National Aeronautics and
Space Administration

Langley Research Center
Hampton, VA 23681-0001

Program 1 in the 1999-2000 Series

# The Measurement of All Things:

## Tools of the Aeronautics Trade



*build and test objects in a wind tunnel*

*use computers to simulate and test an airfoil*

*graph, analyze, and present data*

**Story line:** Students will explore the concept of measurement and the tools used in measuring things, while learning "what" and "how" engineers and scientists use measurement during the process of developing, designing, and testing airplanes.

**Math Concepts:** Number and Number Sense, Units, Conversion, Tools

**Science Concepts:** Logic, Reasoning, Science as Inquiry

**NASA Research:** Fundamental Aeronautics, Measurement Science, Flight Research

| Educator's Guide | |
|---|---|
| Teachers & Students | Grades 4-8 |

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# PROGRAM SUMMARY

## OBJECTIVES

In *The Measurement of All Things: Tools of the Aeronautics Trade*, students will investigate the U.S. Customary and metric systems of measurement. They will also learn about the tools and techniques used by NASA aeronautical engineers and scientists to measure two of the four forces of flight: lift and drag. To apply what they have learned about measurement and the metric system, students will work in groups to construct a wind tunnel, a fundamental tool of aeronautics. *(See Figures 1 and 2.)* This activity is taken from *Mission Mathematics: Grades 5-8* and involves using a wind tunnel to measure the wind resistance, or drag, of four polyhedrons (i.e., cone, cube, pyramid, and tetrahedron). For more information on *The Measurement of All Things: Tools of the Aeronautics Trade*, please visit the following section of the NASA CONNECT web site:
**http://edu.larc.nasa.gov/connect/tools.html**

While visiting the corresponding web page for this program, students can access FoilSim, the technology-based component of the program. FoilSim is the online activity and is located in "Norbert's Lab" at
**http://edu.larc.nasa.gov/connect/tools/norbert/lab.html**
With FoilSim, students will have the opportunity to use the computer, another fundamental aeronautics tool. FoilSim is an interactive simulation software package that can be used to determine airflow around variously shaped airfoils. Using FoilSim, students can manipulate camber, area, angle of attack, and thickness of an airfoil and measure the drag force of a wing.

Access to information is critical to making career decisions. Career Corner, located at **http://edu.larc.nasa.gov/connect/tools/ca1.html,** is a web-based component that highlights the professionals who appear in the program, *The Measurement of All Things: Tools of the Aeronautics Trade.* This web site includes pictures of the professionals; summarizes their duties and responsibilities; and includes details about the person, event, or situation that greatly influenced their career choice.

# TEACHER BACKGROUND

## MEASUREMENT

Measurement is essential to our daily lives. Actually, it would be hard to imagine a day when we did not use measurement and measuring instruments. Measurement is essential to commerce: the making, selling, and purchasing of goods and services. Measurement is a fundamental process of science and technology. We use measurement when we operate our cars, prepare our meals, and play sports. We use measurement in nearly everything we do. There are seven basic categories of measurement: length, time, mass (weight), volume, temperature, electric current, and luminous intensity. The concepts of uniformity, units, and standards are basic to the entire concept of measurement. The Babylonians, Chinese, Egyptians, Greeks, Hindus, Romans, and medieval English all contributed to the development of modern measurement. There are two systems of measurement: (1) the English system, which consists of two related systems, U.S. Customary and the British Imperial, and (2) the metric system. The English system evolved over centuries and drew heavily from the traditional practices (customs) of ancient and medieval civilizations. Basic units of measurement in the U.S. Customary system are the foot, gallon, pound, and mile. The metric system, one of the most significant results of the French Revolution, is used by the world's scientific community and by most nations. Basic units of measurement in the metric system are the gram, meter, liter, and kilometer.

## WIND TUNNELS

Wind tunnels are machines for "flying" aircraft on the ground. They are tube-like structures or passages in which wind is produced, usually by a large fan, to flow over objects such as aircraft, engines, wings, rockets, or models of these objects. A stationary object is placed in the test section of a tunnel and connected to instruments that measure and record airflow around the object and the aerodynamic forces that act upon it. From information gathered in these observations, engineers can determine the behavior of an aircraft or its components at takeoff, while cruising, and during descent and landing.

Wind tunnels also help engineers determine the performance of, and eliminate "bugs" in, new designs of civil and military aircraft without risk to a pilot or costly aircraft. Responses to the flight condition of new materials and shapes for wings, ailerons, tails, fuselages, landing gear, power systems, and engine cowlings can be assessed before these designs are incorporated into aircraft.

Today, no aircraft, spacecraft, space launch vehicle, or reentry vehicle is built or committed to flight until after its design and components have been thoroughly tested in wind tunnels. Every modern aircraft and space rocket has made its maiden flight in a wind tunnel. Wind tunnels have been among the key tools that have made American aircraft and aeronautical equipment the most preferred and most widely used in the world.

# THE ACTIVITY: MAKING AND USING A WIND TUNNEL

## NATIONAL MATH STANDARDS

- Estimate, make, and use measurements to describe and compare phenomena.
- Select appropriate tools to measure the degree of accuracy required for a particular activity.
- Develop formulas and procedures for determining measures to solve problems.
- Apply the power and use of mathematical reasoning.
- Apply mathematical thinking and modeling to problem solving.

## INSTRUCTIONAL OBJECTIVES

Students will (1) apply and use various measurement techniques and tools; (2) use measurement tools and techniques to construct a wind tunnel; (3) learn and use metric units of measurement; (4) measure and record the drag of four polyhedrons; and (5) graph, analyze, and present results.

## TEACHER RESOURCES

**Books**

Nelson, David. (1998). *Dictionary of Mathematics.* NY: Penguin Group.

Seiter, Charles. (1995). *Everyday Math for Dummies.* Foster City, CA: IDG Books Worldwide.

*How Things Work*. (1990). "Flight." Lincolnwood, IL: Publications International, Ltd.

Jennings, Terry. (1992). *Planes, Gliders, Helicopters and Other Flying Machines.* NY: Kingfisher.

NASA. (1998). *Aeronautics: An Educator's Guide with Activities in Science, Mathematics, and Technology Education*. Washington, DC: NASA (EG-1998-09-105-HQ).

**Web Sites**

**The Math Forum**
http://forum.swarthmore.edu/paths/measurement/index.html

**PBS Teacher Resource**
http://www.pbs.org/teachersource/math/index.html

**Measure 4 Measure**
http://www.wolinskyweb.com/measure.htm

**Wind Tunnels**
http://www.quest.arc.nasa.gov

**Foilsim**
http://www.lerc.nasa.gov/www/K-12/aerosim/vufoil.htm

**Norbert's Lab on the NASA CONNECT web site**
http://edu.larc.nasa.gov/connect/tools/norbert/lab.html

***Check out Norbert's Lab!***

# BEFORE THE ACTIVITY

## MATERIALS NEEDED

*clear adhesive tape*
*transparency film*
*glue*
*colored pencils or markers*
*meter stick*
*box /window fan (3-speeds)*
*cardboard*
*strong scissors*
*string*
*duct tape or packing tape*
*2 chairs*
*pencil*
*safety goggles*
*window screen (optional)*
*elastic cord (from a party hat)*

Ask students to share their thoughts or write their responses to the following questions. Encourage students to research measurement and related topics by using the library and the Internet.

What would the world be like without airplanes?
How did the Wright brothers design the wings for the "Wright Flyer"?
What will futuristic aircraft look like?
Why do we test models in wind tunnels?
Can we test things other than airplanes in wind tunnels?
What careers relate to the field of aviation?

## VOCABULARY

**drag** - the surface force of air that slows down the plane as it moves forward
**lift** - the surface flow of air generated around the wings that keeps an airplane up
**mass** - an object's quantity of matter
**mean** - the average of all numbers in a data set
**median** - the middle number in a data set that is arranged from the lowest to the highest
**meter** - the standard unit of length used in the metric system
**mode** - the number that appears most often in the data set
**polyhedron** - any many sided figure (e.g., cone, cube, or pyramid)
**thrust** - the force of the engine that pushes a plane forward (opposite of drag)
**wind tunnel** - a tunnel-like passage through which air is blown at a known velocity to investigate or test airflow around an object (i.e., airplane model)

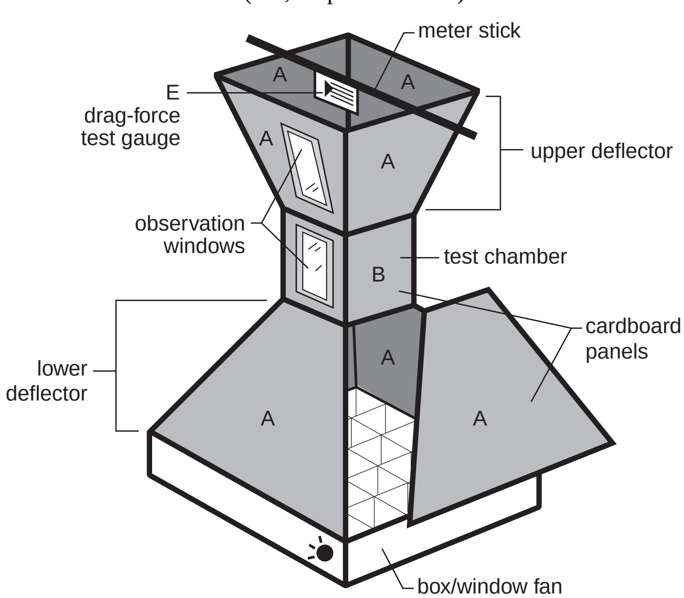
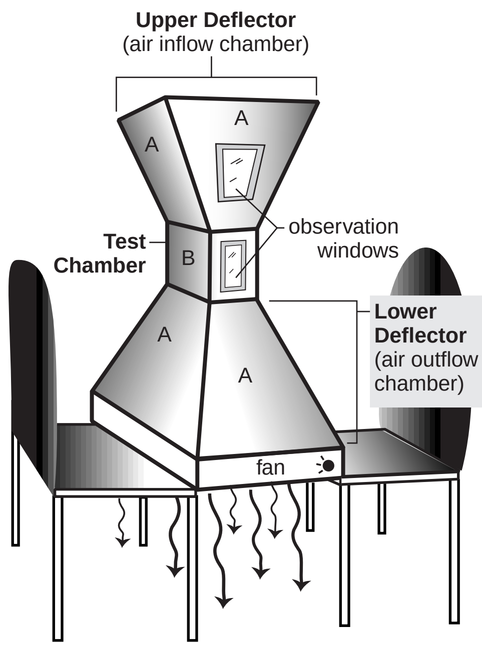



***Figure 1. Wind Tunnel Diagram -** refer to the drawing above when constructing each section.*

## THE ACTIVITY

*__Figure 2. Completed Wind Tunnel__ - with fan on.*




**1. Divide the class into four groups:**
- Engineering Team 1: structure (upper deflector)
- Engineering Team 2: structure (test chamber)
- Engineering Team 3: structure (lower deflector)
- Engineering Team 4: drag force test gauge

**2. Make classroom copies of**
- Cue Cards *(page 10) (__1__ copy per student)*
- Table A: Measured and Calculated Lengths *(page 11) (__1__ copy per student)*
- Patterns for Polyhedrons *(pages 12-15) (__1__ set per team)*
- Student Data Worksheet *(page 16) (__1__ copy per student)*
- Graph of the Drag (Mean) *(page 17) (__1__ copy per student)*

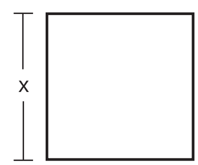
**3. Teams 1, 2, and 3 should complete Table A: Measured and Calculated Lengths and give it to the teacher.** *(page 11)*

**4. Make Team Task Assignments:**

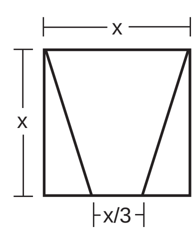
**Engineering Team 1: Structure (upper deflector)**
Section A of wind tunnel diagram *(see Figure 3)*

- Refer to Table A: Measured and Calculated Lengths to measure each panel of the upper deflector. Carefully cut out four panels.
- In the middle of **one** panel in the top section of the wind tunnel, cut out a window and tape a piece of transparency film over the window from the inside.
- Tape the four panels together to form the top section. This section is now ready for attachment to the middle section (test chamber).
- Using the polyhedron patterns, build a cone, a cube, a pyramid, and a tetrahedron *(see pages 12-15)*. Use tape to attach a string to each of these shapes.

*__Figure 3. Section A - Upper Deflector Panels.__*




*box/window fan*



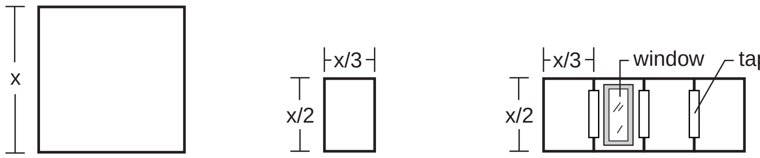

*upper deflector panel*

**Note 1:** For safety reasons, the teacher may precut panels (sections A and B) for construction of the wind tunnel after the students have measured and drawn the panels.

**Note 2:** Emphasize the importance of accuracy in measurement and that the wind tunnels need to be airtight to be effective.

**Note 3:** Address safety factors, such as not dropping items into the fan and not standing on chairs to look into the wind tunnel.

***Figure 4. Section B - Test Chamber Section.***

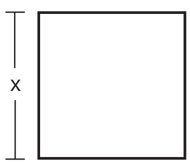



*box/window fan* *test chamber* *test chamber - open view with all four sides showing*

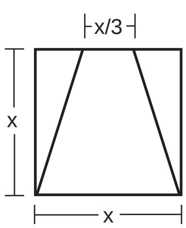
**Engineering Team 2: Structure (test chamber)**
Section B of wind tunnel diagram *(see Figure 4 above)*

- Refer to Table A: Measured and Calculated Lengths to measure each panel of the upper deflector. Carefully cut out four panels.
- In the middle of **one** panel of the test chamber, cut out a window and tape a piece of transparency film over the window opening from the inside.
- Tape the panels together. This section is now ready for attachment to the upper deflector *(see Figure 1)*.
- Using the polyhedron patterns *(pages 12-15)*, build a cone, a cube, a pyramid, and a tetrahedron. Use tape to attach a string to each of these shapes.

***Figure 5. Section A - Lower Deflector Panels.***




*box/window fan*




*lower deflector panel*

**Engineering Team 3: Structure (lower deflector)**
Section A of wind tunnel diagram *(see Figure 5 to left)*

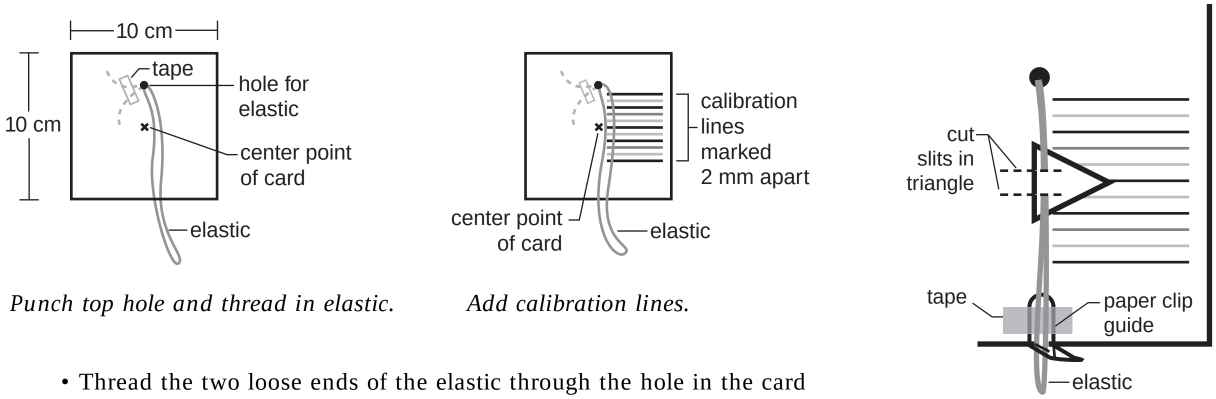
- Refer to Table A: Measured and Calculated Lengths to measure each panel of the upper deflector. Carefully cut out four panels.
- Tape the four panels together to form the bottom section. This section is now ready for attachment to the middle section (test chamber).
- Using the polyhedron patterns, build a cone, a cube, a pyramid, and a tetrahedron. Use tape to attach a string to each of these shapes.

**Teams 1, 2, and 3 should carefully tape their sections together to form the wind tunnel. Make sure the window on the upper deflector and the window on the test chamber are on the same side of the wind tunnel before attaching. Tape the wind tunnel to the window fan and place the fan onto two chairs. (See pages 4 - 5 for diagrams.)**

**Engineering Team 4: Drag Force Test Gauge**
Section E of wind tunnel diagram. *(See Figure 6, page 7.)*

- Cut a 10-cm x 10-cm square from cardboard.
- Punch a 1-mm hole in the cardboard, centered 3-cm from the top.
- Remove the elastic band from inside the party hat. (The elastic band should be approximately 15 cm long unstretched.) Double over the elastic to form a loop.

***Figure 6. Drag Force Test Gauge.***




*Punch top hole and thread in elastic.*

*Add calibration lines.*

*Thread the elastic through 2 slits cut in the triangle gauge and then through the paper clip guide (which is taped to the square).*

- Thread the two loose ends of the elastic through the hole in the card and hold them in place with a piece of tape.
- Mark the center of the card (find center point using diagonals).
- Beginning at the center point, draw a solid line to the right edge. At 2-mm intervals, draw 5 lines above and 5 below the centerline that was just drawn.
- Using cardboard, cut an equilateral triangle with each side equal to 2 cm. Cut two slits in the triangle, place the elastic through the slits, and center the point of the triangle on the centerline.
- Bend a paper clip 90 degrees to form a guide clip for the elastic. Attach the paper clip to the center of the bottom edge with tape. Slip the elastic through the loop of the paper clip.
- Tape the top edge of the card to the center of the meter stick.
- Using the polyhedron patterns, build a cone, a cube, a pyramid, and a tetrahedron. Use tape to attach a string to each of these shapes.

**SUGGESTION:**

*Using the primary colors, alternate the line color (for ease of reading).*

## 5. Testing the Shapes

**Note:** If you want to even out the wind flow, place two window screens 1/8 inch apart on top of the upper (intake) deflector.

**Note:** Students will test each shape **3 times** at each speed.
*(See Table B, page 16)*

- Attach the tetrahedron to a string at the end of the elastic so it can be seen through the window of the test chamber.
- Note the position of the gauge.
- Start the fan on low speed. Read the amount of elastic stretch by using the gauge. The stretch measurement is the drag force exerted by the wind on the object.
- Record the drag in Table B on the Student Data Worksheet *(page 16)*. Turn off the fan and make sure the gauge is registered at the centerline. Test the tetrahedron 2 more times at low speed and record data.

**CHALLENGE:**

*Can you predict which polyhedrons will have more or less drag than the tetrahedron?*

- Continue to test each shape **3 times** at low, medium, and high speeds.
- Calculate the mean, median, and mode for each of the polyhedrons. (Record data on Table C on the Student Data Worksheet *(page 16)*)
- Using the data recorded in Table B, graph the mean of each polyhedron at low, medium, and high speeds using the Graph of the Drag (Mean) worksheet *(page 17)*.
- All groups should share their data and complete the graph.

## 6. Analyzing the Data

Can you answer these questions?

1. Do the shape, mass, and position of the objects in the wind tunnel affect the drag? How? *(Yes, because each will affect how much force is exerted on the object.)*

2. Which factor (shape, mass, wind speed, or drag) is the constant? That means it stays the same throughout the activity. Why is it important to keep the constant? *(Mass is the constant throughout the activity. Constants are needed to eliminate external factors and maintain the only two variables: The independent factor, the one that is changed, and the dependent factor, the one that is observed.)*

3. Which objects experienced the least and most drag? Why? *(See experimental data in Table A, page 11.)*

4. Do the direction and speed of the wind flow affect the drag on the objects? *(Yes, because the direction of the wind will hit different surface areas of the various shapes.)*

5. In which part of the wind tunnel is the wind speed the fastest? Why? *(The wind speed is fastest in the test chamber because the wind is passing from a larger chamber to a smaller one.)*

6. What is the importance of using a wind tunnel for the design of aircraft or lifting bodies? *(Wind tunnels are used to test the design and viability of aircraft and other objects before a full-scale version is built.)*

7. What other objects can be tested in a wind tunnel? *(Cars, wheelchairs, hurricane-proof homes, buildings, and parafoils can be tested in a wind tunnel.)*

8. Describe the relationship between the shape of the object and the drag created? *(Reducing the object's surface area in the wind flow lowers the drag value.)*

## EXTENDING THE ACTIVITY

1. For extension activities, please visit “Norbert’s Lab” on the NASA CONNECT web site at **http://edu.larc.nasa.gov/connect/tools/lab/norbert.html**

*Encourage students to visit **all** the rooms in Norbert’s lab.*

2. Using the data collected and recorded from the NASA CONNECT Activity, have students make comparisons, predictions, and inferences *(see the examples below)*.

*Example: The following tables show the data collected by Prince William County, Virginia students.*

| | Low Speed | | | Medium Speed | | | High Speed | | |
|---|---|---|---|---|---|---|---|---|---|
| | test 1 | test 2 | test 3 | test 1 | test 2 | test 3 | test 1 | test 2 | test 3 |
| Tetrahedron | 1.0 | 1.0 | 1.0 | 2.0 | 2.0 | 2.0 | 3.0 | 2.5 | 3.0 |
| Pyramid | 1.5 | 1.5 | 1.0 | 2.0 | 3.0 | 3.0 | 5.0 | 5.5 | 5.0 |
| Cube | 1.0 | 1.0 | 1.0 | 2.0 | 2.0 | 2.0 | 4.0 | 4.0 | 4.0 |
| Cone | 2.0 | 2.0 | 2.0 | 4.0 | 4.0 | 4.0 | 8.5 | 8.5 | 8.5 |

| | Low Speed Mean | Medium Speed Mean | High Speed Mean |
|---|---|---|---|
| Tetrahedron | 1.0 | 2.0 | 2.8 |
| Pyramid | 1.3 | 2.7 | 5.2 |
| Cube | 1.0 | 2.0 | 4.0 |
| Cone | 2.0 | 4.0 | 8.5 |

# CUE CARDS, TABLES, PATTERNS, CHARTS, GRAPHS

## CUE CARDS

**Peninsula Fine Arts Center in Newport News, VA**

How did the U.S. Standard system of measurement develop?

How was the metric system devised?

How are the two systems different?

**Mike Logan, NASA Langley Research Center**

Explain four forces which affect aircraft performance and tell how they relate to each other.

**Hector Soto, NASA Langley Research Center**

What is a wind tunnel?

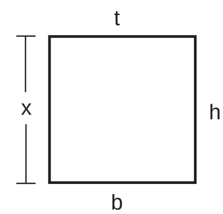
How is it used as a measurement tool?

Why is the SR-71 an ideal research test airplane?

## TABLE A. MEASURED AND CALCULATED LENGTHS

| Objects | Height (h) | Bottom (b) | Top (t) |
|---|---|---|---|
| A. Window fan | | | |
| B. Upper/lower deflectors | | | |
| C. Test chamber | | | |

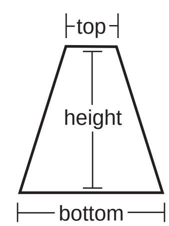
**A. Window fan:** The standard box/window fan is a square. Because the fan is the base of the wind tunnel, the tunnel dimensions or size will be based on the dimensions or size of the fan. Because the fan is square, you need only measure one side of the fan. This measurement represents x.



*box/window fan*

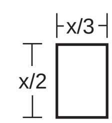
**B. Upper/lower deflectors.** The same pattern is used for the upper and lower deflectors. Each section requires four pieces. To find the dimensions for these pieces, substitute the measurement represented by x.

top measurement = x/3
height = x
bottom = x



*upper/lower deflectors*

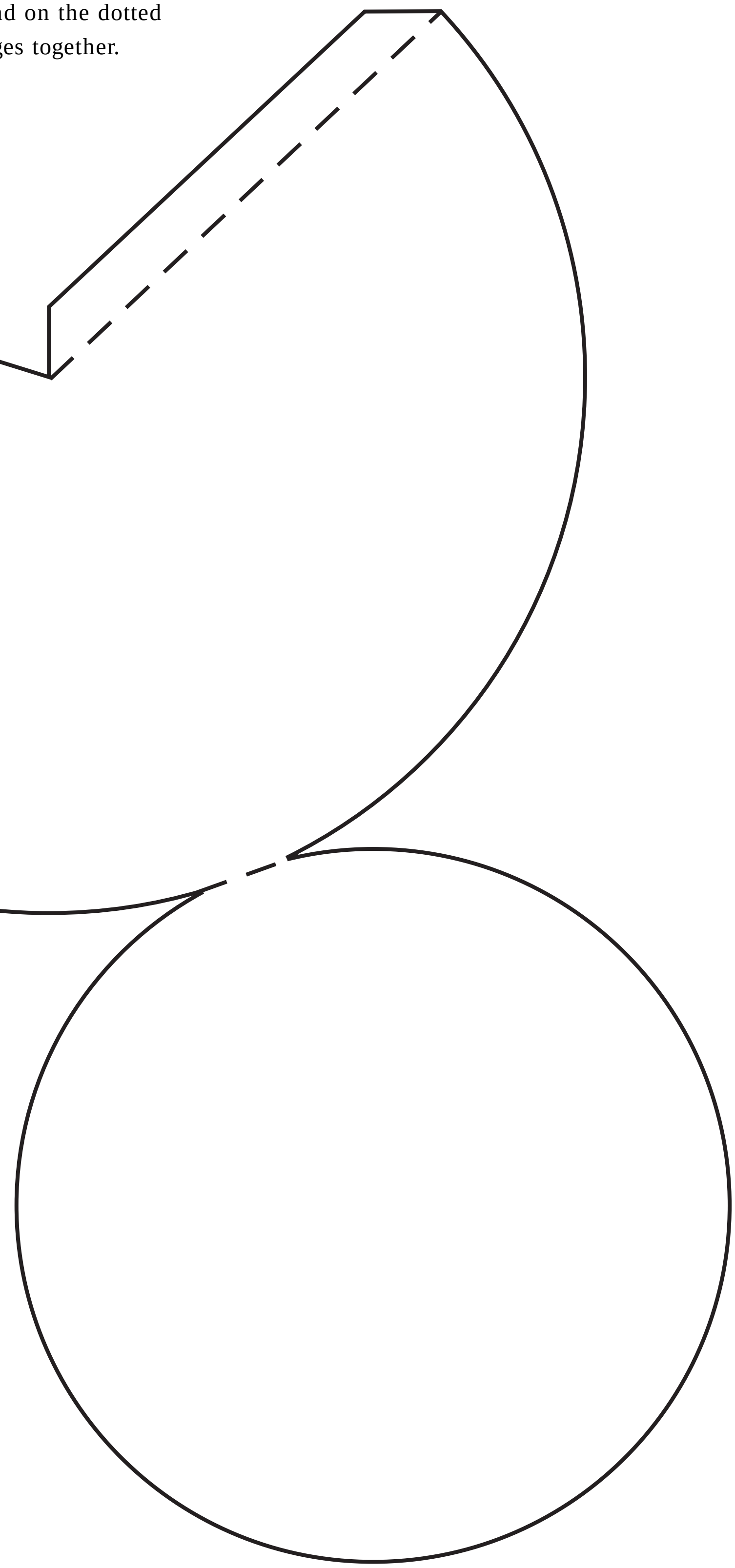
**C. Test chamber.** The test chamber is constructed of four pieces. To find the dimensions for these pieces, substitute the measurement represented by x.



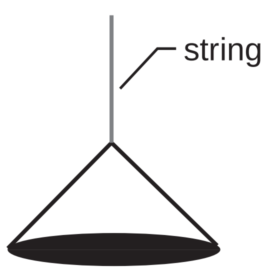
*test chamber*

## CONE

Cut out the shape, bend on the dotted lines, and tape the edges together.

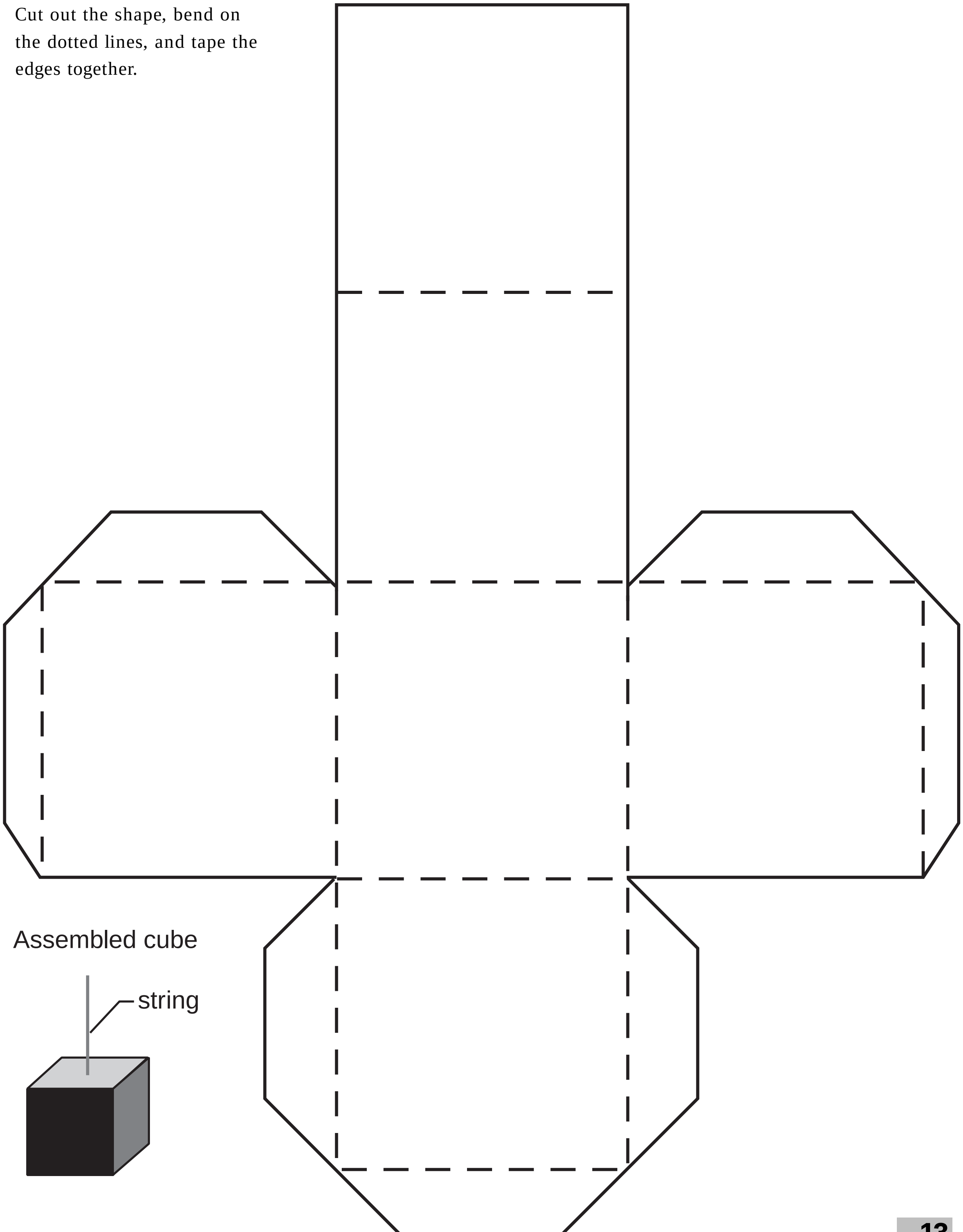


Assembled cone



## CUBE

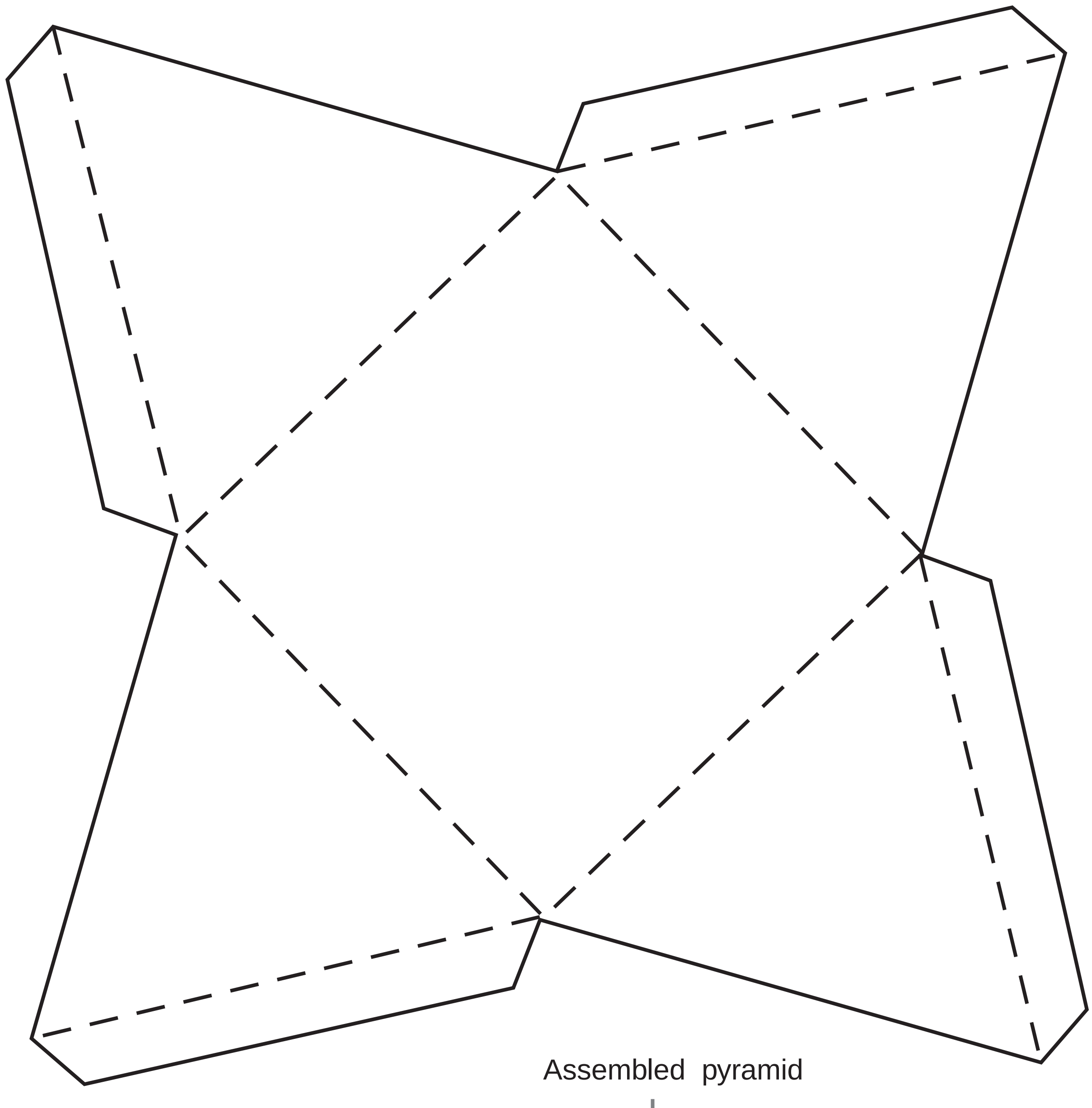
Cut out the shape, bend on the dotted lines, and tape the edges together.



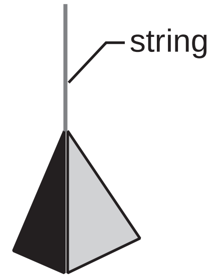

Assembled cube

## PYRAMID

Cut out the shape, bend on the dotted lines, and tape the edges together.

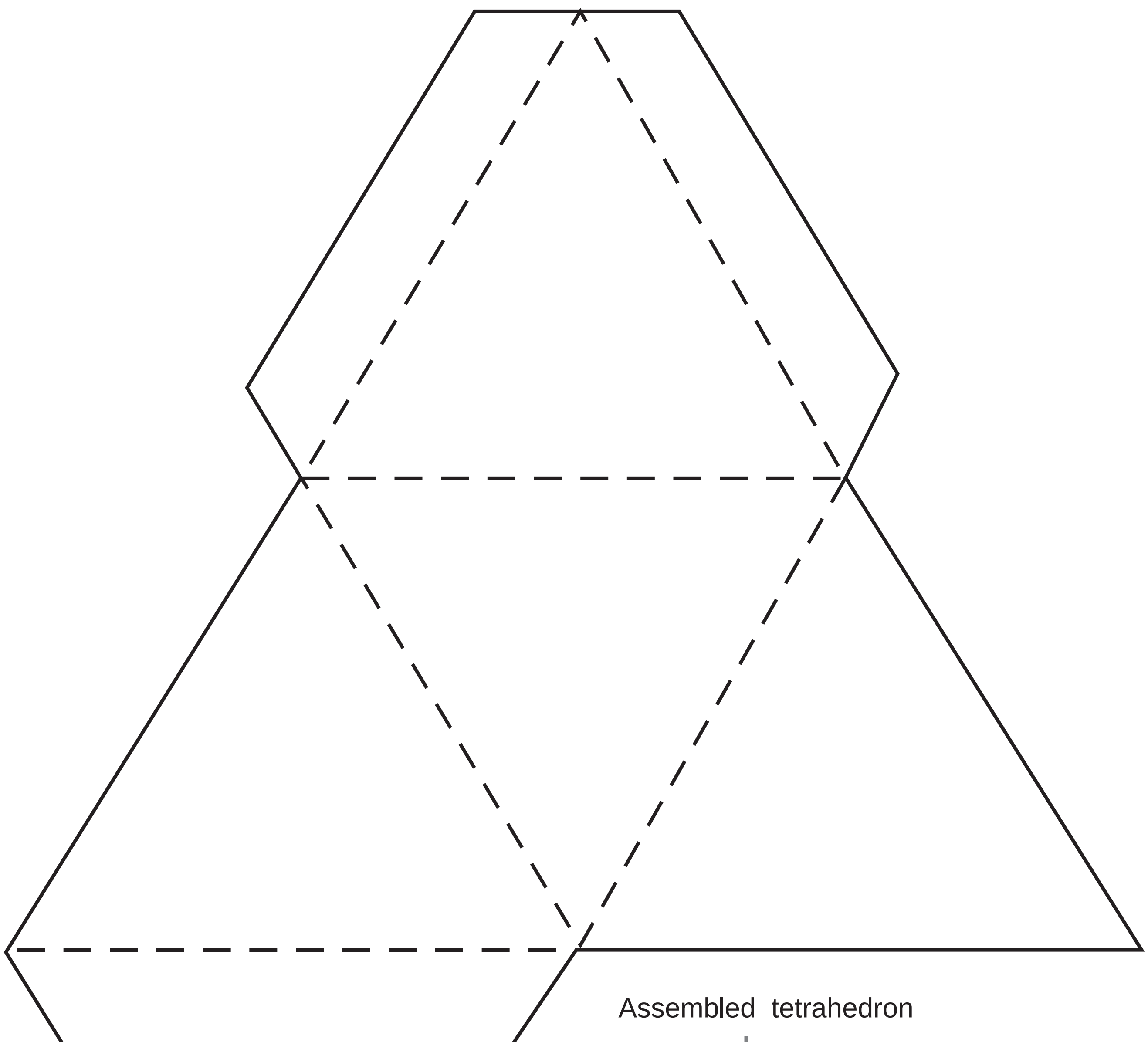


Assembled pyramid

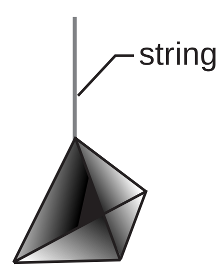


## TETRAHEDRON

Cut out the shape, bend on the dotted lines, and tape the edges together.



Assembled tetrahedron



## STUDENT DATA WORKSHEET

### Table B. Drag Force Value

| | Fan Speeds | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Low Speed | | | Medium Speed | | | High Speed | | |
| | test 1 | test 2 | test 3 | test 1 | test 2 | test 3 | test 1 | test 2 | test 3 |
| Tetrahedron | | | | | | | | | |
| Pyramid | | | | | | | | | |
| Cube | | | | | | | | | |
| Cone | | | | | | | | | |

Observations: ____________________________________________

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### Table C. Drag Force Value Calculations

| | Fan Speeds | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Low Speed | | | Medium Speed | | | High Speed | | |
| | mean | median | mode | mean | median | mode | mean | median | mode |
| Tetrahedron | | | | | | | | | |
| Pyramid | | | | | | | | | |
| Cube | | | | | | | | | |
| Cone | | | | | | | | | |

## GRAPH OF THE DRAG (MEAN)

Directions: Use bars to graph the mean of each shape at low, medium, and high speeds. Use a different colored pencil for each speed.

KEY

low speed = green
medium speed = blue
high speed = red