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P3_3 Around the World in 82Pb

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Abstract

Hot air balloons are often made of lightweight material in order to improve the performance of such a craft. In this paper we discuss whether a hot air balloon made of lead could fly. We considered the lift generated by the heated air inside the balloon and concluded that a lead balloon could fly providing that the lead shell was less than 0.011mm thick.

Introduction

Hot air balloons generate lift by heating an enclosed volume of air, reducing its density. This volume of air is buoyant provided that it has a lower density than the surrounding air; this buoyancy force can be used to lift payloads, such as people. The materials used to build hot air balloons are often very lightweight to increase the maximum payload allowance.

The well-known saying *"go down like a lead balloon"* makes use of the high density of lead, implying that a balloon made of lead would drop to the ground. However, is it possible for a balloon made of lead to actually fly? In this paper we discuss the feasibility of flying a Montgolfier balloon (traditional hot air balloon) out of lead [1].

Theory

For a Montgolfier balloon to fly, a heat source is used to increase the temperature of the air inside the balloon. This temperature increase causes the density of the air to drop, assuming that it is kept at an ambient pressure. An ambient pressure can be expected as there are vents throughout the balloon as well as a large hole at the base. The difference between the densities of the ambient air and the air inside the balloon generates the lift. If we treat the air as an ideal gas, we can use the ideal gas equation

$$PV = NkT, \qquad (1)$$

where P is the pressure, V is the volume, N is the number of particles in the gas, k is the Boltzmann constant and T is the temperature. The variables V and N can be rewritten to give the number density, $\rho_N = N/V$. If we take the pressure as a constant throughout the system, we can write

$$\rho_N = \frac{c}{T}, \qquad (2)$$

where c is a constant equal to P/k. Hence the ambient air and internal air can be compared such that

$$\rho_1 = \rho_2 \frac{T_2}{T_1}, \qquad (3)$$

where the *1* subscript refers to the air inside the balloon, and *2* refers to the air outside. This equation also uses the mass densities instead of the number densities. This change can be made as the number density is proportional to the mass density.

When considering the forces acting on the balloon, we need to include the lift, F_l, the mass of the balloon structure, m_b, and the payload, m_p (including burners, passengers, and the basket). Ultimately we have to satisfy the following equation:

$$F_l \geq g(m_b + m_p), \qquad (4)$$

where g is the acceleration due to gravity. For level flight, the inequality in equation (4) must be equal; we will consider this scenario in the rest of the report. As previously discussed, the lift is generated by air density differences. If we assume that the balloon is in the shape of a sphere and using equation (3) we can write

$$F_l = Vg(\rho_2 - \rho_1) = \frac{4}{3}\pi r^3 g \rho_2 \left(1 - \frac{T_2}{T_1}\right), (5)$$

where V is the volume encased by the balloon and r is its radius. To calculate m_b for a balloon which has a radius much greater than the thickness of the shell, the mass of the shell can be calculated using

$$m_b = 4\pi r^2 \rho_l t, (6)$$

where ρ_l is the mass density of lead and t is the thickness of the shell. By combining and rearranging equations (4), (5), and (6), we can generate an equation to give the maximum thickness of lead allowed to sustain flight,

$$t = \frac{4r\rho_2\left(1 - \frac{T_2}{T_1}\right) - \frac{3m_p}{\pi r^2}}{12\rho_l}. \quad (7)$$

Discussion

Montgolfier balloons can range vastly in size. For this paper we shall take a typical balloon radius of 8m [2]. The ambient air density and temperature will decrease as the balloon's altitude increases. For simplicity we shall treat the case for a balloon flying at 304m (1000ft) [3]. At this altitude the air density, ρ_2, is 1.11kgm^{-3}, and the temperature, T_2, has a value of 282K (8.5°C) [4]. We shall assume T_1 has a value of 393K (120°C), which is often quoted as the maximum typical temperature for sustained flight [5]. The payload mass can vary greatly. However a typical mass for the basket and burner is 250kg, and four passengers would weigh around 320kg, making m_p = 570kg. Finally the density of lead is 11340kgm^{-3} [6].

Substituting these values into equation (7), the balloon would maintain flight as long as the lead shell had a maximum thickness of 0.011mm. This thickness may seem unreasonably small, yet it is comparable to the thickness of typical household aluminium foil, around 70% of the thickness [7].

Conclusion

This foil-like thickness suggests that a lead balloon may have some viability, it may still be capable of supporting the loads it may have to lift. However, this paper has not studied the strength capabilities of such a thin sheet of lead. Further study into this subject could see whether this lead balloon could withstand the tension of holding the payload. This study could also discuss what effects the high internal temperature would have on such a thin lead sheet.

References

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