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# P6_4 Will Luffy's Punch Leave you in One Piece?

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**Abstract**

In this paper, an analysis of the capabilities of the devil fruit powers of Monkey D. Luffy, the main protagonist for the Japanese comic and animation 'One Piece' (1999-Present) is presented [1]. The strain, stress and force required to stretch Luffy's arm to 50.000 m in order to deliver a 'Gum Gum Pistol' punch was calculated. It was shown that a force of $7.380 \times 10^5$ N would be required to stretch his arm to this distance, and his arm would experience a tensile strain and stress of 76.519 and 0.306 GPa, respectively. The impact of such a punch at this distance was found to be 13.828 kN of force, equivalent to approximately 2.766 times that delivered by an elite heavyweight boxer.

## Introduction

At the age of 7, Luffy accidentally ate the 'Gomu Gomu no Mi' devil fruit, which turned his body into rubber, allowing him the ability *"to stretch, bounce, bend, twist, and inflate any part of his body"* [1]. Luffy demonstrates this unique ability through various signature moves, including the 'Gum Gum Pistol' in which he utilises the stretching properties of rubber to extend the reach of his punch [2].

## Tensile Strain

At the start of the series, Luffy is 17-years old and has a height of 1.720 m [1]. An estimation for his resting arm length was made as there is a strong documented correlation between arm span and height [3]. From observations of the anime series, it was assumed that his arm length is 3/8 of his height, giving L = 0.645 m. Therefore, the difference between the maximum arm extension (50.000 m) and resting arm length is $\Delta L = 49.355$ m.

Tensile strain (unit-less) is given by Eq.1. Therefore, the values above were used to calculate the strain, $\epsilon$, on Luffy's arm:

$$\epsilon = \frac{\Delta L}{L} = \frac{49.355}{0.645} = 76.519 \tag{1}$$

## Tensile Stress

The Young's Modulus of a material is defined by Eq.2, which can be rearranged to calculate the tensile stress, $\sigma$, on Luffy's arm:

$$Y = \frac{\sigma}{\epsilon} \tag{2}$$

The Young's Modulus of the entire arm is taken to be that of rubber and therefore equal to 4.000 MPa [4]. As the devil fruit has transformed him into a 'rubber person', his skin, bones and cartilage are assumed to be comprised of rubber, and so this was deemed a reasonable approximation to use. Using this value and the previously calculated strain value, a stress of 0.306 GPa was determined.

## Force Required

Rubber is essentially in-compressible [5], which matches the anime depiction as the width of Luffy's arms does not appear to change as he stretches. Therefore, the area of his arm at the point of 50.000 m was approximated as a cylinder, assuming the same diameter from shoulder to fist. An average wrist circumference for a 17-year old boy was taken to be $173.870 \times 10^{-3}$ m [6], and was used to calculate a radius for the cylinder, and thus a cross-sectional area, A, of $2.411 \times 10^{-3}\,\mathrm{m}^2$.

The calculated cross-section area and tensile stress were then utilised, via the rearrangement of the definition of tensile strain (Eq.3), to determine the force, F, required to stretch to 50.000 m:

$$\sigma = \frac{F}{A} \therefore F = \sigma \times A = 7.380 \times 10^5\,\mathrm{N} \tag{3}$$

### Impact Force of his Punch

Newton's second law of motion was then used to determine the acceleration of Luffy's fist (assuming the displacement is only occurring in one spatial dimension, in this case the horizontal direction, as well as uniform acceleration):

$$F = ma \therefore a = \frac{F}{m} \tag{4}$$

where m is the effective mass behind the punch. This assumes that the alignment of the force is applied along a vector perpendicular to the punching surface, neglecting air resistance, resulting in the maximum amount of force (and therefore kinetic energy) being exerted on the target. Notably, conservation of energy is assumed, and no heat energy is lost as the 'rubber' stretches. As Luffy has had experience in fighting, the effective mass of Luffy's punch was taken to be 2.620 kg [7], therefore giving an acceleration, a, of $2.817 \times 10^5\,\mathrm{m}s^{-2}$.

The final velocity, v, of the fist at the point of impact can be determined using the SUVAT equation below:

$$v^2 = u^2 + 2as \tag{5}$$

where u is the initial velocity of the fist ($0.000\,\mathrm{m}s^{-1}$), a is the acceleration calculated above, and s is equivalent to $\Delta L = 49.355$ m. Eq.5 provided a final velocity of $5.278 \times 10^3\,\mathrm{m}s^{-1}$.

The impact force, $F_i$, directly depends on the kinetic energy and time in which the force of the punch is released, $t_i$, which is itself dependent on the distance in which the energy is released during the punch, $d_i$. The work done and kinetic energy are equated to one another, therefore providing the following expression for the impact force:

$$F_i = \frac{mv^2}{2d_i} \equiv F_i = \frac{mv}{t_i} \tag{6}$$

For this investigation, the impact duration was assumed to be 1.000 s. Also of note, is that these calculations approximated the punch to be completely stopped at 50.000 m, therefore neglecting any distance the fist would travel due to the recoil of the target's head. The arm was assumed to behave elastically and return to its original length with no permanent deformation after the impact duration.

This yields an impact force of $1.383 \times 10^4$ N for Luffy's 'Gum Gum Pistol' at a distance of 50.000 m.

### Discussion and Conclusions

In conclusion, if Luffy stretched his arm to 50.000 m, to deliver a 'Gum Gum Pistol' to you, the target, the strain experienced on his arm would be 76.519. Assuming that his skin has a Young's Modulus of that of rubber, the tensile stress on the arm would be 0.306 GPa, requiring a force of $7.380 \times 10^5$ N for this extension. Due to the velocity of the fist on impact, (found to be $5.278\,\mathrm{kms}^{-1}$), experienced for a duration of 1.000 s, the blow would be equivalent to 13.828 kN of force exerted on the target. Given that the punch force of an elite heavyweight boxer is approximately 5.000 kN [8], the power behind Luffy's punch is 2.766 times greater. As it only takes 3.053 kN to break a human femur by impact loading [9], Luffy's punch would definitely not leave you in 'One Piece'.

It should be noted that a number of assumptions were made due to the lack of physical parameters available. The force required to stretch his arm to such a distance is significantly high, and it begs the question whether a 17-year old boy could produce such magnitudes of force, despite his rubber composition. Future studies could possibly look into Luffy's elastic limit, provided they are able to quantify his maximum stretch of '72 Gomu Gomus' in SI units, as well as the maximum length at the point at which his arm would break.

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