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Could Elastigirl stop the "METROLEV" train in *Incredibles 2*?

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Abstract
This paper examines the feasibility of Elastigirl being able to stop the runaway "METROLEV" train, by stretching into the form of a parachute, in the film, *Incredibles 2*. Based on the "METROLEV" travelling at a speed of 150 mph, Elastigirl would need to stretch to a diameter of 6.16 m. This value appears too large given the relative dimension of the train and a construction worker, as shown in the scene. However, when using a speed of 375 mph (the maximum speed a maglev train can reach) her diameter would be 3.90 m instead. This is a more accurate value in comparison to the relative dimensions of the train and the construction worker.

Background
Incredibles 2 is a Disney-Pixar animated film, released in 2018, and is the sequel to *The Incredibles* (2004) [1, 2, 3]. The premise of the film is that some individuals have superhuman abilities, with the film's plot centred on the Parr family, who use their superpowers to fight crime, while also attempting to live a normal family life [1]. In the film, the mother of the family, Helen Parr (also known as Elastigirl), is recruited to undertake a series of missions that are recorded on camera to restore public trust in superheroes [4]. One such mission sees Elastigirl tasked with chasing after and stopping a runaway "METROLEV" train on its maiden voyage.

This paper investigates whether Elastigirl would have been able to stop the "METROLEV" train before it reached the end of the completed train track, assuming she used her elastic superpower to stretch into the form of a parachute.

Assumptions
- The "METROLEV" train is assumed to be based on the real-life Japanese maglev (magnetic levitation) train known as the L0 Series [5].
- The distance of completed track Elastigirl had to stop the carriage from moving is based on the speed that the storyboard supervisor has stated the train was travelling at (150 mph or 67.10 ms^{-1}) [6].
- Frictional forces generated between the train and the track, seen as sparks in the scene, will be discounted from calculations.
- In the film, Elastigirl detached the front carriage of the train and only stopped this first carriage, which has an assumed mass of 25,000 kg [5]. This mass is revised to 25,840 kg, assuming that the front carriage was half-filled with 12 adult males who each have an assumed mass of 70 kg [7].
- Due to her superhuman abilities to stretch, it is assumed that Elastigirl is able to change her shape to form a two-dimensional circular parachute to stop the train from moving, with her adapted supersuit providing an assumed drag coefficient of 0.70 [8].
- No kinetic energy of the moving train is lost as sound or heat energy to the surrounding environment, with energy only transferred in the form of heat to her body, due to drag forces, while acting as a parachute.

Results
In order to determine how great a cross-sectional area (hereafter CSA) Elastigirl would need to stretch her body to act as a parachute, various prior calculations need to be made.

The kinetic energy of the first carriage was calculated using the following equation:

$$KE = \frac{1}{2}mv^2, \quad (1)$$

where m is the mass of the front carriage and 12 passengers (25,840 kg) and v is the train's velocity of 150 mph (67.10 ms^{-1}) [5, 6, 9]. This yielded a kinetic energy of 5.82×10^7 J.

The length of track available to stop the train was determined using equation 2:

$$d = vt, \quad (2)$$

where d is distance and t is the time taken to stop the train. In the scene where Elastigirl stops the train, from the time she stretches into the shape of a parachute to the time the train stops moving is approximately 15 s [1]. The product of this time period with the aforementioned velocity of the train gives a remaining track length of 1006.50 m [9].

The force, F_{stop}, required to stop the first carriage of the "METROLEV" train was calculated using equation 3:

$$F_{stop} = \frac{KE}{d}. \quad (3)$$

Substituting the values obtained from equations 1 and 2 into 3 gave a force of 57,824.14 N. The equation to calculate the drag force, F_{drag}, acting on a parachute, in this instance Elastigirl's body, is:

$$F_{drag} = \frac{C_d A \rho v^2}{2}, \quad (4)$$

where C_d is the drag coefficient of the parachute and assumed to be 0.70 [8], ρ is the density of air (1.23 kgm^{-3}) [10] and v is the velocity of the train (67.10 ms^{-1}). A is the CSA of the parachute and assuming the force from equation 3 is equal to the drag force, equation 4 can be rearranged to calculate the CSA of Elastigirl's body. This yielded a CSA of 29.83 m^2. As stated in the assumptions above, Elastigirl's body when acting as a parachute was assumed to have the CSA of a circle. The diameter of this circle can be evaluated through use of the equation:

$$r = \sqrt{A/\pi}, \quad (5)$$

where A is the CSA of Elastigirl's body (29.83 m^2) and r is the radius of her circular body, calculated to be 3.08 m [9]. This radius value can be multiplied by two to give the diameter of Elastigirl's body (6.16 m) required to bring the train to a halt within the calculated remaining distance of the track. Based on the average height of a male in the United States of America (1.76 m), a construction worker seen at the climax of the scene appears to be roughly one half the height of Elastigirl's stretched body [11].

Analysis

From the calculations obtained in the results section, under the various assumptions made, the CSA of Elastigirl's body when acting as a parachute was 29.83 m^2. This is the calculated CSA that Elastigirl would need to stretch her body in order to counteract the force generated by the runaway front carriage of the train. This value is highly dependent on the assumption that the length of track available to stop the train was 1006.5 m, as calculated previously.

From the calculated CSA, Elastigirl's diameter was found to be 6.16 m. In the scene, the construction worker's height is approximately one third the diameter and thus height of Elastigirl's stretched body [1]. However in the film, the worker appears to be half the height of Elastigirl's body. This discrepancy could be due to the worker being situated in the foreground of the scene which causes the worker to appear taller relative to Elastigirl's height when acting as a parachute.

The prior calculations carried out in this paper are based on the speed of the runaway train (150 mph) as stated by the film's scriptwriters [6]. However, modern maglev trains such as the L0 Series can reach maximum speeds of 375 mph (167.60 ms^{-1}) [5]. Inputting this faster speed, with the same time period, into the equations used in this paper results in a larger stopping distance (2514 m) and Elastigirl's diameter to be 3.90 m, which is almost half the calculated value of 6.16 m at 150 mph. Considering the width of the L0 Series train is 2.90 m, the speed value of 375 mph was used in this paper as in the scene, Elastigirl only appeared slightly wider than the train and thus the value of 3.90 m is more feasible than the diameter value (6.16 m) at 150 mph.

Conclusion

In conclusion, under the various assumptions made in the paper, it would be possible for Elastigirl to stop the runaway "METROLEV" train, travelling at 150 mph, by stretching into the form of a parachute with a diameter of 6.16 m. However, when using a more realistic maglev train speed of 375 mph, her new diameter of 3.90 m gives a more reasonable value when compared to the relative dimensions of the train (2.90 m in width) and the construction worker (1.76 m in height).

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