Experimental Investigation of Ping Pong Ball Levitation via Vertical Air Jets

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Abstract. The experiment of levitating a ping pong ball with a vertically oriented hair dryer is a classic and significant demonstration in fluid dynamics. By using an upward air jet, the ball can be lifted and maintained in a stationary suspended position. The core principle is straightforward: when the upward force exerted by the air stream balances the downward gravitational force acting on the ball, it remains suspended in equilibrium. It clearly demonstrates Bernoulli's theory, showing how the relationship between flow velocity and pressure can produce a lift force and ensure that an object can be suspended steadily. It forms the foundation for applications in various industries, such as airplane lift and aerospace engineering. However, there are also some limitations, including scale effects, idealized conditions (e.g., turbulence), and simplified models. Additionally, the measurements in the experiment are quite complex, and the experimental values cannot be extremely precise. According to the experiment, the ball can remain steadily suspended in the specially designated region. As the flow velocity increases, the height of the ball also rises. Moreover, when the flow is disrupted, the suspended ball moves up and down. Yet, after the disruption, it returns to its original position and remains stable. This demonstrates dynamic stability and self-correction after minor perturbations due to pressure differentials. This research has a strong influence on future developments because it involves many fields, such as sports science and aerospace engineering. Overall, the experiment is not only an interesting demonstration but also a vital illustration of fundamental theory.

Keywords: Bernoulli's principle, Fluid dynamics, Air jet levitation, Dynamic stability.

1. Introduction

Using a hair dryer to blow a ping-pong ball is a very common experiment in daily life. For example, in magic shows, magicians often use this experiment as part of their performance, and the audience usually thinks it is magic. However, it is not magic, and it is fluid mechanics. It is a very meaningful experiment, containing a lot of knowledge that can be applied in many areas.

Why is it essential? Firstly, it plays an unchangeable role. Fluid mechanics is the study of fluids and the forces acting on them. Its study is critical in predicting rainfall, ocean currents, reducing drag on cars and airplanes, and designing engines [1]. Fluid mechanics studies the motion of fluids (liquids and gases) and is inseparable from the principles of fluid mechanics, whether it involves drinking water, driving a car, or an airplane taking off [2]. This experiment mainly demonstrates Bernoulli's theory.

It can be observed that in a fluid, when the flow velocity is constant, the suspension height of a sphere decreases as its weight increases. Conversely, when the weight of the sphere is kept constant, the suspension height increases with flow velocity—though not necessarily in a linear manner, as turbulence also influences the result. Moreover, when the speed of the flow increases, the pressure decreases. In addition, when the flow is gently moving, the ball will always follow the flow. A ping-pong ball, if placed above a vertical stream of air created by a hair dryer, will levitate over the stream with remarkable stability, even if the stream is tilted diagonally [3]. The fast-moving column of air from the hair dryer has less pressure than the surrounding air. The ping-pong ball bounces off the higher-pressure air in the room and stays inside the lower-pressure column of air coming from the dryer [4].

When the ball is placed in the air stream created by the hair dryer, the air flows around the ball and creates an area of lower pressure. The still air surrounding the air stream has higher pressure, pushing the ball to remain centered in the stream [5]. Additionally, in some engineering fields, this experiment can clearly demonstrate theory, making complex concepts easier to understand. For example, it is often applied to improve car aerodynamics.

At present, there are also some errors associated with the experiment. One major challenge is that it is not very accurate due to many factors that can interrupt experimental precision, such as the rotation of the sphere, environmental disturbances, and other factors. These can all affect measurement accuracy. However, there are also advantages. Firstly, it is easy to investigate because the experimental equipment is minimal. Furthermore, it is very inexpensive, and similar tests can be conducted online quickly. Finally, the experiment is easy to repeat.

This research will use determined values and some specialized methods to conduct systematic exploration. The equipment includes an adjustable hair dryer, a standard ping-pong ball or other objects that can be blown, measurement tools, and a camera.

The procedure consists of three parts:

- Use a camera and computer system to measure the height at which the ball floats.
- Compare the experimental results with theoretical predictions to evaluate their consistency.
- Test different objects to observe their levitation behavior.

2. Methods

This experiment is based on Bernoulli's theory: in an incompressible, non-viscous, and steady fluid, the pressure decreases when the flow velocity increases, and the pressure increases when the flow velocity decreases. Bernoulli's equation states that the sum of the pressure, kinetic energy density, and potential energy density for an incompressible fluid is constant along a streamline [6]. The Bernoulli principle is often misapplied in popular explanations of lift. This paper seeks to clarify that it is the combination of Newton's third law and the Coanda effect, guided by the conservation of energy as described by Bernoulli, that provides a more complete picture of aerodynamic lift [7]. In the context of airway narrowing, Bernoulli's principle explains the drop in lateral pressure, which can lead to dynamic compression of the airways during forced expiration—a critical factor in obstructive lung diseases [8].

The Bernoulli's equation can be described as follows:

$$P+\frac{1}{2}\rho v^{2}=C \tag{1}$$

2.1. Experimental Requirements

The experiment requires:

- A hair dryer with adjustable speed settings and a cold air function
- A measuring tape
- A large garbage bag (approximately 30 gallons in volume)
- A lightweight spherical object, such as a Styrofoam sphere, ping-pong ball, or any light ball whose weight can be measured
- An electronic device capable of video recording (e.g., a camera or smartphone)
- Tracker software for motion analysis

2.2. Experimental Procedures

2.2.1. Airflow Rate and Levitation Measurement

1. Determine the airflow rate of the hair dryer: securely attach the garbage bag around the dryer's nozzle, turn on the dryer, and record the time it takes to fully inflate the bag. Calculate the flow rate by dividing the bag's volume by the inflation time (m^3/s). Repeat for each speed setting if dryer speed is varied.

2. For the levitation experiment: secure the hair dryer to a chair with tape, ensuring it is firmly positioned and pointing upward. Turn on the dryer and gently place the selected ball into the airflow, adjusting its position until it levitates steadily. Gently perturb the ball to assess stability.

3. Record a video of the levitating ball using a camera or smartphone, ensuring the footage is clear enough for distance measurement.

4. Upload the video to Tracker software and perform the following steps:

1) Open the video file
2) Select frames to analyze
3) Calibrate the video scale using a known reference length
4) Set the origin and adjust the angle of the reference frame
5) Track the ball's position using the mouse
6) Generate and analyze trajectory plots
7) Save the project as a Tracker file
8) Export the tracking data to a spreadsheet
9) Save relevant images for inclusion in reports

5. Repeat the procedure for each variable condition (e.g., different dryer speeds). If available, also repeat the experiment with non-spherical objects of similar weight to compare levitation behavior.

2.2.2. Tilt and Temperature Variation Experiment

1. Place the ping-pong ball in the airflow. When the ball is stably suspended, slowly tilt the hair dryer (increments of 5°) and record the maximum tilt angle at which the ball remains suspended.

2. Repeat the experiment using different air temperatures (hot air has lower density than cold air) to observe changes in suspension height and stability.

3. Repeat the entire experiment at least three times to ensure consistency.

2.2.3. Multi-Object Levitation Experiment

1. Place the first ball in the airflow and wait until it is stably suspended.

2. Gradually add additional balls into the air stream to determine the maximum number of spheres that can be simultaneously suspended. Typically, the flow can only support one ball at a time.

3. Repeat the process at least three times to improve measurement accuracy. Tips: insert each ball slowly and perform the experiment in a room with minimal disturbances.

3. Results and Discussion

Upon analyzing the experimental data, we determined the average hovering height of the sphere. Based on the force balance condition (drag force equals effective weight), denoted as Equation 1, we calculated the local air velocity at the sphere's position. Furthermore, using the annular jet height relation (Equation 2) with a ring radius *R* as specified in the Dyson product manual, and assuming a jet decay constant *K*, the theoretically predicted hovering heights are as shown in Table 1.

Table 1. The data of experience with different radius of ring, jet decay constant and setting

Radius	18mm	19mm	20mm
jet decay constant	5.8	5.2	5
Low setting	0.038m	0.052m	0.045m
Medium setting	0.068m	0.087m	0.075m
High setting	0.142m	0.158m	0.135m

By back-calculating the value of *K* from the measured heights, we found that the discrepancy between theoretical and experimental values is likely due to the fact that *K* is not constant but increases with higher dryer exit velocity—a variation that may be attributed to the specific structural design of the Dyson dryer. Similarly, back-calculating *R* suggests that the effective jet radius also tends to increase with higher flow speed.

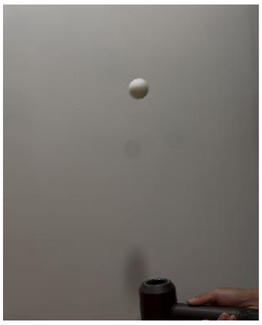
Experimental errors cannot be overlooked. Factors such as air turbulence in the test environment, fluctuations in air density due to temperature changes, and unavoidable movement of the handheld dryer during operation may have introduced interference into the measurements.

In summary, although the overall trend of increasing hovering height with air flow rate is consistent with theoretical predictions, improving predictive accuracy would require precise calibration of K and R for different operating conditions. Future studies should focus on accurately measuring these parameters under actual conditions to reduce model uncertainty.

$$U = \sqrt{\frac{z(m-\rho V)g}{\rho C_d A}} \tag{2}$$

$$y = \frac{kQ}{\pi R u_{req}} \tag{3}$$

Figure 1. Experiment in the constant speed of flow



second	fig	height
1	1	40cm
2	2	38cm
3	3	35cm
4	4	32cm
5	5	34cm
6	6	36cm
7	7	36cm

Figure 2. Experiment data correspond to the pictures one by one

Figure 3. Experiment in the flow of angle 30 degrees

second	fig	height
1	1	35cm
2	2	36cm
3	3	34cm
4	4	35cm
5	5	33cm
6	6	36cm

Figure 4. Experiment data in the flow of angle 30 degrees

Figure 5. Experiment when 2 spheres were put into the constant flow

Table 2. Experiment data when 2 spheres were put into the constant flow

Second	Figure	Height (ball A)	Height (ball B)
1	1	35 cm	
2	2	35 cm	
3	3	30 cm	30 cm
4	4	29 cm	29 cm
5	5	30 cm	5 cm
6	6	31 cm	26 cm
7	7	29 cm	29 cm
8	8	40 cm	20 cm
9	9	43 cm	15 cm

Figure 1 and 2 shows the experimental data in the constant speed of flow. When the first ball is stably suspended in the air, a second ball is introduced into the airflow, as shown in Figure 3. Initially, both spheres were unstable in the airflow (Figure 4). After approximately one second, the two balls collided and were subsequently ejected from the airflow (Figure 5).

According to experimental measurements and theoretical models, different conditions lead to varying outcomes. When the flow velocity is constant, the suspension height of a sphere decreases as its weight increases. Conversely, when the weight of the sphere is held constant, the suspension height increases with flow velocity, though not necessarily in a linear manner, as turbulence also influences the result. Moreover, when non-spherical objects are used, their suspension heights are generally lower than those of spheres, and they often exhibit prolonged vertical oscillations. Lighter spheres (with Reynolds number Re<10^3) yield more consistent results compared to heavier ones (Re>10^3) (as shown in Table 2).

According to Bernoulli's equation, the suspension height should be inversely proportional to the flow velocity. However, experimental results show a more gradual decrease, likely due to energy dissipation caused by turbulence, which deviates from initial theoretical expectations. To improve future experiments, it is recommended to measure flow speed fluctuations to account for disruptive factors such as environmental disturbances and turbulence, using the formula $I=(u'/U)\times 100\%$. Safety is another important consideration; appropriate protective clothing should be worn, and each experimental condition should be repeated at least three times.

In conclusion, the observed suspension height of the sphere was approximately 10% higher than theoretically predicted. This discrepancy may be attributed to factors not fully accounted for in the model, such as turbulence effects and the limitations of the drag coefficient in representing all fluid conditions. Once the flow stabilizes, oscillations of the ball are commonly observed.

In conclusions, Bernoulli's equation is very suitable with this experiment. When the speed is increasing, the height of suspension will also increase. Because the low level's velocity of fluid is faster than higher. So, the low-pressure area and the high-pressure area is made by velocity low-pressures, there is a push force appear which can counteract the weight of sphere and make the ball in a steady suspended. A ball can be suspended in an air jet. The ball remains in the jet due to the balance of forces, including the lift force from the jet and the gravitational force [9]. When a hair dryer is used to generate an upward air jet, the ping-pong ball is suspended. The higher the jet velocity, the higher the stable suspension height [10]. The stability of a ping-pong ball suspended in an air jet is affected by the jet's Reynolds number and the ball's size. Smaller balls are more stable than larger ones at the same jet velocity [11]. Using a hair dryer as an air jet source, the suspension height and stability of a ping-pong ball can be easily observed and measured [12].

Although this experiment vividly demonstrates fluid mechanics, it has limitations. It is primarily qualitative rather than quantitative, providing visual insight but not precise numerical data, such as exact airflow speed, pressure differences, or forces acting on the ball. Turbulence is a major source of experimental error. Additional minor factors, such as hair dryer instability and surface roughness of the sphere, can also affect the results.

For future work, this experiment offers potential insights for engineering applications. Parameters such as jet Reynolds numbers, impingement height, and the distance between jet centerlines can be varied to explore different behaviors [13]. Studies have shown that the hydrodynamic dispersion coefficient depends on the effective Lagrangian Peclet number of a packed bed [14], and creeping flow of a Newtonian fluid in a hemispherical region has been used to model Marangoni flow induced by a local source at the liquid–gas interface [15]. Numerical methods in fluid mechanics have applications across engineering fields, including aeronautics, civil, environmental, hydraulic, and mechanical engineering [16].

4. Conclusion

Introducing precision measurement equipment, such as hot-wire anemometers to quantify wind speed and high-speed cameras to improve data accuracy, can enhance experimental reliability and enable direct verification of the underlying mechanisms. Expanding the range of measured values and using different air temperatures (which affect density) can further enrich the experimental study.

The classic "hair dryer and ping-pong ball" experiment provides an intuitive demonstration of Bernoulli's principle: high-velocity airflow creates a region of low pressure around the ball. The resulting pressure difference, together with ambient static pressure, generates an upward force that balances the ball's weight, stably suspending it within the airflow. A notable feature of the experiment is its self-stabilizing behavior; if the ball moves away from the center, the asymmetry in flow velocity induces a lateral restoring force, returning it to equilibrium.

Although this experiment effectively illustrates fundamental fluid dynamic mechanisms, such as the pressure differentials contributing to lifting generation over an airfoil. It is subject to several inherent limitations. Environmental turbulence disturbs the uniformity of the airflow, and the absence of precision instruments limits measurement of key parameters such as flow velocity, pressure distribution, and lift force. As a result, this setup serves primarily as a pedagogical tool for introducing core concepts in fluid mechanics rather than as a quantitative research method.

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