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P3_6 Can Thumbelina Fly?

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Abstract

In the *Warner Bros.* animated film of the same name; Thumbelina, along with the rest of the 'flower-fairies', demonstrates an innate ability for air flight. This paper investigates if Thumbelina would be able to fly in a world constrained by physical laws outside of the realms of fairy tale and fantasy. It is found that it is likely that she would, indeed, be able to fly and would need to beat her wings 192 times per second in order to do so.

Introduction

Thumbelina was originally written by Hans Christian Andersen in December 1835 and, much later, was made into an animated feature length film by *Warner Bros. Pictures* in 1994. Towards the latter end of the film, Thumbelina demonstrates the ability to fly using four wings consisting of two forewings and two hindwings, very similar in design to those of a butterfly or moth. This paper will look into the physical processes required to allow flight and will thus determine if this is possible for someone of Thumbelina's physical dimensions in a world bound by physical laws.

Theory

Flight can be achieved through a variety of ways. Many animals and manmade designs achieve it using slightly different mechanisms but ultimately the goal is to exert a force equal to or greater than one's weight in the opposite direction to gravity in order to overcome it. As mentioned previously, Thumbelina's wings are most similar in nature to those of a butterfly or moth and many other types of insects so the mechanism used by these will be studied.

The majority of insects, including butterflies, achieve flight intuitively through use of a simple principle. This involves beating their wings rapidly, many times per second, in order to displace air which in turn exerts a force in the opposite direction on the insect itself. This is essentially Newton's third law but is more usefully described in this situation by Archimedes principle. Archimedes principle states that a when a body displaces a fluid, the fluid buoys up the body by a force equal to the weight of the fluid displaced. This is essentially what is occurring in this situation. The insect beats its wings, displacing a volume of air, and is buoyed up as a result.

In the case of the butterfly, this is an oversimplification as they are very efficient fliers by the standards of any flier, including birds and planes [1]. They are able to use a variety of techniques in order to boost their efficiency such as using the air flows generated in previous beats of the wings to propel them higher and maximise the force generated per beat. It is, therefore, necessary to state that the subsequent calculations may only provide a lower limit of the force generated per beat as it assumes force is generated entirely mechanically.

The greatest challenge in assessing the feasibility of this process is gaining good estimates of Thumbelina's physical specifications. These include the surface area of her wings, her mass and the angle through which her wings beat in order to determine the volume of air displaced per beat. An upper limit estimate for her mass was determined through analysis of a particular scene in the film. In this scene it is shown that Thumbelina and the male lead fly on the back of a bumblebee. Assuming both Thumbelina and the male lead are of equal weight and the bumblebee is carrying it's maximum capacity, then using the fact that bumblebees on average have a mass of 0.05g [2] and can carry up to 75% [3] of their mass then the mass of Thumbelina is, at most, 0.0188g. This gives her a weight of 0.0188*g,* or 0.184N, where *g* is the acceleration due to gravity on Earth of 9.81m s^{-2}. For Thumbelina to fly, she needs to use her wings to exert a force equal to this. Substituting this into the equation for buoyancy,

$$F = V\rho g, \qquad (1)$$

where, from equation 1, *F* is the buoyant force, *V* is the volume of air displaced and ρ is the density of the air displaced. Rearranging for *V* and substituting for the values previously stated and ρ = 1.3kgm^{-3}, it is found that 0.0144m^3 of air needs to be displaced per second to balance the forces.

The surface area of her wings is also estimated using analysis of footage. Figure 1 shows the way her wings are shaped. During flight, both parts of the wing couple to form one large wing, as occurs when butterflies are in flight [4]. Approximating the forewing as a triangle and the hindwing as a square, the total wing area is 0.0016m^2 (remembering to multiply by 2 for each wing). Estimating the angle through which she flaps her wings to be 70° based on the footage, it can be found that the maximum displacement of the flap is equal to 0.046m using trigonometry. Thus, through multiplying the area of the wing by the displacement of the wing, the volume of air displaced per flap is found to be 7.34 x 10^{-5} m^{-3}. Hence, by dividing the required volume displaced per second previously calculated by the volume displaced per wing beat, it can be found that Thumbelina needs to beat her wings at least 196 times per second to defy gravity.

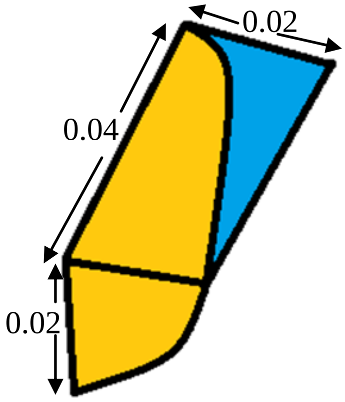

Figure 1 shows the way Thumbelina's wings are shaped modelled from the film footage, with the orange area being the area of the wing. Measurements are in units of metres (m) and were derived from the fact that Thumbelina is assumed to be of dimensions roughly equal to those of a lady's thumb of 6cm x 2cm. As can be seen, the forewing is roughly triangular in shape whereas the hindwing is more rectangular in shape (the neglected excess area of the forewing should balance the lacking area of the hindwing).

Conclusion

It was calculated that Thumbelina must flap her wings at least 196 times per second in order to achieve flight. It is observed that butterflies can beat their wings up to 100 times per second. It would seem that Thumbelina would be unable to fly in the real world, however, only an upper limit on her mass could be derived and other techniques, (previously mentioned) used by butterflies to maintain flight have been neglected. These facts alone mean that it is likely that she can fly as there is only a factor of two in difference between the numbers, but also, it is questionable if the benchmark value (found from studies of the butterfly) is the correct value to use. Only a crude approximation was made as to Thumbelina's likeness to butterflies. Other insects, such as the midge fly, can beat their wings up to 1000 times per second [5]. It is likely that, given these considerations, and bearing in mind that there is less than a factor of two difference in the values, Thumbelina would be able to fly.

References

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