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P3_10 How Strong is Rapunzel's Hair?

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Abstract

In the *Disney* animated motion picture entitled *Tangled*; Rapunzel, located in a tower 70 feet tall, lowers her hair down to allow a fully grown adult man to climb up it and into the tower. This paper investigates the feasibility of this. It was determined that it is easily possible and that her hair could, in fact, support a maximum mass of just over 2750kg.

Introduction

The story of Rapunzel was originally written by the Brothers Grimm in 1812 and was included as part of the book titled *Children's and Household Tales*. In 2010 it was adapted by *The Walt Disney Company* in the form of an animated motion picture named *Tangled.* During the course of the film, it is shown that Rapunzel lives at the top of a 70 foot tall tower [1] and, first, allows her mother to climb up her hair into the tower and, later, allows the male lead of the film to do the same thing. This paper investigates if it would be possible for a fully grown man to climb up a 70 foot tower using hair lowered down from the top.

How much weight must the hair support?

It is assumed that the male lead weighs more than Rapunzel's elderly mother so this investigation is centred on him. Not only must Rapunzel's hair support the weight of the male lead, it must also support its own weight. When the hair is lowered down to the ground, there will be a tension force associated with the total mass of the hair, plus the mass of anything suspended from it. As such, in addition to the weight of the male lead, the weight of Rapunzel's hair itself must also be supported. This is shown in Figure 1. The total force that must be supported is given by equation 1,

$$F = 2(M + m)g, \qquad (1)$$

where *M* is the mass of the male lead, *m* is the mass of Rapunzel's hair and *g* is the acceleration due to gravity. The factor of two arises as the hair and the man are suspended in equilibrium, meaning that their weight is balanced by a force equal to this acting in the opposite direction. This means that the middle of the length of hair will be being pulled equally in both directions resulting in a tension which is the sum of their magnitudes. This is where the tension force is at its strongest. The mass of Rapunzel's hair was estimated using the mass measurements of hair. This hair wasn't quite as long as hers so was scaled up to the length of her hair. This assumes that the mass of the hair is uniformly distributed throughout and doesn't change in structure or mass with increased length. It was found that 45 inches of hair weighs 14 ounces [2], meaning that 70 feet of hair weighs 7.41kg when scaled up. It is assumed that the male lead has a mass of 60kg. Using equation 1, it was found that Rapunzel's hair must support 1322.5N. This force is assumed to be spread equally between each of the hairs on Rapunzel's head. Her hair is assumed to consist of 140,000 [3] individual hairs, meaning that each hair must support 9.45 x 10^{-3} N.

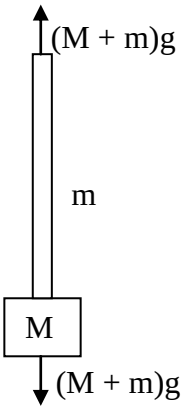

Figure 1shows a force diagram of the situation, where M is the man and m is the length of hair.

How much weight can the hair support?

To test if this is possible, the maximum force a human hair can withstand before it will snap must be determined. It should be noted that these calculations are based on the hairs themselves snapping, not being pulled out by the roots from the head. It is assumed that Rapunzel at the top of the tower will be holding her hair such that the force isn't acting directly on her head but is acting at the point where it is being held. It was found that the ultimate tensile strength of human hair is 380MPa [4] and that the diameter of human hair is 10^{-3} inches or 2.54 μm [5]. Assuming hair to be cylindrical in shape, the cross sectional area is equal to that of a circle. Using the diameter previously stated it was found that the cross-sectional area of her hair is equal to $5.07 \times 10^{-10} m^2$. This can be used in conjunction with the ultimate tensile strength to give a maximum load per hair of 0.193N. This means that Rapunzel's hair could support a maximum weight of 27kN.

Conclusion

In order to determine if Rapunzel's hair could support the weight of both itself and that of a man assumed to have a mass of 60kg, the force required by each of the 140,000 hairs on her head was calculated. This was found to be smaller than the maximum force that could be supported by each hair by a considerable margin. In fact, it was found that her hair could support a weight of 27kN, or just over 2750kg. It is, therefore, safe to conclude that Rapunzel's hair could easily support the weight of a man.

References

[1] *Rapunzel's Hair*, Yummy Math.Com, accessed November 13, 2011.
http://yummymath.com/wp-content/uploads/2011/03/rapunzels-hair.pdf

[2] Springer, M.; *The Physics of Rapunzel*, Built on Facts, May 4, 2009.

[3] *Did you Know?*, Hair To Go (HTG), accessed November 13, 2011.
http://htg.addr.com/didyou.htm

[4] Robbins, C. (2007). Hair breakage during combing. III. The effects of bleaching and conditioning on short and long segment breakage by wet and dry combing of tresses, *Journal of Cosmetic Science*, vol. 58, pg. 477.

[5] Elert, G.; *Diameter of a Human Hair*, The Physics Factbook, accessed November 13, 2011.
http://hypertextbook.com/facts/1999/BrianLey.shtml