

Journal of Physics Special Topics

An undergraduate physics journal

A5 6 Superhero Landings: Do Not Try This at Home

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December 10, 2025

Abstract

Superhero films often show characters dropping several storeys and landing in a one-knee “superhero pose” without injury. We model a 70 kg human-sized hero in free fall from a range of heights, landing with one leg taking most of the vertical load. Assuming a rigid surface, a stopping distance of 0.30 m and an effective tibial cross-sectional area of $1.5 \times 10^{-4} \text{ m}^2$, we estimate decelerations and compressive stresses and compare them to typical bone failure values [1]. Even under optimistic assumptions, “superhero landings” from more than a few metres appear likely to cause serious injury, and multi-storey drops are inconsistent with normal human bone strength.

Introduction

The dramatic “superhero landing” is a familiar visual trope: the character drops from several storeys and impacts the ground on one foot, one knee and one hand, before standing up apparently unharmed. In reality, uncontrolled falls from even modest heights are dangerous and often fatal [2].

Here we ask a simpler, quantitative version of the question: *could an ordinary human survive a superhero-style one-legged landing from the heights commonly shown in films?* We use a basic mechanics model to estimate deceleration, impact force and compressive stress in the tibia of the load-bearing leg, and compare with representative values for human bone strength.

Model

We model a human-sized hero of mass $m = 70 \text{ kg}$ falling under gravity $g = 9.81 \text{ m s}^{-2}$ from rest from a height h onto a rigid surface. On impact they perform a “superhero landing” in which one leg bears most of the vertical load;

we assume a fraction $\alpha = 0.7$ of the total impact force passes through a single tibia. The hero’s centre of mass is brought to rest over a vertical distance $d = 0.30 \text{ m}$, corresponding to a deep, rapid knee bend that maximises the stopping distance and therefore minimises the forces.

The tibia is represented as a column with effective cross-sectional area, $A = 1.5 \times 10^{-4} \text{ m}^2$ [3], and we take a representative compressive failure stress for cortical bone of $\sigma_{\text{fail}} = 150 \text{ MPa}$ [1]. This model is clearly idealised, but sufficient for an order-of-magnitude estimate.

Theory

Impact speed

The hero falls from rest a distance h under constant acceleration, g . Using

$$v^2 = u^2 + 2gh \quad (1)$$

with $u = 0$, the impact speed is

$$v = \sqrt{2gh}. \quad (2)$$

Deceleration during the landing

After impact, the hero is brought from speed v to rest over distance d . Taking a constant average deceleration a , we use

$$v_f^2 = v_i^2 + 2ad, \quad (3)$$

with $v_f = 0$ and $v_i = v$ giving $a = -\frac{v^2}{2d}$.

We take the magnitude, and substitute $v^2 = 2gh$:

$$|a| = \frac{2gh}{2d} = \frac{gh}{d}, \quad (4)$$

so the g-load is simply

$$\frac{|a|}{g} = \frac{h}{d}. \quad (5)$$

With $d = 0.30$ m, the g-force in this model is approximately $3.3h$ per metre of fall.

Impact force and tibial stress

The average vertical impact force on the body is

$$F = m|a| = m \frac{gh}{d}. \quad (6)$$

If one leg bears fraction α of the total load, the force through that leg is

$$F_{\text{leg}} = \alpha F = \alpha m \frac{gh}{d}. \quad (7)$$

The compressive stress in the tibia is then

$$\sigma = \frac{F_{\text{leg}}}{A} = \frac{\alpha mg}{dA} h \quad (8)$$

Thus σ grows linearly with fall height. Equating $\sigma = \sigma_{\text{fail}}$ gives an estimated failure height

$$h_{\text{fail}} = \frac{\sigma_{\text{fail}} dA}{\alpha mg}. \quad (9)$$

Results

We evaluate the model for three illustrative heights: $h = 3$ m, 5 m and 10 m. Using the expressions above and the parameter values in the Model section, we obtain the values in Table 1.

A 3 m drop already produces an average deceleration of about $10g$ and a tibial stress of \sim

30 MPa. At 10 m, the model predicts more than $30g$ and $\sigma \approx 100$ MPa, approaching the adopted failure range.

From Equation 9, we find numerically $h_{\text{fail}} \approx 14$ m, so, within this optimistic model, superhero landings from heights of order $10 - 15$ m would be expected to break the tibia.

h (m)	v (m s^{-1})	$ a $ (m s^{-2})	$ a /g$	F_{leg} (N)	σ (MPa)
3	7.7	98	10.0	4.8×10^3	32
5	9.9	164	16.7	8.0×10^3	53
10	14.0	327	33.3	1.6×10^4	107

Table 1: Predicted impact speed, g-load and tibial stress for superhero landings from $3 - 10$ m

Discussion and Conclusions

Even in this very forgiving model (deep knee bend, controlled motion and all energy dissipated through the leg), the forces involved in a superhero landing are substantial.

For falls of $3-5$ m, predicted decelerations of $10-17g$ and tibial stresses of $30-50$ MPa are already likely to be injurious, even though they remain below idealised compressive failure thresholds [4]. By 10 m, the combination of $\sim 30g$ average deceleration and ~ 100 MPa compressive stress approaches typical cortical bone strength, and in reality ligament, joint or spinal injuries would probably occur at even lower loads [1].

The analysis neglects potentially helpful effects such as rolling or sliding, but also idealises the ground and the deceleration profile, so the estimates are optimistic for a human.

Overall, the model suggests that one-legged superhero landings from multi-storey heights are incompatible with ordinary human physiology; without superhuman strength or a much larger stopping distance, a real hero attempting such a landing from more than a few metres is far more likely to sustain serious injury than to hold a dramatic pose.

References

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