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P1_02 Up Like a Lead Balloon

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Abstract

We analyse the physics behind constructing a balloon out of lead foil of 0.5 mm thickness, with the intent of calculating the minimum radius for constructing a spherical balloon capable of floating under its own buoyancy. We find this radius to be 15.3 m.

Introduction

In episode 2, Season 6, of the popular television show Mythbusters, the cast challenge the old adage "to go down like a lead balloon" (i.e. to fail miserably) by attempting to prove that building a functioning balloon out of lead is indeed possible [1]. Using lead foil of unspecified thickness and a mixture of air and helium gas of an unspecified ratio, they successfully constructed a rough cube of lead foil 10 feet (3.048 m) on a side [2] that achieved lift-off. They proved that it is possible for a balloon of lead to float, but nothing more. In this paper we find the minimum radius of a spherical lead balloon, comprised of lead foil 0.5 mm (5×10^{-4} m) thick.

Background

In order for an object to float, it must weigh less than however much fluid or gas its volume displaces. Thus, the downward force on the balloon due to the gravitational pull on the net mass of the lead and helium that make it up, each being related to the radius r of the balloon in meters, must be less than the upward force L on the balloon in newtons. Thus, the net force $F\Delta$ becomes positive. This follows the Archimedes principal, as shown in equation 1 [3]:

$$F\Delta = L - W\Delta = L - (W_l + W_{He}) \tag{1}$$

In which W_l is the weight of the lead of the balloon in newtons, and W_{He} is the weight of the helium the balloon contains in Newtons. W_l is equal to the outer volume of the spherical balloon minus the volume of the helium inside the lead skin of the balloon. We decided to model the balloon using foil of a thickness 5×10^{-4} m [4], as thinner foils would be even more prone to tearing. Finding the volume of the lead by subtracting the volume of the inner sphere of the balloon from the volume of the full sphere using a value of $r - 5 \times 10^{-4}$, we found that the total weight of the lead W_l using the equation

$$W_l = \rho_l \pi \frac{4}{3} g(r^3 - (r - 5 \times 10^{-4})^3) \tag{2}$$

in which ρ_l is the mass density of lead at standard temperature and pressure of $11,340$ kgm^{-3} [5] and g is the acceleration due to gravity at sea level 9.81 ms^{-2}). Using just the volume of the inner sphere, we found that the weight of the helium in the balloon could be expressed using the equation:

$$W_He = \rho_{He} \pi \frac{4}{3} g(r - 5 \times 10^{-4})^3 \tag{3}$$

in which ρ_{He} is the mass density of helium at standard temperature and pressure 0.1785 kgm^{-3} [6]. In order to find the total weight of the air the balloon displaces, we simply found the mass of the air that occupies a sphere equal to the volume of the balloon using the equation:

$$L = \rho_{air} \pi \frac{4}{3} g r^3 \tag{4}$$

In which ρ_{air} is the average mass density of air at standard temperature and pressure 1.293 kgm^{-3} [6]. Thus, the only variable in the calculation of $F\Delta$ is the radius of the spherical balloon. By writing a simple script in MATLAB, we plotted a graph of $F\Delta$ in Newtons (N) against r in meters (m).

Results

Plotting the graph as described above, we mapped out a curve showing that as the radius of the balloon increases from 5.1×10^{-4} m (the smallest balloon we deemed necessary to model), we found as expected that initially the downward force on the balloon is dominant, before curving back up to reach an upward force as r increases, as illustrated in figure 1. By finding

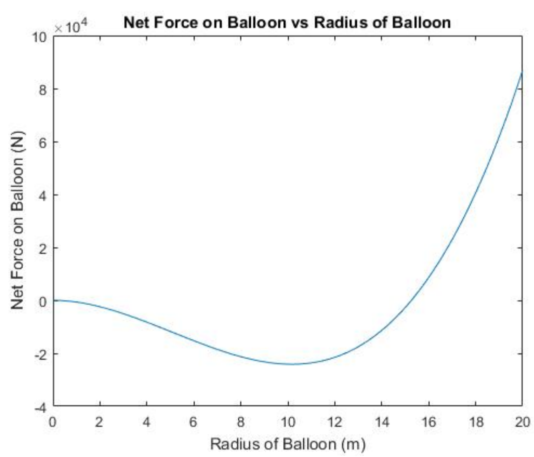

Figure 1: A graph showing the relationship between the radius of the balloon and the net force on the balloon, clearly showing that until a critical radius the balloon cannot float as the net force is negative.

the point on the graph at which the curve intercepts the x-axis, thus finding the point at which the net force on the balloon has reached 0 N, we found that the minimum possible radius for a functional balloon made of lead foil of 5×10^{-4} m thickness is 15.3 m. This is the point at which the balloon no longer falls, nor rises, the exact point at which the balloon can hold itself aloft by buoyant force alone, our chosen definition for a functional balloon.

Conclusion

We found that the minimum radius for a spherical lead balloon to functionally float under its own buoyant force is 15.3 m. While this seems rather large, this may well be because the Mythbusters used a thinner foil than we used in our calculations. Lead foil is sold in sheets as thin as 0.1 mm [4], a thickness that we deemed too fragile. The Mythbusters had to patch their balloon during construction [2] before it was able to take off, meaning that while a thicker foil would require far more helium, it may be better suited to making a balloon.

References

[1] `https://www.imdb.com/title/tt1177696/` [Last Accessed 11 Oct 2018]

[2] `https://www.imdb.com/title/tt1177696/?ref_=tt_ep_pr` [Last Accessed 24 Oct 2018]

[3] `http://physics.bu.edu/~duffy/sc527_notes01/buoyant.html` [Last Accessed 11 Oct 2018]

[4] `http://modelshop.co.uk/Shop/Raw-Materials/Metal/Item/Lead-sheet/ITM1076` [Last Accessed 11 Oct 2018]

[5] `https://www.engineeringtoolbox.com/metal-alloys-densities-d_50.html` [Last Accessed 11 Oct 2018]

[6] `https://www.engineeringtoolbox.com/gas-density-d_158.html` [Last Accessed 11 Oct 2018]