Optimized Heating Strategies for Aluminum: A Theoretical and Experimental Study

Minghao[1], Omar Tawakol[2,3]

[1]Iroquois Ridge High School, Canada

[2]Illinois Institute of Technology

[3]The University of Chicago

Abstract

This paper investigates the motion of a projectile inside the International Space Station (ISS), focusing on how air resistance and microgravity affect the velocity of an object. We develop a mathematical model to estimate the motion of an object inside the ISS by considering both horizontal and vertical components, while accounting for air resistance and the small gravitational forces in the microgravity environment. Through vector analysis and calculus, we solve the differential equations governing the motion and derive the equations for the velocity over time. Results show significant deviations from ideal models due to the influence of air resistance and microgravity, highlighting the importance of accounting for these factors in space-based experiments.

1 Introduction

The motion of objects in a microgravity environment, such as inside the ISS, differs substantially from motion under standard gravitational conditions on Earth [1]. While space is often assumed to be a frictionless environment, the ISS maintains an internal air pressure similar to that on Earth, leading to air resistance that affects the movement of objects [2]. Additionally, while microgravity is much weaker than Earth's gravity, it still exerts a small force on moving objects.

Previous studies on projectile motion often assume either ideal vacuum conditions or ignore the combined effects of air resistance and microgravity. In this paper, we aim to bridge this gap by developing a mathematical model that accounts for both factors. By comparing the motion of a projectile in the ISS with an idealized model without air resistance or gravity, we will highlight the significant impact of these forces.

This research has important implications for understanding the behavior of objects in space stations, as well as for designing experiments and mechanical systems that function in microgravity environments. The study is motivated by the need to improve the accuracy of motion predictions for objects in low-gravity, enclosed environments such as the ISS.

2 Methods

Assuming the object is thrown inside the International Space Station (ISS), we need to consider both air resistance and microgravity. Let:

g_{micro} be the small acceleration due to microgravity.

b be the drag coefficient.

m be the mass of the object.

v_{x0} and v_{y0} be the initial horizontal and vertical velocities, respectively.

t be the time elapsed since the object was thrown.

2.1 Horizontal Motion with Linear Drag

The equation of motion for the horizontal component is:

$$m\frac{dv_x}{dt} = -bv_x \tag{1}$$

Solving this differential equation:

$$v_x = v_{x0}e^{-\frac{b}{m}t} \tag{2}$$

2.2 Vertical Motion with Linear Drag and Microgravity

The equation of motion for the vertical component is:

$$m\frac{dv_y}{dt} = -bv_y - mg_{\text{micro}} \tag{3}$$

Solving this differential equation using an integrating factor:

$$v_y = -\frac{mg_{\text{micro}}}{b} + \left(v_{y0} + \frac{mg_{\text{micro}}}{b}\right)e^{-\frac{b}{m}t} \tag{4}$$

2.3 Combined Velocity

The total velocity at any moment is given by:

$$v(t) = \sqrt{v_x(t)^2 + v_y(t)^2} \tag{5}$$

Substituting the expressions for $v_x(t)$ and $v_y(t)$:

$$v(t) = \sqrt{\left(v_{x0}e^{-\frac{b}{m}t}\right)^2 + \left(-\frac{mg_{\text{micro}}}{b} + \left(v_{y0} + \frac{mg_{\text{micro}}}{b}\right)e^{-\frac{b}{m}t}\right)^2} \tag{6}$$

3 Results

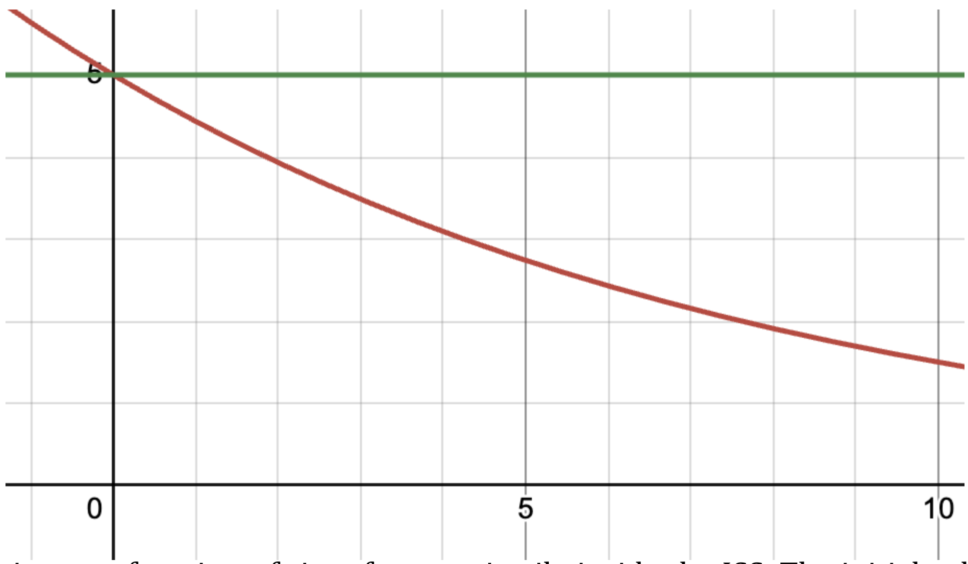

Figure 1: Velocity as a function of time for a projectile inside the ISS. The initial velocity is 5 m/s, with a drag coefficient of 0.009kg/s and a mass of 75g.

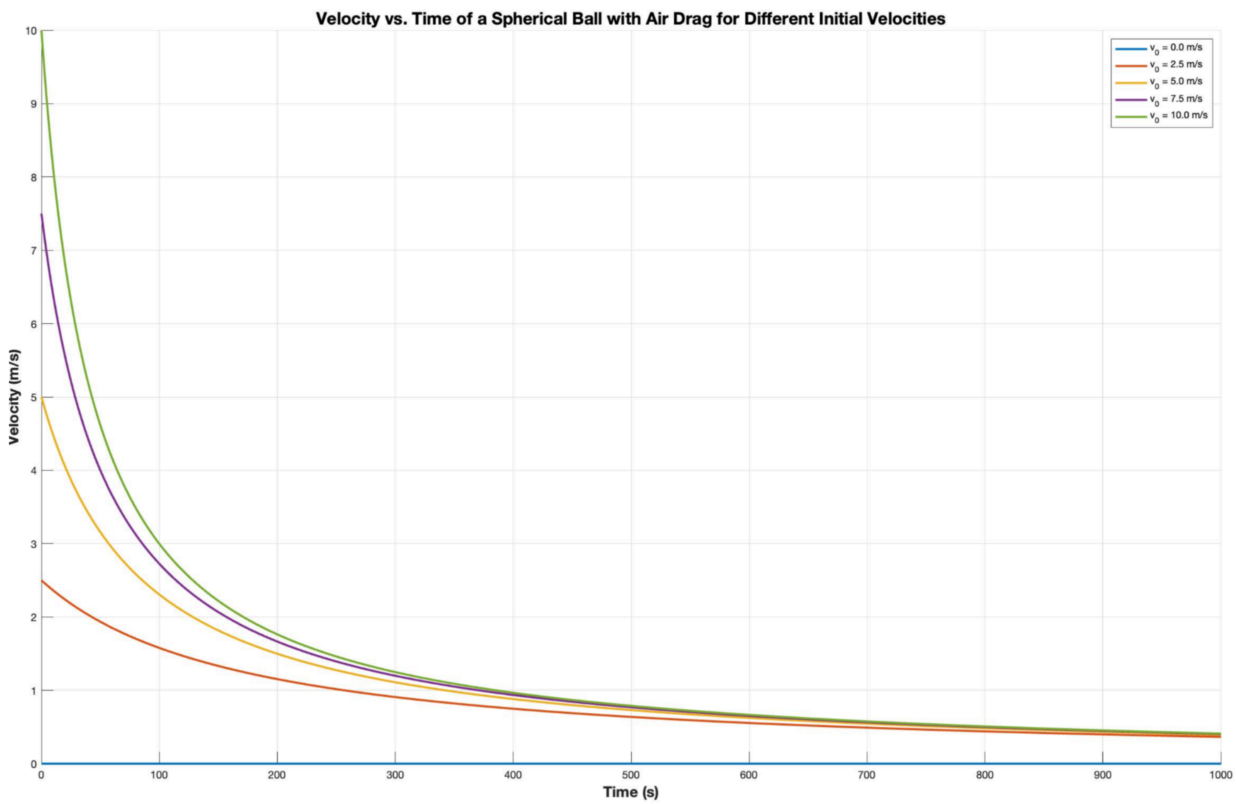

Figure 2: The effect of drag on the velocity of the projectile over time.

For this analysis, we used typical values from the Shenzhou 14 mission inside the ISS. The initial horizontal velocity was assumed to be 5 m/s, with a drag coefficient b=0.009kg/s, a mass m=75 g, and a microgravity value of g_{micro} = 9.8 *10^-6N/kg. The initial vertical velocity was set to zero.

Figure 1 shows the function between velocity (m/s) and time (s). The velocity of the object decreases significantly over time. After approximately 5 seconds, the velocity halved due to the resistance to air. This demonstrates that, even in a microgravity environment, air resistance cannot be neglected when analyzing the motion of objects. The drag coefficient plays a significant role in slowing down the object. While microgravity has a minor effect compared to air resistance, it still influences the motion over longer periods.

4 Discussion

This work was inspired by a problem that was introduced to the author during a physics class. The problem was stated as follows:

18. (2 points) At 15:40 on March 23, 2022, the second lesson of Tiangong Classroom started at the Chinese Space Station. Teacher Wang Yaping can live in the space station, so the air pressure inside Tiangong is (optionally greater than, less than or equal to) the air pressure outside Tiangong. In the space parabolic experiment, we invited the top assistant teacher Bingdundun. Teacher Wang Yaping applied a force to Bingdundun, and Bingdundun moved. When Bingdundun left Teacher Wang Yaping's hand, we saw that Bingdundun's motion state was:

This work has shown that the assumptions made by the problem were fundamentally flawed and that air resistance and microgravity do have an effect on the velocity of a projectile aboard the ISS.

Future work could extend this model by including rotational dynamics or exploring other environments with varying pressures and gravitational forces. Additionally, this model could be applied to the motion of astronauts or robotic systems in similar conditions. By accurately modeling the motion of objects in space stations, we can better design experiments, tools, and systems for low-gravity environments. This understanding is crucial for long-term missions and the continued exploration of space.

5 Conclusion

In this paper, it was shown that air resistance and microgravity have significant effects on the motion of an object inside the ISS. While microgravity is much weaker than Earth's gravity, its effect becomes noticeable when combined with the decelerating force of air resistance. Our model predicts that an object's velocity can halve within seconds due to drag, highlighting the importance of considering air resistance even in enclosed environments like the ISS.

6 Bibliography

[1] D. M. Ruden, D. D. Bolnick, L. Nguyen, R. C. Garbe, C. G. Lu, S. L. Simon, M. B. Ulbrich, K. H. Beckingham, and T. E. Zwaka, "Effects of Gravity, Microgravity or Microgravity Simulation on Early Mammalian Development," Stem Cells and Development, vol. 27, no. 18, pp. 1230–1236, Sep. 2018, doi: 10.1089/scd.2018.0024.

[2] L. Mahrt et al., "Determination of the surface drag coefficient," Boundary-Layer Meteorology, vol. 99, no. 2, pp. 249–276, May 2001, doi: 10.1023/A:1018915228170.