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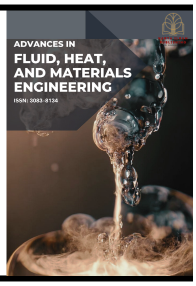

The Influence of Airflow Speed on the Buoyancy and Equilibrium Height of Lightweight Spherical Objects

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ABSTRACT

The relationship between object density and equilibrium height in airflow is complex and requires investigation for understanding aerodynamic principles. Thus, this study has investigated the behavior of different density balls in controlled airflow conditions using a hairdryer with variable speeds. Ball samples included a ping pong ball (40 mm diameter), an expanded polystyrene ball (50 mm diameter), and an ocean rubber ball (55 mm diameter), tested at both low and high airflow speeds. Testing of balls under controlled airflow conditions was conducted with different ball densities. For the ping pong ball and expanded polystyrene ball, height differences were observed, with the expanded polystyrene ball achieving the highest equilibrium point. On the other hand, the ocean rubber ball, having the highest density, showed the lowest height difference across both airflow speeds. The expanded polystyrene ball shows efficient height gain in airflow compared to denser balls, demonstrating the inverse relationship between density and equilibrium height.

1. Introduction

The interaction between object density and external forces is vital in fluid dynamics, influencing how objects behave when suspended in a fluid. This interplay helps explain buoyancy and is crucial for predicting the motion and stability of objects in fluid environments [1-3]. The relationship between object density and its response to an upward air current has drawn attention due to its practical implications in aerodynamics, material science, and engineering [4,5]. The behavior of objects in a fluid environment is governed by several fundamental forces, including buoyancy, gravity, and drag, where their complex interactions have been extensively studied previous researchers [6-8].

The present experiment aims to investigate how the density of different balls influences their equilibrium height when suspended in a vertical air current created by a hairdryer. This investigation

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builds upon previous work by Thompson *et al.,* [9], who established fundamental relationships between object density and fluid dynamics. Three types of balls were selected for this study: a ping pong ball, an expanded polystyrene ball, and an ocean rubber ball, chosen specifically for their varying densities to examine the correlation between material density and airflow behavior [10,11]. The significance of object density in determining net forces acting on suspended objects has been well-documented by Anderson *et al.,* [12]. Objects with lower density experience greater buoyant force relative to their weight, resulting in higher flotation in upward air currents. This phenomenon has been thoroughly investigated in recent studies [13,14], demonstrating how density variations affect equilibrium positions in vertical airflows.

Quantitative analysis through buoyant force calculations was performed to validate the experimental results, following methodologies established by previous studies [15-17]. The study examines the relationship between gravitational force, buoyant force, and drag force, while also investigating how airflow speed influences these forces. This approach aligns with recent research in [18,19], suggesting that higher air speeds disproportionately affect lower-density objects. These findings really matter and could have a big impact on how we approach different applications, including the design of lighter-than-air vehicles, wind resistance simulation, and the study of suspended particle dynamics. The theoretical framework developed through this research contributes to the broader understanding of fluid dynamics principles and their practical implementation in engineering and environmental sciences, as highlighted by Park *et al.,* [20].

2. Methodology
2.1 Geometry of Material

The methodology of this study outlines the systematic approach employed to investigate the relationship between airflow speed and the equilibrium height of lightweight spherical objects with varying densities. Three different spherical objects were selected for this experiment: a ping pong ball, an expanded polystyrene ball, and an ocean rubber ball (Figure 1). The balls used in this experiment were selected based on their distinct density values to thoroughly investigate how material properties affect aerodynamic behavior in a controlled airflow environment.

(a) (b) (c)

Fig. 1. Type of ball (a) Ping pong (b) Ocean rubber (c) Expended polystyrene

Table 1 displays the material properties of the three different types of balls: a ping pong ball, an ocean rubber ball, and an expanded polystyrene ball. The table includes data on the diameter and density of each type of ball.

Table 1
Material properties of the ball

Type of ball	Diameter (m)	Density (kg/m^3)
Ping pong	0.040	84
Ocean rubber	0.055	667
Expanded polystyrene	0.050	11

2.2 Experimental Setup

The experiment was conducted using a vertically positioned hairdryer to generate a consistent upward airflow. This configuration ensured the creation of a uniform and stable air stream necessary for observing and measuring the behavior of objects within it. The setup consisted of a standard household hairdryer securely positioned to prevent any movement during operation, a ruler for precise height measurement, and a flat, stable surface to maintain alignment (Figure 2). The hairdryer was placed in an upright position, directing airflow vertically upward. A lightweight spherical object, such as a ping pong ball, was used as the test object, allowing it to levitate in the airflow. The setup ensured minimal external interference and consistent environmental conditions for accurate and repeatable measurements.

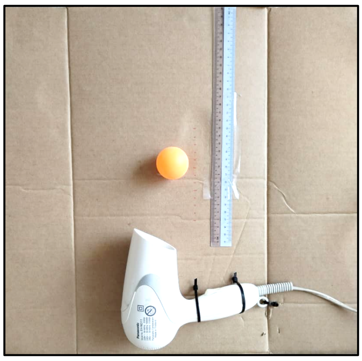

Fig. 2. Experiment setup

2.3 Experiment Procedure

This experiment aims to investigate how the equilibrium height of spherical objects set in an upward air stream will be affected. First, the hairdryer is positioned vertically so that a controlled amount of air and flow can be achieved. Then the spherical objects, which started with the standard ping-pong ball, were individually allowed to drop into the air stream centered above the nozzle. Each target was able to attain and settle in at its equilibrium height, which is where upward force of air flow balances out downward gravitational force.

The measurements were obtained by placing the ruler next to the airflow and from this measuring the height of the object accurately once it reached a stable condition. Two speeds, low and high, were achieved by adjusting the setting on the hairdryer. For each speed, three separate measurements of height were obtained to ensure reliability and then an average was found. For this experiment, the manipulated variables were spherical object type and speed of airflow; the responding variable was equilibrium height realized. The procedures of measurement were standardized as much as possible, and every effort was made to minimize external disturbances to ensure accurate and repeatable results.

2.4 Gravitational Force, Mass and Volume of Sphere

Several key parameters were considered in this methodology, including the mass, volume, and density of the spherical objects, which are essential for calculating the forces acting upon them. The gravitational force exerted on each ball was determined using the fundamental equation:

$$F_{\text{gravitational}} = m \cdot g \quad (1)$$

where m represents the mass of the ball and g denotes the acceleration due to gravity (9.81 m/s²). The mass of each ball was derived from the relationship between density and volume, calculated using the formula:

$$m = \rho \cdot V \quad (2)$$

here, ρ refers to the density of the material, and V is the volume of the sphere, which was computed using the standard volume formula for a sphere:

$$V = \frac{4}{3}\pi r^3 \quad (3)$$

2.5 Buoyant Force

Once the mass and volume were established, the buoyant force acting on each ball was calculated based on Archimedes' principle, which states that the buoyant force is equal to the weight of the displaced air. The equation used for this calculation was:

$$F_{Buoyant} = \rho_{air} \cdot V \cdot g \quad (4)$$

where ρ_{air} represents the density of air, typically considered to be 1.225 kg/m³ under standard atmospheric conditions.

2.6 Estimating Relative Heights

The equilibrium height of each ball was determined by analyzing the ratio of the buoyant force to the gravitational force, leading to the proportional relationship:

$$h_{equilibirum} \propto \frac{F_{buoyant}}{F_{gravity}} \quad (5)$$

This proportionality indicates that a higher buoyant force relative to gravitational force results in a greater equilibrium height, which is expected to be observed for lower-density objects. The experimental setup was carefully designed to minimize external factors that could influence the results, such as air turbulence and measurement errors. The manipulated variables in the experiment were the type of ball and airflow speed, while the equilibrium height served as the primary responding variable. This approach allowed for a detailed examination of how changes in density and airflow velocity influence the floating behavior of spherical objects in a vertical air column.

3. Results

3.1 Height for Each Ball

The results of the experiment provide a comprehensive analysis of the equilibrium heights achieved by the different spherical objects under varying airflow conditions. The data collected from the trials at low and high airflow speeds were systematically recorded and analyzed to identify trends and correlations between object density and equilibrium height (Table 2). At low airflow speed, the expanded polystyrene ball, having the lowest density of 0.011 g/cm³, achieved an average equilibrium height of 3.00 cm. In contrast, the ping pong ball, with a higher density of 0.084 g/cm³, reached a height of 4.84 cm, while the ocean rubber ball, with the highest density of 0.667 g/cm³, demonstrated the lowest equilibrium height of 0.60 cm. These findings highlight the inverse relationship between density and equilibrium height, as the least dense object achieved a higher position in the airflow.

Table 2
Low airflow speed results

Type of ball	Density of the object (g/cm^3)	Average height (cm)
Ping pong	0.084	4.840
Ocean rubber	0.667	0.600
Expended polystyrene	0.011	3.000

When the airflow speed was increased, the equilibrium heights of all balls increased. The expanded polystyrene ball exhibited the most substantial height gain, reaching an impressive 28.00 cm, compared to its previous height at low speed. The ping pong ball's equilibrium height increased to 8.10 cm, while the ocean rubber ball, despite the increased airflow, only reached 1.50 cm (Table 3).

Table 3
High airflow speed results

Type of ball	Density of the object (g/cm^3)	Average height (cm)
Ping pong	0.084	8.100
Ocean rubber	0.667	1.500
Expended polystyrene	0.011	28.000

3.2 Height Comparison

The comparison of equilibrium heights at low and high airflow speeds as shown in Table 4 provides further insight into how airflow intensity affects the behavior of objects. The expanded polystyrene ball showed the largest difference in height, followed by the ping pong ball, while the ocean rubber ball exhibited the smallest increase. This trend shows that less dense objects respond more easily to changes in airflow speed. The relatively minor increase in height for the ocean rubber ball suggests that the gravitational force acting on denser objects is stronger, limiting their response to variations in airflow.

Table 4
Height difference between low and high speed

Type of ball	Difference in height
Ping pong	3.26
Ocean rubber	0.90
Expended polystyrene	25.0

3.3 Mass and Volume of the Ball

The mass and volume of each ball were determined using the relationships described in Eq. (2) and Eq. (3). The calculated mass and volume values for each ball demonstrate the impact of density on physical properties. The expanded polystyrene ball, which has the lowest density, also shows the smallest mass. In contrast, the ocean rubber ball, being the densest, had the largest mass, while the ping pong ball fell between these two extremes. The summarized values can be found in Table 5.

Table 5
The mass and volume for each ball

Type of ball	Volume (m^3)	Mass (kg)
Ping pong	3.35×10^{-5}	2.81×10^{-3}
Ocean rubber	6.76×10^{-5}	4.50×10^{-2}
Expended polystyrene	6.54×10^{-5}	7.19×10^{-4}

3.4 Gravitational Force

The gravitational force acting on each ball was calculated using Eq. (1). This force was determined based on the respective masses of the balls. The ocean rubber ball experienced the highest gravitational force due to its greater density and mass, while the expanded polystyrene ball had the lowest force. These results emphasize the important role of gravitational force in counteracting buoyancy. Denser objects experience stronger downward forces, which limit their equilibrium height in the airflow. The gravitational forces for each ball are summarized in Table 6.

Table 6
The gravitational force for each ball

Type of ball	Gravitational force, F_g (N)
Ping pong	0.02760
Ocean rubber	0.00190
Expended polystyrene	0.00705

3.5 Buoyant Force

The buoyant force acting on each ball was calculated using Eq. (4). The results are summarized in Table 7. The calculated buoyant forces for the different balls show that variations in volume contribute to differences in lift. The expanded polystyrene ball experienced the highest buoyant force, followed closely by the ocean rubber ball, and then the ping pong ball. Although the ocean rubber ball has a relatively high volume, its greater density limited the effectiveness of buoyancy, resulting in lower equilibrium heights compared to the expanded polystyrene ball. This finding further supports the inverse relationship between density and the effectiveness of buoyant force in airflow.

Table 7
The buoyant force for each ball

Type of ball	Buoyant force (N)
Ping pong	4.04×10^{-3}
Ocean rubber	4.17×10^{-3}
Expended polystyrene	4.48×10^{-3}

3.6 Estimating Relative Heights

The equilibrium heights were estimated using the proportionality relationship provided in Eq. (5). The ratio of buoyant force to gravitational force was consistent with the experimental observations. The expanded polystyrene ball achieved the highest estimated height, while the ocean rubber ball recorded the lowest. These results validate the theoretical framework used in the study, demonstrating that lower-density materials experience greater equilibrium heights due to a more balance of forces. The estimated equilibrium heights, based on the calculated force values, are summarized in Table 8.

Table 8
The equilibrium height for each ball

Type of ball	Height (cm)
Ping pong	27.93
Ocean rubber	0.05
Expended polystyrene	0.43

4. Conclusions

In conclusion, the experiment demonstrates the relationship between an object's density and its equilibrium height when suspended in a vertically moving air current. The results indicate that lower-density balls, such as the expanded polystyrene ball, are more easily influenced by the buoyant force and can achieve higher equilibrium heights compared to higher-density objects like the ocean rubber ball. The ping pong ball, with medium density, performed at an average level, confirming the trend that higher densities lead to lower heights in a column of vertically flowing air. Additionally, the experiment revealed that increased air speed amplifies these differences, particularly for less dense objects, as the upward force from the air current grows stronger. These findings highlight the importance of material properties such as density in fluid dynamics and have practical applications in aerodynamics, materials science, and the design of lighter-than-air vehicles.

Furthermore, this study paves the way for further investigation into how factors like ball shape, surface texture, and varying air speeds affect the behaviour of objects in air currents, ultimately contributing to a deeper understanding of the interplay between density, buoyancy, and airflow with broader implications in engineering and environmental sciences.

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