Investigating the relationship between the height of fall and drag Force

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This investigation aims to explore how the height from which a ball is dropped affects the drag force it experiences. Understanding this relationship is crucial in fields such as aerodynamics and engineering, where predicting the motion of objects through fluids is essential.

Background Information:

When an object falls, it falls due to gravity and continues to accelerate continuously at that rate $9.81ms^{-2}$, which happens when it falls through a vacuum. When an object starts falling through the air an opposing force acts upon that object, this stops the object from continuously accelerating due to gravity and balances out the forces reaching terminal velocity, this force is known as the **Drag Force**.

Drag force is a type of friction that acts opposite to the motion of an object moving through a fluid, such as air. It arises due to the interactions between the surface of the object and the fluid molecules. The drag force is influenced by several factors, including the object's shape, size, velocity, and the fluid's properties.

The drag force (F_d) acting on an object is calculated using the drag equation:

$F_d = \frac{1}{2}C_d \rho A v^2$ [1]

- C_d: Drag coefficient of a sphere, 0.47 [2]
- ρ: Air density (kgm^{-3}), 1.225 kgm^{-3}.[3] which affects the magnitude of drag force, the higher the air density, the higher the drag force produced
- A: Cross-sectional area of the G-ball ($0.03141\ m^2$), which determines how much air the object displaces as it falls
- v: Velocity (ms^{-1}), the speed of the object relative to the fluid that it's falling through, which affects the drag force since they are directly proportional

[1] https://www1.grc.nasa.gov/beginners-guide-to-aeronautics/drag-coefficient/

[2] https://www1.grc.nasa.gov/beginners-guide-to-aeronautics/shape-effects-on-drag/

[3] https://skybrary.aero/articles/international-standard-atmosphere-isa

The drag equation is derived from fluid dynamics principles, balancing the forces acting on an object moving through a fluid. It is based on the assumption that drag is proportional to the velocity squared, reflecting the increased resistance encountered at higher speeds.

Bernoulli’s equation states that the pressure difference created across an object moving through a fluid is proportional to the dynamic pressure which is shown by the equation:

$$P_{dynamic} = \frac{1}{2}\rho v^2$$

The pressure difference generated a force which acts against the objects motion, and that force is proportional to the product of the pressure and the object’s cross-sectional area so we egt the following equation

$$F_d \propto P_{dynamic} \times A = (\frac{1}{2}\rho v^2) \times A$$

Then the drag coefficient (C_d) is added to the equation to account for the objects shape and surface roughness, variations in flow regime, and other interactions between the object and the fluid, this value is determined through experimentation and is a constant for each object, with that we get the final equation:

$$F_d = \frac{1}{2}C_d\rho A v^2$$

Fundamental Units

- Drag Force (F_d): N
- Air Density (ρ): kgm^{-3}
- Cross-sectional Area (A): m^2
- Velocity (v): ms^{-1}

The drag coefficient of a sphere varies from 0.07 to 0.5, and 0.47 is an appropriate drag coefficient value for a G-ball as it is a rough sphere, air density was set as 1.225 kgm^{-3} which is the density of air at sea level, and the cross-sectional area of the G-ball has been calculated as $0.03141\ m^2$

Varying the fall height allows for the exploration of how drag force develops as the object reaches different velocities. Since the drag force is proportional to v^2, then according to the equation, as the height increases, the drag force would subsequently also increase, thus I hypothesize that the graph would take a linear form

Research Question:

How does the height from which a ball is dropped (1.00m, 1.20m, 1.40m, 1.60m, 1.80m, 2.00m), affect the drag force it experiences

Hypothesis:

As the height from which the ball is dropped increases, the drag force exerted on the ball will increase. This is because higher drop heights result in greater velocities, leading to increased drag forces according to the drag equation.

Variables:

Independent Variable: The height from which the ball is dropped, measured using the ruler
Dependent Variable: The time it takes for the ball to hit the ground, measured using the built in timer in G-ball
Controlled Variables:

Controlled variable	**how are they controlled?**	**Why are they controlled?**
Mass of the ball	The same ball is used for all trials, 121.01 grams	Because the mass of the ball affects the velocity of the ball when falling through air
Cross-Sectional Area	The same ball is used for all trials, with a radius 5cm	Because the Cross-Sectional Area of the ball affects the drag the ball experiences, the higher the cross-sectional area the higher the drag force the ball experiences
Initial Velocity of the ball	The same release mechanism is used in all trials, thus the initial velocity of the ball is 0	The force that the ball experiences initially will affect both the velocity and time taken for the ball to reach the ground, so it has to be kept constant to find the effect of height on the drag force
Air Density	The trials were all conducted in closed room with the same environmental conditions	Because the higher air density the higher the drag forced experiences and the opposite is true

Table 1: Controlled Variables

Materials:

Manual apparatus

- 1m Ruler (±0.05m)
- Pen

Digital Apparatus:

- G-ball with a built-in timer (±0.01s)

Methodology:

1. Place a ruler on the wall, and mark the heights 1.00m, 1.20m, 1.40m, 1.60m, 1.80m, and 2.00m with a pen
2. Drop the G-ball from the 1m height
3. Record the reading in the g-ball when it hits the ground
4. Repeat steps 2 and 3 for 5 trials
5. Repeat steps 2,3, and 4 for each of the heights marked on the wall

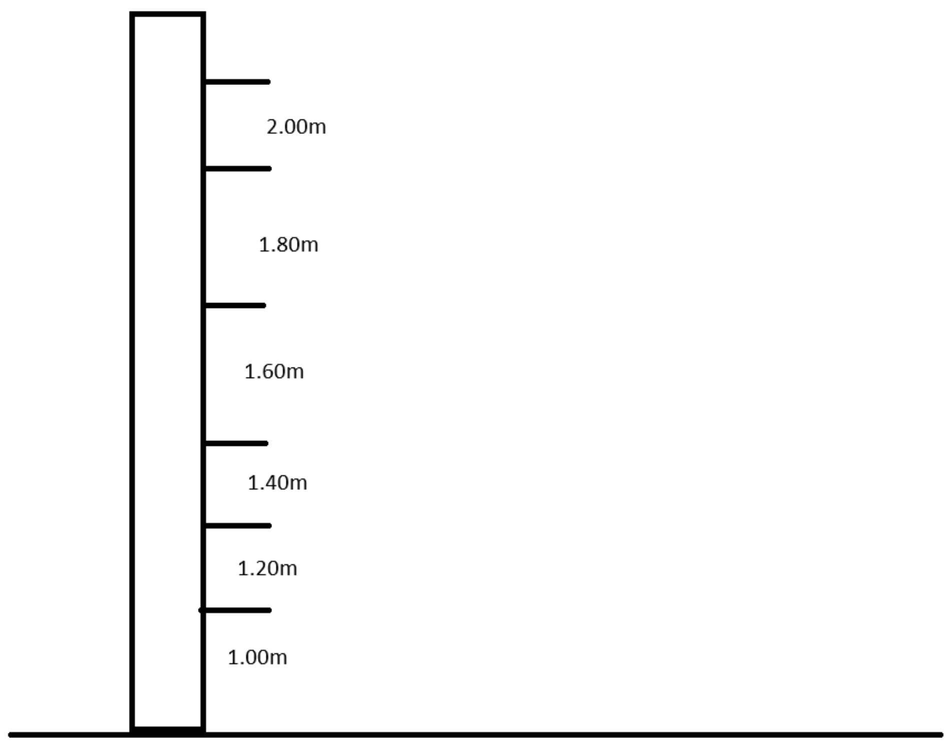

Fig 1: A rough sketch of the experiment setup

Risk Factors:

Environmental: No environmental issues were linked with the expriment.
Ethical: No ethical concerns were identified.
Safety: Be cautious of falling objects and ensure the area is clear of obstruction

Raw Data:

Height(H) ±0.05m	(Time Elapsed)				(s ±0.01s)
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
1.00	0.44	0.46	0.46	0.45	0.44
1.20	0.50	0.48	0.48	0.49	0.48
1.40	0.53	0.55	0.55	0.53	0.53
1.60	0.57	0.58	0.59	0.58	0.58
1.80	0.60	0.62	0.60	0.62	0.62
2.00	0.65	0.66	0.63	0.64	0.64

Table 2: Raw Data

Processed Data:

Calculations:

$$Average\ Time = \frac{\sum Trials\ Times}{Number\ of\ Trials}$$

$$Average\ Time = \frac{0.44+0.46+0.46+0.45+0.44}{5} = 0.45s$$

$$\Delta t = \frac{Max - Min}{2} = \frac{0.46-0.44}{2} = \pm\ 0.01s$$

$$v = \frac{2h}{t_{avg}}$$

$$v = \frac{2x1}{0.45} = 4.44ms^{-1}$$

$$\Delta v = 2\Delta h + \Delta t$$

$$\Delta v = 2(0.05) + 0.01 = \pm 0.11$$

$$F_d = \frac{1}{2} C_d \rho A v^2$$

$$F_d = \frac{1}{2} \times 0.47 \times 1.225 \times 0.03141 \times 4.44^2 = 1.78$$

$$\Delta F_d = \frac{1}{2}(2\Delta v) = \Delta v$$

$$\Delta F_d = \Delta v = \pm 0.11$$

Height (m) ± 0.05	Average Time (s) ± 0.01	Velocity ms^{-1} ± 0.11	Drag Force (N) ± 0.11
1.00	0.45	4.44	1.78
1.20	0.49	4.90	2.17
1.40	0.54	5.19	2.44
1.60	0.58	5.52	2.76
1.80	0.61	5.90	3.15
2.00	0.64	6.25	3.53

Table 3: Processed Data

Graph:

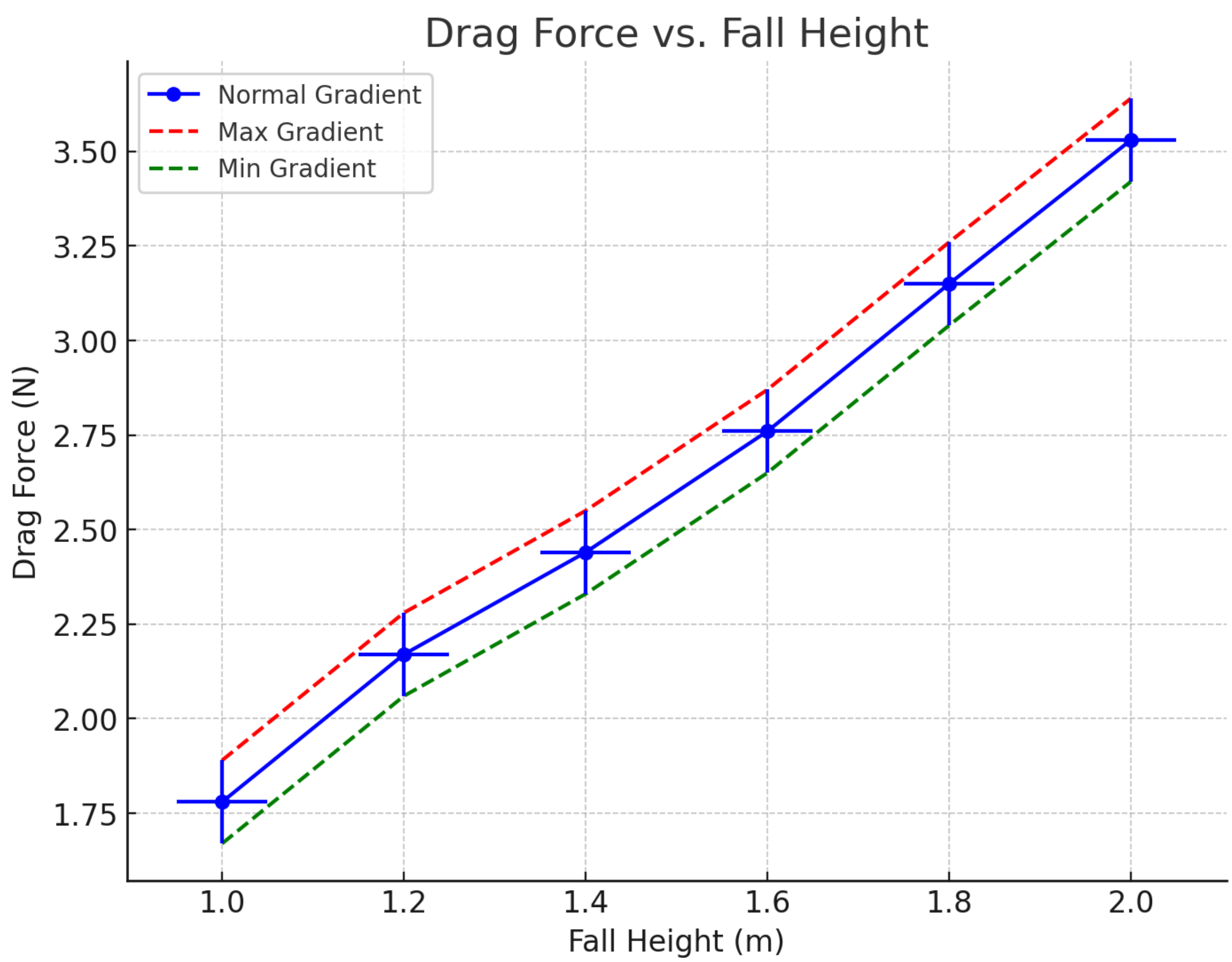

Fig 2: Graph of Drag Force vs Fall Height

Data Analysis:

When looking at the normal gradient line, it can be observed that as the fall heigh increases, the drag force also increases which is consistent with what was hypothesized, According to the drag equation, the minimum gradient line which represents the lower bound of the data shows a similar trend but at a less steeper increase in drag force with height, which indicates the minimum possible that height can have on drag force. The maximum gradient line also shares the same trend when it represents the upper bound of the data and it shows the maximum possible effect that height can have on drag force.

What these trends imply is that at lower heights, 1.00 m to 1.20 m, the drag force increases linearly with height, suggesting that the ball has yet to reach a velocity in which drag force has a significant effect on its motion. At heights beyond 1.20 m, the increase in drag force becomes nonlinear, meaning that now the ball has reached velocity values that cause higher drag force to act upon it, and at the highest heights of 1.80 m and 2.00 m, the drag force increases less. This is due to the ball possibly reaching velocities in which both the drag force and the gravitational force have balanced out, causing the ball to fall at terminal velocity.

Conclusion:

The experiment shows the effect of height on drag force, which is as height increases, the drag force would also subsequently increase to balance out the forces of drag and gravity acting on the ball; furthermore, it shows the differences in the levels of increase in drag force at different heights as the increase initially starts of linear and then becomes nonlinear and then it’s lower increases in drag force, each showing the different phases that the ball goes through.

What his means is that at lower heights the ball has not fallen long enough to reach a velocity that causes a high drag force to be present, but as the height of the fall increases, the ball has more time to gain velocity, which then leads to an increase in the opposing drag force. This cycle will repeat until both the velocity and drag force balance out .

These findings are crucial in fields of aerodynamics, sports, and engineering, as understanding drag forces and what affects them is initial when designing and optimizing vehicles, aircraft, sports equipment, and structures.

Evaluation:

Limitations	How do they Limit the experiment
Simplistic Setup	The setup for the experiment had minimal equipment as well as it being very basic, which causes it to be unable to account for complexities such as turbulences, air currents, or any external force that acts on the ball
Assumption of Constant Drag Coefficient	The drag force in the experiment is assumed to be constant, but in reality it can vary depending on the velocity and surface roughness of the ball
Neglect of Other Forces	The experiment's sole focus is drag force and neglects other forces such as buoyancy or the Magnus effect
Human Error in Timing	Despite the G-ball containing a built-in timer, slight delays are still present when recording the time taken for the ball especially if the ball does not land with enough force to stop the timer, or a delay is present between the time in which the timer is pressed and the ball being released
Environmental Factors	It is assumed in the experiment that the room is closed and the environmental conditions are constant, but in a real-world scenario many factors are present, such as air currents, temperature and humidity changes which all can affect the results
Limited Data Points	The experiment cant account for extreme scenarios, as the data points available only account for simple and basic scenarios.

Table 4: Limitations

Weakness	Way to improve the weakness
Manual Measurement of Heights	The Height is measured using a rule and this is method is prone to human error, meaning that heights marked are not exactly as intended, this can be solved by using a digital height-measuring device or a laser level, which will eliminate human error and the experiment will have precise and consistent measurements of heights
Ball Damage Upon Impact	The repeated impacts that the ball suffers when hitting the ground can cause potential alterations in surface area and shape, which can affect the drag force experienced by the ball, to eliminate this weakness, a cushion can be palace at the area in which the ball will land, which will absorb impact and the ball won't be damaged
Air density Variations	The experiments is conducted under the assumption of constant air density, but any small change in temperature or humidity can alter the air density, to solve this issue, the experiment can be conducted in a closed, controlled environment and the air density is measured using a barometer
Single Object Used	Only a single type of ball with the same shape and surface area, this limits the generalizability of the findings of the experiment to objects that share the same shape and surface area of the ball, this can be improved upon by repeating the experiment with different objects that differ in shape and surface area and compare the results of how height affects drag force

Small Range of Heights	The experiment only tested a small range of heights from 1.00m to 2.00m and this cant fully show the relationship between height and drag force at higher heights in which the ball has more to time to gain velocity, so the experiment can be conducted at an extended range of heights.

Table 5: Weaknesses

Whilst the experiment provides insight into the relationship between fall height and drag force, the simplicity of it and it's many assumptions cause limitations to how generalizable the data can be, but it serves as a good basis for further research that can account for real-world factors.

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