Equipment Setup

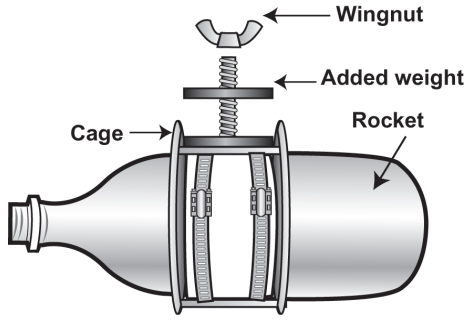
Investigation Guides

Force, Motion and Energy (continued)

B-4 The Rocket and Newton's Laws of Motion

Key Question: How does the mass of the air rocket affect its speed?

In this Investigation, students design an experiment that uses the air rocket to see how mass influences acceleration. In the process, students prove Newton's second law of motion that acceleration is equal to force divided by mass. Because the air rocket also demonstrates Newton's first and third laws of motion, the Investigation provides students with an excellent review of Newton's laws of motion.



Preparation

A challenging part of this Investigation is finding the mass of the air rocket and the rod that supports it. The method demonstrated in the Investigation will not give the exact mass, but it is simplistic. The method will give you a mass of about 371 grams. This value is about the mass of the rocket end plus half the mass of the rod. If you measure the individual pieces of the supporting rod and take into account that the more massive centerpiece of the apparatus includes in its mass more than half the mass of the rod, the mass of the air rocket end is closer to 420 grams.

In some cases, you can use a 400-gram balance to measure more than 400 grams. You simply need to place a mass on the balance that weighs 400 grams or nearly that and then tare the balance. This will mean that when you place a 600-gram object on the balance, for example, the balance will read "200 grams."

Setup and Materials

Students work in groups of four at tables.

Each group should have:

- The air rocket apparatus with a pump
- A timer and two photogates
- A simple calculator
- A digital balance designed to measure up to 400 grams or greater

The Investigation

Time One class period

Leading Questions

- How does the mass of the air rocket affect its speed?
- How do Newton's three laws of motion apply to the air rocket?

Learning Goals In this Investigation, students will:

- Explore how the mass influences the speed of the air rocket.
-

Key Vocabulary inertia, Newton's laws of motion

1

My hypothesis is that the speed of the rocket should decrease as the mass of the rocket increases. I believe this hypothesis is correct because mass is a measure of an object's inertia (resistance to acceleration). Therefore, more mass means less acceleration for a given amount of force. Less acceleration should result in lower speed.

B-4 The Rocket and Newton's Laws of Motion

B-4

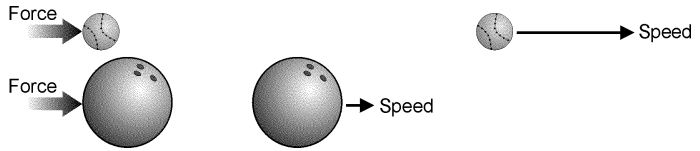
Question: How does the mass of the air rocket affect its speed?

In this Investigation, you will:

1. Test whether the mass of the air rocket affects its speed.
2. Learn how Newton's three laws of motion apply to a rocket.

Applying a force makes an object move. Since Aristotle's time, people have struggled to understand how and why objects move. The rocket provides a tool for seeing how mass resists acceleration, a property often called **inertia**. Sir Isaac Newton was the first to put all the pieces together in the *Principia* where the three laws of motion were published for the first time. All three laws are important for understanding rocket motion, as you will see in this Investigation.

1 Making a hypothesis



Imagine throwing a baseball and then throwing a bowling ball. The bowling ball has a much greater mass than the baseball. If you apply the same force to each, how will their speeds compare? The real experiment would be difficult to do because there are variables that are hard to control. For example, it would be difficult for you to apply exactly the same force the same way to each ball. The rocket is a better experiment to test the relationship between mass and speed because you can precisely control the applied force by varying the pressure.

Newton's first law states that the rocket should stay at rest or continue at constant speed unless acted on by a net force.

The second law says that the acceleration of the rocket should be equal to the ratio of the force acting on the rocket divided by the mass of the rocket.

Force causes acceleration, which results in the increase in speed of the rocket. The speed of the rocket increases from zero (when it starts) to the speed you measure as the rocket goes through a photogate.

Force → ***Acceleration*** → ***Speed***

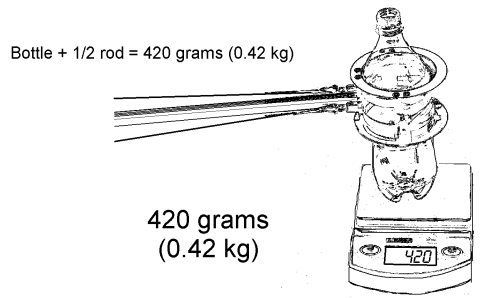
F $\qquad a = \frac{F}{m}$ $\qquad v = ?$

The third law states that for every force acting on the rocket there will be an equal and opposite reaction force acting on something else.

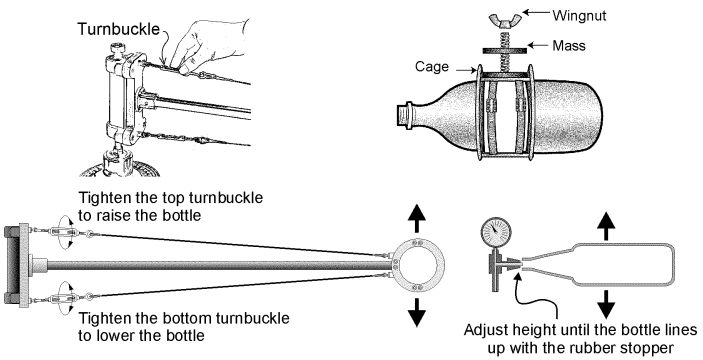
Write a hypothesis that answers the question at the start of the Investigation. Your answer should include at least one reason why you think your hypothesis may be the correct one.

2 Setting up the experiment

B-4



1. The mass of the rocket, including 1/2 the rod is about 420 grams. Part of the rod needs to be included because it moves with the rocket. You should NOT disassemble the rocket and try to make the measurement yourself.
2. Set a single photogate to measure the speed of the rocket where it has reached the end of its acceleration (after the end of the boost phase).
3. Use a balance to measure the mass of one steel weight.



ALWAYS tighten one side and loosen the other to maintain balanced tension in the cables.

4. You can add mass to the air rocket by adding steel weights to the top of the rocket. When adding weights, you need to adjust the turnbuckles on top and bottom so the rocket nozzle is centered on the rubber cork on the launcher. ALWAYS tighten and loosen the turnbuckles together. If you tighten the top one (to raise the rocket) loosen the bottom one a corresponding amount.
5. Calculate the rocket mass by adding the mass of the added weights to the starting mass of the rocket without any added weights (from step 1).

2

2

1. The mass of the air rocket and supporting rod is about 420 grams.
2. The photogate will be placed at 90°.
3. The average mass of a steel weight is 189 grams.
5. Mass of air rocket with different weights.

Number of weights	Mass of air rocket (grams)
0	420
1	609
2	798
3	987

3

3a. In the experiment, I am investigating how the air rocket's speed changes as mass changes. The variable, mass, will be changed while other variables are kept constant.

3b. The independent variable is mass. The dependent variable is speed.

3c. See Table 1 listed in part 4.

3d. In my group's experiment, we will measure the speed of the air rocket at 90 degrees. We will measure speed for three masses of the air rocket by adding 1, 2, and 3 weights to the rocket. The pressure that will be used during the experiment is 50 psi.

4

Table 1 Answers

Variable	Value (units)
Pressure	The pressure of the rocket will be held constant during the experiment; 50 psi
Position	Data will be recorded at 90°.

Table 2 Answers

Pressure (psi)	Mass of air rocket (grams)	Time through A (t_a, sec)	Speed at A (v_A, m/sec)
50	420	.0098	5.10
50	609	0.0131	3.82
50	798	0.0169	2.96
50	987	0.0197	2.54

3 Design your experiment

B-4

It is important that the weights be firmly attached to the rocket!

By answering the questions below, you will come up with the design of your experiment.

a. Fill in the blanks of this statement: In the experiment, I am trying to see how the air rocket's _____ changes as _____ changes. The variable, _____, will be changed while other variables are kept constant.

b. What is the independent variable in your experiment? What is the dependent variable?

c. Use Table 1 to record the name and value of important variables that will remain constant throughout the experiment.

d. Based on your work in parts 1 and 2 and your answer to questions 4(a) - (c), write a paragraph that describes the experiment you will perform to answer the Investigation question. You may want to perform more than one trial for each set of conditions.

Be very careful and pay attention when working near the air rocket! Make sure everyone is out of the way before triggering the air rocket!

4 Collecting your data

Table 1: Variables kept constant

Variable	Value (units)

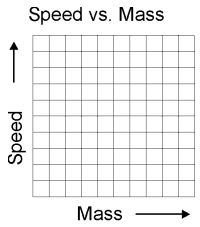
Table 2: Air rocket speed vs. mass data

Pressure (psi)	Mass (kg)	Time Through Photogate A (t_A, sec)	Speed at A (v_A, m/sec)

3

5 **Graphing and analyzing the results** B-4

a. Make a graph showing the relationship between speed and mass. The independent variable, mass, is on the *x*-axis, and the dependent variable, speed, is on the *y*-axis. When you have plotted your data, answer the questions below.



b. Since the air rocket does not have a motor, what keeps it going around in its orbit?

c. Describe the shape of the plot of your data. Are the data points linear, an upward curve, or a downward curve?

d. Write a few sentences that describe the relationship between the mass of the air rocket and its speed. Include answers to these questions: Does your data suggest that the speed of the rocket is independent of the mass? Does the speed decrease or increase with added mass?

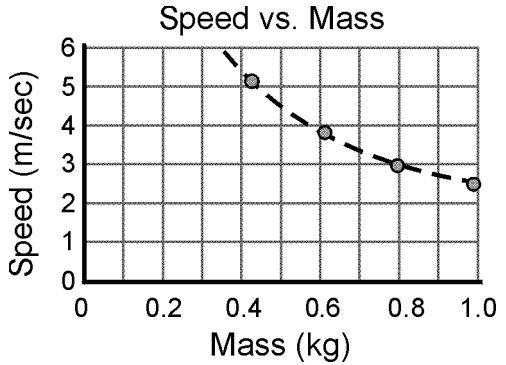
e. If the mass of the rocket were doubled, what would happen to the speed? You answer should say numerically how much you expect the speed to change, based on your experimental observations. For example, you might say that doubling the mass reduces the speed by 1/4. It is not enough to just say you expect the speed to go down as the mass increases.

f. Write a short paragraph that explains whether or not the results of the experiment provide evidence of Newton's second law of motion.

4

5

5a. Graph of speed vs. mass



5b. The initial force on the rocket is created by the air escaping from the rocket just after launch. After the air is gone, the rocket keeps going because if its own inertia according to Newton's first law.

5c. The graph is a downward curve showing that speed is inversely related to mass. As the mass of the rocket increases the speed decreases.

5d. The data suggests that there is an inverse relationship between the mass of the rocket and its speed. As the mass of the rocket increases and the force on the rocket is held constant, its speed at a certain point in its path decreases.

5e. If the mass of the air rocket were doubled, then the speed of the rocket would decrease by half. Our data showed that increasing mass from 420 to 798 grams, a factor of 1.9, resulted in the speed going from 5.1 m/sec to 2.96 m/sec, a reduction of 1.7 times.

5f. In this experiment, the force (the launching pressure) on the air rocket bottle was constant. The mass of the bottle was changed. As mass increased, the speed of the air rocket decreased. This observation supports Newton's second law of motion — as force is kept constant and mass increased, the acceleration decreased, and we observed lower speeds.

1. Added mass increases an object's inertia. A definition of inertia is "resistance to acceleration." Therefore, an object with more mass requires more force to accelerate. It also takes more force to stop an object with more mass.
2. The second law of motion states that the acceleration of an object is directly proportional to the force applied to the object and indirectly proportional to the mass of the object.
3. The force can be changed by changing the launching pressure.
4. In this case, the engine is a source of force. For both cars, the available force would be the same since they have the same engine. According to Newton's second law of motion, acceleration is equal to force divided by mass. Therefore, the smaller car, with less mass, would have greater acceleration than the large car.
5. There are many possible answers here. You are looking for sound physical reasoning more than any one 'correct' answer.

   Answer #1
   As an action-reaction pair, the rocket and air push on each other. The argon gas, with greater mass, can generate more pushing force on the rocket. Therefore, the rocket will go faster when it contains argon than when it contains air.

   Answer #2 (not true but good physical reasoning)
   The argon gas is heavier than air so it will leave the rocket with less velocity than air at the same pressure. As a result, the lower velocity air jet will create less force on the rocket, and the rocket will go slower.

   Answer #3 (not true but good physical reasoning)
   Argon is heavier and can create more reaction force, tending to make the rocket go faster. But, heavier argon atoms cannot move as fast coming out of the rocket, which would lower the exhaust speed and reduce the force available to push the rocket. These two effects cancel each other and the rocket should go about the same speed with argon as with air.

Curriculum Resource Guide: Air Rocket

Credits

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