Exploring Air Friction and its Effects on Acceleration

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Abstract

In this experiment we studied the effects of increasing the cross-sectional area of a cart on its acceleration and velocity. Through this, we proved that air resistance exists and is directly correlated to the cross-sectional area of an object, as well as its shape. Furthermore, we found that air resistance can be decreased by keeping cross-sectional area constant and changing the shape of an object.

Introduction

Throughout high school physics, we have been calculating the range of projectiles, the velocity of carts, and even the acceleration of planes - all by assuming that air resistance is negligible. In this experiment, we set out to prove that air resistance does exist, and that it has a significant impact on acceleration and velocity of an object relative to its cross-sectional area

Background

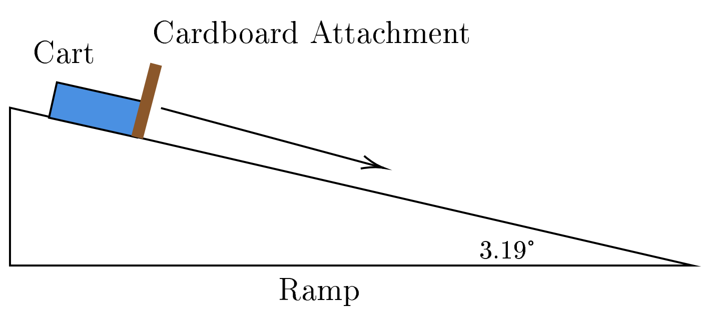

Figure 1. General experimental setup with a Smart Cart rolling down a ramp. Cross-sectional area of the cart is changed using a cardboard attachment.

Figure 1 shows the basic experimental configuration of this experiment. The cart was rolled down a ramp with an attachment on its front. Said attachment modified the cart's cross-sectional area as well as its aerodynamic properties.

We can break down the forces experienced by the cart into components 1 as shown in the free body diagram below.

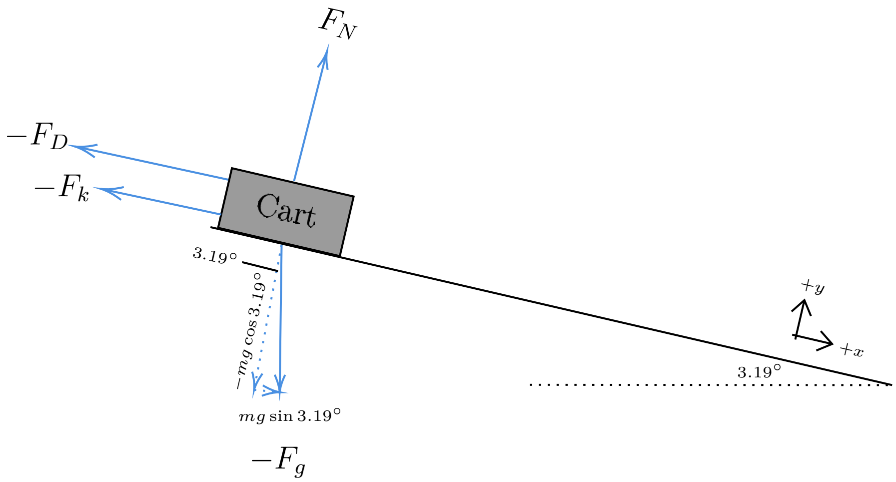

Figure 2. Free body diagram illustrating various forces acting upon the Smart Cart

In the free body diagram in figure 2, the cart is on the ramp, with the forces of air resistance (F_D) and kinetic friction (F_k) acting against the cart in the horizontal direction. The cart is also accelerated down the ramp by the horizontal component of gravity ($mg\sin(3.19°)$).

$$F_{\text{net}} = mg\sin(\theta) - \mu mg\cos(\theta) - kv^2$$

$$ma = mg\sin(\theta) - \mu mg\cos(\theta) - kv^2$$

$$a = \frac{mg\sin(\theta) - \mu mg\cos(\theta) - kv^2}{m} \tag{1}$$

Methods

1. A 250g weight was taped onto the Smart Cart to make the effect of additional weight negligible

2. A 1.22m ramp was placed on top of a textbook so that it made a 3.14 degree angle with the lab bench counter
3. Depending on the trial being run, a cardboard attachment was measured and cut to proper dimensions and taped to the front of the Smart Car
4. The Smart Car's position, velocity, force, and acceleration were all recorded relative to time using Pasco Capstone software
5. The above steps were repeated eight more times until all trial data were successfully collected

Results

Table 1

K values relative to cross-sectional area and the shape of the attachment

Attachment	**Length**	**Width**	**Area (cm^2)**	**K**
None			22	0.244
Orange Pocket	29	33	957	0.623
Cardboard	9.4	26.5	249	0.498
Cardboard	15.78	15.78	249	0.538
Orange	29	33	957	0.732
Equilateral Wedge	9.4	26.5	249	0.380
Sharp Wedge	9.4	26.5	249	0.313
Sharp Wedge on Orange	29	33	957	0.492

Discussion

Our results partially support our hypothesis, as we were correct to assume that increasing the pullback distance would increase the range, however, the trend we found was quadratic rather than linear. The assumption was made that the elastic was a linear spring, which follows Hooke's Law - the force exerted by a spring as it returns to its original position is directly proportional to the distance of deformation. However, substituting Hooke's Law into the equation $F = 1/2mv^2$ reveals that a linear increase in the force applied to an object results in only a square root increase in the velocity (and therefore range) of the projectile. Therefore, we should expect a square root trend in the range of the projectile, however, the data shows a quadratic increase in the range. This could be due to not pushing the elastic to its extremes, either too low or too high, which would present as skewed data in our experimental observations. In order to test if there is actually a square root increase, a stronger elastic should be used, in order to test higher forces. Because of the v^2 term, the trend would appear linear at low forces, and only become noticeably curved at higher forces. Using a stronger elastic would allow testing of higher forces while still ensuring that the spring is behaving linearly.

One potential source of error in the experiment is the human error involved in firing the projectile. Sometimes, the projectile would be fired at an angle or the elastic would get twisted, putting spin on the projectile, both of which would reduce the measured range. To account for this, as many trails as possible were completed and outliers were removed where there were serious problems when the projectile was fired. That being said, it would be beneficial to automate the launch mechanism by connecting it to a switch or button that would be pressed to release the elastic. This would make the launcher more precise and remove the systematic error. Furthermore, the materials used in the experiment were of lower quality, and were not particularly sturdy. This caused the launcher to shift around as projectiles were being fired, which would introduce random error into the experiment. With more time and a larger budget, better materials could be purchased and assembled to improve the quality of the launcher and the reliability of the data gathered.

Overall, our data modelled a strong correlative trend between Distance Travelled and Pullback Distance as shown in Figure **??**, with an R^2 value of 0.992. However, we expected the elastic to behave linearly, indicating that there were errors present in either experimental design, or some other extraneous error that could have skewed our results. Even with the slightly skewed data, we can still conclude that when pullback distance of a catapult is increased, the range will increase at an almost-linear rate.

References

What is hooke's law? (n.d.). Retrieved March 7, 2020, from https://www.khanacademy.org/science/physics/work-and-energy/hookes-law/a/what-is-hookes-law

Appendix A

Data Tables

Table A1

Observed projectile range at a pullback distance of 5cm

Pullback Distance (cm)	**Distance Travelled (cm)**
5	60
5	60
5	63
5	61
5	62
5	62
5	63
5	63
Average Range	61.8

Table A2

Observed projectile range at a pullback distance of 10cm

Pullback Distance (cm)	**Distance Travelled (cm)**
10	191
10	220
10	203
10	190
10	175
10	222
10	216
Average Range	202.4

Table A3

Observed projectile range at a pullback distance of 12.5cm

Pullback Distance (cm)	**Distance Travelled (cm)**
12.5	338
12.5	333
12.5	332
12.5	336
12.5	332
Average Range	334.2

Table A4

Observed projectile range at a pullback distance of 15cm

Pullback Distance (cm)	**Distance Travelled (cm)**
15	392
15	450
15	418
15	410
15	426
15	422
15	425
15	423
15	427
Average Range	421.4

Appendix B

Sample Calculations

Average Range

$$\text{Average Range} = \frac{R_1 + R_2 + R3 + ... + R_n}{n} \tag{2}$$

$$\text{Average Range}_{12.5\text{cm}} = \frac{338 + 333 + 332 + 336 + 332}{5} \tag{3}$$

$$\text{Average Range}_{12.5\text{cm}} = 334.2 \text{ cm} \tag{4}$$