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P2_1 James' Giant Peach Transport across the Atlantic

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Abstract
In Roald Dahl's children's classic *James and the Giant Peach* a magically enlarged fruit travels across the Atlantic Ocean, partly floated on the water and partly airlifted by a flock of seagulls. Through examining the buoyancy and modelling the seagulls as aerofoils it has been found that although the initial part of the journey is possible, given a sufficiently hollow peach, James would have to tether approximately two and a half million Common Gulls, rather than the 501 as described in the book.

Introduction

In Roald Dahl's novel *James and the Giant Peach* the eponymous hero embarks on a journey across the Atlantic Ocean on a peach the size of a house. For the initial part of the journey he sails the enlarged, partly hollow, fruit, using the surface of the non-submerged half as a deck. The peach is then airlifted by 501 seagulls, tethered by the thread of a giant silkworm [1]. The viability of both components on the journey has been examined through analysis of the fluid dynamical processes involved.

Buoyancy of the Giant Peach

The density of peach flesh, ρ_p, of 1100 kg m^{-3} [2], is greater than that of seawater at standard temperature and pressure, ρ_w, of 1025 kg m^{-3} [3]. Hence the giant peach would float only due to its core being hollow, which decreases the overall density, ρ_{net}, sufficiently.

In the novel the peach grows to the size of a small house [1], hence an outer radius, r, of 6 m was assumed. From footage of the Disney movie adaptation [4] the height of the peach above the water-level, h, was estimated to be 5.7 m. Both sphere and hollow core were approximated as spherical and the mass of the peach's crew was neglected in subsequent calculations.

In hydrostatic equilibrium the weight of the peach is balanced by the buoyant force from the displaced volume of water, V_{sub},

$$\rho_{net} V\, g = \rho_w V_{sub}\, g\,, \qquad (1)$$

where g is the acceleration due to gravity on Earth and V is the total volume enclosed by the outer surface of the peach. Equation 1 gives,

$$\rho_{net} = \rho_w \left(1 - \frac{V_{cap}}{V}\right), \qquad (2)$$

where V_{cap} is the volume enclosed by the outer surface of the peach above water level, as shown in Figure 1.

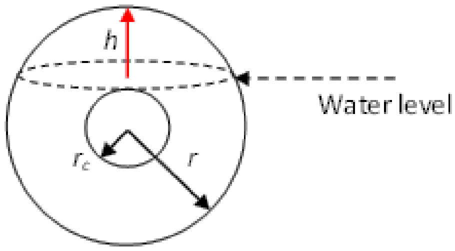

Figure 1: Schematic of the peach showing radii and spherical cap volume above water level.

Substituting formulae for the volumes of a sphere for V, and spherical cap of height, h, for V_{cap}, results in a required density given by,

$$\rho_{net} = \rho_w \left(1 - \frac{h^2(3\,r - h)}{4\,r^3}\right). \qquad (3)$$

This is equal to 551 kg m^{-3} for the previously specified values of r, h and ρ_w. It can be shown using basic geometry that the dependence of ρ_{net}, on the radii, r_c and r, densities of the core, ρ_{air}, and outer shell, ρ_p, of the sphere is,

$$\rho_{net} = \rho_{air}\left(\frac{r_c}{r}\right)^3 + \rho_p\left[1-\left(\frac{r_c}{r}\right)^3\right]. \quad (4)$$

Rearranging for the core radius gives,

$$r_c = r\left(\frac{\rho_{net}-\rho_p}{\rho_{air}-\rho_p}\right)^{1/3}. \quad (5)$$

Substituting the values specified above, where ρ_{air} is 1.217 kg m^{-3} [3], gives a core radius of 4.76 m. Therefore the highly buoyant peach shown in the movie requires a peach flesh layer of thickness 1.24 m.

Flight of the Giant Peach

The vertical motion of the birds’ flight has been regarded as independent of the horizontal motion. It was assumed that the flapping provides sufficient forward motion to maintain a velocity, v, and that for the majority of the journey the lift is created through the gliding motion of the wings, which have been modelled as thin aerofoils.

Bernoulli’s principle can be used to approximate the lift force, F, upon a thin aerofoil,

$$F \approx \frac{1}{2}(m^2-1)\rho A v^2, \quad (6)$$

where m is the ratio between the upper and lower path lengths of the streamlines above and below the aerofoil, ρ, is the density of the fluid medium, in this case ρ_{air}, and A is the area of the aerofoil [5]. This force must be greater than or equal to the birds’ weight, W_B, to maintain flight.

The difference between the lift force and weight of a bird results in a net lift per bird, F_{NET}. Scaling this by the number of birds, N, gives a total net lift force for the flock of birds, F_{TOTAL}. Therefore to maintain flight whilst carrying the peach this total net lift must be greater than or equal to the weight of the peach, W_p, as below,

$$F_{TOT} = F_{NET} \times N = (F - W_B) \times N \geq W_P. \quad (7)$$

An individual Common Gull was taken to weigh 3.67 N, have a total wing area, A, of 0.115 m^2, travel at a velocity of 9.2 ms^{-1} [6] and have an estimated m value of 1.4 [5], based on the assumption that bird wings are similar to the aerofoils of planes. With the values above an individual gull provides a net lift of nearly 2.02 N. Therefore 501 gulls have a total carrying capacity of 1010 N. The total weight of the peach was calculated from the data in the previous section as 4890579 N. This greatly exceeds the carrying capacity of 501 Common Gulls.

Rearranging equation (7) for N, to calculate how many birds would be needed to lift the weight of the peach, results in James needing 2,425,907 seagulls to maintain flight.

Conclusion

Although James could have successfully sailed his peach in the manner described by Roald Dahl, for a peach of the dimensions calculated, it would not be possible to fly such a heavy object with the assistance of such a diminutive number of birds. He would have to harness 2,425,907 seagulls in order to fly to America. Whether the Silkworm and Mrs Spider could have managed this is unknown.

Further areas of research with this problem could include work on the drag of the peach and its effect of the horizontal motion of the flight. The loading of the silk threads used to suspend the peach could also be investigated.

References

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