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P3_4 Flight of the Battle Bus

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Abstract

This article estimates the minimum volume needed for the hot air balloon on the Battle Bus in the game “Fortnite” for the it to fly with all its passengers. This was done by treating the air as an ideal gas and using Archimedes’ principle. Our calculated estimate for the volume was about 65,000 m^3.

Introduction

In the 100-man battle royale game “Fortnite”, players start off in what is known as the “Battle Bus”. This carries 100 people in a straight line over the game area, players then skydive into play at various points. In-game, the Battle Bus is pictured to be the size of a very large bus and uses a hot air balloon directly attached to the roof of the bus to fly across the map. We wanted to estimate the size the hot air balloon would have to be in real life to carry the battle bus. Moreover, this will be an order of magnitude estimate.

Theory

Hot air balloons essentially work by exploiting Archimedes’ principle which is the physical law of buoyancy. They do this by generating a difference in density between the air in the balloon and the air outside. This is done by heating – via a burner - the air inside the balloon. We will assume that all the weight of the system comes from just the bus and the 100 passengers. This is because the weight of the hot air balloon will be a small fraction of the total mass. Additionally, the mass of each person will be 70kg [1]. If we also assume the air behaves as an ideal gas we can calculate how the density changes as a function of temperature using the ideal gas law, shown in Equation 1. [2]

$$\rho_{Balloon} = \frac{P}{RT} \tag{1}$$

Where $P = 100$ kPa is the air pressure, $R = 290$ $Jkg^{-1}K^{-1}$ [3] is the specific gas constant for dry air and $T = 400$ K [4] is the temperature. This gives $\rho_{Balloon} = 0.86$ kgm^{-3}. The force due to the difference in air density is known as the buoyant force. For hot air balloons to fly this buoyant force must overcome the weight of the system. Where the weight is

$$F_g = mg \tag{2}$$

Where $m = 22{,}000$ kg, which is the total mass of the bus (15000 kg) [5] and the passengers (7000 kg). The acceleration due to gravity on Earth is $g = 9.8$ ms^{-2} and the buoyant force is given by Equation 3.

$$F_b = Vg(\rho_{Air} - \rho_{Balloon}) \tag{3}$$

Where V is the volume of the balloon and ρ_{air} = 1.2 kgm^{-3} [2] is the density of the ambient air.

The magnitude of the buoyant force in this case is proportional to the difference in air density, as well as the volume of the balloon. The volume of the balloon is the quantity we are interested in as there is a limit to which we can generate a difference in air density. This will give us the air density inside the balloon via Equation 1. In practice there is a temperature limit as too much heat can compromise the material of the hot air balloon [4]. We assume the condition defined in equation 4 is satisfied.

$$\frac{F_b}{F_g} = 1 \tag{4}$$

This is the point where the buoyant force and weight are balanced. Substituting in the forces and making the volume the subject we get an estimate of the volume of the balloon. The value for the volume for this condition will be an underestimate as both forces are balanced. The real value will be slightly higher as the buoyant force needs to be greater than the weight for flight. The value gives us an indication of the order of magnitude for the size of the hot air balloon. Equation 5 gives this.

$$V = \frac{m}{\rho_{Air} - \rho_{Balloon}} \tag{5}$$

Substituting the respective values in equation 5 we get $V = 65{,}000\ \mathrm{m}^3$ which would be the minumum volume required for lift off. Assuming that the hot air balloon is spherical we can use the equation for the volume of a sphere and approximate the radius of the hot air balloon. This is shown in Equation 6.

$$V = \frac{4}{3}\pi r^3 \tag{6}$$

Rearranging this equation for the radius gives a value of about 25 m.

Discussion

The typical volume of a hot air balloon is about 2,800 m^3 [2] which corresponds with a radius of about 9 m. Our estimate in volume is more than an order of magnitude greater. In terms of radius it is close to three times bigger. A hot air balloon of this size would be very large and impractical. With only one burner it will be very difficult to uniformly heat the air inside the hot air balloon resulting in a smaller buoyant force. Furthermore, if one were to add more burners this would contribute to the weight of the system resulting in the need for a greater buoyant force for lift to be generated.

Conclusion

We estimated that for the Battle Bus to fly the hot air balloon used would need to have a volume greater than 65,000 m^3 running at a temperature of 400 K. This is the lower limit at which flight occurs. To take this situation further the attitude at which the battle bus hovers at could be considered. This is because the ambient air density decreases with respect to altitude. This would mean the magnitude of the buoyant force would decrease with increasing height. Additionally, the mass of the hot air balloon including the equipment could be considered, the larger the volume the bigger the balloon is resulting in more material contributing to the weight of the system.

References

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