Journal of Physics Special Topics

P2_3 Like Looking for an Assassin in a Haystack

Z Rogerson, M Walach, D Staab, E Watkinson

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

November 13, 2012

Abstract

The "Leap of Faith" is an extraordinary and repeatable stunt, whereby people jump from buildings into haystacks, performed by characters in the popular computer game series *Assassin's Creed*. By considering the elastic deformation of wheat straw it was found that if a person were to attempt this they would experience deceleration nearly 8000 times that of gravity, resulting in certain death.

Introduction

In the computer game series *Assassin's Creed* characters routinely find themselves leaping from atop high buildings, in various settings from the Middle Eastern Middle Ages to renaissance Rome, only to land safely and comfortably in bales of hay [1]. As the action is infinitely repeatable and the bales do not change shape through the game, a simplified analysis was undertaken, considering the one dimensional elastic compression of wheat straw and the deceleration experienced by a person having completed a typical leap.

Theory

The vertical velocity, *v*, of an object accelerated, from rest, by gravity, *g*, over a height, *h*, is given by the equation [2],

$$v^2 = 2gh, \quad (1)$$

assuming air resistance is negligible as the height, *h*, considered is in the order of 100 m and the person falls in a diving position to minimise any drag.

Similarly if an object with an initial velocity, *v*, is uniformly decelerated, at *a*, through a distance, *ΔL*, until it is at rest then,

$$-v^2 = 2a\Delta L. \quad (2)$$

Therefore the subsequent equation holds for a person first accelerated from the top of a building of height, *h*, who then comes to rest having been uniformly decelerated over a distance *ΔL*,

$$-a = \frac{h}{\Delta L}g. \quad (3)$$

As the characters are unhurt after jumps it is assumed that the haystacks therefore absorb all the energy of the falling person, such that it is an inelastic collision. Further to this, as the stunts are repeatable, it has been postulated that the hay must elastically store this energy and not result in permanent deformation of the structure. It does this by vertically compressing, from a total height, *L*, by an amount *ΔL*, where *L* << *h*. The elastic potential energy stored is the integral of the compressive force, *F*, over the length *ΔL*,

$$U = \int_0^{\Delta L} F dx = \int_0^{\Delta L} \frac{YA}{L} x dx = \frac{YA\Delta L^2}{2L}, \quad (4)$$

where the compressive force is expressed in terms of the Young's modulus of the material *Y*, the area of compression, *A*, the total length *L* and change in length *ΔL* of the haystack [2].

Assuming all the gravitational potential energy of the person, of mass *m*, at the top of the building is converted to kinetic energy and then to elastic potential in the material then the amount it compresses can be expressed as,

$$\Delta L = \sqrt{\frac{2LU}{YA}} = \sqrt{\frac{2Lmgh}{YA}}. \quad (5)$$

Assumptions

An approximate fall height of 100 m was assumed. This is comparable to some of the landmarks in the games, e.g. the Duomo in Firenze [3]. An approximate mass of the character of 80 kg was also assumed. The full height of the haystack was estimated to be 2 m, and the area of compression as 2 m^2 from gameplay footage [1]. The Young's modulus of hay was estimated at 1 GPa under the assumption it would be comparable to that of known values for wheat straw [4] and that the hay is densely packed enough to be modelled as a solid.

Results

With the stated assumptions a character was found to be travelling at a velocity of approximately 45 ms^{-1} when they reach a haystack after a "Leap of Faith". As a result, from equation (5), a 2 m haystack would contract a distance of approximately 1.25 cm in total. Considering that this is the distance through which the person must decelerate then equation (3) shows that a person would feel an acceleration of 7982 times that of gravity.

Discussion

In vehicle crashes people have been known to survive short periods of acceleration with magnitudes around 100 times that of gravity [5]. However an acceleration of the magnitude found would certainly be fatal.

If however it is assumed the haystack would compress to half its extent, such that ΔL is 1 m, then equation (5) can be used to find the Young's modulus of a material with these compression properties. It was found that a material would have to have a Young's modulus of approximately 157 kPa. This is comparable, within an order of magnitude, to the Young's modulus of marshmallow [6], however such a material is not elastic for the magnitudes of stresses and strains considered i.e. they have low yield and ultimate strength.

If such a material was able to perform in these conditions, with the required elastic properties, then, from equation (3), a person would experience an acceleration of 100 times that of gravity and potentially could survive the fall.

Conclusion

It was found that the hay alone wound not compress sufficiently to allow a person to decelerate gently enough to survive. However in the analysis a perfectly elastic haystack was considered, to match gameplay experience. It is suggested for further work that a more realistic 3D computation, such as finite element analysis, be conducted to assess whether a more detailed description of individual hay strands may allow a single leap to be completed, allowing for permanent deformation of the bale. This could also include a consideration for how much deformation a human body could survive, thus allowing a lower limit of jump height to be considered.

References

[1] *Assassin's Creed II*, Ubisoft Montreal (Developers), 2009.

[2] P. Tipler and G. Mosca, *Physics for Scientists and Engineers, 6th Edition*, (W.H. Freeman and Company, New York, 2008).

[3] http://www.italyguides.it/us/florence/ the_dome_of_brunelleschi.htm accessed on 28/10/12.

[4] H. Tavakoli, S.S. Mohtasebi and A. Jafari, *Physical and mechanical properties of wheat straw as influenced by moisture content*, Int. Agrophysics, **23**, 175-181 (2009).

[5] D. F. Shanahan, *Human Tolerance and Crash Survivability*, Pathological Aspects and Associated Biodynamics in Aircraft Accident Investigation, RTO-EN-HFM-113, available at: ftp://ftp.rta.nato.int/PubFullText/RTO/EN/RTO-EN-HFM-113/EN-HFM-113-06.pdf accessed on 28/10/12.

[6] K. A. Pestka, *Young's Modulus of a Marshmallow*, The Physics Teacher, **46**, Issue 3, 140-141 (2008).