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Investigate a Twirling Toy

Flinn STEM Design Challenge™

Introduction

In the spring, maple trees release multitudes of seeds into the air. They carelessly spin and drift in the wind until landing at their final destination, the ground. What causes the flight patterns the seeds follow? A twirling toy demonstrates the same careless flight and by manipulating different factors of the twirling toy, you can discover which factors are more influential.

Concepts

- Force
- Air resistance
- Engineering design

Background

A *force* is any push or pull that one object exerts on another. An object's *motion*—change in position with respect to time—is influenced by forces. Several forces act on the motion of a falling object, such as a maple seed or a twirling toy.

Objects fall toward Earth at the same rate regardless of size, shape or mass due to the force of gravity (in a vacuum). The vacuum, or absense of air, eliminates drag, which is created by the force of friction between the object and air. However, we do not live within a vacuum, so it appears that objects fall at different rates. The reason a hammer falls faster in air than a feather is because of *air resistance*. Air creates friction and drag on the falling objects. The drag tends to increase the descent time of lighter objects or objects with more surface area more than heavier objects or objects with less surface area. Air resistance acts in the direction opposite to that of the object's motion; in this case, it acts against gravity. Air resistance is influenced by the object's size, speed and shape. For example, if you record the descent time of a crumpled piece of paper and then un-crumple, flatten and drop that same piece of paper, the descent time will increase (see Figure 1). The mass of the paper has not changed, but the descent time will increase due to air resistance because the flat sheet of paper has a greater surface area, increasing the effect of air resistance and slowing descent.

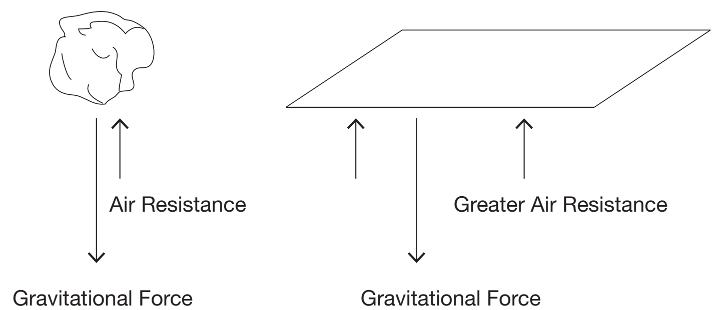


Figure 1. Air Resistance

A twirling toy will spin as it falls because air is being pushed out of the way. As the toy falls, air pushes the rotors (blades) up into a slanted position. The slanted rotors come into contact with air in a vertical direction and a horizontal direction. The vertical air maintains the slanted position of the rotors and slows the twirling toy's descent. The horizontal air pushes on the base directly under each rotor in opposite directions causing the twirling toy to spin (see Figure 2). As the twirling toy spins faster, less air flows past the rotors and the descent slows.

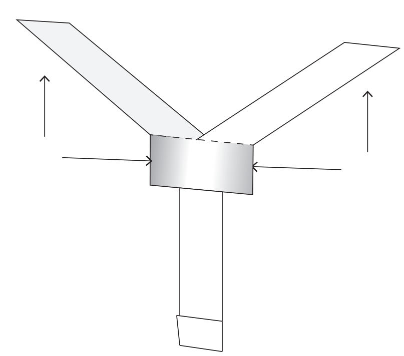


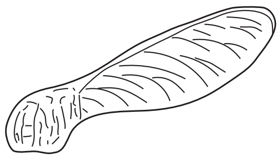
Figure 2. How a Twirling Toy Spins

Experiment Overview

In this activity, several twirling toy models will be investigated to learn which variables are most influential in the twirling toy's descent.

Pre-Lab Questions

1. If a feather and a marble are dropped at the same time from the same height, explain which object would hit the floor first based on air resistance.
2. Describe how air resistance would benefit a maple seed like the one seen below.



3. Identify and explain two variables that may affect the descent time of a twirling toy.

Materials

Paper clips

Scissors

Target, paper

Timer or stopwatch

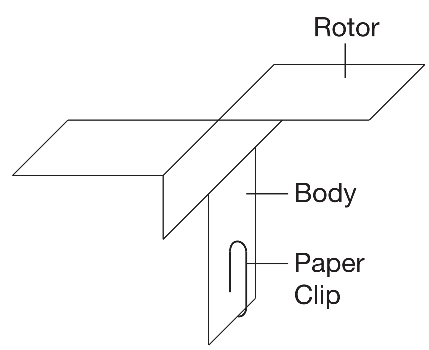
Twirling toy template, cardstock

Safety Precautions

All items in this procedure are considered nonhazardous. Use caution when testing twirling toys. Do not test while other students are in the drop path. Wash hands thoroughly with soap and water before leaving the laboratory. Please follow all laboratory safety guidelines.

Procedure

Part A. Investigating Twirling Toy Variables



1. Obtain the twirling toy templates.
2. Using scissors, cut out each template. Cut along the solid lines and fold along the dashed lines.
3. Take two paper clips, a timer, the twirling toy designs, the worksheet and pencil to the testing location.
4. Follow the data table on the *Investigating a Twirling Toy Worksheet* for variables to test, unless assigned variables were given by your instructor.
5. One partner stands at the top of the testing location with the twirling toys and paper clips.
6. The other partner stands at the bottom of the testing location with the timer and the target. Place the target below the extended arm of the partner with the twirling toy.
7. Release the twirling toy and say "go." Start timing immediately.
8. Stop the timer when the twirling toy hits the ground.
9. Record the number of seconds it takes for the twirling toy to reach the floor (time for descent) in the data table.
10. Record whether or not the twirling toy hit the target.
11. Record the following observations:
    a. Spin: when does the twirling toy start spinning (immediately, ¼, ½, or ¾ of the way through the descent, or not at all); does it spin in the same direction (clockwise or counter-clockwise)?
    b. Pathway: does the twirling toy fall straight down, in a wavy pattern or erratically?
    c. Stability: does the twirling toy stay vertical (upright) when falling or not?
    d. Other observations: add notes as to how the design worked and what modifications and ideas can be utilized in the design challenge.

12. Repeat steps 7–11 for a total of three trials.
13. Continue testing according to the data table or your instructor's assignments.
14. Answer questions 1 and 2 on the worksheet.

Part B. Design Challenge

Form a group with other students and discuss the following questions.

1. Calculate and record the average descent time for each twirling toy tested.

Twirling Toy Variables	Average Time of Descent (s)
Short rotors 0 paper clips	
Short rotors 1 paper clip	
Short rotors 2 paper clips	

Twirling Toy Variables	Average Time of Descent (s)
Long rotors 0 paper clips	
Long rotors 1 paper clip	
Long rotors 2 paper clips	

Twirling Toy Variables	Average Time of Descent (s)
Rounded rotors 0 paper clips	
Rounded rotors 1 paper clip	
Rounded rotors 2 paper clips	

2. Consider all the data gathered.
   a. Which twirling toy design from the template had the slowest descent (longest flight time)?
   b. Which twirling toy design from the template was best at hitting the target?
3. What effect, if any, did adding paper clips to the toy have on its time of descent, flight path or stability?
4. What factors other than the ones tested, might affect the flight time and stability of the twirling toy? Which factors can be controlled and which ones cannot be controlled?
5. Design a prototype of a twirling toy that is capable of landing on a target with the longest flight time.
6. Test your prototype and make modifications.
7. Create the final design from the materials provided by the instructor.

Disposal

Consult your instructor for appropriate disposal procedures.

Name: ______________________________

Investigating a Twirling Toy Worksheet

Data Table A. Short Rotors

Twirling Toy Variables	**Time of Descent (s)**	**Target Hit** (yes/no)	**Spin** (starting point, direction)	**Path** (straight, wavy, erratic)	**Stability** (vertical or not)	**Other Observations**
Short rotors 0 paper clips						
Short rotors 1 paper clip						
Short rotors 2 paper clips						

Data Table B. Long Rotors

Twirling Toy Variables	**Time of Descent (s)**	**Target Hit** (yes/no)	**Spin** (starting point, direction)	**Path** (straight, wavy, erratic)	**Stability** (vertical or not)	**Other Observations**
Long rotors 0 paper clips						
Long rotors 1 paper clip						
Long rotors 2 paper clips						

Data Table C. Rounded Rotors

Twirling Toy Variables	**Time of Descent (s)**	**Target Hit** (yes/no)	**Spin** (starting point, direction)	**Path** (straight, wavy, erratic)	**Stability** (vertical or not)	**Other Observations**
Rounded rotors 0 paper clips						
Rounded rotors 1 paper clip						
Rounded rotors 2 paper clips						

Post-Lab Questions

1. Did the twirling toy design from the template with the slowest descent also have the straightest path and best stability?

2. Since the surface area of each individual design remained the same without paper clips as with one or two paper clips, give a possible explanation for the difference in time of descent without and with paper clips.

3. The design challenge was to design a twirling toy capable of landing on a target with the longest flight time.

   a. Which characteristic of the twirling toy—time of descent, spin, path, or stability—do you consider most important in meeting the challenge?

   b. If you were limited to the designs from the templates, what combinations of variables that were tested seem to be the best design solution?

4. Describe the twirling toy your team first designed. Draw and label it on a separate sheet of paper and attach to the worksheet.
5. List each modification your team performed on the twirling toy. Explain the reasoning behind each change (what was the purpose of each design change?).

6. What trade-offs did you need to make in deciding upon the best design solution to the challenge?

7. Describe the success of your twirling toy compared to other groups in your class. Explain the results.

8. After observing other twirling toys in your class, what other improvements might make your twirling toy better at landing on the target with the longest flight time?

Teacher's Notes

Investigate a Twirling Toy—Flinn STEM Design Challenge™

Materials Included in Kit (for 15 groups of students)

Twirling Toy templates, 15

Paper clips, box of 100

Additional Materials Required (for each lab group)

Printed target or paper plate

Ruler

Scissors

Timer or stopwatch

Other materials for twirling toy designs (optional)

Pre-Lab Preparation

1. Cut off the bottom half of the twirling toy template cardstock and retain for the design challenge.
2. Have a target for each group (either a printed target sign or a paper plate).

Safety Precautions

All items in this procedure are considered nonhazardous. Remind students to use caution when testing twirling toy, not to test while other students are in the drop path and to wash their hands thoroughly with soap and water before leaving the laboratory. Please follow all laboratory safety guidelines.

NGSS Alignment

This laboratory activity relates to the following Next Generation Science Standards (2013):

Disciplinary Core Ideas: Middle School

MS-PS2 Motion and Stability: Forces and Interactions
- PS2.A: Forces and Motion
- PS2.B: Types of Interactions

MS-ETS1 Engineering Design
- ETS1.A: Defining and Delimiting Engineering Problems
- ETS1.B: Developing Possible Solutions
- ETS1.C: Optimizing the Design Solution

Disciplinary Core Ideas: High School

HS-PS2 Motion and Stability: Forces and Interactions
- PS2.A: Forces and Motion
- PS2.B: Types of Interactions

HS-ETS1 Engineering Design
- ETS1.A: Defining and Delimiting Engineering Problems
- ETS1.B: Developing Possible Solutions
- ETS1.C: Optimizing the Design Solution

Science and Engineering Practices

Asking questions and defining problems
Developing and using models
Planning and carrying out investigations
Analyzing and interpreting data
Constructing explanations and designing solutions
Engaging in argument from evidence

Crosscutting Concepts

Cause and effect
Systems and system models
Structure and function
Stability and change

Lab Hints

- Enough materials are provided in this kit for 30 students working in pairs, or for 15 groups of students. Part A, *Investigating Twirling Toy Variables* can be completed in one or two 50-minute class periods (depending on testing structure). Allow a 50-minute class period for designing and modifying the prototype for Part B, *Design Challenge*. The final design can be tested in a final 50-minute class period.
- Dropping twirling toys from the top of a stairwell or bleachers will allow for a longer descent time and more accurate data.
- Discuss with students how to minimize errors by brainstorming constants.
- You may want constraints for the design challenge such as size or materials allowed.

Teaching Tips

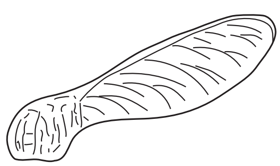
- Depending on class size, altering data collection for Part A may be necessary. Students test several variables (three rotor lengths and three different masses by adding paper clips) with multiple trials each. If time is an issue, it may be more efficient to assign specific variables to each group and share class data.
- Students can determine the spin of the twirling toy by shading one side of one rotor. The orientation of the rotors (shaded side up or down) sets the direction of the twisting force, which makes the toy spin either clockwise or counterclockwise.
- Incorporate a math component by asking students to calculate the average speed of the toy.
- An easy demonstration related to air resistance affecting descent time of an object is dropping a piece of paper that is crumpled up and then dropping an identical piece of paper not crumpled up. Students often assume the crumpled up piece of paper fell faster because it is somehow heavier. The flat piece of paper has a larger surface area and air resistance slows its descent. A way to demonstrate that air resistance causes the difference in descent time is to place the flat piece of paper on a book and drop it. Then place the crumpled up piece of paper on the book and drop it.

Answers to Pre-Lab Questions *(Student answers will vary.)*

1. If a feather and a marble are dropped at the same time from the same height, explain which object would hit the floor first based on air resistance.

   The marble would hit the floor first because it has less surface area for air resistance to act upon.

2. Describe how air resistance would benefit a maple seed like the one seen below.

   Air resistance will act opposite to that of gravity. Gravity will pull the seed down while air resistance pushes the seed up. Slowing the descent time gives the seed the ability to "drift" away from the parent tree, thus giving it a chance to land in an area that may permit growth.

3. Identify and explain two variables that may affect the descent time of a twirling toy.

   Rotor length: longer rotors will have more surface area, slowing the descent.

   Material: thin paper will allow more flexibility for slanting of the rotors allowing more air to push on the base of the twirling toy increasing spinning.

Sample Data Tables *(Student data will vary.)*

A. Short Rotors

Twirling Toy Variables	Time of Descent* (s)	Target Hit (yes/no)	Spin (starting point, direction)**	Path (straight, wavy, erratic)	Stability (vertical or not)
Short rotors 0 paper clips	*2.59*	*no*	*spinning started ½ through the descent*	*wavy*	*not vertical*
Short rotors 1 paper clip	*1.47*	*yes*	*spinning started between ¼ and ½ way of the descent*	*straight*	*vertical*
Short rotors 2 paper clips	*1.38*	*yes*	*spinning started last ¼ of the descent, very slow*	*straight*	*vertical*

*Data is an average of three trials.
**Direction is either clockwise or counterclockwise. See *Teacher Notes*.

B. Long Rotors

Twirling Toy Variables	Time of Descent* (s)	Target Hit (yes/no)	Spin (starting point, direction)**	Path (straight, wavy, erratic)	Stability (vertical or not)
Long rotors 0 paper clips	*2.98*	*no*	*spinning started last ¼ of the descent, very slow*	*wavy*	*not vertical*
Long rotors 1 paper clip	*2.22*	*no*	*did not spin*	*wavy*	*not vertical*
Long rotors 2 paper clips	*1.89*	*no*	*did not spin*	*wavy*	*not vertical*

*Data is an average of three trials.
**Direction is either clockwise or counterclockwise. See *Teacher Notes*.

C. Rounded Rotors

Twirling Toy Variables	Time of Descent* (s)	Target Hit (yes/no)	Spin (starting point, direction)**	Path (straight, wavy, erratic)	Stability (vertical or not)
Rounded rotors 0 paper clips	*3.06*	*no*	*spinning started in the first ¼ of descent*	*wavy*	*not vertical*
Rounded rotors 1 paper clip	*2.85*	*no*	*spinning started in the first ¼ of descent*	*wavy*	*vertical*
Rounded rotors 2 paper clips	*2.69*	*yes*	*spinning started in the first ¼ of descent*	*straight*	*vertical*

*Data is an average of three trials.
**Direction is either clockwise or counterclockwise. See *Teacher Notes*.

Answers to *Design Challenge* Questions *(Student answers will vary.)*

1. Calculate and record the average descent time for each twirling toy tested.

   See sample data tables above.

2. Consider all the data gathered.

   a. Which twirling toy design from the template had the slowest descent (longest flight time)?

   The twirling toy with rounded rotors and no paper clips had an average descent time of 3.06 s. The toy with the long rotors and no paper clips had an average descent time of 2.98 s.

b. Which twirling toy design from the template was best at hitting the target?

The toy with the short rotors had more consistent stability and straight flight paths.

3. What effect, if any, did adding paper clips to the toy have on its time of descent, flight path or stability?

   Adding paper clips usually decreased the time of descent. Adding two paper clips usually resulted in a straighter flight path and increased stability, the exception being the toy made with long rotors.

4. What factors other than the ones tested, might affect the flight time and stability of the twirling toy? Which factors can be controlled and which ones cannot be controlled?

   Include possible answers from controlled variables such as width of rotors, length of body, position of paper clips, and shape of rotors. Angle of rotors for uncontrolled variable, consistency of release, etc.

5. Design a prototype of a twirling toy that is capable of landing on a target with the longest flight time.

   Student designs will vary.

Answers to Post-Lab Questions *(Student answers will vary.)*

1. Did the twirling toy design from the template with the slowest descent also have the straightest path and best stability?

   No, the toy with the longest flight time had a wavy flight path and did not fall vertically.

2. Since the surface area of each individual design remained the same without paper clips as with one or two paper clips, give a possible explanation for the difference in time of descent without and with paper clips.

   In general, the paper clips increased the stability and resulted in a straighter flight path. Since the toy did not waver back and forth as much, the total distance covered was less, resulting in a shorter flight time.

3. The design challenge was to design a twirling toy capable of landing on a target with the longest flight time.

   a. Which characteristic of the twirling toy—time of descent, spin, path, or stability—do you consider most important in meeting the challenge?

   Student answers will vary. Time of descent and stability would be important in meeting the challenge of landing on a target with the longest flight time.

   b. If you were limited to the designs from the templates, what combinations of variables that were tested seem to be the best design solution?

   Student answers will vary based on their data.

4. Describe the twirling toy your team first designed. Draw and label it on a separate sheet of paper and attach to the worksheet.

   Student designs will vary.

   Ex: A twirling toy designed with long rotors, a long base, 3 paper clips and printer paper versus cardstock had an average descent of 3.60 s.

5. List each modification your team performed on the twirling toy. Explain the reasoning behind each change (what was the purpose of each design change?).

   Student answers will vary.

   Ex: Modifications that were made to the original twirling toy included adding and removing paper clips, altering the position of the paper clips along the base, lengthening the rotors and base, and the final modification was widening the rotors. The increased and decreased number of paper clips was due to a wavy pathway observed from the template data. The goal was to keep the twirling toy on a straight path (hitting the target). The positioning of the paper clips was to see if the path was affected as well as the descent (the twirling toy lost the spinning ability with one arrangement). The increased length of the base and rotors was to slow and straighten the twirling toy which worked. The longer rotors with longer base and two paper clips averaged a 5.0-s descent.

Teacher's Notes *continued*

6. What trade-offs did you need to make in deciding upon the best design solution to the challenge?

   Student answers will vary.

   Ex: In order to get a longer descent the final twirling toy was no as accurate landing on the target. Target was hit two out of three trials.

7. Describe the success of your twirling toy compared to other groups in your class. Explain the results.

   Student answers will vary based on class data.

8. After observing other twirling toys in your class, what other improvements might make your twirling toy more successful at landing on the target with the longest flight time?

   Student answers will vary.

References

Crismond, D., Soobyiah, M., and Cain, R. "Taking Engineering Design Out for a Spin," *Science and Children* (January 2013): 52-56.

The *Investigating a Twirling Toy—Flinn STEM Design Challenge™* is available from Flinn Scientific, Inc.

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