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# A3_5 Falling into Straw

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**Abstract**

The video game "Assassin's Creed" often depicts and encourages the player to leap off tall buildings into piles of straw/hay. This article looks into whether this is survivable, and finds the maximum height to which the depicted hay piles are safe to jump into to be about a 12-13m fall, and the max survivable fall height to be about 50m.

**Introduction**

The popular game franchise "Assassin's Creed" often depicts game characters leaping off tall buildings into piles of loose hay or straw lying on the ground or in a cart, by diving head first off a building, then executing a half-summersault to land on their back into the pile of straw. While loose straw does undoubtedly provide cushioning from falls, the amount of straw used to cushion a character's fall is always the same, no matter the height of the jump. Common sense dictates that the amount of cushioning, in this case, the height of a pile of straw, should be related to the height of the fall being cushioned. This is due to the increased kinetic energy of the jumper, which needs to be dispersed slowly.

**Theory**

The cushioning force provided by a pile of straw can be found by calculating the force required to compress the volume of straw, relating to its bulk modulus:

$$K = -V\frac{dP}{dV}, (1)$$

where K is the bulk modulus, V is the volume of the straw, and P is the compressive force applied by an impact with a falling object. This should give the minimum amount of straw required for a given pressure. The pressure applied by a falling object is

$$P = \frac{ma}{A}, (2)$$

where $m$ is the mass of the falling object, $a$ is the deceleration experienced; and $A$ is the area of the object interacting with the pile of straw. Solving the integral between $0 \rightarrow P$, and $V_1 \rightarrow V_2$, then substituting equation (2) into the result, gives

$$\frac{V_2}{V_1} = e^{-\frac{ma}{AK}}. (3)$$

This equation gives the ratio of the final volume of the pile of straw $V_2$, over the initial volume $V_1$. This holds true as long as the collision is very brief, as a longer collision with the pile of straw would have a varying pressure as it got more compressed.

The amount of compression could also be calculated if you consider the deceleration of the falling body:

$$s = ut + \frac{1}{2}at^2, (4)$$

where $s$ is the distance travelled through the straw, $u$ is the initial impact velocity, $a$ is the deceleration experienced, and $t$ is the time of the collision. As

$$t = \frac{\Delta v}{a} = \frac{u}{a}, (5)$$

because $\Delta v = u$. This gives:

$$s = \frac{u^2}{a} + \frac{1}{2}\frac{u^2}{a} = \frac{3}{2}\frac{u^2}{a}. (6)$$

$s$ can also be expressed as

$$s = h_1 - h_2, (7)$$

with $h_1$ denoting the initial pile height, and $h_2$ the final height. Therefore, including the area of the impact $A$ would give the volume change of the collision:

$$sA = V_1 - V_2 = \frac{3}{2}\frac{Au^2}{a}. (8)$$

The substitution of equations (3) and (6), and dividing through by the collision area, gives a solution for $h_1$, the initial pile volume:

$$h_1 = \frac{3u^2}{2a\left(1 - e^{-\frac{ma}{AK}}\right)}. (9)$$

The bulk modulus for a loose-packed pile of straw is not well defined. This can be surmounted by taking a known pressure and volume change and working out the bulk modulus from that, from equation (3):

$$-K = \frac{ma}{Aln\frac{V_2}{V_1}}.$$

As there is no previous work to determine the bulk modulus of large, loose piles of straw, we assumed an example pile of straw which compresses by 10% under the influence of the weight of a single person (75kg, at 9.81ms$^{-1}$); this gives a bulk modulus of:

$$K = 7350.701\text{Pa}.$$

The maximum deceleration that a human can survive ($a$), over instantaneous impact times, is roughly $100g$, or 100 times acceleration due to gravity [1]. While not practical, (this acceleration would cause serious injury) this is a good upper bound for a survivable impact. A more comfortable impact deceleration is 25g. The maximum velocity that a body could be falling at is the terminal velocity, ($u$) 56ms$^{-1}$ [2], which is the upper limit for speed for a person falling on their back/front. The mass was taken to be that of a human male, 75kg. In this case, it is assumed that area $A$ is half the surface area of a human, falling on their back into the straw, 0.95m$^2$ [3]. This gives the minimum height of a pile of straw to cushion a person falling at terminal velocity, the value was calculated for both $a = 100g$ $(h_{100g})$, and $a = 25g$ $(h_{25g})$:

$$h_{100g} = 4.795\text{m},$$
$$h_{25g} = 20.664\text{m}.$$

However, the highest drop a character can achieve in the game “Assassin’s Creed” is the dive off the top of The Cathedral of the Holy Cross at Acre. The height and velocity at the ground can be backwards-calculated by measuring the time it takes to fall. The fall takes $\sim 4$ seconds, as viewed from in-game footage. This value, neglecting air resistance (while $v$ remains less than $v_{terminal}$), gives minimum straw pile heights of:

$$h_{100g} = 2.354\text{m},$$
$$h_{25g} = 10.146\text{m}.$$

**Conclusion**

The height of the piles of straw in the game “Assassin’s Creed” is approximately 1.5m. Even using the most optimistic survivable impact accelerations, incurring severe injuries in the process, the leap off the cathedral in Acre requires a greater amount of cushioning than is depicted. The actual height the depicted amount of straw (1.5m) should correctly cushion was calculated to be a drop of $\sim 12 - 13$m, giving a safe deceleration of 25g for a short duration of time. If the jumper is willing to suffer severe injuries (100g impact), the maximum jump height increases to 50m.

**References**

[1]http://en.wikipedia.org/wiki/G-force#Human_tolerance_of_g-force Last accessed 24/10/2014

[2] Tipler, Paul A. *College Physics*. New York: Worth, 1987: 105

[3]http://en.wikipedia.org/wiki/Body_surface_area Last accessed 24/10/2014