Journal of Physics Special Topics
An undergraduate physics journal

A4_1 How Hungry Was The Very Hungry Caterpillar?

A. Hogan, B. Henderson, J. Terry, N. Jinnah

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

November 9, 2018

Abstract

The Very Hungry Caterpillar follows the story of a caterpillar on its journey from hatching to becoming a butterfly. Over the course of a week the caterpillar eats through a variety of foods, by approximating the caterpillar as a cylinder, the final mass of the caterpillar was calculated to be 61.8 g with a length of 85.3 mm and a radius of 8.53 mm. By extrapolating data of the mass of butterflies versus their wing length, the wing length of the butterfly created by the caterpillar was calculated to be 1.88 m, approximately the same size as a common ostrich or flamingo.

Introduction

The Very Hungry Caterpillar is a children's book published in 1969, authored by Eric Carle [1]. As the title suggests, the book outlines the story of a caterpillar's journey from hatching to becoming a butterfly, whilst eating inordinate amounts of food along the way [1].

In order to calculate the amount of food eaten by the caterpillar it is neccesary to first make some assumptions. Firstly, the caterpillar is assumed to be cylindrical, with a constant ratio of 1:10 between the measurements of the radius and the length of the caterpillar. Next, for each food that is consumed, a cylinder is presumed to be eaten through the food, where the cylinder eaten is assumed to have radius equal to that of the radius of the caterpillar. Finally, all foods and the caterpillar are assumed to have a constant mass distribution and density.

Caterpillars generate copious amounts of waste, called frass [2], caterpillars produce frass every 2 to 3 hours on average and lose a generous amount of their body mass due to this. For this reason it has been assumed that on the days the caterpillar is said to be eating in the novel, the caterpillar will eat for a total of 12 hours from 7 am to 7 pm. For simplicity, the caterpillar will then generate frass from 7 pm to 7 am the following day with each frass equal to 2.5% of it's starting body weight at 7 pm. The time frames chosen correlate with the novel stating that the caterpillar hatched at sunrise, assumed to be 7am and the assumption that the caterpillar will only eat during daylight hours of 7am to 7pm. Despite the large amount of frass produced, caterpillars are considered to have a very efficient metabolism, hence it is assumed no energy is expended whilst digesting food.

Methodology and Results

The author of the novel, Eric Carle grew up in New York [1] and hence a caterpillar was picked that was native to this region whilst also having the physical attributes as illustrated in the book [2]. The Horace's Duskywing Caterpillar was chosen which has a mass of approximately 0.1 g, a length of 10 mm and a radius of 1.0 mm. From the initial dimensions, the density of the caterpillar can be calculated using equation (1) and the volume calculated simply.

$$\rho = m/V \tag{1}$$

Where ρ represents density, m represents mass and V represents volume.

The book begins on Sunday morning when the caterpillar hatches. The caterpillar searches for food until Monday morning when it consumes an apple, to calculate the mass of apple consumed, the apple is assumed to be spherical and a cylinder is considered to be eaten through the centre of the apple. As the radius of the cylinder is considerably smaller than the radius of the apple [3], the ends of the cylinder are approximately flat. Using the density of the food [4] and the volume of the cylinder, the mass can be calculated and added to the initial mass of the caterpillar. From this final mass value, utilising the previously calculated value for density, the final volume of the caterpillar can be calculated. By multiplying the initial values for the radius and length of the caterpillar by a constant value, ensuring the 1:10 ratio is maintained, values can be found that satisfy the final volume required. The new value for the radius can then be used to calculate the volume and hence mass, of the next food item consumed. For ease this can be done iteratively using a computer programme. The same methodology can be used for mass lost to frass by using a multiplication factor less than one.

This process is repeated for the first five days of the book, running from Monday to Friday, until the final day where the caterpillar eats one leaf. The results of this can be seen in Figure 1.

Time interval (hours)	Initial Mass (g)	Initial Radius (mm)	Initial Length (mm)	Food Density (kgm^{-3})	Food Mass (g)	Frass Weight (g)	Final Mass (g)	Final Radius (mm)	Final Length (mm)
0–24	0.10	1.0	10	-	-	0.03	0.070	0.88	8.80
24-36	0.070	0.88	8.8	240	0.029	-	0.099	0.99	9.90
36-48	0.099	0.99	9.9	-	-	0.0099	0.089	0.96	9.60
48-60	0.089	0.96	9.60	935	0.22	-	0.31	1.46	14.6
60-72	0.31	1.46	14.6	-	-	0.031	0.28	1.41	14.1
72-84	0.28	1.41	14.1	1030	0.675	-	0.96	2.12	21.2
84-96	0.96	2.12	21.2	-	-	0.096	0.86	2.05	20.5
96-108	0.86	2.05	20.5	940	0.99	-	1.85	2.64	26.4
108-120	1.85	2.64	26.4	-	-	0.185	1.67	2.55	25.5
120-132	1.67	2.55	25.5	1030	8.42	-	10.1	4.65	46.5
132-144	10.1	4.65	46.5	-	-	1.009	9.08	4.50	45.0
144-156	9.08	4.50	44.5	705	3.59	-	12.7	5.01	50.1
	12.7	5.01	50.1	720	2.84	-	15.5	5.38	53.8
	15.5	5.38	53.8	1014	2.77	-	18.3	5.67	56.7
	18.3	5.67	56.7	915	1.85	-	20.2	5.86	58.6
	20.2	5.86	58.6	1505	3.25	-	23.4	6.16	61.6
	23.4	6.16	61.6	1600	5.43	-	28.8	6.61	66.1
	28.8	6.61	66.1	1140	12.5	-	41.3	7.44	74.4
	41.3	7.44	74.4	550	2.86	-	44.2	7.60	76.0
	44.2	7.60	76.0	1180	10.7	-	54.9	8.19	81.9
	54.9	8.19	81.9	650	8.22	-	63.1	8.58	85.8
156-168	63.1	8.58	85.8	-	-	6.31	56.8	8.28	82.8
168-180	56.8	8.28	82.8	-	5	-	61.8	8.53	85.3

Figure 1: A table of data outlining how the dimensions of the caterpillar change with time, including food consumed and mass lost to frass, densities obtained from [4] and diameters from [3]

Discussion and Conclusion

As can be seen in Figure 1, the final mass of the caterpillar is calculated as 61.8 g with a length of 85.3 mm. An average caterpillar has a maximum mass of around 2 g [5] meaning the Very Hungry Caterpillar is approximately 30 times larger than average. Supposing a caterpillar could accumulate this much mass, the next logical step is to investigate how large the butterfly would be that this caterpillar would create.

By obtaining a set of data outlining how the wing length of butterflies varies with mass [5] it is possible to observe the trend and extrapolate to the mass of the very hungry caterpillar, assuming that the entire mass of the caterpillar is used in the creation of the butterfly. The data is presented in Figure 2, where a linear relationship is clearly visible.

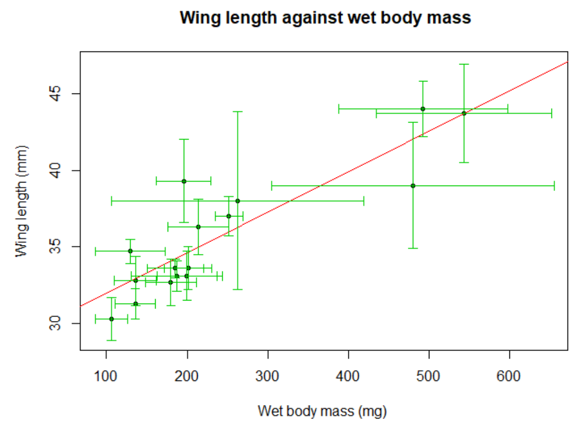

Figure 2: A graphical representation of wing length versus wet body mass, data obtained from [5]

By completing a linear regression on the data, equation (3) was generated, outlining the relationship between the two variables.

$$y = 0.03x + 29 \qquad (2)$$

Where x is the wet body mass in mg and y is the wing length in mm.

Substituting the mass of 61.8 g into equation (3) and using propagation of errors, a wing length of 1.88 $\pm$ 1.2x10^{-4} m was calculated, a wing length comparable to that seen for a flamingo or a common ostrich.

References

[1] A. Silvey, *100 Best Books for Children* (Houghton Mifflin Harcourt, 2004)

[2] K. Lotts, T. Naberhaus `https://www.butterfliesandmoths.org/species/Erynnis-horatius` [Accessed 29 September]

[3] U. Rudrappa `https://www.nutrition-and-you.com/fruit-nutrition.html` [Accessed 30 September 2018]

[4] U. Ruth Charrondiere, D. Haytowitz and B. Stadlmayr, *FAO/INFOODS Density Database Version 2.0* (2012)

[5] R. Dudley and R.B. Syrgley, *Airspeed adjustment and lipid reserves in migratory Neotropical butterflies* (Functional Ecology, 2008) Vol.22, p.264-270.