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A1_6 How many Balloons does it take to lift a House?

T Glossop, S Jinks, R Hopton

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

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Abstract

We look into whether or not a house can be lifted up by balloons, for both a model for the house used in the film "Up" and for a common house in the United Kingdom, and find that the number of balloons required to lift them are 10^7 and 4×10^8 balloons respectively. However, we also briefly look at the downfalls of such an idea in the real world.

Introduction

The film "Up", created by Pixar, involved a house that floated from (presumably somewhere in The United States of America) to South America using nothing but balloons. The aims of this paper is to find whether such a journey is possible for both a small wooden house (as in the film) and for a common house in the United Kingdom.

Theory

Below is a force diagram of the problem.

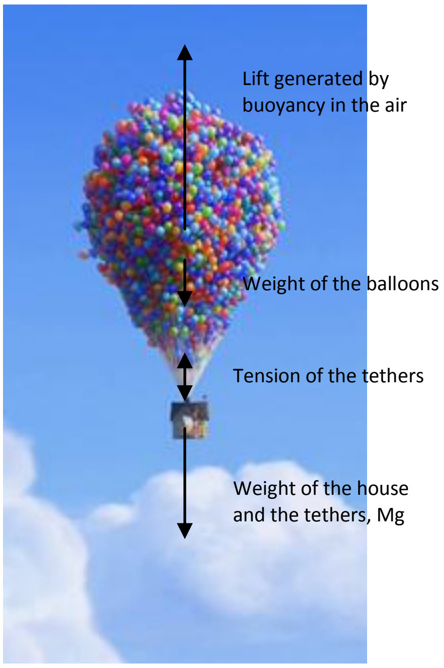

Figure 1: A force diagram showing some balloons lifting a house with some tethers [1].

Buoyancy is the force that causes a balloon to rise in the air. Since the mass of the helium that is contained in the volume of the balloon is much less than that of the mass of the air that it is displacing, it experiences a net upward force due to buoyancy. Therefore, we know that for each balloon the amount of lift, L_b, is given by equation (1) assuming that the tethers are inextensible:

$$L_b = g(m_{air} - m_{He}) = gV_b(\rho_{air} - \rho_{He}), (1)$$

where m_{air} and ρ_{air} are the mass and density of air under normal atmospheric conditions, m_{He} and ρ_{He} are the mass and density of helium under atmospheric conditions at sea level, V_b is the volume of the balloon and g is the acceleration due to gravity (9.81 ms^{-2}).

In order for the house to float it needs N balloons to counteract the weight of the house and the tethers, Mg:

$$Mg = NL_b = NgV_b(\rho_{air} - \rho_{He}). \quad (2)$$

Re-arranging this for the number of balloons we get that:

$$N = \frac{M}{V_b(\rho_{air} - \rho_{He})}. \quad (3)$$

The density of Helium gas at about 300K is 0.164 kgm^{-3} and the density of air at sea level at the same temperature is 1.161 kgm^{-3} [2].

Now we need an estimate of the mass of the wooden house and the volume of a balloon. Assuming that the average volume of a helium balloon is 5 litres (0.005 m^3) and that the house is approximately a cube of length 5m (this is based on a rough estimate of the scale between the owner of the house and the house itself in the film), of which about half of this is hollowed out to live in we get that M is given by:

$$M = \frac{1}{2}(5^3)\rho_{oak}\,, \qquad (4)$$

where we estimate the density of the wood to be similar to the density of oak (as it is very common), ρ_{oak}, is given between 590 and 930 kgm^{-3} [3], so taking the average value of this and substituting into (4) we get $M = 50000kg$, to one significant figure.

Substituting the values for M and V_b into (3) we get that we need approximately 10^7 balloons to lift the house off the ground.

We can do a similar calculation using a common house in the United Kingdom made of brick (of density 1922 kgm^{-3} [4]) that is a cuboid of estimated dimensions 20m × 10m × 8m which is a volume of 1600 m^3, these values can be substituted into (4) to get:

$$M = \frac{1}{2}(1600)\rho_{brick} \approx 2 \times 10^6\ kg\,. \quad (5)$$

Substituting this into (3) gives the number of balloons as N=4×10^8.

Discussion

Since the air density decreases with altitude this would not be enough to let it climb indefinitely, even assuming that no helium can escape from the balloons. This is because the air density (and therefore the buoyancy force) is inversely proportional to N. This means that N would have to be even higher to reach an altitude of normal aeroplanes (37000 ft or 11277m [5]).

At an altitude of 11277m the air density is approximately 0.3471kgm^{-3} [6] which is more than 3 times smaller than at sea level. This means that N would have to be more than 3 times greater than that calculated previously at this altitude than at sea level.

The balloons will also deflate over time which will also be exacerbated by altitude, even at different altitudes close to sea level [7]. This is due to the diffusion in the balloons [8] to a space of much lower pressure, which at an altitude of 11277m is going to be a massive effect.

Conclusion

While it is possible to lift a house using helium balloons, it would be very impractical for a number of reasons. These include a large number of balloons (of the order 10^8 for a normal house) which will deflate very quickly at high altitudes. Also that the foundations and drainage of the house would be removed making the structure very unstable, if by some miracle the journey is possible.

References

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[2]http://physics.info/density/ (17/2/11)
[3] http://www.simetric.co.uk/si_wood.htm (17/2/11)
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[8] http://www.helium.com/items/1246954-what-causes-helium-to-escape-from-balloons (17/2/11)