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Energy Expenditure of Monsters University's 'Slug Monster'

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Abstract

This paper looks to find the energy expenditure of the Slug monster comically depicted in the film Monster's University as running incredibly slowly to his lesson. As the Slug is seemingly unaware of time passing by, it is assumed that either due to hypoglycaemia or susceptibility to cold temperatures, the slug occasionally blacks out, meaning he is only running for 6 hours a day for 32 weeks - though to him this seems like one long day. Likening the Slug to the American banana slug, and making suitable assumptions for the Slug's physical parameters allowed its total energy expenditure to be calculated. It was found he exerts 5.22×10^{9} J of energy in total, which can be attributed to the rapid motion of his arms.

Introduction

Monster's University is the 2013 sequel to the highly successful animated Pixar film, Monster's Inc. An early scene in the film comically depicts the journey of the 'Slug Monster' from a location outdoors on campus to the classroom of his first lesson of the semester. Following the end-credits, a final scene shows that upon arriving at the classroom, he finds that not only has he missed his lesson, but that the academic year has already finished [1].

In this paper, we calculate the total energy expenditure of the Slug for the journey he makes, based on a variety of assumptions including his height, shape and density.

Assumptions

We first need to make an estimate of the Slug's dimensions; this will enable us to calculate his volume. Figure 1 depicts the scene in the movie where he arrives at the classroom. By comparing the Slug to the height of the door, an estimate of his height (excluding his eyes) can be made.

Next, the volume of the Slug can be calculated by relating its shape to that of a frustum, where R is the larger radius (base) and r is the smaller radius (top). The equation for the volume of a frustum [2] is given by:

$$V_f = \frac{\pi h}{3} \left(R^2 + Rr + r^2\right) \qquad (1)$$

Similarly, the volume of his arms can be calculated by likening its shape to that of cylinders (equation 2 [3]):

$$V_c = \pi r^2 h \qquad (2)$$

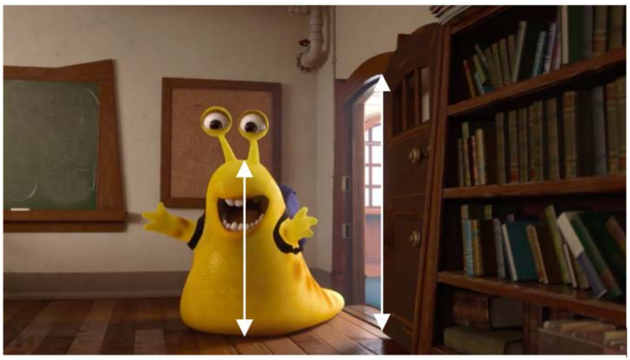

Figure 1) The end scene of Monster's University [1]. The height of the Slug compared to that of the door shown by vertical white arrows. Using ImageJ to measure the pixels in this image from the film, it was shown that the height of the Slug was found to be 68.8% of the door.

If we assume the Slug Monster is of the North American Banana Slug species, we can use existing data on the mass, length and width of an actual American banana slug, and model it as a cylinder to find a volume [4]. This in turn enabled us to find its density to be 521.07 kg m^{-3}, which is taken to be equivalent to the density of the Slug Monster. From this, we can relate volume and density to obtain his mass by equation 3, which relates mass, m, density, ρ and volume, V:

$$\rho = \frac{m}{V} \tag{3}$$

We can also assume he travels approximately 600m to get to class, owing to the large area of US campuses. Given that slugs are cold blooded, and the slug seems unaware of being alone in his surroundings (i.e. when the school is closed and students are not attending lessons), it is fair to assume that he spends 6 hours a day travelling for the 32 teaching weeks of the US academic year [5]. The time he isn't running is due to loss of consciousness from the cold and hypoglycaemia.

Calculating Gravitational Energy Expenditure

Based on the video clip, the slug is shown to expend much of his energy through arm movement. This gravitational potential energy can be calculated by first determining the volume and mass of the Slug's arms.

The standard height of a door seen in figure 1 [1] was taken to be 1981mm, the standard height of a UK door [6]. In ImageJ, we determined that the height of the Slug was 68.8% that of the door, giving the Slug's height as 1.36 m.

We have modelled the arms as cylinders and, again in ImageJ, determined the arm length to be 0.997 m and radius to be 0.113 m. Hence, the volume and mass of one arm is 0.0396 m^3 and 20.7 kg respectively.

Using equation 4, the gravitational potential energy of an object, we have found that the energy expenditure for one arm moving an estimated vertical distance of 0.547 m is 111 J. In one second, the motion of the arm circulates approximately 7 times and therefore the energy expenditure of both arms in one second is 1550 J.

$$U = mg\Delta h \tag{4}$$

(Note: g = 9.81 ms^{-2})

Calculating kinetic energy expenditure

In addition, we can also calculate the slug's kinetic energy expenditure by modelling his body as a frustum, in addition to the cylindrical arms. The equation for kinetic energy K relating mass, m, and velocity, v [7] is:

$$K = \frac{mv^2}{2} \tag{5}$$

Again, in ImageJ, we used scenes from the film to measure the Slug's physical dimensions. Basing his body shape on a frustum, his bottom radius was found to be 1.53 m and his top radius 0.523 m. Using equation 1 the volume of the slug was calculated and hence his body mass was found to be 691 kg. By including the mass of his arms, his total body mass is 732.4 kg.

Based on the assumption that the Slug is travelling every weekday of the 32 teaching weeks for 6 hours a day, the total time spent travelling is 3456000 seconds. Given that he travels approximately 600 m to get to class, his average speed is 0.000174 ms^{-1}.

Therefore, the Slug's kinetic energy expenditure is one second is 0.0000111 J, negligible when compared to the contribution of GPE.

Energy expenditure over whole journey

Adding the kinetic and gravitational energy gives an energy expenditure of 1550 J in one second. During the 3456000 seconds of travelling, he therefore exerts 5.22×10^9 J of energy, most of which results from the motion of his arms.

Conclusion

An energy expenditure of 5.22×10^9 J on the scale of the amount of energy in an average lightning bolt. To put this into perspective: given that he travels for 21600 seconds per day, the Slug Monster expends 3.35×10^7 J daily, which is equivalent to the kinetic energy of the armour-piercing round fired by the assault guns of the ISU-152 tank [8].

References

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