground is locally flat and there's constant air density. We find the lower bound range of the *C3 Pluriel* to be 429 m.

Dover is $\approx$ 40 km away from Calais [13]. We can investigate what counterweight we would need to use on this trebuchet to make the *C3 Pluriel* reach Calais using Code 2 [14], with a similar system progressively increasing the counterweight for varying drag forces as the release velocity of the projectile increases. This results in a needed counterweight of 6.14×10^{23} kg to make the 40 km distance. This is $\approx 2\times$ the mass of Mercury, which results in a release velocity of $\approx 985c$, meaning that if this was a real scenario, a classical system would not be sufficient to accurately predict the range of the *C3 Pluriel*.

Eq.	**Equation**
(5)	$v_0 = \sqrt{\frac{2\,E_\mathrm{k}}{m_\mathrm{C3}}}$
(6)	$v_{x0} = v_0 \cos\theta,\ v_{y0} = v_0 \sin\theta$
(7)	$a_x = -\frac{1}{2}\frac{\rho\, C_d A}{m_\mathrm{C3}}\, v\, v_x$ [15]
(8)	$a_y = -\frac{1}{2}\frac{\rho\, C_d A}{m_\mathrm{C3}}\, v\, v_y - g$ [15]
(9)	$v_0 = \sqrt{\frac{2\,\eta\, m_\mathrm{w}\, g\, h_\mathrm{drop}}{m_\mathrm{C3}}}$

Table 1: **Extra equations used in the code.** v, velocity magnitude and v_x and v_y, velocity components are deduced using code. a_x and a_y parameters also found using the code. (9) is derived from equation (1).

Discussion and Conclusion

Modelling *The Grand Tour* trebuchet results in a realistic range of the *C3 Pluriel* between 429 m to 492 m [16], meaning the *C3 Pluriel* did not reach France in the episode and other methods of transport should be considered to send it back. A 6.14×10^{23} kg counterweight results in a sufficient release velocity to complete the Dover to Calais distance, neglecting thermal effects. However, this velocity exceeds the speed of light, proving the unfeasibility of covering this distance using such an unaerodynamic projectile (given the trebuchet could handle the counterweight), making it physically impossible to return the *C3 Pluriel* back to France, just like simpler energy-transfer models can predict aswell.

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