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How High Is It?

An Educator's Guide with Activities Focused on Scale Models of Distances

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About the cover: The cover design is not to scale. Creative license was taken in order to represent the different aircraft, spacecraft, and satellites that orbit and operate above Earth's surface.

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National Aeronautics and
Space Administration

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INTRODUCTION

Most of us have no idea how far the Moon really is from Earth, or how high the International Space Station orbits. Why should we? Vertical distances don't play a big role in most of our lives. People like sky divers, scuba divers, pilots, and mountain climbers have reason to be familiar with vertical distances. For the rest of us, measuring vertical distances, or altitudes, is not part of our daily experience. Creating different types of models of these altitudes begins to make the unfamiliar more understandable. Distances become easier to grasp when compared to something familiar, like the layers of the atmosphere. When middle school students study the layers of the atmosphere, they may use the activities in this guide to better visualize where satellites, spacecraft, aircraft, and other NASA vehicles orbit or operate with respect to the layers of the atmosphere.

Some of the altitudes involved are surprisingly close, like the Space Shuttle's orbit; others are vast, like geostationary satellites. Using models in various scales makes these distances easier to grasp and provides an excellent real-world opportunity to help students develop number sense and proportional reasoning. We have created different types of models, in different scales, showing relative distances using proportions, percentages, and ratios. In the course of these activities, we hope to give students a new perspective on the Earth-Moon system and to dispel common misconceptions. Students often have inaccurate ideas about how far away the Moon really is and what realistic altitudes are for different types of satellites, spacecraft, and aircraft.

By and large, the activities in this guide focus on mathematics. However, these aircraft, spacecraft, and satellite data may also be used in science or technology classes.

Satellites: Anything orbiting Earth is classified as a satellite. Earth's only natural satellite is the Moon. Many artificial satellites orbit our planet, including weather satellites, the Hubble Space Telescope, and the International Space Station.

Objectives

The objectives of this educator's guide are to have students

- create a variety of scaled models of the altitudes of NASA aircraft and spacecraft, natural and artificial satellites, and the layers of Earth's atmosphere; and
- develop number sense by representing scale factors in terms of ratios, decimals, and percentages.

HOW TO USE THIS GUIDE

Teachers may use a single activity from this guide or combine some or all of the activities to form a mini-unit, according to the needs and capabilities of their students. Read through the descriptions below for some suggestions.

Introductory Activities

A common tool teachers use to determine what students already know about a topic is a KWL chart. KWL stands for Know, Want to know, and Learned. The teacher can facilitate a discussion to find out what current class understanding is about the altitude at which objects orbit around Earth, the layers of the atmosphere, and types of NASA research vehicles: aircraft, spacecraft, and satellites. A KWL chart also provides an opportunity to find out what students want to learn about the topic. After using the core activities, the teacher can revisit the KWL chart to help students summarize what they have learned.

The Ball and String Earth-Moon Model activity (page 13) is a good hook for getting students to determine how far away the Moon is from Earth and where the International Space Station orbits. This is a dramatic demonstration, because students often do not realize that the Moon is about 30

Earth-diameters away. With a basketball-sized model Earth, the string stretches to the far side of the classroom to reach the scaled Earth-Moon distance. The International Space Station is a mere centimeter above the ball's surface. At this point, students begin their exploration of scaled distances by creating their own Earth-Moon models using different-sized balls.

Core Activities

Core activities provide a big picture for students: where objects orbit Earth in relationship to the layers of the atmosphere. These three activities flow nicely together in sequence, or teachers may choose to use a single activity as a stand-alone lesson.

How High Is It?

In the title activity, students make a six-page-high wall chart that shows the layers of the atmosphere. On the chart they place thumbnail pictures of NASA aircraft, spacecraft, and satellites at the appropriate altitudes. The model graphically puts these distances into perspective for students. However, satellites orbit much higher than the chart goes. The scale in the Altitude Walk activity encompasses satellites in the upper layers of the atmosphere, including our one natural satellite, the Moon.

Layers of the Atmosphere

After completing How High Is It, the class can do the Layers of the Atmosphere activity to review the language of percentages. Students compare each layer of the atmosphere to an altitude of 80 km. Humans who travel beyond this distance are considered astronauts. Circles representing 10 percent of this altitude are color coded to model the lowest four layers of the atmosphere.

Altitude Walk

Here students take the altitudes of aircraft, spacecraft, and satellites, including the Moon, and represent these distances using a scale where 1 cm = 100 km. Students can lay out this model on half of a football field or in a gymnasium, and then take a walk to the Moon and back. The distances may be surprising.

Activity/Assessments

Teachers can choose from several activities that can be used as classwork, homework, and/or assessments to show mastery of concepts.

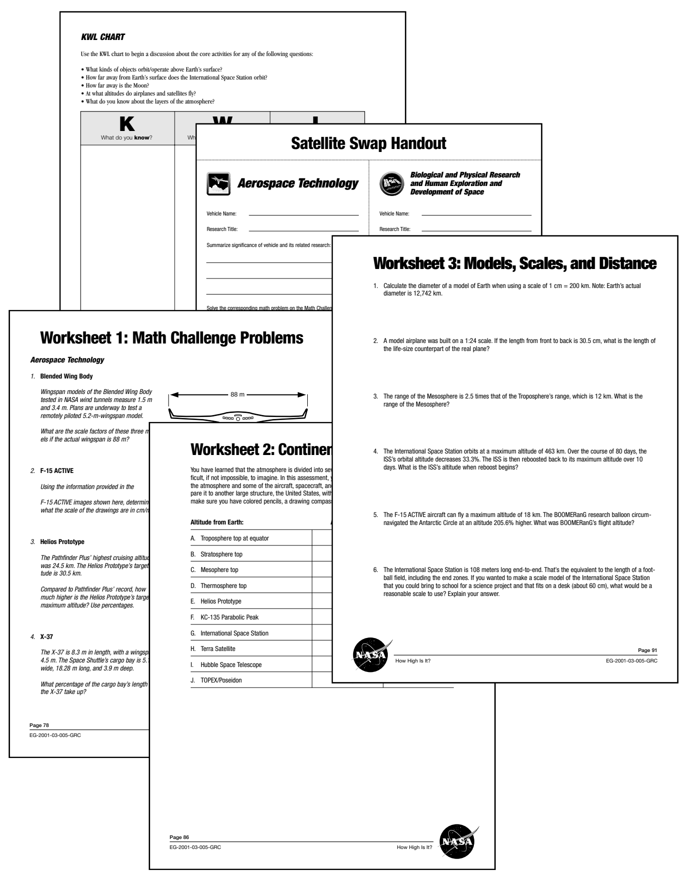
1. Students go back and complete the last "L" section of the KWL chart, individually or as a class.

2. Students play Satellite Swap to learn about NASA vehicles and the research done on them. This game can also be used as an assessment.

3. The Math Challenge Problems Handout (Worksheet 1) can be used with the Satellite Swap game as an assessment, or it can be given as homework.

4. Worksheet 2 requires students to use a specific scale to fit NASA vehicles and atmospheric layers on a map of the continental United States.

5. Worksheet 3 offers a variety of open-ended problems about models and scales that use decimals, ratios, and percentages.



NATIONAL EDUCATION STANDARDS

The activities in this guide help students achieve mastery of national standards for mathematics, science, and technology.

Principles and Standards for School Mathematics *by National Council of Teachers of Mathematics, 2000, Grades 6–8*

Measurement
Apply appropriate techniques, tools, and formulas to determine measurements.

- Using ratio and proportion, solve problems involving scale factors.

Number Operations
Understand numbers, ways of representing numbers, relationships among numbers, and number systems.

- Develop meaning for percentages greater than 100 and less than 1.
- Understand and use ratios and proportions to represent quantitative relationships.

Standards for Technological Literacy: Content for the Study of Technology *by the International Technology Education Association, 2000, Grades 6–8*

Nature of Technology
Students will develop an understanding of the relationships among technologies and the connections between technologies and other fields of science.

National Science Education Standards *by the National Research Council, 1996, Grades 5–8*

Unifying Concepts and Processes
- Evidence, models, and explanation
  Models are tentative schemes or structures that correspond to real objects, events, or classes of events, and that have explanatory properties. Models help scientists and engineers understand how things work. Models take many forms, including physical objects, plans, mental constructs, mathematical equations, and computer simulations.
- Constancy, change, and measurement
  Effective use of scale includes understanding that different characteristics, properties, or relationships within a system might change as its dimensions are increased or decreased.

Earth and Space Science
- Structure of the Earth System
  The atmosphere is a mixture of nitrogen, oxygen, and trace gases that include water vapor. The atmosphere has different properties at different elevations.

Science and Technology
- Understanding science and technology
  Science and technology are reciprocal. Science helps drive technology, as it addresses questions that demand more sophisticated instruments and provides principles for better instrumentation and technique. Technology is essential to science, because it provides instruments and techniques that enable observations of objects and phenomena that are otherwise unobservable due to factors such as quantity, distance, location, size, and speed. Technology also provides tools for investigations, inquiry, and analysis.

MASTER MATERIALS LIST

Ball and String Earth-Moon Model
- ☐ Inflatable ball (~75 cm in circumference)
- ☐ Tennis ball
- ☐ Balls of assorted sizes (1 per pair of students)
- ☐ Modeling clay (1 piece per pair of students, optional)
- ☐ String (1 per pair of students)
- ☐ Markers (1 per pair of students)
- ☐ Rulers (1 per pair of students)
- ☐ Earth-Moon Model Worksheet (1 per student)
- ☐ Calculators (1 per pair of students)
- ☐ Small plastic beads (optional)

How High Is It?
- ☐ How High Is It? Worksheet (1 per student)
- ☐ Altitude Chart (6 pages total, 1 set per student)
- ☐ Atmospheric Layers Table (1 per student)
- ☐ NASA Vehicles Template (1 per student)
- ☐ NASA Vehicle Altitude Table (1 per student)
- ☐ Clear tape (1 per pair of students)
- ☐ Scissors (1 per student)
- ☐ Colored pencils or markers (1 per pair of students)
- ☐ Small sticky notes (1 pad per pair of students)
- ☐ Glue stick (1 per pair of students)
- ☐ Ruler or straight edge (1 per student)
- ☐ Gallon-sized sealable bags
- ☐ Empty box
- ☐ Permanent marker

Layers of the Atmosphere
- ☐ Layers of the Atmosphere Worksheet (1 per student)
- ☐ Construction paper strips, 3 x 20 cm (7 per student)
- ☐ 3/4" circle stickers (assorted colors)
  Quantity per student: 54 red, 4 blue, 5 green, 2 yellow
- ☐ Clear tape (1 per pair of students)
- ☐ Scissors (1 per pair of students)
- ☐ Ruler or straight edge (1 per student)
- ☐ Markers (1 per pair of students)
- ☐ Sandwich-sized sealable bags (1 per student)

Altitude Walk
- ☐ NASA Vehicle Cards (pages 60–64)
- ☐ Altitude Walk Worksheets Part 1 & 2 (1 per student)
- ☐ Tape measures or meter sticks (1 per group)
- ☐ Ball of string
- ☐ Scissors
- ☐ Masking tape
- ☐ Whistle
- ☐ Chalk
- ☐ Cardboard (optional)
- ☐ Laminate for pictures (optional)
- ☐ Camera (optional)

Satellite Swap Assessment
- ☐ Satellite Gamecards (set of 32 colored pictures)
- ☐ Satellite Swap Handout (1 per student)
- ☐ Math Challenge Problems (1 per student)

INTRODUCTORY ACTIVITIES

KWL CHART

Use the KWL chart to begin a discussion about the core activities for any of the following questions:

- What kinds of objects orbit/operate above Earth's surface?
- How far away from Earth's surface does the International Space Station orbit?
- How far away is the Moon?
- At what altitudes do airplanes and satellites fly?
- What do you know about the layers of the atmosphere?

K What do you **know**?	W What do you **want** to learn?	L What did you you **learn**?

BALL AND STRING EARTH-MOON MODEL ACTIVITY

Description

Determine how far away the model Moon and International Space Station are from a playground ball used to represent Earth. Unwrap a string to show the scaled distances. Students make their own models based either on a ball's circumference or on its diameter.

Objectives

Students will

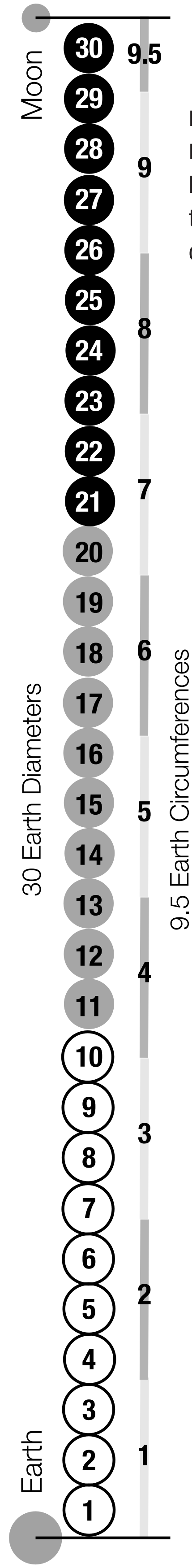
- predict the distances of the Moon and the International Space Station from a model Earth,
- create appropriate scales to make models of the Earth-Moon system using a ball's circumference or diameter, and
- explain how a model helps them understand distances.

Materials

- ☐ Inflatable ball (~75 cm in circumference)
- ☐ Tennis ball
- ☐ Balls of assorted sizes (1 per pair of students)
- ☐ Modeling clay (1 piece per pair of students, optional)
- ☐ String (1 per pair of students)
- ☐ Markers (1 per pair of students)
- ☐ Rulers (1 per pair of students)
- ☐ Earth-Moon Model Worksheet (1 per student)
- ☐ Calculators (1 per pair of students)
- ☐ Small plastic beads (optional)

Background

Students usually do not know how far the Moon or the International Space Station is from Earth. This activity will give you insight into your students' thinking and begin to show them the power of using models to make sense of distances.



Ball and String Earth-Moon Model: The Earth-Moon distance is 9.5 times Earth's circumference, or 30 times Earth's diameter.

Preparation

- Go to a discount store to find an inexpensive supply of balls of different sizes, or have students bring in some. Try inflatable balls, marbles, tennis balls, golf balls, table tennis balls, softballs, superballs, plastic toy balls, basketballs, soccer balls, volleyballs, etc. You will need one ball per pair of students.

- Make sure you have an inflatable ball or a playground ball with a circumference of about 75 cm. With a model Earth this size, you can use a tennis ball to represent the Moon (about 7 cm in diameter).

- Tape one end of the string to the ball.

- Measure the string to represent the Earth-Moon distance to scale. To use circumference as a unit of measure, wrap the string 9.5 times around the ball. To use the ball's diameter as the unit, measure 30 times the ball's diameter (diameter = circumference / π).

- Note the beginning point where the string is taped to the ball. As you wrap the string around the ball, mark the string each time you come to the beginning point. This way you know each wrap is one circumference of the ball.

- Color every other circumference length with a marker. This will help students see nine-and-a-half circumference units.

- On this scale, you can represent the height of the International Space Station at a typical orbit by coloring a segment of the string 1 cm from the ball's surface. Below this point are the three lower layers of the atmosphere.

- For a complete mathematical explanation about calculating the model Earth-Moon string length, see the teacher note at the end of the activity on page 19.

Procedure

1. Hold up a ball to represent the size of Earth. If a ball with a circumference of 75 cm represents Earth, a tennis ball represents the Moon.

2. Ask students to estimate how far they think the model Moon is from the model Earth. You may want to suggest a few distances to get a discussion started, such as 15 cm (~ 6 in), 30 cm (~ 1 ft), 60 cm (~ 2 ft), 1 meter (~ 3 ft), 2 meters (~ 6.5 ft).

3. Ask them to estimate how far away from Earth the International Space Station orbits with this model.

4. Ask how they could find out how far away the Moon (tennis ball) is from the Earth (ball). Consider encouraging them to research the answer instead of just spoon-feeding them.

5. The Moon orbits Earth at a distance of 384,430 km. Does that number mean anything to them? How far away is that?

6. Discuss why it's helpful to use models.

   - make big numbers smaller, more human-sized;
   - break the distance into parts;
   - examine the smaller parts more closely; and
   - compare the unfamiliar to the familiar.

   More information on models appears on page 39, step 3, and on page 9, Science Standards, 1st bullet.

7. You'll need a volunteer to help you show the distance using the scaled model.

8. While you hold the ball, have the volunteer take the loose end of the string and begin to walk across the room. Rotate the ball to help unravel the string as the student walks, and walks, and walks! The distance is pretty dramatic. Ask who is surprised with the answer.

9. Explain the markings on the string as being distances that use units of either the model Earth's circumference or its diameter, depending on which method you choose. The Earth-Moon distance is about 9.5 times

Earth's circumference, or 30 times Earth's diameter. Do these units seem more meaningful than 384,430 km? Why is that?

10. Ask where the International Space Station orbits in this model. Point to the tiny segment of the string where the International Space Station orbits 1 cm above the surface of the ball. Isn't this amazingly close to Earth's surface? The real International Space Station orbits at around 400 km above the surface.

11. To put these distances into perspective, identify what and where the three lower layers of the atmosphere are: Troposphere, Stratosphere, and Mesosphere.

    The Troposphere is the one that contains our oxygen. The lower three layers of the atmosphere end halfway to the International Space Station. Surprise!

12. Have students complete the worksheet to build their own Earth-Moon models.

13. When students have completed their models, have them stand in order by the size of their models, from smallest to largest. Have them compare the size of their models and share observations about other models.

Discussion

1. What is a model? *A model is a replica or copy of something we want to study. It lets us explore things that are really big, really small, really far away, or really complex.*

2. How is a model like the real thing? *A model has some characteristics of the real thing. In the Ball and String model, the distance between Earth and the Moon is to scale.*

3. How is a model different from the real thing? *A model is not completely accurate because it is a copy of the real thing; it only has a few of the characteristics of the real object.*

4. How does a model help you understand the Earth-Moon distance? *It makes a big number more human-sized and breaks the distance into parts.*

5. Complete the following sentence: "One thing I was surprised to learn is. . . ." *Answers will vary.*

6. Complete the following sentence: "One thing I don't understand about making a model to scale is. . . ." *Answers will vary.*

7. Based on this activity, do you think you could make another Earth-Moon model given a different-sized ball? *Answers will vary.*

8. How do you find the scale of a model compared to the real thing? *Set up a ratio. (scale size):(real size)*

9. How do the different models compare in size? *The smaller the scale, the smaller the distance between the objects.*

Extensions

- Discuss the teacher facts on page 19 with students if appropriate.
- Calculate and make a scaled Earth-Moon model using toilet paper sheets as a method of measurement.
- Make a model using a huge Earth ball for parents' night, and have the string taped to the wall going down the hallway.

Name ________________________________

Teacher ________________________________

Period ________________________________

Date ________________________________

Earth-Moon Model Worksheet

Materials

- ☐ 1 ball
- ☐ Modeling clay (optional)
- ☐ String
- ☐ Markers
- ☐ Ruler or meter stick
- ☐ Calculator

Getting Ready

- For this activity, you will work with a partner to make a model of the Earth-Moon system to scale using a ball of any size.
- Have one partner get the first three materials in the list and the other get the last three items on the list.
- Choose the method you will use to find the scaled Earth-Moon distance: Earth's circumference or Earth's diameter. Be sure to follow that method below.

Begin

1. Wrap a string once around the ball. Mark the string carefully. Remove the string and measure it.

2. a. What is the circumference of the ball? ________________

   b. Circumference Method: The Earth-Moon distance is about 9.5 times the circumference of Earth.

   What length should the string be for your model? ________________

   or

3. a. What is the diameter of the ball (diameter = C / π)? ________________

   b. Diameter Method: The Earth-Moon distance is about 30 times Earth's diameter.

   What length should the string be for your model? ________________

4. Add an extra 2 cm to the length you calculated. This leaves room to tape the string to the ball. Cut the string to this new length.

5. Cover the extra 2 cm of string with tape and attach the string to the ball.

6. The circumference of Earth is 40,030 km. Determine the scale you will use to create the rest of your model, using this formula: Scale = C_{ball} / C_{Earth}

7. Find the scaled measurements for the following, using the scale from step 7.

Real Object	Actual Measurement (km)	Scaled Measurement (cm)
Moon's Radius	1,738	
International Space Station Orbital Altitude	400	

8. Make a Moon to scale using modeling clay, or find a ball close to the appropriate size. Place the model Moon at the end of the string to complete your model.

9. Use a red marker to color a dot on the string to mark the International Space Station's orbit.

Worksheet Answer Key

The following table contains measurements for a variety of balls that could be used in this activity. Approximate answers for the Earth-Moon Model Worksheet are included in the table. NOTE: Ball sizes may vary, so student responses are likely to vary as well. The chart below is designed to give "ballpark" answers. The important thing to remember is that the distance to the Moon is about 9.5 times Earth's circumference or 30 times Earth's diameter. The abbreviation for the International Space Station is ISS.

Ball	Ball Circumference (cm)	Ball Diameter (cm)	Scale (cm/km)	Scaled Distance to Moon (cm)	Scaled Moon Radius (cm)	Scaled ISS Altitude
3/8" Steel Shot	3.5	1.1	0.00009	34	0.2	0.0
Marble	5.5	1.8	0.0001	53	0.2	0.1
Marble Shooter	8.0	2.5	0.0002	77	0.3	0.1
Superball	8.5	2.7	0.0002	82	0.4	0.1
Table Tennis Ball	8.5	2.7	0.0002	82	0.4	0.1
Golf Ball	13.4	4.3	0.0003	129	0.6	0.1
Baseball	23.0	7.3	0.0006	221	1.0	0.2
Softball	30.5	9.7	0.0008	293	1.3	0.3
Inflatable Ball	74.5	23.7	0.002	716	3.2	0.7
Soccer Ball	70.0	22.3	0.002	673	3.0	0.7
Volleyball	65.0	20.7	0.002	625	2.8	0.6
Basketball	75.5	24.0	0.002	725	3.3	0.8

TEACHER FACTS: THE MATHEMATICS BEHIND THE BALL AND STRING MODEL

This note is meant to give further clarification for teachers interested in knowing precisely what factors affect how to create the model, and it introduces several discussion/research topics that you may want to use as an extension for this activity. While you and your students create your own model, keep in mind what you know and teach about the accuracy and precision of measurements, significant digits, and rounding.

Distances between planetary bodies are typically cited as being between the centers of each body. This needs to be taken into account when designing a scale Earth-Moon system using playground balls and string because it is not possible to start the string at the center of the ball. We will account for the radii of Earth and Moon when we connect the string to the surface of the ball. The exact scale for your model will depend on the size of the ball you use to represent Earth. Here's how to do it.

Start with an average inflatable ball from a retail store, a kickball, or basketball. Keep in mind that such balls tend to lose air over time and, once you have made your model, you should check the ball's circumference if you haven't used it in a while.

1. Use a piece of string to measure the circumference of the ball. From the circumference, determine the radius of the ball. Our ball's circumference is 74.5 cm.

   Circumference = $2\pi r$
   $\pi = 3.14$
   Therefore, $r = C / 2\pi$
   $C_{ball} = 74.5$ cm
   $r_{ball} = C_{ball} / (2\pi) = (74.5 \text{ cm}) / (2\pi) = 11.8$ cm

2. Determine the scale you will use to create the rest of your model.

   Scale = $C_{ball} / C_{Earth} = (74.5 \text{ cm}) / (40{,}030 \text{ km}) = 0.002$ cm/km

3. Determine the scale model radius of the Moon and check to make sure that your calculated ball radius matches the scaled radius of Earth.

   $r_{Moon} = 1{,}738$ km
   Scaled Moon radius $r_{SMoon} = (1{,}738 \text{ km}) * (0.002 \text{ cm/km}) = 3.5$ cm
   $r_{Earth} = 6{,}371$ km
   Scaled Earth radius $r_{SEarth} = (6{,}371 \text{ km}) * (0.002 \text{ cm/km}) = 12.7$ cm

   Why is the scaled Earth radius not the same as the radius of the ball? This is because we rounded when we calculated our scale factor of 0.002 cm/km. Where does that leave us? Well, in a really good position to explore or revisit rounding of numbers and to discuss when an "order of magnitude" answer is sufficient.

   To continue to create a model for this activity, use the actual ball radius in the calculations.

4. Determine the scaled distance between the center of Earth and the center of the Moon.

   $d_{E\text{-}M} = 384{,}430$ km
   Scaled distance $d_{SE\text{-}M} = (384{,}430 \text{ km}) * (0.002 \text{ cm/km}) = 769$ cm

5. The string will extend between the surface of the two balls, so the scaled distance needs to be adjusted.

   String Length SL = $d_{SE\text{-}M} - (r_{ball} + r_{SMoon}) = 769 \text{ cm} - (11.8 \text{ cm} + 3.5 \text{ cm}) = 754$ cm

6. Measure a piece of string the length determined in Step 5. Wait! Don't cut your string yet. Mark the string at the designated length. Measure off an additional 2 cm and cut the string there.

7. Use your model's scale to determine where on the string to mark the average orbital altitude of the

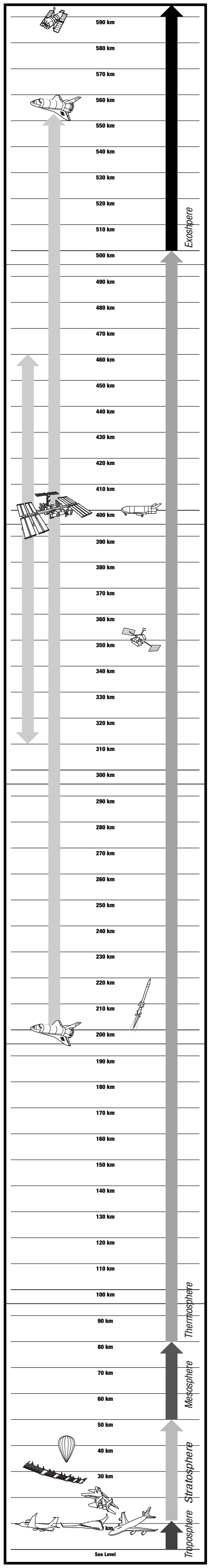
International Space Station. Mark this position on the string (from the previous mark back towards the length of the string).

d_{ISS} = 400 km * 0.002 cm/km = 0.8 cm

8. Attach the string to your ball with tape so that the first mark you made is at the surface of the ball. The International Space Station altitude mark should then be very close to the surface. Wrap the remaining string around the ball and you are ready to test your class's appreciation of how far away from Earth the Moon and the International Space Station orbit. The string should end up going approximately 9.5 to 10 times around the ball.

9. Note that at the scale used in our example, the scaled Moon would be comparable in size to a tennis ball or baseball.

CORE ACTIVITIES



HOW HIGH IS IT? ACTIVITY

Description

Students make a six-page-high chart showing five layers of Earth's atmosphere. They cut out pictures of NASA aircraft, satellites, and spacecraft and graph where these NASA vehicles fly or orbit.

Objectives

Students will

- make a model of Earth's atmospheric layers;
- graph where aircraft, satellites, and spacecraft operate;
- interpret which objects operate in which layers of the atmosphere; and
- infer conclusions about why the objects operate where they do in the atmospheric layers.

Materials

☐ How High Is It? Worksheet (1 per student)
☐ Altitude Chart (6 pages total, 1 set per student)
☐ Atmospheric Layers Table (1 per student)
☐ NASA Vehicles Template (1 per student)
☐ NASA Vehicle Altitude Table (1 per student)
☐ Clear tape (1 per pair of students)
☐ Scissors (1 per student)
☐ Colored pencils or markers (1 per pair of students)
☐ Small sticky notes (1 pad per pair of students)
☐ Glue stick (1 per pair of students)
☐ Ruler or straight edge (1 per student)
☐ Gallon-sized sealable bags
☐ Empty box
☐ Permanent marker

Preparation

- Copy enough templates for each student, plus extra for your own practice model.

- If you choose, direct the students to work in groups of two or three.

- Have students or teams store their unfinished projects in a gallon-sized resealable bag. Store the bags in a box for the class. Bags will lie flat if students snip off a tiny corner of the bag bottom.

- Instruct students to write their names on the bag in permanent marker.

- Review the layers of the atmosphere with the class. (See the Teachers Facts: Layers of the Atmosphere on page 44.)

Procedures

1. As a class, name the five layers of the atmosphere: Troposphere, Stratosphere, Mesosphere, Thermosphere, and Exosphere. Discuss the characteristics of each layer.

2. Explain that students are going to make a six-page-high model of the layers of the atmosphere (Altitude Chart) that shows where NASA aircraft, spacecraft, and satellites orbit or operate.

3. Pass out copies of the Altitude Chart pages found on pages 27–32. To make the chart, tape the six pages end to end, then fold them so that they fit on the desk in a tidy stack.

4. Have students put their names on the backs of the charts.

5. Find Sea Level (Earth's surface) at the bottom of the graph. Color this area blue for water. Each horizontal black line represents 10 km above the last.

6. Pass out an Atmospheric Layers Table (page 33) to each team. Instruct students to add each layer of the atmosphere to the chart. They can color in the layers of the atmosphere with colored pencils or markers and should draw an arrow from the base of each layer to the top of the layer. Label the layers of the atmosphere in large letters.

7. Pass out a NASA Vehicles Template (page 34) to each team. Have students cut out each vehicle and paste it on a small sticky note. Have students estimate where the NASA vehicles fly or orbit by placing the sticky notes at the appropriate places. Students should record their estimates in step five of the worksheet.

8. After students have made their estimates, pass out the NASA Vehicle Altitude Table (page 35). Have students write the flight or orbital altitude on the sticky notes above the picture and then move it to the correct place on the chart if necessary.

9. When they are done, have them hang their graphs on the room walls where appropriate.

10. Have them complete the worksheet questions.

11. Discuss the project as a class.

Discussion

1. How has students' understanding of "How high is it?" changed? *Students should have a better sense of the altitudes at which NASA aircraft, spacecraft, and satellites fly or orbit in relation to the layers of the atmosphere.*

2. How accurate were students' estimates? *Have students explain how they made their estimates. Answers will vary.*

3. If the atmosphere is so big, why do planes primarily operate in the Troposphere? *Aircraft are going to fly low to the ground for many reasons. The Troposphere contains most of the oxygen in the atmosphere, which aircraft engines need to operate. Logistically speaking, the higher something flies, the more fuel is needed and the greater the cost.*

4. Why didn't all of the spacecraft fit on this graph? *Some spacecraft and satellites have orbital altitudes that exceed the chart's range.* Why is this fact significant? *This model has a limitation. It does not show all of the fifth layer of the atmosphere, where some Earth-orbiting satellites and spacecraft orbit.*

Extension

To extend the activity, or as an additional homework assignment, have students add the spacecraft and satellites to their ball and string model (page 13). Challenge students to color in the lower layers of the atmosphere on the string as well; the scaled layers will be mere millimeters thick.

Name ________________________________

Teacher ________________________________

Period ________________________________

Date ________________________________

How High Is It? Worksheet

Materials
- ☐ 6 pages with lines
- ☐ Vehicle template
- ☐ Clear tape
- ☐ Scissors
- ☐ Colored marker sets
- ☐ Small sticky notes
- ☐ Glue stick
- ☐ Ruler or straight edge
- ☐ 1 gallon-sized resealable bag
- ☐ Atmospheric Layers Table

Getting Ready

- For this activity you will work with a partner to a make a six-page model of the layers of the atmosphere.
- Have one partner get the first four items on the list and the second get the rest.

Procedures

1. Find the six pages numbered from Sea Level to 590 km. Tape these pages end-to-end like a banner, using clear tape on the back.
2. Fold the pages accordion-style into a stack.
3. Use the information from the Atmospheric Layers Table to draw a line across the chart to indicate the top of each atmospheric layer. Draw an arrow from the bottom to the top of each layer. Label and color in each layer.
4. Find the NASA Vehicles Template. Cut out each square. Glue each picture to the front of a small sticky note with the glue stick.

5. Estimate at which altitude you think each aircraft, spacecraft, and satellite either flies or orbits. Take each picture and place it on the chart to show your estimates. Record your estimated altitudes below.

________ Blended Wing Body	________ KC-135
________ BOOMERanG	________ SOFIA
________ Chandra	________ Sounding Rocket
________ F-15 ACTIVE	________ Space Shuttle
________ GOES	________ Terra Satellite
________ Helios Prototype	________ TOPEX/Poseidon
________ Hubble Space Telescope	________ TRMM
________ International Space Station	________ X-37

6. Get a copy of the NASA Vehicle Altitude Table. Using the table, position the vehicles at the correct altitude and glue them in place.

7. Were any of your estimates close? If so, which ones? Draw a star by estimates that were close.

Questions

1. Which vehicles fly in the Troposphere?

2. Which vehicles fly in the Stratosphere?

3. Which vehicles fly in the Mesosphere?

4. Which vehicles fly in the Thermosphere?

5. Which vehicles fly mostly in the Exosphere?

6. Where do you think Earth-observing satellites orbit?

   What determines their orbital altitude?

7. Why do you think the Hubble Space Telescope orbits in the Exosphere?

8. The lines on the chart are about 2.5 cm apart. What is the scale of this chart?

   Explain how you determined this. 1 cm = ___ km

9. What scale could you use so that this chart fits on one page? Explain how you determined this.

10. Finish this sentence: “One thing I learned from this activity was. . . .”

11. Finish this sentence: “One thing I was surprised to learn was. . . .”

12. Finish this sentence: “Something I’m still confused or have a question about is. . . .”

90 km

80 km

70 km

60 km

50 km

40 km

30 km

20 km

10 km

Sea Level

190 km

180 km

170 km

160 km

150 km

140 km

130 km

120 km

110 km

100 km

290 km

280 km

270 km

260 km

250 km

240 km

230 km

220 km

210 km

200 km

390 km

380 km

370 km

360 km

350 km

340 km

330 km

320 km

310 km

300 km

490 km

480 km

470 km

460 km

450 km

440 km

430 km

420 km

410 km

400 km

590 km

580 km

570 km

560 km

550 km

540 km

530 km

520 km

510 km

500 km

Atmospheric Layers Tables

Atmospheric Layers	Metric (km)
Troposphere Top	12
Stratosphere Top	50
Mesosphere Top	80
Thermosphere Top	500
Exosphere Top	above 500

Atmospheric Layers	Metric (km)
Troposphere Top	12
Stratosphere Top	50
Mesosphere Top	80
Thermosphere Top	500
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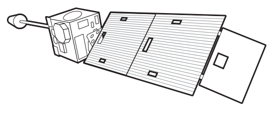
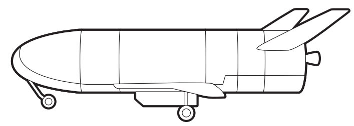
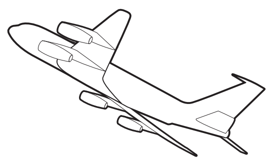
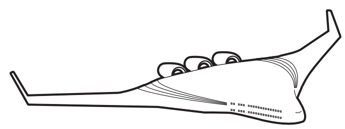
Atmospheric Layers	Metric (km)
Troposphere Top	12
Stratosphere Top	50
Mesosphere Top	80
Thermosphere Top	500
Exosphere Top	above 500

NASA Vehicles Template


GOES


X-37


KC-135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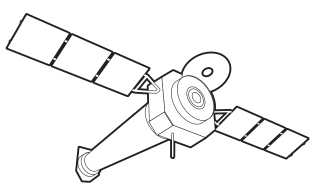
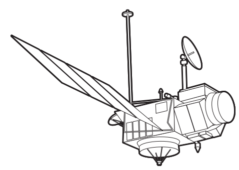
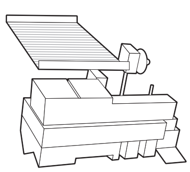
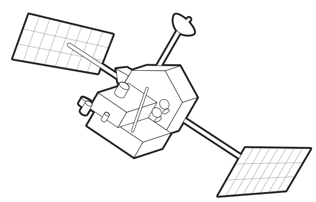
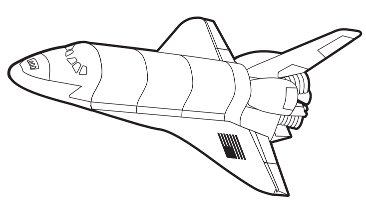
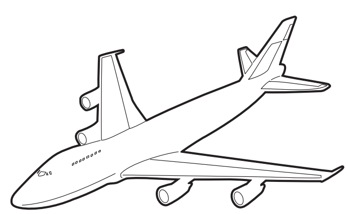

Chandra


TOPEX/Poseidon


Terra


TRMM


Space Shuttle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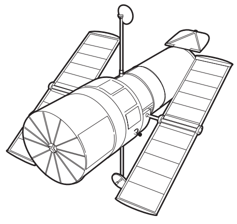
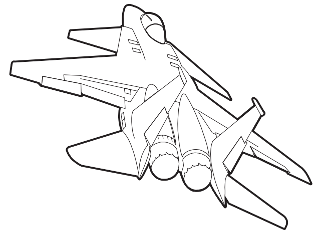
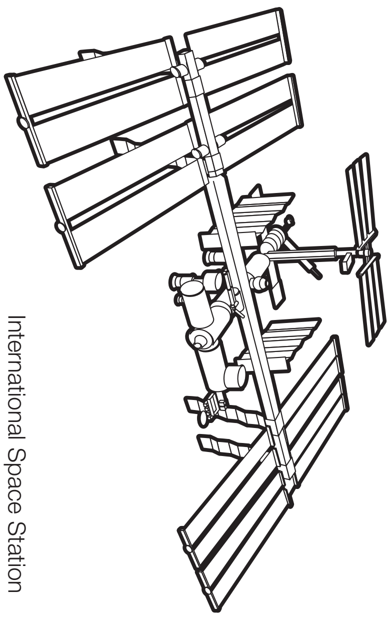
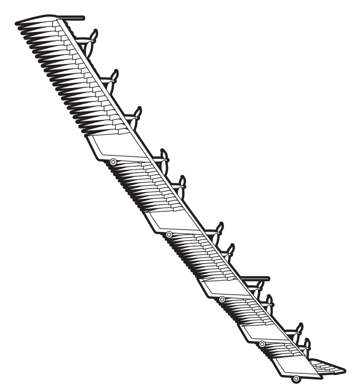
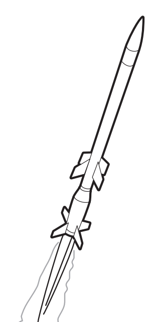
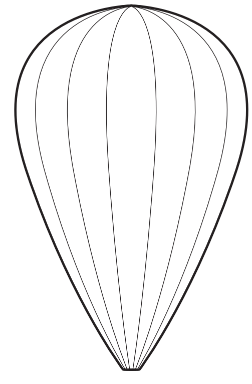

Hubble Space Telescope


F-15 ACTIVE


International Space Station


Helios Prototype


Sounding Rocket


BOOMERanG

NASA Vehicle Altitudes Tables

NASA Vehicle Altitude	Altitude (km)
Blended Wing Body	12
BOOMERanG	37
Chandra	9,942
F-15 ACTIVE	18
GOES	36,000
Helios Prototype	31
Hubble Space Telescope	595
International Space Station	309–463
KC-135	8–11
SOFIA	13
Sounding Rocket	209
Space Shuttle	195–556
Terra Satellite	705
TOPEX/Poseidon	1,336
TRMM	350
X-37	400

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TOPEX/Poseidon	1,336
TRMM	350
X-37	400

Worksheet Answer Key

1. Which vehicles fly in the Troposphere? *Blended Wing Body and the KC-135.*

2. Which vehicles fly in the Stratosphere? *BOOMERanG, F-15 ACTIVE, and the Helios Prototype.*

3. Which vehicles fly in the Mesosphere? *None of these NASA aircraft, spacecraft, or satellites.*

4. Which vehicles fly in the Thermosphere? *The Space Shuttle, International Space Station, Sounding Rocket, TRMM, and X-37.*

5. Which vehicles fly mostly in the Exosphere? *Chandra, GOES, Hubble Space Telescope, SOFIA, Terra, and TOPEX/Poseidon.*

6. Where do you think Earth-observing satellites orbit? *Most Earth observing satellites orbit at 705 km.* What determines their orbital altitude? *They need to be far enough away from Earth to see large portions of Earth at one time. Some need to be high enough that they revolve in sync with Earth's rotation, so that they always see the same part of Earth. These geostationary satellites orbit at tens of thousands of kilometers.*

7. Why do you think the Hubble Space Telescope orbits in the Exosphere? *The higher a spacecraft functions in the atmosphere, the less interference or obstruction the atmosphere causes in the data collected.*

8. The lines on the chart are about 2.5 cm apart. What is the scale of this chart? *1 cm = 4 km.*

9. What scale could you use to make this chart fit on one page? *Answers will vary; 1 cm = 25 km works well, using a total of 24 cm. A page is 28 cm long.*

10. Finish this sentence: "One thing I learned from this activity was. . . ." *Answers will vary.*

11. Finish this sentence: "One thing I was surprised to learn was. . . ." *Answers will vary.*

12. Finish this sentence: "Something I'm still confused about or have a question about is. . . ." *Answers will vary.*

The general positioning of the various aircraft and spacecraft for easy reference is presenting on the following page.

NOTE: Not all NASA vehicles fit on the chart. Students will not be able to place Chandra, GOES, SOFIA, Terra, and TOPEX/Poseidon. This is intentional, so that the teacher can discuss the limits of a model and the scale chosen. If you change the scale, you can fit greater distances on the paper. As the model's scale changes, the distance between objects alters. For the How High Is It? model, the aircraft and spacecraft are farther apart, whereas they all appear on top of each other in the Altitude Walk model.

Did you know?

The ISS will be the size of two football fields when completely assembled, and it will appear as a bright star visible at dawn and dusk. When fully assembled, the ISS will be the third-brightest object in the sky. It will orbit Earth every 90 minutes, experiencing 16 sunrises and sunsets in one day.

The ISS does not always orbit at a constant altitude. Although it is high in the upper atmosphere, an object this size feels the effect of air drag. It free falls for 80 days and is then reboosted over 10 days.

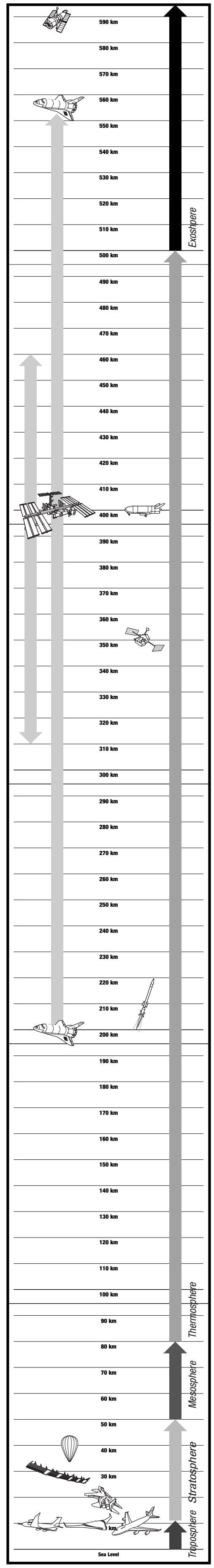
Hubble Space Telescope, 595 km

International Space Station, 309–463 km
X-37, 400 km

TRMM, 350 km

Sounding Rocket, 209 km
Space Shuttle, 200 km

BOOMERanG, 37 km
Helios Prototype, 31 km
F-15 ACTIVE, 18 km
SOFIA, 13 km
Blended Wing Body, 12 km
KC-135, 8–11 km



Exosphere, above 500 km to interplanetary space

Thermosphere, 500 km

Mesosphere, 80 km

Stratosphere, 50 km

Troposphere, 12 km

LAYERS OF THE ATMOSPHERE ACTIVITY

Description

Students compare the heights of the layers of Earth's atmosphere to the top of the Mesosphere, which is "astronaut altitude," the distance from the Earth at which one officially becomes an astronaut. Above this altitude, planes cannot fly because there is not enough air to allow planes to operate. Using this comparison, students will work in percentages of the astronaut altitude to create a model of four of the atmospheric layers.

Objectives

Students will

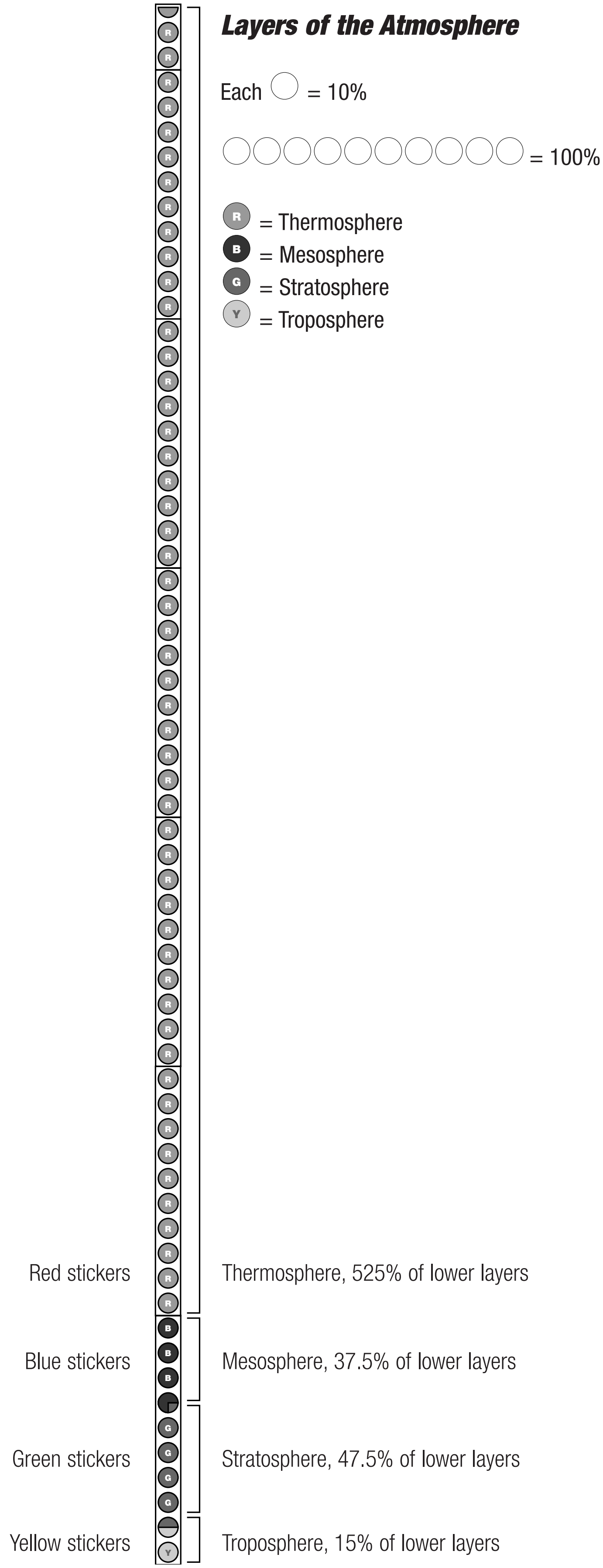
- use percentages less than and greater than 100 percent;
- make a model of Earth's atmospheric layers; and
- research characteristics of the layers of the atmosphere to find out where most of the mass of the atmosphere occurs, as well as ozone, oxygen, and the ionosphere.

Materials

- ☐ Layers of the Atmosphere Worksheet (1 per student)
- ☐ Construction paper strips, 3 x 20 cm (7 per student)
- ☐ 3/4" circle stickers (assorted colors)
  Quantity per student: 54 red, 4 blue, 5 green, 2 yellow
- ☐ Clear tape
- ☐ Scissors
- ☐ Ruler or straight edge
- ☐ Markers
- ☐ Sandwich-sized sealable bags

Preparation

- Copy enough worksheets for each student.
- Make a sample of the construction paper strips and tape them together to use as an example.
- Have students or teams store their unfinished projects in sandwich-sized, sealable bags. Store the bags in a box for the class. Bags will lie flat if students snip a tiny corner off the bag bottom.



- Instruct students to write their names on the bags in permanent marker.

- Review the concepts of models, percentages, and layers of the atmosphere.

- Cut out strips of construction paper that measure 3 cm in width and 20 cm in length. Each student will need 7 strips. Save the scraps for students to use as labels.

Procedures

1. Have the class name the layers of atmosphere and, using a KWL (page 12), tell what they have learned about them. You might ask,

   - What are the layers of the atmosphere?
   - How many layers are there?
   - Which is the lowest layer? Highest? In between?
   - Which layer is the narrowest? Widest?
   - Which layer contains the most oxygen?
   - Which layers do planes or spacecraft use?

2. Explain that today the class will make a model of the atmosphere using percentages to compare the sizes of four of the different layers.

3. Discuss what a model is and is not:

   - A model is a simple replica or copy of something we want to study.
   - Models allow us to explore things that are really big, really small, really far away, or really complex.
   - A good model is sized so that users can easily manipulate it and see it.
   - Each model has a scale that lets you know how much bigger or smaller it is than the actual object it represents.
   - A model is not a completely accurate replica of the real object. It only has a few of the real object's characteristics. It may not be made of the same materials or be able to do what the real thing does.

4. Refer back to other activities from this guide that your students have done. Did these activities meet the criteria of a model? If so, how?

5. Explain that students will make a model of the atmosphere using percentages instead of a scale of cm to km.

6. Ask students how far a person must travel from Earth to officially be considered an astronaut. *80 km.* This is the top of the Mesosphere. This distance is significant because aircraft cannot operate above this point because there is not enough air. For this reason, we have chosen to call the distance from Earth's sea level to 80 km 1 unit, or 100 percent. Students may be familiar with the distance from the Sun to Earth being called 1 Astronomical Unit, or AU. The concept is similar, although astronaut altitude is *not* an official unit.

7. The class will calculate what percentage of this astronaut altitude is contained in the lower layers of the atmosphere.

8. Use a 2-cm-diameter sticker to represent 10 percent of astronaut altitude. How many stickers do you need to represent

   - 20 percent? *2*
   - 50 percent? *5*
   - 75 percent? *7.5*

9. What percentage of astronaut altitude do you have if you have 10 stickers? *100 percent.*

   3 stickers? *30 percent.*
   0.5 sticker? *5 percent.*
   0.25 sticker? *2.5 percent.*
   6.25 stickers? *62.5 percent.*

10. Reinforce the concept that 1 sticker = 10 percent, so half a sticker is half of 10 percent, or 5 percent. Half of 5 percent is 2.5 percent, or 1/4 of a sticker.

    How much would 3/4 of a sticker be? *7.5 percent.*

    The way to make the sticker represent this is to fold the sticker in half, then in half again. Open the sticker up. The circle is now in quarters. Cut out one wedge. What is left represents 7.5 percent.

11. Have the class figure out how many stickers they would need to model the lower three layers of the atmosphere.

    Troposphere depth: 15 percent = *1 1/2 stickers*
    Stratosphere depth: 47.5 percent = *4 3/4 stickers*
    Mesosphere depth: 37.5 percent = *3 3/4 stickers*

12. Add up these percentages. What is the total percentage? *100 percent.* How many stickers should they use total? *10.* Does this make sense? Why or why not?

13. Use a different color to represent each layer of the atmosphere:

    Yellow = Troposphere
    Green = Stratosphere
    Blue = Mesosphere

    Models, like a map, should have keys. After all, a map is a model of a geographic area. Make a key for your chart that shows what color represents each layer of the atmosphere. On an American map, a key commonly shows how many miles are represented by an inch. Indicate what each sticker represents.

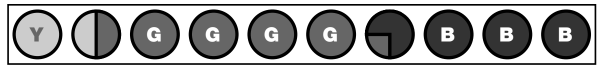
14. Give each student seven strips of construction paper and a sheet of different-colored stickers. Students can share several sheets so that everyone has enough of each color.

15. Students are now ready to assemble their model of the 3 lower layers of the atmosphere by putting the correct number of stickers on a strip of paper to represent an astronaut level, or the top of the Mesosphere.

    For example, the Troposphere is 15 percent of the area beneath the top of the Mesosphere, so students will use 1.5 yellow stickers to represent the first layer of the atmosphere.

16. Put the stickers on one strip of construction paper so that the stickers touch edges.

17. Give the class some time to finish putting together their model of the lower 3 layers of the atmosphere. They will need 4 3/4 stickers for the Stratosphere and 3 3/4 stickers for the Mesosphere. Remind students that only 10 stickers will fit on a strip, so they will have to arrange 1/2 and 3/4 creatively to stay within the right layer. Hint: 1/2 + 1/4 = 3/4



18. Have them share their work and review their answers. How many stickers did they use for each layer? How many stickers did they use total? What is the total percentage when you add up all of the stickers?

19. What if you had a second strip with 10 stickers on it and added it to the first strip? What percentage of astronaut altitude would this represent? *200 percent of the astronaut altitude.* What if you had 3 strips of 10 stickers? *300 percent.*

22. So, if the Thermosphere is 525 percent of the astronaut altitude, how many strips of stickers do you need to represent the Thermosphere? *5 and part of a 6th strip.* How many stickers will you need? *52.5 stickers.*

23. Pass out 5 strips and a scrap of a 6th one to each student. Pass out sheets of red stickers. Have students place stickers on the strips of construction paper to make the Thermosphere.

24. When they are done, have them tape the strips end to end with clear masking tape. They should fold up like an accordion after assembly.

25. When that task is complete, have students use the paper scraps and heavy-tip markers to make a label for each layer of the atmosphere.

26. Have students hang up their models with labels and keys around the room.

27. Students should complete their worksheets and discuss what they learned from this model. Use the discussion questions that follow.

Discussion

1. Which layers are about the same size? *Stratosphere and Mesosphere.*

2. When you add these 2 layers together, what percentage of the astronaut altitude are they? *85 percent.*

3. What percentage of the first strip is the Troposphere? *15 percent.* What fraction can this be reduced to? *15/100 or 3/20.* What decimal? *0.15*

Extensions

As a science extension, you may want students to research characteristics of the layers of the atmosphere to discover the following:

- Where is most of the mass of the atmosphere? *Troposphere and Stratosphere*
- Which layer contains the most oxygen? *Troposphere.*
- Which layer has the most ozone? *Stratosphere.*
- Which layers contains the ionosphere? *Mesosphere and Thermosphere.*
- What is the ionosphere? *Electrically charged particles (positively charged ions and negatively charged electrons), which are important to radio communication.*
- Which layer contains cloud formations? *Troposphere.*
- Which layer absorbs harmful ultraviolet radiation? *Stratosphere.*
- In what layer does the weather occur? *Troposphere.*

Name ______________________

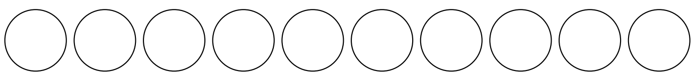
Teacher ______________________

Period ______________________

Date ______________________

Layers of the Atmosphere Worksheet

1. If 1 = 10 percent, color in 30 percent red and 50 percent blue.



2. What percentage does half a sticker represent?

3. What percentage does a quarter of a sticker represent?

4. A strip of paper has 10 stickers, representing 100 percent. How many strips of paper represent 400 percent?

5. A strip of paper has 10 stickers, representing 100 percent. How many strips of paper represent 720 percent?

6. You have 1 strip of 10 blue stickers and 5 times as many red stickers. If a strip of blue stickers is 100 percent, what is the new percentage of stickers if you include both the blue and the red stickers?

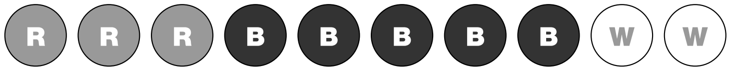
7. You have 4 yellow stickers that represent 100 percent. The number of blue and yellow stickers together is 250 percent. How many stickers are blue?

8. You have 6 strips of 10 stickers, and 25 percent of them are green. How many stickers are green?

9. What is 0.75 of 20 stickers?

10. You have 6 green stickers and 3 times as many red stickers. What percentage more of your stickers are red?

Worksheet Answer Key

1. 

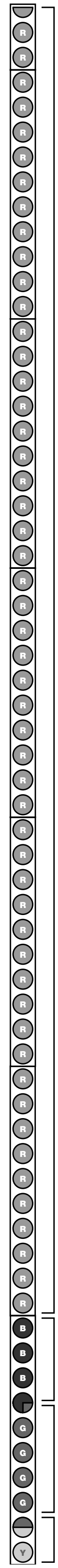
2. 5 percent
3. 2.5 percent
4. 4 strips of paper
5. 7 1/5
6. 600 percent
7. 6 blue stickers
8. 15 green stickers
9. 200 percent more

Layers of the Atmosphere Key

Each ○ = 10%

○○○○○○○○○○ = 100%

R = Thermosphere
B = Mesosphere
G = Stratosphere
Y = Troposphere



Red stickers — Thermosphere, 525% of lower layers

Blue stickers — Mesosphere, 37.5% of lower layers

Green stickers — Stratosphere, 47.5% of lower layers

Yellow stickers — Troposphere, 15% of lower layers

TEACHER FACTS: LAYERS OF THE ATMOSPHERE

The atmosphere is a mixture of gases that surrounds our planet Earth. The atmosphere contains the gases that we need to breathe. It blankets the planet, holding in heat to keep the planet warm and hospitable for life and absorbing harmful ultraviolet radiation from the Sun.

Some planets and moons do not have enough gravity to keep an atmosphere. Fortunately for us, Earth does have enough gravitational pull to keep the atmosphere from drifting into space.

The atmosphere is made of a mixture of gases. The main atmospheric gases are 78 percent nitrogen, 21 percent oxygen, and 1 percent argon. The atmosphere also contains water vapor, with concentrations varying with latitude and season, and a number of other trace gases, including carbon dioxide, methane, carbon monoxide, oxides of nitrogen, and ozone. Most of the mass (85 percent) in the atmosphere is in the lowest 12 km above Earth's surface. Scientists defined five atmospheric regions or layers based on whether the temperature is increasing or decreasing within the layer. NOTE: Temperatures and conditions in the atmosphere vary over the course of years, months, and even days. So, the extent of the layers varies with time.

The regions or layers of the atmosphere include, from lowest to highest, the Troposphere, the Stratosphere, the Mesosphere, the Thermosphere, and the Exosphere. The height of the layers varies from the equator to the poles and from day to day.

Troposphere (From the surface to 12 km)
The lowest layer of the atmosphere is the layer in which we live. Temperature decreases with height in the Troposphere. Weather systems and clouds are found in this layer. The bulk (about 85 percent) of the total mass of the atmosphere is found in the Troposphere. In this layer, a strong, high-altitude wind called the jet stream blows eastward, horizontally in the northern hemisphere. The jet stream has a large impact on the weather at Earth's surface.

Stratosphere (12 to 50 km)
The second layer of the atmosphere is the Stratosphere. Temperature increases with altitude in this layer. The Stratosphere contains about 15 percent of the total mass of the atmosphere, but it contains about 90 percent of the ozone in the atmosphere. Ozone is an important trace gas that acts as a shield for Earth's surface by absorbing harmful ultraviolet radiation from the Sun.

Mesosphere (50 to 80 km)
The temperature decreases with altitude in the third layer, with the upper part of the Mesosphere being the coldest region in the atmosphere. Most meteors burn up in the Mesosphere due to atmospheric friction.

Thermosphere (80 to 500 km)
Temperatures increase and soar over 2,000 degrees Celsius in the fourth layer of the atmosphere. Air pressure is very low here, about one ten-millionth of that at Earth's surface. Most of the ionosphere is found in the Thermosphere. The ionosphere contains electrically charged particles—positively charged ions and negatively charged electrons—which are important for radio communication.

Exosphere (Beginning at 500 km and continuing to interplanetary space)
The outer region of the atmosphere is by far the largest layer in vertical extent. Satellites orbit in this layer, far enough away to get good global views of Earth and far enough beyond the atmosphere that can hinder the view of the other planets, their moons, asteroids, comets, stars, and galaxies. The Exosphere is the transitional region between the atmosphere and vacuum of interplanetary space.

ALTITUDE WALK ACTIVITY

Description

Students represent vehicle altitudes using a scale of 1 cm = 100 km. Teams lay out and walk this scaled satellite model across a gymnasium, football field, or parking lot.

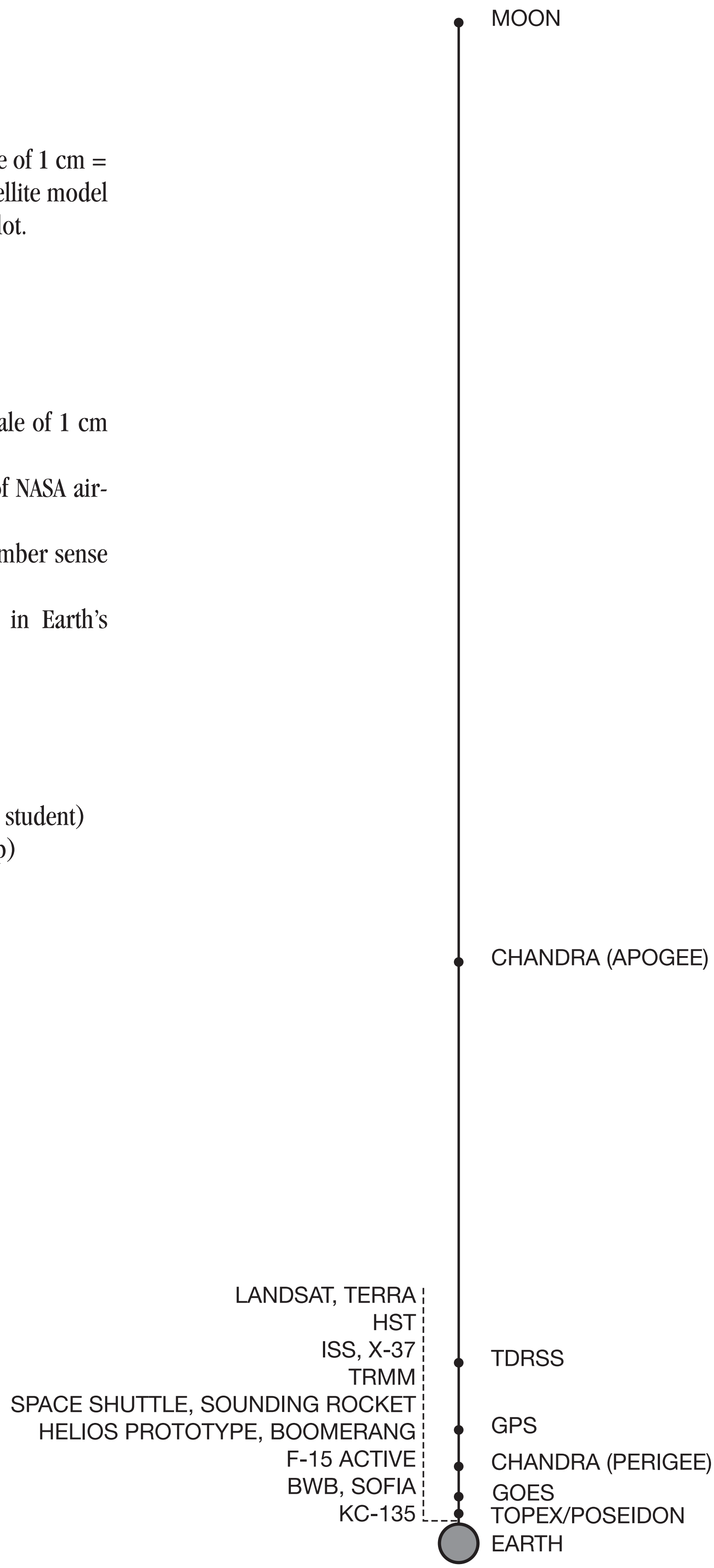
Objectives

Students will

- convert orbital and flight altitudes using a scale of 1 cm = 100 km;
- create a scale model of Earth and altitudes of NASA aircraft, satellites, and spacecraft;
- lay out and walk the scaled model to gain number sense of these altitudes; and
- research types of objects that fly or orbit in Earth's atmosphere.

Materials

☐ NASA Vehicle Cards (pages 60–64)
☐ Altitude Walk Worksheets Part 1 & 2 (1 per student)
☐ Tape measures or meter sticks (1 per group)
☐ Ball of string
☐ Scissors
☐ Masking tape
☐ Whistle
☐ Chalk
☐ Cardboard (optional)
☐ Laminate for pictures (optional)
☐ Camera (optional)



Preparation

- Copy enough worksheets for each student.

- Laminate the pictures of the NASA aircraft, spacecraft, and satellites (pages 60–64). Sheet protectors work well, too. Another alternative is to download and print colored versions of these vehicles at *http://spacelink.nasa.gov/products*

- Decide how to divide the class into teams. Groups of two or three work best.

- Divide the vehicles up so that groups get the same number of pictures and the same amount of work. You'll want each group to have a close, medium, and far away vehicle. The Earth requires drawing and takes a while, so the group drawing Earth should have fewer vehicles with which to work. Chandra and the Moon are extremely far away, so these objects should be given to different groups.

- Figure out where you will have the class lay out this model. The model distance from Earth to the Moon is 38.5 meters, so you'll need about a half a football field to lay out this model! You might use a hallway, gymnasium, empty parking lot, or athletic field. You may need to reserve this space ahead of time. If you want to do this activity outside, be sure to check the weather forecast beforehand and have a contingency plan in case of bad weather.

- Set aside one class period for students to figure out scaled distances and a second to lay out the model.

- Before class, measure a 10-meter distance and mark it off with masking tape or chalk. This will help teams that have to lay out Chandra and the Moon.

- To make a scaled drawing of Earth, cut a piece of string 75 cm in length. Tie a piece of chalk to the string 64 cm from one end. This represents the radius of the model Earth on a scale where 1 cm = 100 km. You will demonstrate how to use the chalk and string like a compass to draw a model Earth. Plan on having one piece of string and chalk for each Earth model your class will complete.

- If you are laying out the model on a grassy area, chalk cannot be used to draw the model Earth and mark vehicle altitudes. Students can make a model Earth ahead of time out of cardboard or tagboard. Place rocks or other weights on the pictures of the vehicles to keep them in position.

- Consider doing the Ball and String Earth-Moon Model activity as an introduction if you have not done so already.

Procedures

1. Do a KWL with the class to discover the extent of the students' familiarity with objects that orbit or fly in Earth's atmosphere. Make a transparency of the KWL form (page 12), or just list the items on the chalkboard.

2. Some NASA vehicles are only up in the atmosphere for a short time, like aircraft, rockets, weather balloons, and the Space Shuttle. Others, like satellites, deep space probes, and the International Space Station, stay up for longer periods. Space junk stays up indefinitely.

   Steer the discussion to cover specific examples and get the students to start classifying their examples when appropriate. Objects in space can be classified under one of the headings below. As the discussion continues, you can describe each of the categories based on the information and examples in the Up in the Atmosphere Fact Sheet (page 59).

   - Crewed Spacecraft
   - Deep Space Probes
   - Earth Orbiting Satellites
   - Research Aircraft/Rockets/Spacecraft
   - Space Junk

3. Most of us have no idea what some of these things are, or what they do, let alone how high they orbit. Gauging vertical distances is difficult. One way to understand these altitudes is to make models that represent the real thing. Another way is to compare something unfamiliar to something that is familiar, like the layers of the atmosphere.

4. Students will take the actual altitude of various NASA research vehicles and represent the altitude using a scale where 1 cm = 100 km. For example, the F-15 ACTIVE flies at 18 km. To represent this on a scale where 1 cm = 100 km, divide the flight altitude by 100 km/cm. The F-15 ACTIVE will fly at 0.18 cm on this scale.

5. Pass out Part 1 of the Altitude Walk Worksheets (page 49) for students to complete. Have students finish the worksheet in class or as homework.

6. Provide enough NASA research vehicle cards for each student to have one. Each team member is designated as the resident expert on that one vehicle. The expert must know what type of object it is, its purpose, an interesting fact about it, and why it operates at that particular altitude. They will share four facts about their craft with the class after the altitude walk. To help students begin their research, suggest that they visit the Web site listed at the bottom of each card.

   If you team teach, you may discuss having the English teacher assign students to write a report about the NASA research vehicle.

7. Allow time at the end of the class to call up the groups doing Earth, the Moon, and Chandra.

   Earth: Demonstrate how to use the chalk and string to draw a circle. Have a student hold one end of the string firmly to the chalkboard. The student's finger becomes the center of the circle. Pull and keep the string taut while drawing a circle around the student's finger.

   Earth: If you plan to do this layout on the grass, have students cut out a cardboard Earth ahead of time.

   Moon and Chandra: Demonstrate how to use pacing to walk longer distances. Tape off a 10-meter length in your room or hallway, so students can walk the distance 3 times counting steps and taking an average of the 3 trials.

8. Review the worksheet answers. For the longer distances, students should convert cm to m.

9. Limit instructions so that there is enough time to lay out the model and get back to class. Give all instructions to students before going outside. You might want to have students recite the process back to you to make sure they know what they are to do and where they are to be. Take a whistle and have one reliable student keep track of the time, signaling every 10 minutes so that students will know how much time is left.

10. Go outside with the teams and lay out the models. Bring a camera along to capture the moment. Plan 15 minutes to lay out their craft, 10 minutes to walk the model, and 10 minutes to get back to class.

11. Be aware that the model Earth needs to be marked first. Mark the surface end of an Earth radius at one point so that all of the teams can get started. The Earth team can then figure out where the center is and draw the rest of the model.

12. Once the model is complete, have the class start at Earth and take a walking tour of each craft to the Moon. Students will be amazed at how far away the Moon really is and how close to Earth the vehicles and spacecraft operate and orbit.

13. On the way back from the Moon, have students pick up their vehicle cards. Place yourself by the door to collect all of the pictures before the students leave for the next period.

14. Back in the classroom, have teams share their facts about each research vehicle. Encourage students to share their thoughts about the model they walked.

15. Have students complete Part 2 of the Altitude Walk Worksheet in class or at home.

16. Discuss answers to Part 2 and ask other discussion questions.

Discussion Questions

1. What did you like about this activity? *Answers will vary.*

2. How long does it take to walk the modeled distance to the Moon? *Answers will vary.*

3. Which model helped you better understand the distance to the Moon, the ball and string model or the altitude walk? *Answers will vary.*

4. What types of objects fly or orbit closest to Earth? *Research aircraft and crewed research spacecraft.* Why do these craft orbit in the lower layers of the atmosphere? *Their trips into the atmosphere are of short duration and involve humans, so lower is less expensive and the easiest to reach.*

5. Which objects orbit the highest? *The Moon, followed by Chandra at its farthest orbital point away from Earth (its apogee), GOES, SOFIA, and GPS satellites.*

6. How close were your original estimates of the distances of research vehicles from the KWL? *Answers will vary; however, students tend to vastly underestimate the distances, especially if they have not done the Ball and String Earth-Moon activity.*

Extensions

- Have students calculate where their team's crafts would be on their ball and string model.

- Have students create a walkable model of the solar system using Challenger Center's free downloadable activity *Voyage of Discovery* at *http://www.challenger.org/tr/tr_act_set.htm*. Find the tab for "Student Activities." Then click on "Solar System."

Name ______________________________

Teacher ______________________________

Period ______________________________

Date ______________________________

Altitude Walk Worksheet, Part 1

1. Convert the following orbital altitudes to a scale where 1 cm = 100 km.

Examples	**Altitude (km)**	**Scaled Altitude (cm)**
Earth's Radius	6,371	63.7
Moon's Radius	1,738	17.4
Earth-Moon Distance	384,430	3,844.3

Layers of the Atmosphere		
Top of the Troposphere	12	
Top of the Stratosphere	50	
Top of the Mesosphere	80	
Top of the Thermosphere	500	

Research Aircraft/Rockets	Altitude (km)	Scaled Altitude (cm)
Blended Wing Body	12	
BOOMERanG	37	
F-15 ACTIVE	18	
Helios Prototype	31	
KC-135	8–11	
SOFIA	13	
Sounding Rockets	209	
Crewed Spacecraft		
International Space Station*	400	
Space Shuttle**	200	
X-37	400	
Earth Orbiting Satellites		
Chandra (Perigee)	9,942	
Chandra (Apogee)	139,970	
Geostationary Operational Environmental Satellite (GOES)	36,000	
Global Positioning Satellites (GPS)	20,200	
Hubble Space Telescope	595	
Landsat	705	
Tracking and Data Relay Satellite System	35,700	
Terra Satellite	705	
TOPEX/Poseidon	1,336	
Tropical Rainfall Measuring Mission (TRMM)	350	

2. Research a NASA aircraft, spacecraft, satellite, or other research vehicle based on a NASA card your teacher assigns to you. Use the Web site on the bottom of the card to gather the information below.

Craft Name

Object Type

Atmospheric Layer(s)

Purpose

Interesting Fact

* *The ISS's highest orbital altitude is 463 km. It free-falls for 80 days, decreasing in altitude to 309 km, before being reboosted for 10 days.*

** *The Space Shuttle has an orbital altitude range of 195 to 556 km, depending on mission requirements.*

Altitude Walk Worksheet Answer Key: Part 1

Examples	Altitude (km)	Scaled Altitude (cm)
Earth's Radius	6,371	63.7
Moon's Radius	1,738	17.4
Earth-Moon Distance	384,430	3,844.3
Layers of the Atmosphere		
Top of the Troposphere	12	0.1
Top of the Stratosphere	50	0.5
Top of the Mesosphere	80	0.8
Top of the Thermosphere	500	5.0
Research Aircraft/Rockets		
Blended Wing Body	12	0.1
BOOMERanG	37	0.4
F-15 ACTIVE	18	0.2
Helios Prototype	31	0.3
KC-135	8–11	0.1
SOFIA	13	0.1
Sounding Rockets	209	2.1
Crewed Spacecraft		
International Space Station	400	4.0
Space Shuttle	200	2.0
X-37	400	4.0

Earth Orbiting Satellites

Chandra (Perigee)	9,942	99.4
Chandra (Apogee)	139,970	1,399.7
Geostationary Operational Environmental Satellite (GOES)	36,000	360.0
Global Positioning Satellites (GPS)	20,200	202.0
Hubble Space Telescope	595	5.9
Landsat	705	7.1
Tracking and Data Relay Satellite System	35,700	357.0
Terra Satellite	705	7.1
TOPEX/Poseidon	1,336	13.4
Tropical Rainfall Measuring Mission (TRMM)	350	3.5

NOTE: Each student will be assigned one satellite, aircraft, or spacecraft to research, so they will only have one of the following entries on their worksheets. Answers in the Purpose and Interesting Fact columns are **not** the "only right answers." Answers **should** vary because students are doing independent research. Web sites have been provided for each vehicle so that the teacher can check students' Purpose and Interesting Fact answers.

	Type	Atmospheric Layer	Purpose of Research	Interesting Fact
Blended Wing Body *http://oea.larc.nasa.gov/PAIS/BWB.html*	Research Aircraft	Troposphere	To develop future commercial aircraft that are more efficient and hold more passengers.	In addition to the wings, the body of the plane will provide lift. The aircraft will seat 800 passengers and have 2 decks.
BOOMERanG *http://www.physics.ucsb.edu/~boomerang/*	Research Aircraft (Balloon)	Stratosphere	To collect data about the early universe.	BOOMERanG is the name of a balloon mission. It flew a circle around Antarctica in 1998 and collected data that looked back in time at early universe plasma that has evolved into clusters of galaxies today.

	Type	Atmospheric Layer	Purpose of Research	Interesting Fact
F-15 ACTIVE *http://www.dfrc.nasa.gov/PAO/PAIS/HTML/FS-048-DFRC.html*	Research Aircraft	Stratosphere	To enhance the performance and maneuverability of future civil and military aircraft.	Such innovations reduce engine noise and increase fuel efficiency and flight range.
Helios Prototype *http://www.dfrc.nasa.gov/PAO/PAIS/HTML/FS-068-DFRC.html*	Research Aircraft	Stratosphere	To develop high-flying, solar-powered, remote-controlled aircraft.	Its goal is to stay up for 4 days at a time without a pilot to monitor the environment. It can be used as a communications station.
KC-135 *http://microgravity/kjenks/kc-135.htm*	Research Aircraft	Troposphere	To produce microgravity conditions for research.	It flies in parabolas to produce microgravity conditions.
SOFIA *http://sofia.arc.nasa.gov/*	Research Aircraft	Stratosphere	To conduct infrared astronomy research in the Stratosphere.	It will be the largest airborne telescope in the world. It flies above water vapor in the Troposphere that absorbs infrared radiation.
Sounding Rocket *http://rscience.gsfc.nasa.gov/*	Research Rocket	Thermosphere	To provide about 10 minutes of microgravity conditions for research purposes.	A parachute deploys to slow the payload's descent before landing.
International Space Station *http://spaceflight.nasa.gov/station/*	Crewed Spacecraft	Thermosphere	To provide a permanent, international research facility in orbit.	It will be the third-brightest object in the sky when fully assembled; it will span the area of two football fields.
Space Shuttle *http://spaceflight.nasa.gov/shuttle/*	Crewed Spacecraft	Thermosphere	To shuttle astronauts, supplies, equipment, and modules to the International Space Station, and to provide a microgravity research environment.	The Space Shuttle is a reusable launch vehicle. It orbits Earth every 90 minutes, experiencing 16 sunsets and sunrises per day.

	Type	Atmospheric Layer	Purpose of Research	Interesting Fact
X-37 *http://www.msfc.nasa.gov/news/background/facts/x37.htm*	Research Spacecraft	Thermosphere	To demonstrate technologies that could be used in future spacecraft.	The X-37 is small enough to fit in the Shuttle's cargo bay for reentry tests.
Chandra *http://chandra.harvard.edu/*	Earth Orbiting Satellite	Exosphere	To collect sharper x-ray data on black holes and other astronomical objects.	Chandra is NASA's newest great observatory. It has a highly elliptical orbit, traveling as far as a third of the way to the Moon.
GOES *http://goes2.gsfc.nasa.gov/*	Earth Orbiting Satellite	Exosphere	To study weather and storms.	GOES is a geostationary satellite, which means it seems to "hover" in one spot over Earth.
GPS *http://leonardo.jpl.nasa.gov/msl/Programs/gps.html*	Earth Orbiting Satellite	Exosphere	To provide navigation data.	GPS has a series of 24 satellites as part of its system. To figure out where you are, you need data from 3 different satellites.
Hubble Space Telescope *http://hubble.stsci.edu/*	Earth Orbiting Satellite	Exosphere	To study different objects in the universe, above the obscuring elements of the lower layers of the atmosphere.	Hubble has been in operation for 10 years. Astronauts have serviced it to provide new instruments and fix existing ones, like a faulty mirror.
Landsat *http://landsat.gsfc.nasa. gov/*	Earth Orbiting Satellite	Exosphere	Landsat satellites gather remotely sensed images of the land surface and surrounding coastal regions for global change research, regional environmental change studies, and other civil and commercial purposes.	Landsat images of your area are available online or can be ordered.

	Type	Atmospheric Layer	Purpose of Research	Interesting Fact
TDRSS *http://nmsp.gsfc.nasa.gov/tdrss/tdrsshome.html*	Earth Orbiting Satellite	Exosphere	To track and relay data between low Earth orbiting spacecraft and NASA data-processing facilities.	TDRSS relays data from the Hubble Space Telescope and the Space Shuttle, among others.
Terra Satellite *http://terra.nasa.gov/*	Earth Orbiting Satellite	Exosphere	To collect data on global climate by looking at the land, sea, and atmosphere.	Terra's orbit is nearly from pole to pole, so the data it collects cover the entire Earth as it rotates.
TOPEX/Poseidon *http://topex-www.jpl.nasa.gov/*	Earth Orbiting Satellite	Exosphere	To measure ocean sea levels in order to better forecast global climate.	This satellite is a joint mission by the U.S. and France. TOPEX/Poseidon predicted and monitored El Niño conditions by examining ocean levels.
TRMM *http://trmm.gsfc.nasa.gov/*	Earth Orbiting Satellite	Thermosphere	To collect data on the rainfall in tropical areas, which affects global climate patterns.	This is a joint mission between the U.S. and Japan. Instruments on TRMM can see structures inside clouds.

Name ______________________________

Teacher ______________________________

Period ______________________________

Date ______________________________

Altitude Walk Worksheet, Part 2

1. Explain why these vehicles orbit or fly at their specific altitudes.

   a. SOFIA
   b. International Space Station
   c. GOES

2. What NASA research vehicles reach 1/3 of the way to the Moon?

3. A heavy concentration of space junk orbits throughout the atmosphere at distances from 800 to 1,500 km. Give a reason to explain why there is space debris at these altitudes. Visit this Web site for information: *http://sn-callisto.jsc.nasa.gov/faq/faq.html*

4. Why must space junk be monitored?

5. Deep space probes were not included in the altitude listing in Part 1. Give a reason why they were omitted.

6. Complete this sentence: “One thing I learned from laying out this model that I thought was interesting is. . . .”

7. Complete this sentence: “One thing I’m still confused about or would like to know more about is. . . .”

Altitude Walk Worksheet Answer Key: Part 2

1. Give a reason why these vehicles orbit or fly at their specific altitudes. Here are examples of possible answers. NOTE: Student responses should vary.

   a. *SOFIA flies above the Troposphere to better study infrared radiation, which gets absorbed in the Troposphere.*

   b. *The International Space Station orbits in the Thermosphere because there are fewer air particles to cause the ISS to slow down and lose altitude.*

   c. *GOES has to be far enough away from Earth to orbit Earth at Earth's rotational speed; that way it will stay in the same place over the planet.*

2. What NASA research vehicle reaches 1/3 of the way to the Moon? *Chandra.*

3. A heavy concentration of space junk orbits throughout the atmosphere at distances from 800 to 1,500 km. Give two reasons to explain why there is space debris at these altitudes. Visit this Web site for information: *http://sn-callisto.jsc.nasa.gov/faq/faq.html. Satellites go out of commission and are left in orbit; flecks of paint from rockets and satellites fall off due to thermal expansion and stay in orbit.*

4. Why must space junk be monitored? *Small pieces travel as fast as bullets and can damage sensitive solar arrays or other parts of satellites and spacecraft.*

5. Deep space probes were not included in the altitude listing in Part 1. Give a reason why they were omitted. *They do not orbit between Earth and the Moon, but travel to other places in the Solar System.*

6. "One thing I learned from laying out this model that I thought was interesting is. . . ." *Answers will vary.*

7. "One thing I'm still confused about or would like to know more about is. . . ." *Answers will vary.*

TEACHER FACTS: UP IN THE ATMOSPHERE

What kinds of things can be found beyond Earth's surface?

- Crewed Spacecraft
- Earth Orbiting Satellites
- Research Aircraft/Rockets/Spacecraft
- Space Junk
- Deep Space Probes

Crewed Spacecraft

Crewed spacecraft allow humans to travel above the lower three layers of the atmosphere. The Space Shuttle and the International Space Station are examples of crewed spacecraft.

Earth Orbiting Satellites

A satellite is any object that orbits a celestial body, such as Earth. Satellites can be natural or artificial. Earth has one natural satellite, the Moon, but there are thousands of other types of satellites orbiting Earth. Artificial satellites include the following:

- Communication Satellites
- Earth Observing Satellites
- Navigational Satellites
- Space Observatories

Communication satellites transmit news, television, and phone calls. NASA's Tracking and Data Relay Satellite System (TDRSS) is an example of a communication satellite that transmits data from other research satellites so they can be processed at one NASA facility.

Earth Observing Satellites monitor different aspects of our planet, including water, land, and atmosphere, to better understand the health of the planet and to predict weather more accurately. TOPEX/Poseidon is an example of an Earth observing satellite that monitors the conditions of the oceans.

Navigational satellites help ships and aircraft travel from place to place by pinpointing their precise location. Global Position System (GPS) is a well-known navigational satellite system.

Space Observatories orbit Earth but look outward to study objects in the Solar System or elsewhere in the universe. Hubble Space Telescope (HST) is an example of a space observatory.

Research Aircraft/Rockets/Spacecraft

Vehicles that launch from the ground, fly in the atmosphere to perform a task, and return to Earth afterwards fall under the heading of Research Aircraft/Rockets. Planes like SOFIA and the F-15 ACTIVE, weather balloons like BOOMERanG, and sounding rockets belong in this category.

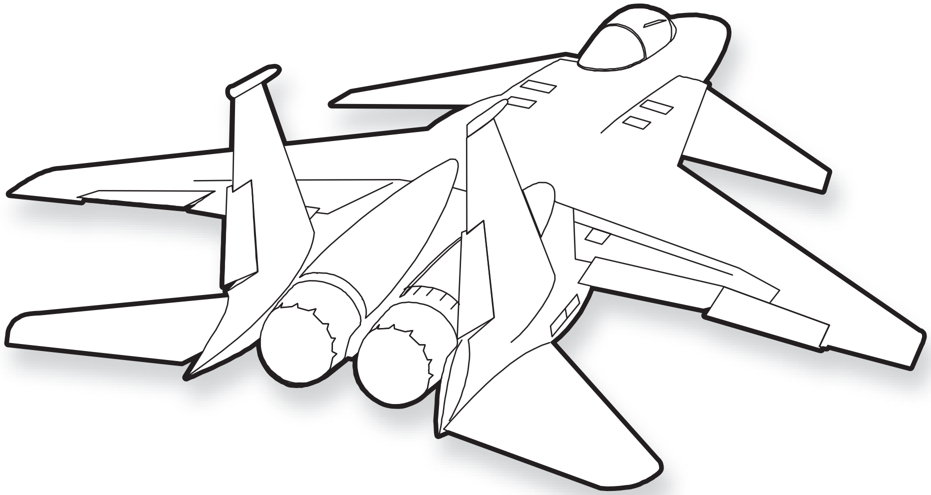
Space Junk

Orbital debris is any human-made object that orbits Earth but no longer serves a purpose. Orbital debris is also called space junk or space trash. Space junk ranges in size from microns to over 10 cm in diameter. Tens of millions of pieces of space junk orbit Earth and have to be closely monitored to protect spacecraft and satellites. Examples of orbital debris include broken satellites, upper stages of rockets, debris from explosions or collisions of spacecraft, solid rocket motor effluents, and flecks of paint that separate from spacecraft due to thermal stresses or small particle impacts.

Deep Space Probes

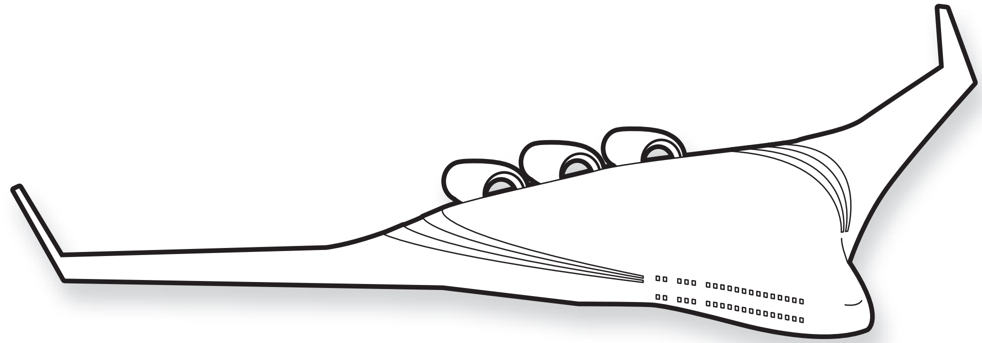
Many spacecraft travel beyond Earth's orbit to explore other worlds where humans cannot travel. NASA has sent spacecraft to study the different planets in the Solar System. Some deep space probes orbit other planets, moons, and even asteroids, like NEAR Shoemaker, which orbited the asteroid Eros until February 2001. Some deep space probes, like the Carl Sagan Memorial Station, land on the surface of other planets. STARDUST is an example of a spacecraft that will rendezvous with comet Wild-2 (pronounced Vilt), collect particles outgassing from the head of the comet in 2004, and return these particles to Earth in 2006.

F-15 ACTIVE



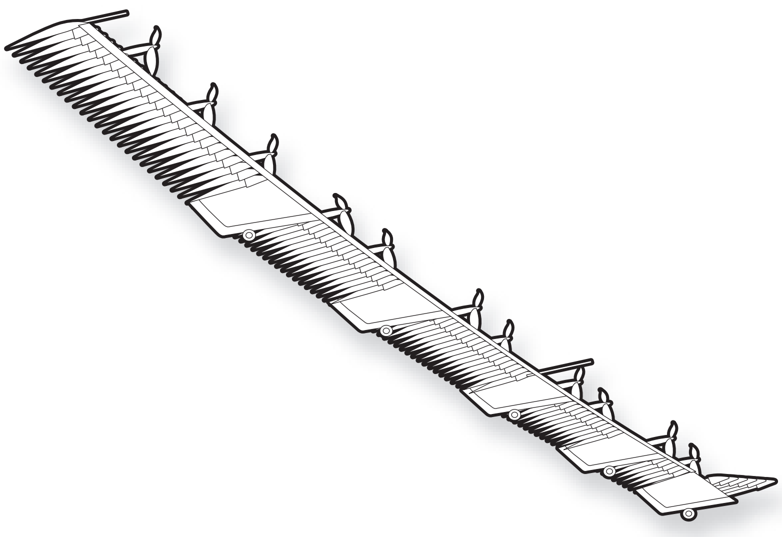
http://www.dfrc.nasa.gov/PAO/PAIS/HTML/FS-048-DFRC.html

Blended Wing Body



http://oea.larc.nasa.gov/PAIS/BWB.html

Helios Prototype



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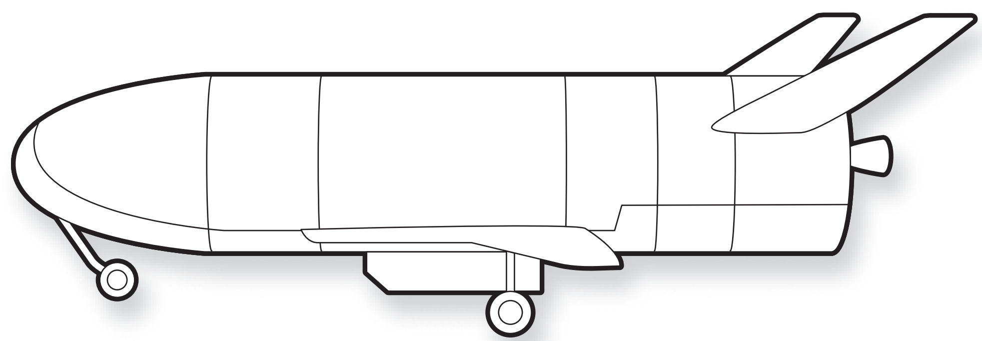
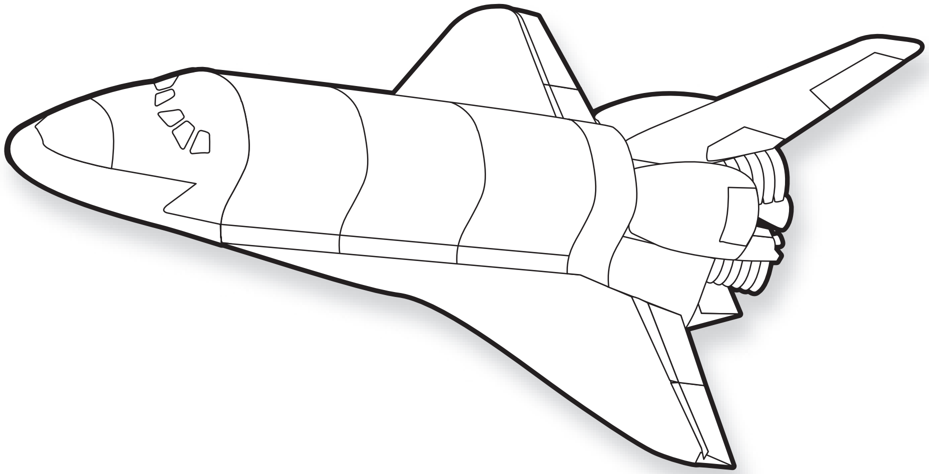
X-37



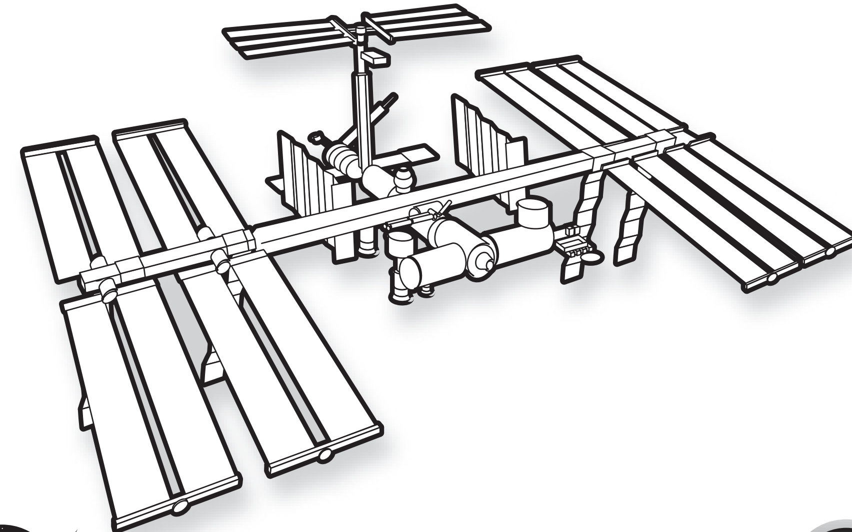
http://www.msfc.nasa.gov/news/background/facts/x37.htm

Space Shuttle



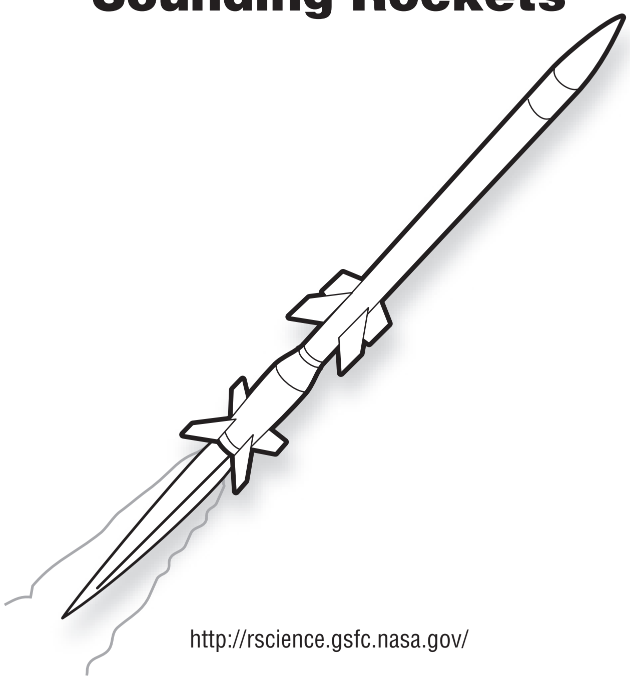
http://spaceflight.nasa.gov/shuttle/

International Space Station



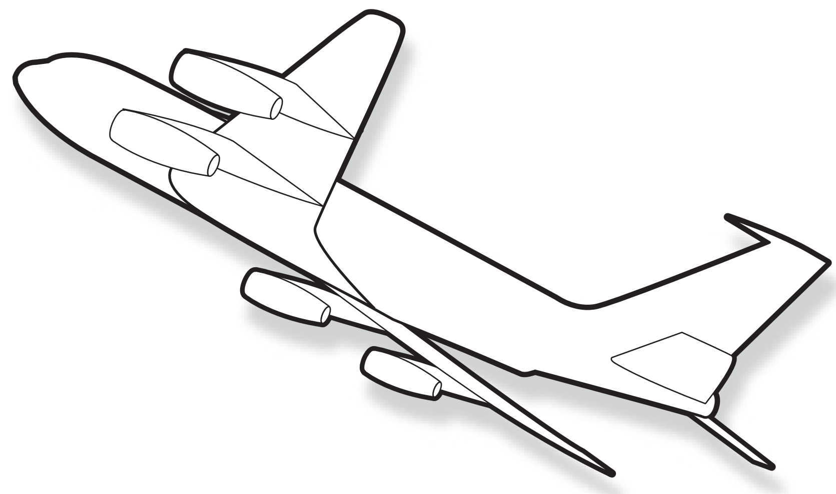
http://spaceflight.nasa.gov/station/

Sounding Rockets



http://rscience.gsfc.nasa.gov/

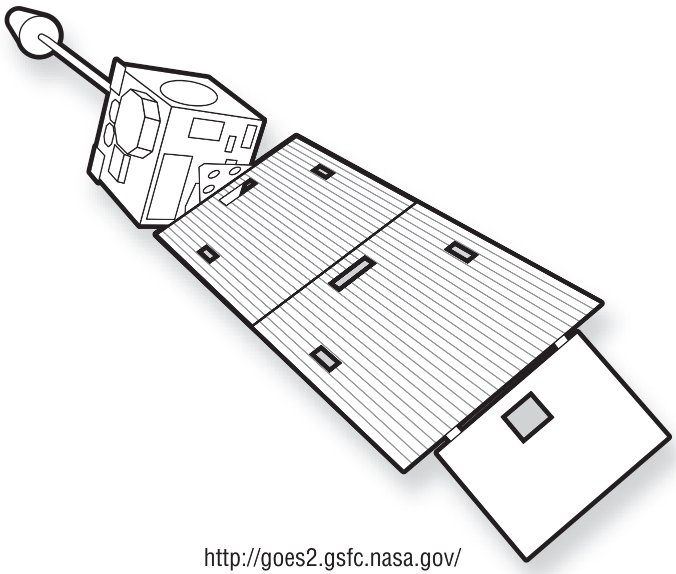
KC-135



http://micrograverity/kjenks/kc-135.htm

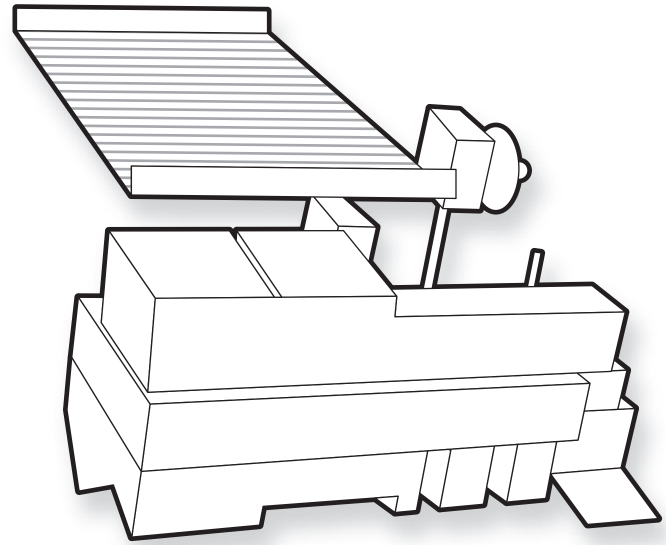
GOES

Geostationary Operational Environmental Satellite



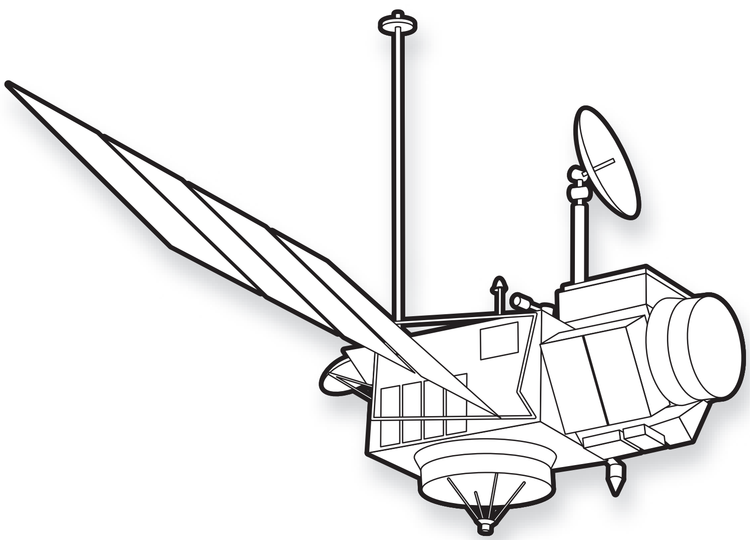
http://goes2.gsfc.nasa.gov/

Terra



http://terra.nasa.gov/

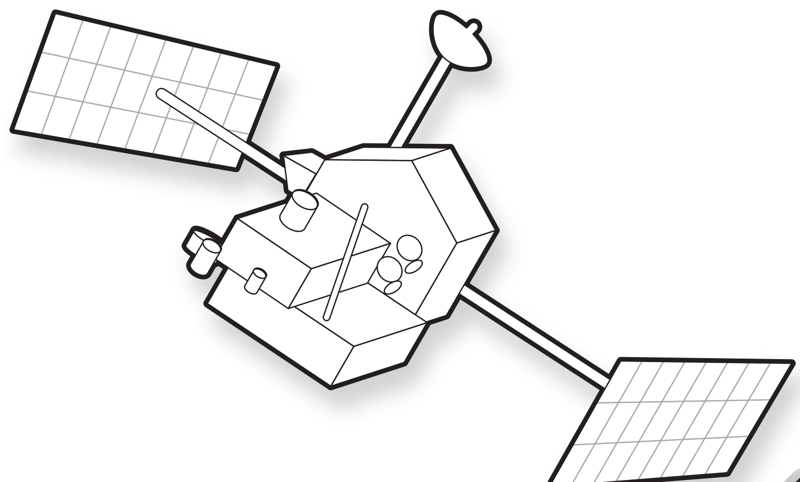
TOPEX/Poseidon



http://topex-www.jpl.nasa.gov/

TRMM

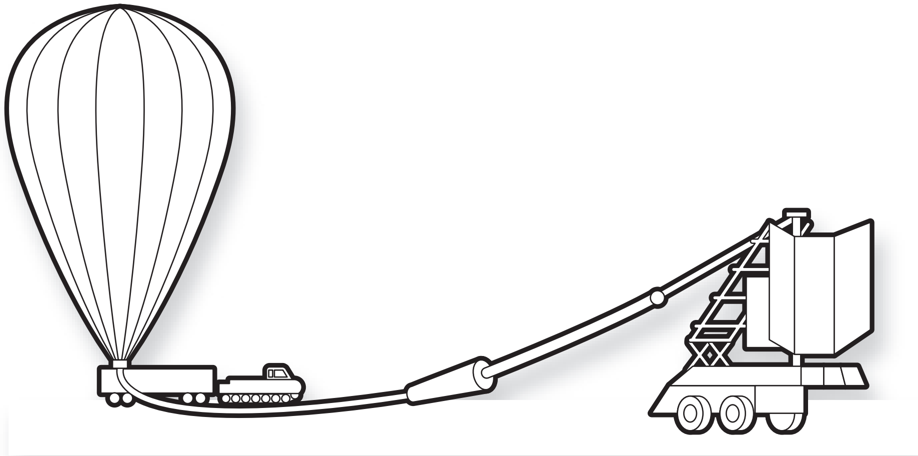
Tropical Rainfall Measuring Mission



http://trmm.gsfc.nasa.gov/

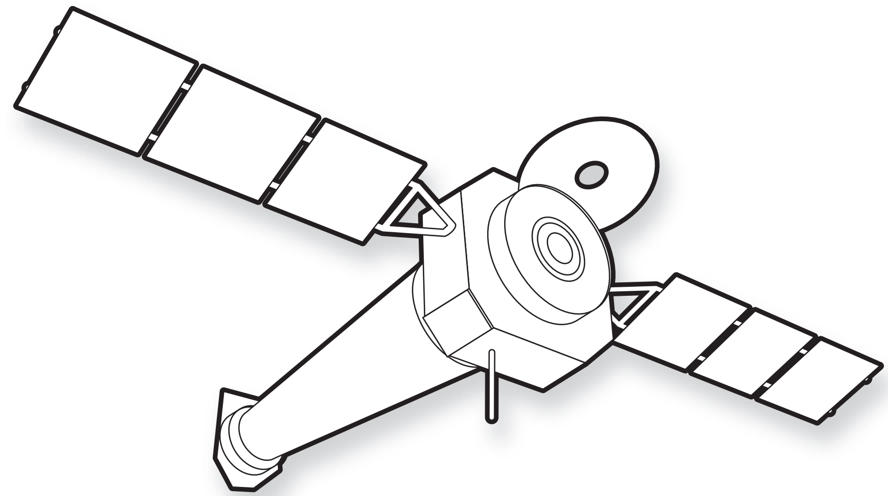
BOOMERanG

Balloon Observations of Millimetric Extragalactic Radiation and Geophysics



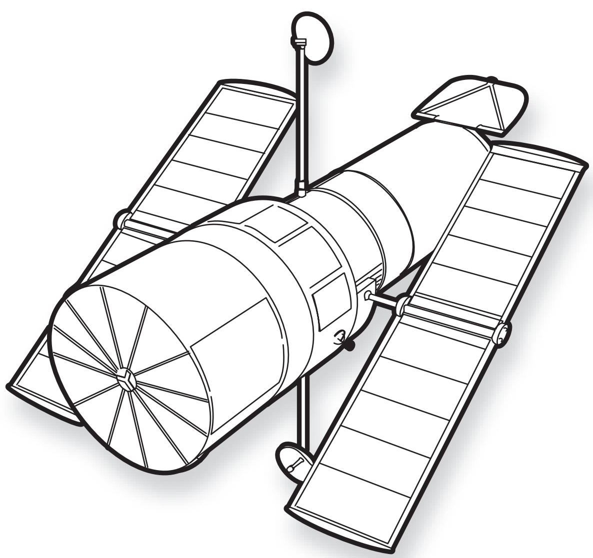
http://www.wff.nasa.gov/pages/scientificballoons.html

Chandra Space Observatory



http://chandra.harvard.edu/

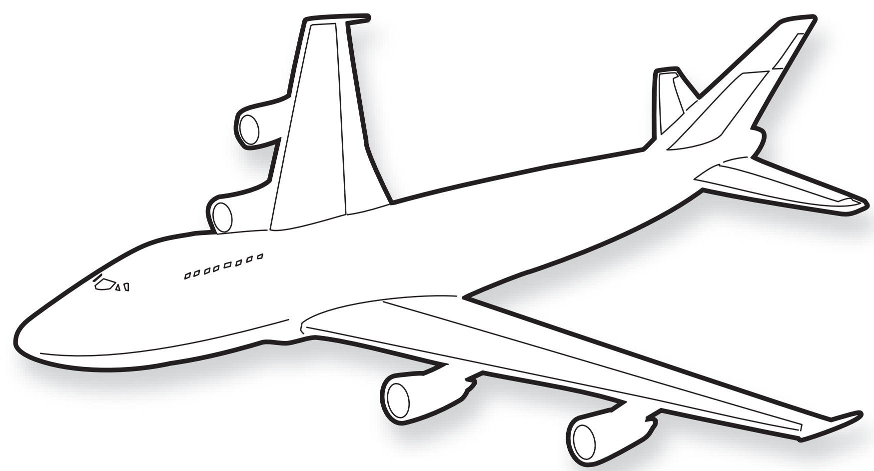
Hubble Space Telescope



http://hubble.stsci.edu/

SOFIA

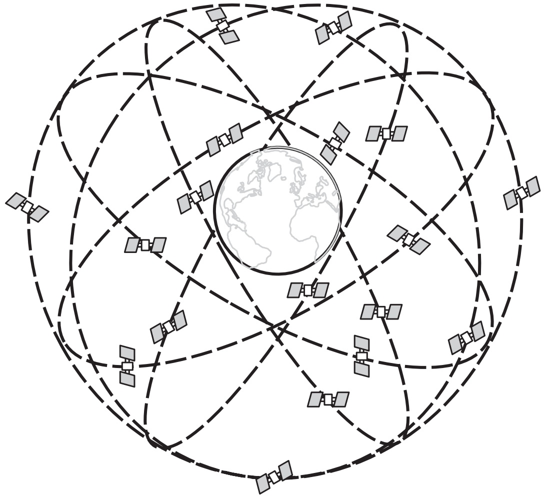
Stratospheric Observatory for Infrared Astronomy



http://sofia.arc.nasa.gov/

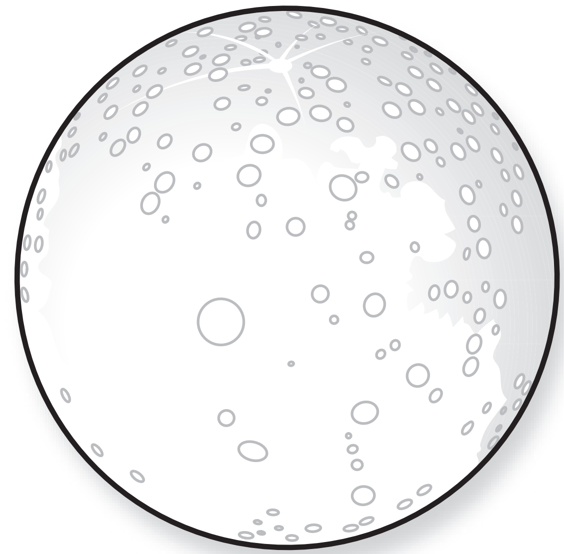
GPS

Global Positioning System



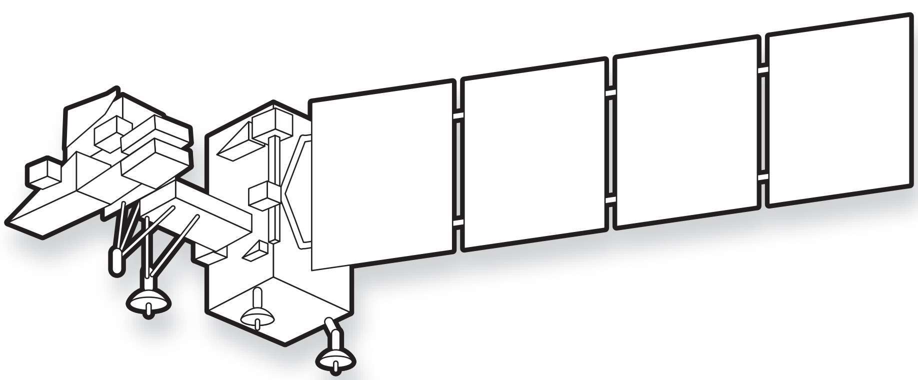
http://www.navcen.uscg.mil/faq/gpsfaq.htm

The Moon



http://www.tsgc.utexas.edu/everything/moon/

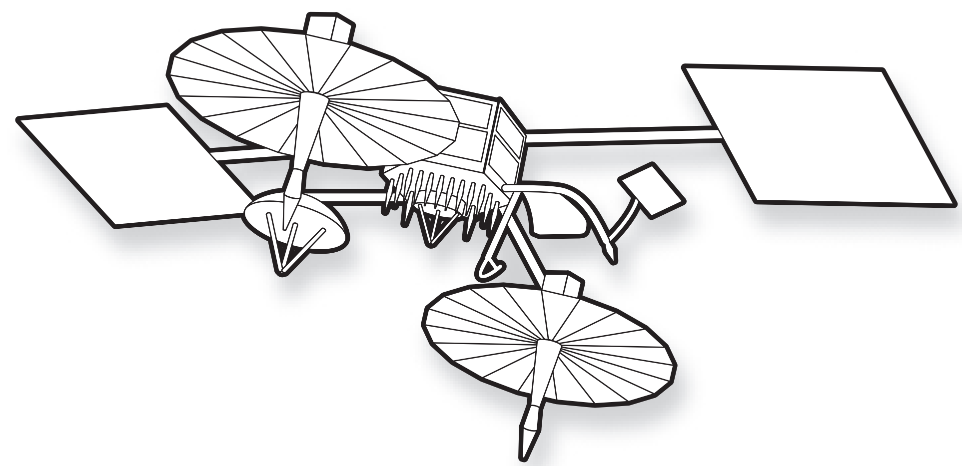
Landsat



http://landsat.gsfc.nasa.gov/

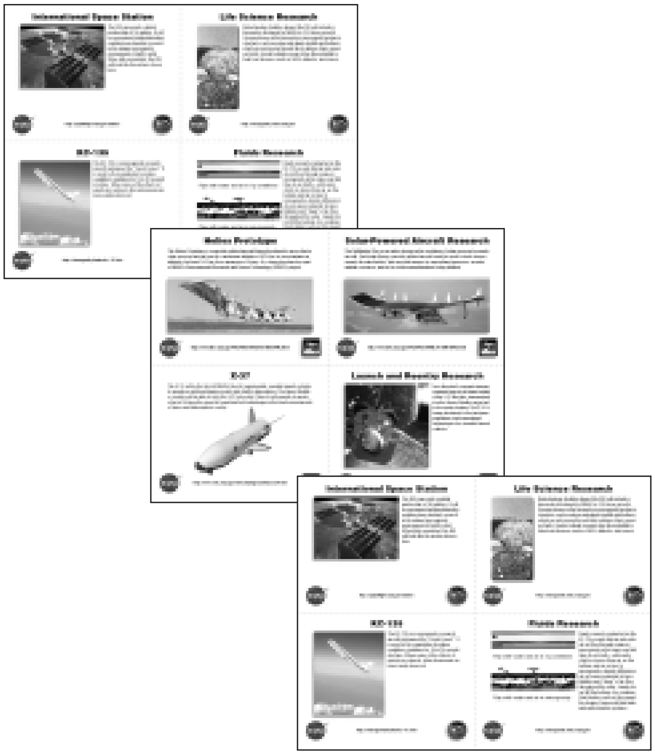
TDRSS

Tracking and Data Relay Satellite System Communication Satellite



http://nmsp.gsfc.nasa.gov/tdrss/tdrsshome.html

ACTIVITY/ASSESSMENT



Satellite Swap Game Cards

SATELLITE SWAP GAME

Description

Students play Satellite Swap to learn about NASA vehicles and the research they help to accomplish. This game can also be used as an assessment.

The game has 32 cards that go together as 16 pairs, and it can be played like several common card games, such as Go Fish, Concentration, Old Maid, or Rummy. Pairs consist of one NASA research vehicle and a corresponding research card that describes an aspect of the research conducted on the vehicle. NASA research enterprises replace the suits found in an ordinary deck of cards. Enterprises (as seen below) are indicated by a small icon on the card. Each enterprise has four NASA vehicle/research pairs.

Materials

- ☐ Satellite Swap Game Cards (set of 32 colored pictures)
- ☐ Satellite Swap Handout
- ☐ Math Challenge Problems

Preparation

1. The Satellite Swap Gamecards are the colored cards included with this educator’s guide. Before cutting the cards apart, make copies of the cards to use as an answer key.
2. Cut the cards apart.
3. Discuss the NASA Enterprises and which pairs go together using the Teacher Facts: NASA Enterprises on page 72.

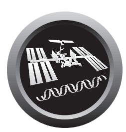
Game Suggestions

Play games with formats that students know, introducing one enterprise at a time.

To become familiar with the enterprises and pairs, a good game to start with is Concentration. For Go Fish, students can ask for a card by enterprise: “Do you have any Earth Science cards?” For Rummy, students may make pairs (Vehicle/Research) or four of a kind (same enterprise).

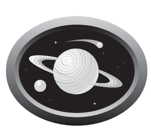
Aerospace Technology

Biological and Physical Research and Human Exploration and Development of Space



Earth Science

Space Science



NOTE: Additional sets of Satellite Swap Gamecards may be downloaded in color, printed, cut, and laminated for classroom use at NASA Spacelink and the National Center for Microgravity Research on Fluids and Combustion.

- *http://spacelink.nasa.gov/Instructional.Materials/NASA.Educational.Products/How.High.Is.It/*

- *http://www.ncmr.org/education/k12/classroom.html*

Assessment

To use Satellite Swap as an assessment, students play any of the games suggested here to get a match for each enterprise (Figure 1).

In order to finish the assessment, students must complete the Satellite Swap Handout. This handout has four NASA enterprise sections (Figure 2).

Students write down the names of the two cards in the match in the appropriate enterprise square (Figure 3). Then, they write a sentence to summarize the purpose of the NASA vehicle and the research it helps to accomplish (Figure 3).

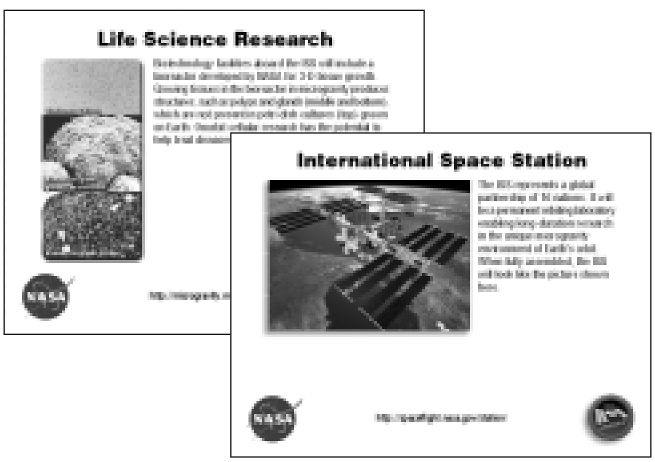
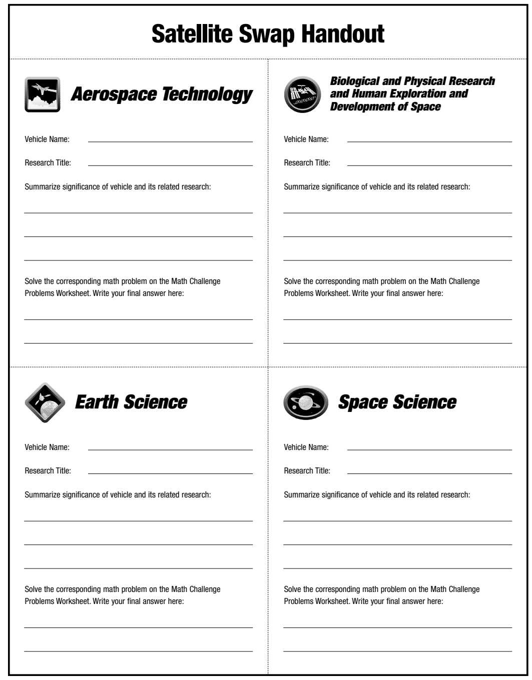


Figure 1: A set of paired game cards.



Satellite Swap Handout

Aerospace Technology

Vehicle Name:

Research Title:

Summarize significance of vehicle and its related research:

Solve the corresponding math problem on the Math Challenge Problems Worksheet. Write your final answer here:

Biological and Physical Research and Human Exploration and Development of Space

Vehicle Name:

Research Title:

Summarize significance of vehicle and its related research:

Solve the corresponding math problem on the Math Challenge Problems Worksheet. Write your final answer here:

Earth Science

Vehicle Name:

Research Title:

Summarize significance of vehicle and its related research:

Solve the corresponding math problem on the Math Challenge Problems Worksheet. Write your final answer here:

Space Science

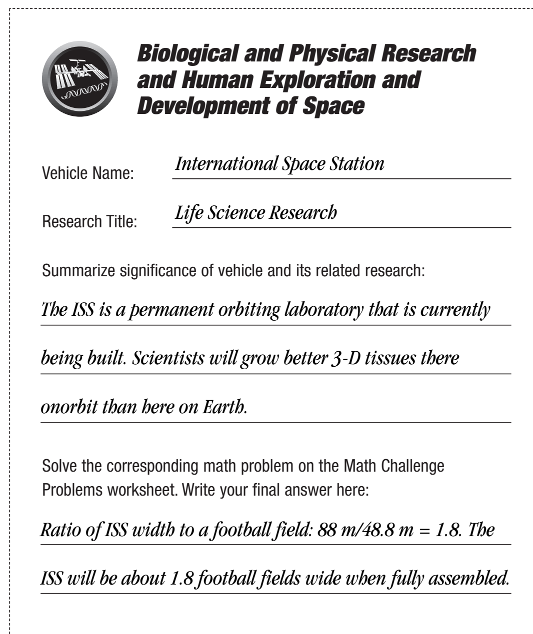
Vehicle Name:

Research Title:

Summarize significance of vehicle and its related research:

Solve the corresponding math problem on the Math Challenge Problems Worksheet. Write your final answer here:

Figure 2: The Satellite Swap Handout.



Biological and Physical Research and Human Exploration and Development of Space

Vehicle Name: *International Space Station*

Research Title: *Life Science Research*

Summarize significance of vehicle and its related research:

The ISS is a permanent orbiting laboratory that is currently being built. Scientists will grow better 3-D tissues there onorbit than here on Earth.

Solve the corresponding math problem on the Math Challenge Problems worksheet. Write your final answer here:

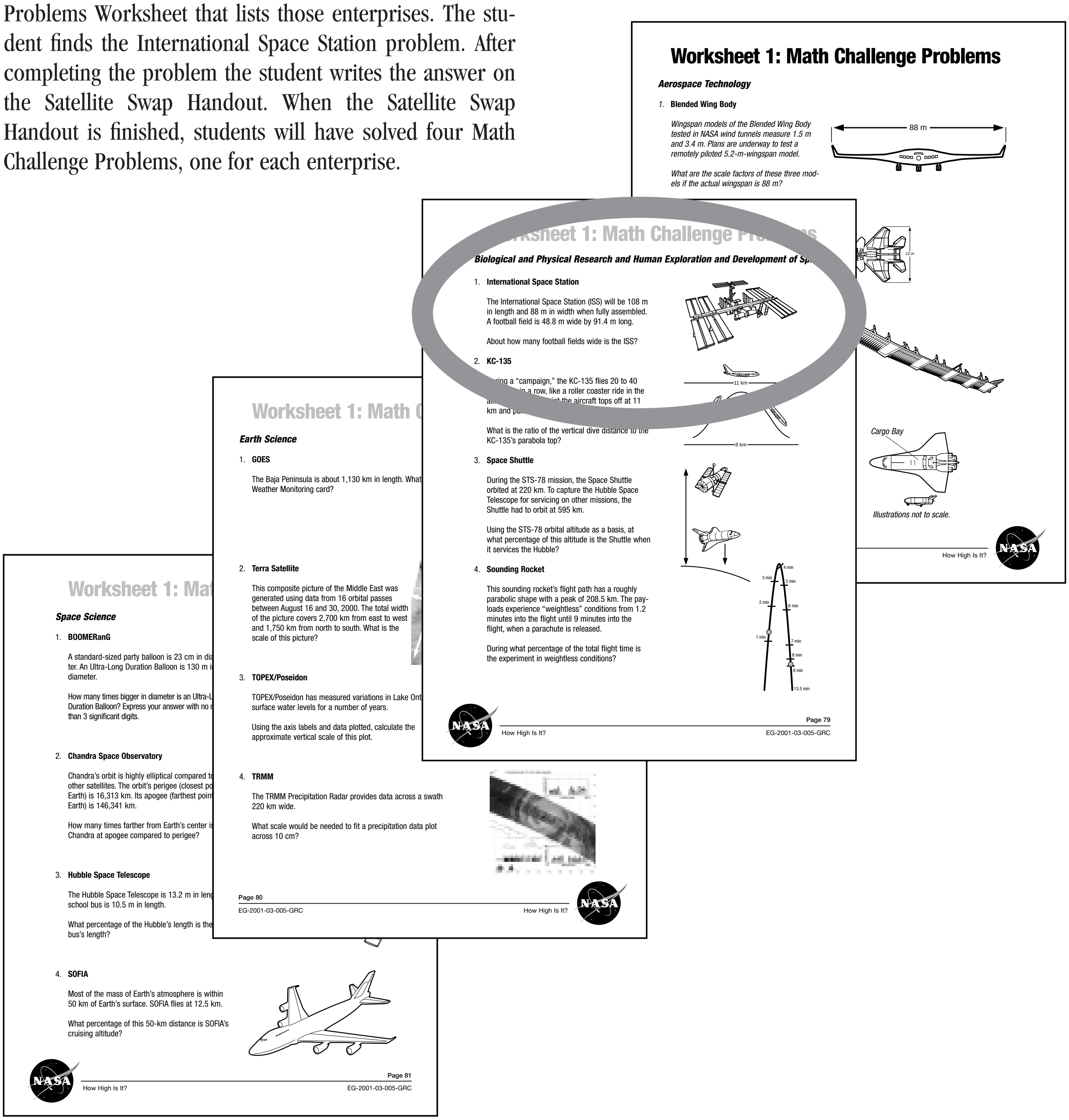
Ratio of ISS width to a football field: 88 m/48.8 m = 1.8. The ISS will be about 1.8 football fields wide when fully assembled.

Figure 3: A competed section from the Satellite Swap Handout. Note that the names of the cards and the summary sentence match.

Finally, they answer a Math Challenge question for each of their four enterprise matches. Math Challenge questions for all sixteen matches are on a separate handout called Math Challenge Problems (Figure 4).

For example: The International Space Station pair falls under the enterprises Biological and Physical Research and Human Exploration and Development of Space. So the student should flip to the page on the Math Challenge Problems Worksheet that lists those enterprises. The student finds the International Space Station problem. After completing the problem the student writes the answer on the Satellite Swap Handout. When the Satellite Swap Handout is finished, students will have solved four Math Challenge Problems, one for each enterprise.

Figure 4: The Math Challenge Problems Handouts



Satellite Swap Handout

Aerospace Technology

Vehicle Name: ______________________________

Research Title: ______________________________

Summarize significance of vehicle and its related research:

____

____

____

Solve the corresponding math problem on the Math Challenge Problems Worksheet. Write your final answer here:

____

____

Biological and Physical Research and Human Exploration and Development of Space

Vehicle Name: ______________________________

Research Title: ______________________________

Summarize significance of vehicle and its related research:

____

____

____

Solve the corresponding math problem on the Math Challenge Problems Worksheet. Write your final answer here:

____

____

Earth Science

Vehicle Name: ______________________________

Research Title: ______________________________

Summarize significance of vehicle and its related research:

____

____

____

Solve the corresponding math problem on the Math Challenge Problems Worksheet. Write your final answer here:

____

____

Space Science

Vehicle Name: ______________________________

Research Title: ______________________________

Summarize significance of vehicle and its related research:

____

____

____

Solve the corresponding math problem on the Math Challenge Problems Worksheet. Write your final answer here:

____

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Satellite Swap Answer Key

Each student's assessment will be different. They will make different matches and have different Math Challenge Problems.

This Answer Key corresponds to the first two fill-in-the-blanks for each enterprise listed on the Satellite Swap Handout.

Enterprise Name, Vehicle, and Research

To grade students' answers, locate the enterprise first and then the matching pair in which Card 1 is the NASA vehicle name and Card 2 is the Research Title. See game card pair in Figure 1 on page 67.

Summary Sentence

Summary Sentences are not included in the answer key table because answers will vary. However, the text on the two cards is included, and this is the information that students will summarize.

Math Challenge Problem

To correct the Math Challenge Problem for each enterprise section of the Satellite Swap Handout consult the Math Challenge Problems Answer Key (pages 82–85). Again, problems are listed by enterprise.

Enterprise Name

Vehicle Name and Research

Biological and Physical Research and Human Exploration and Development of Space

Vehicle Name: ______________________________

Research Title: ______________________________

Summarize significance of vehicle and its related research:

____

____

____

Solve the corresponding math problem on the Math Challenge Problems Worksheet. Write your final answer here:

____

____

Summary Sentence

Math Challenge Problem

TEACHER FACTS: NASA ENTERPRISES

The National Aeronautics and Space Administration (NASA) conducts research in five areas called enterprises:

1. Aerospace Technology
2. Biological and Physical Research
3. Earth Science
4. Human Exploration and Development of Space
5. Space Science

Two enterprises (Biological and Physical Research and Human Exploration and Development of Space) are closely aligned, so they will be grouped together to simplify the Satellite Swap game.

Aerospace Technology

http://aerospace.nasa.gov

This enterprise conducts research to make possible safer, cleaner, quieter, and faster air travel and routine space transportation. A part of its mission is to develop and commercialize innovative technologies using research facilities like wind tunnels and other technologies to improve aeronautics safety and reliability. The following are four examples of NASA aerospace technology research vehicles:

- Blended Wing Body
- F-15 ACTIVE
- Helios Prototype
- X-37

Biological and Physical Research

http://spaceresearch.nasa.gov

The enterprise of Biological and Physical Research seeks to create an interdisciplinary research program focused on biology and brings together physics, chemistry, biology, and engineering. This newest enterprise leads the Nation's efforts in life and microgravity sciences. This includes studying the three fundamental states of matter—solids, liquids, and gases—and the forces that affect them. Related aspects of research and technology using the space environment will improve the quality of life on Earth and strengthen the foundations for continuing the exploration and utilization of space. This enterprise typically uses research vehicles managed by the Human Exploration and Development of Space Enterprise for its research. Four research aircraft and spacecraft follow:

- International Space Station
- KC-135
- Sounding Rocket
- Space Shuttle

Earth Science

http://www.earth.nasa.gov/

Earth Science is dedicated to understanding the total Earth system and the effects of natural and human-induced changes on the planet's environment. Earth Science is pioneering the new interdisciplinary field of research called Earth System Science, born of the recognition that Earth's land, oceans, atmosphere, ice, and life are both dynamic and highly interactive. The following are four examples of Earth Science satellites:

- Geostationary Operational Environmental Satellite (GOES)
- Terra
- TOPEX/Poseidon
- Tropical Rainfall Measuring Mission (TRMM)

Human Exploration and Development of Space

http://spaceflight.nasa.gov

Human Exploration and Development of Space (HEDS) seeks to increase human knowledge of nature's processes using the space environment, to explore and settle the solar system, to achieve routine space travel, and to enable the commercial development of space. This enterprise involves the astronauts, human space flight, living and working in space, and space product development.

Space Science

http://spacescience.nasa.gov/osshome.htm

The Space Science enterprise seeks to solve the mysteries of the universe; to explore the solar system; to discover planets around other stars; to search for life beyond Earth; to chart the evolution of the universe; and to understand its galaxies, stars, and planets. Research areas of particular interest involve the origins of life, planetary bodies, galaxies, and the universe; the use of robotics to explore Earth and other planets; and the exploration of the connection between the Sun and Earth. NASA Space Science research vehicles include balloons, aircraft, and orbiting space observatories. Four examples are given below:

- Balloon Observations of Millimetric Extragalactic Radiation and Geophysics (BOOMERanG)
- Chandra Space Observatory
- Hubble Space Telescope (HST)
- Stratospheric Observatory for Infrared Astronomy (SOFIA)

Satellite Swap Answer Key for Aerospace Technology Enterprise

Vehicle Name	*Research Title*
Blended Wing Body Someday airplanes may have blended wing bodies. This revolutionary aircraft design includes the engines, wings, and body in one structure that provides the aircraft's lift. A double-deck passenger compartment would blend into the wings and would hold 800 persons.	**Aircraft Design** To make the Blended Wing Body closer to becoming a reality, extensive model development and testing must be done. Here a technician works on a 3.3-meter-wide BWB wind tunnel test model. Data will be collected to determine the performance and stability of the current design.
F-15 ACTIVE The Advanced Control Technology for Integrated Vehicles (ACTIVE) program at NASA's Dryden Flight Research Center is a research effort to enhance the performance and maneuverability of future civil and military aircraft. For this program, advanced flight control systems and thrust vectoring of engine exhaust have been built into a highly modified F-15 research aircraft.	**Aircraft Performance Research** The ACTIVE research team uses a modified F-15 jet to improve the way aircraft perform and maneuver. The newly developed nozzles can redirect the engine exhaust up, down, left, and right.
Helios Prototype The Helios Prototype is a remotely piloted aircraft being developed to prove that a solar-powered aircraft can fly a maximum altitude of 30.5 km or can maintain an altitude of at least 15.2 km for a minimum of 4 days. It is being developed as part of NASA's Environmental Research and Sensor Technology (ERAST) project.	**Solar-Powered Research Aircraft** The Pathfinder Plus is an earlier design in the evolution of solar-powered research aircraft. Such high-flying, remotely piloted aircraft could be used to track storms, sample the atmosphere, take spectral images for agricultural purposes, monitor natural resources, and act as a telecommunications relay platform.
X-37 The X-37 will be the first of NASA's fleet of experimental, reusable launch vehicles to operate in orbit and during reentry into Earth's atmosphere. The Space Shuttle or rockets will be able to ferry the X-37 into orbit. There it will operate at speeds of up to 25 times the speed of sound and test technologies in the harsh environments of space and atmospheric reentry.	**Launch and Reentry Research** As in the artist's concept drawing, scientists hope to do future testing of the X-37 like this, transporting it in the Space Shuttle cargo bay to do reentry testing. The X-37 is being developed to test airframe, propulsion, and operational technologies for reusable launch vehicles.

Satellite Swap Answer Key for Biological and Physical Research and Human Exploration and Development of Space Enterprises

Vehicle Name	*Research Title*
International Space Station The ISS represents a global partnership of 16 nations. It will be a permanent orbiting laboratory enabling long-duration research in the unique microgravity environment of Earth's orbit. When fully assembled, the ISS will look like the picture shown here.	**Life Science Research** Biotechnology facilities aboard the ISS will include a bioreactor developed by NASA for 3-D tissue growth. Growing tissues in the bioreactor in microgravity produces structures, such as polyps and glands (middle and bottom), which are not present in petri dish cultures (top) grown on Earth. Onorbit cellular research has the potential to help treat diseases such as AIDS, diabetes, and cancer.
KC-135 The KC-135 is a microgravity research aircraft nicknamed the "Vomit Comet." It is used to fly in parabolas to induce weightless conditions for 15 to 20 seconds at a time. When some of the effects of gravity are reduced, other phenomena are more easily observed.	**Fluids Research** Fluids research conducted on the KC-135 reveals that air and water do not flow through a pipe in microgravity in the same way that they do on Earth—with water, which is denser than air, on the bottom and air on top. In microgravity, density differences do not cause materials to layer. Bubbles and "slugs" of air flow throughout the water. Liquids do not fill the bottom of a container. Fluid studies such as this impact the design of spacecraft fuel tanks and water transfer systems.
Sounding Rockets Sounding rockets, such as the Black Brant shown here, are used for a broad range of scientific research. These rockets top out in the Thermosphere before falling back to Earth. Once the engine thrust is cut off, rocket payloads are in freefall and experience microgravity conditions for 6 to 10 minutes. At this point, a parachute deploys to slow the payload's descent.	**Combustion Research** Combustion scientists hope that by studying flame spread in a microgravity environment, they will gain a deeper understanding of how fire burns and of potential fire hazards onorbit. Because combustion phenomena occur quickly, much research is done in drop towers and on sounding rockets.
Space Shuttle The Space Shuttle is NASA's reusable launch vehicle that is used to conduct scientific research in the unique environment of Earth's orbit, and to help construct the International Space Station. This picture shows the cabin of the Space Shuttle Atlantis, its remote manipulator system (RMS) arm in operational mode, and a part of the International Space Station during Shuttle mission STS-106.	**Materials Science** This image shows a "forest" of dendrites, which are fern-like microstructures found in metals. Materials scientists study dendrites in space to improve the output of foundries here on Earth. Scientific data from the Isothermal Dendritic Growth Experiment are being adapted into computer models, thus reducing the casting design process from a couple of weeks to about a day.

Satellite Swap Answer Key for Earth Science Enterprise

Vehicle Name	*Research Title*
GOES The Geostationary Operational Environmental Satellite (GOES) is a key part of U.S. weather monitoring and severe storm forecasting. GOES orbits high above the equator at 36,000 km and remains above a specific point on Earth's surface in what is known as a geostationary orbit. The high altitude allows the satellite to observe a large area, such as the entire continental United States, and to continually monitor weather systems in that area.	**Weather Monitoring** This picture of a hurricane coming up from the southwest of the Baja peninsula is a composite image. The GOES satellite took the cloud image in visible and thermal infrared, while the colorized background is a Landsat composite map.
Terra Terra is NASA's flagship Earth observing satellite. In February 2000 it began collecting global data on Earth's climate. Terra will circle around Earth, very nearly from pole to pole. The data it collects are analyzed to determine the cause-and-effect relationships among Earth's lands, oceans, and atmosphere well enough to predict future climate conditions.	**Global Climate Change** This graphic shows data collected from Terra's multiple sensors integrated into one image. The three-dimensional cloud measurements were taken by one sensor. Another sensor collected ocean temperatures. The red area in the Pacific Ocean shows an El Niño anomaly. Red dots on land show the locations of forest fires. Together, Terra's instruments help us understand Earth as a whole, integrated system.
TOPEX/Poseidon Every 10 days, the TOPEX/Poseidon satellite measures global sea level with unparalleled accuracy and monitors global ocean circulation. These studies reveal ties between the oceans and atmosphere and improve global climate predictions.	**Ocean Climatology** After three years of devastating El Niño and La Niña climate patterns, the Pacific Ocean is finally calming down to near normal sea levels (green). Above-normal sea-level heights appear in red and white, ranging from 10 to 32 cm. Blue and purple areas indicate below-normal levels, from 4 to 18 cm.
TRMM The Tropical Rainfall Measuring Mission (TRMM) is a joint mission between NASA and the National Space Development Agency (NASDA) of Japan. It was designed to monitor and study tropical rainfall and the associated release of energy that helps power global atmospheric circulation, which shapes both weather and climate around the globe.	**Storm Studies** One of the unique features of TRMM's instrumentation is that it allows scientists to peer inside clouds. Using radar, scientists study the reflection of cloud drops, raindrops, and ice crystals within various parts of the energy spectrum, and they construct a picture of what the cloud looks like inside. TRMM's ability to distinguish between various ice and water particles in storms is beginning to shed light on how and why lightning is produced.

Satellite Swap Answer Key of Space Science Enterprise

Vehicle Name	*Research Title*
BOOMERanG (Balloon Observations of Millimetric Extragalactic Radiation and Geophysics) For 10 days in 1998, BOOMERanG, a balloon-borne telescope, circumnavigated Antarctica at an altitude of 32 km, which is above much of Earth's atmospheric mass. The telescope collected data about the early universe.	**Early Universe Research** In this picture, we see the universe as it makes its transition from a glowing plasma to a transparent gas approximately 14 billion years ago. The color scale of the image has been enhanced to bring out the temperature variations in the primordial plasma, which has since evolved into giant clusters and superclusters of galaxies today.
Chandra Space Observatory The Chandra X-ray Observatory was launched in 1999 and is NASA's newest Great Observatory. Chandra detects and images x-ray sources that are billions of light-years away. The images from Chandra are twenty-five times sharper than the best previous available. Chandra provides more detailed studies of black holes, supernovae, and dark matter.	**X-ray View of the Crab Nebula** The Crab Nebula is the remnant of a supernova explosion that was seen on Earth in A.D. 1054. It is 6,000 light-years from Earth. At the center of the bright nebula is a rapidly spinning neutron star, or pulsar, that emits pulses of radiation 30 times a second.
Hubble Space Telescope Launched in 1990, the Hubble Space Telescope was the first major telescope to be placed into orbit around Earth, high above Earth's obscuring atmosphere. Its mission is to provide the clearest views of the universe possible using optical astronomy. Hubble's telescope can resolve astronomical objects with an angular size of 0.05 arc seconds, which is like seeing a pair of fireflies in Tokyo from Maryland.	**Colliding Galaxies** What appears as a bird's head leaning over to eat a meal is a striking example of a galaxy collision in NGC 6745. The "bird" is a large spiral galaxy. Its "prey" is a smaller passing galaxy (lower right). The bright blue beak and bright, whitish-blue top feathers show the distinct path taken during the smaller galaxy's journey. These galaxies did not merely interact gravitationally as they passed one another; they actually collided.
SOFIA The U.S. and German space agencies are developing the Stratospheric Observatory for Infrared Astronomy (SOFIA), a 747SP aircraft that carries a 2.5-m reflecting telescope. SOFIA will be the largest airborne telescope in the world. It will make observations that are impossible for even the largest and highest ground-based telescopes. Its planned cruising altitude of 12.5 km puts it above the water vapor in the Troposphere, which absorbs infrared radiation.	**Infrared Astronomy** Astronomical objects emit many forms of energy which neither the human eye nor ordinary telescopes can detect. Infrared is one form of this invisible energy. Infrared radiation can pass through dusty regions of space without being scattered. This means we can study objects hidden by gas and dust which we cannot see in visible light, such as the center of our galaxy and regions of newly forming stars.

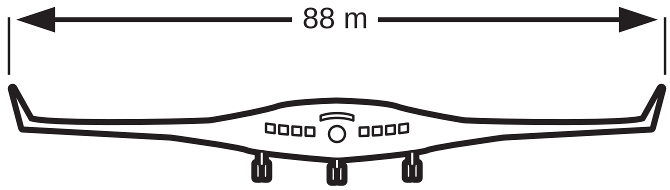
Worksheet 1: Math Challenge Problems

Aerospace Technology

1. **Blended Wing Body**

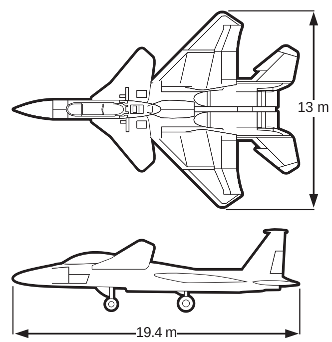
   Wingspan models of the Blended Wing Body tested in NASA wind tunnels measure 1.5 m and 3.4 m. Plans are underway to test a remotely piloted 5.2-m-wingspan model.

   What are the scale factors of these three models if the actual wingspan is 88 m?



2. **F-15 ACTIVE**

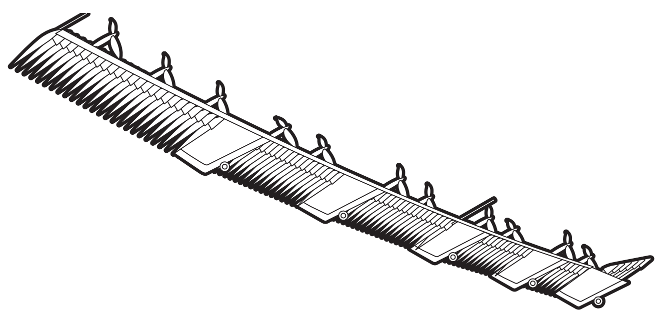
   Using the information provided in the F-15 ACTIVE images shown here, determine what the scale of the drawings are in cm/m.



3. **Helios Prototype**

   The Pathfinder Plus' highest cruising altitude was 24.5 km. The Helios Prototype's target altitude is 30.5 km.

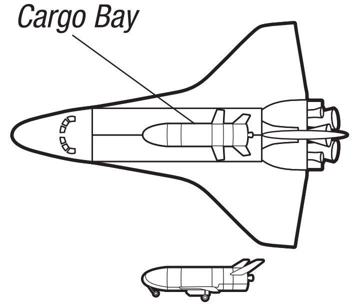
   Compared to Pathfinder Plus' record, how much higher is the Helios Prototype's target maximum altitude? Use percentages.



4. **X-37**

   The X-37 is 8.3 m in length, with a wingspan of 4.5 m. The Space Shuttle's cargo bay is 5.18 m wide, 18.28 m long, and 3.9 m deep.

   What percentage of the cargo bay's length does the X-37 take up?



Illustrations not to scale.

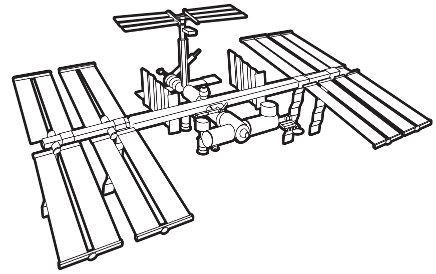
Worksheet 1: Math Challenge Problems

Biological and Physical Research and Human Exploration and Development of Space

1. **International Space Station**

   The International Space Station (ISS) will be 108 m in length and 88 m in width when fully assembled. A football field is 48.8 m wide by 91.4 m long.

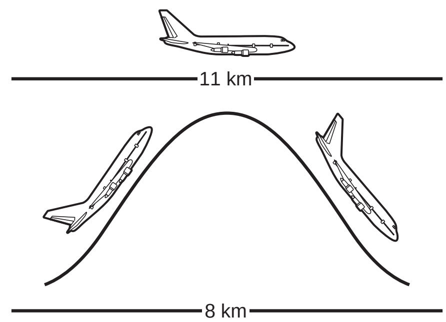
   About how many football fields wide is the ISS?



2. **KC-135**

   During a "campaign," the KC-135 flies 20 to 40 parabolas in a row, like a roller coaster ride in the air. At the highest point the aircraft tops off at 11 km and pulls out of the dive at 8 km.

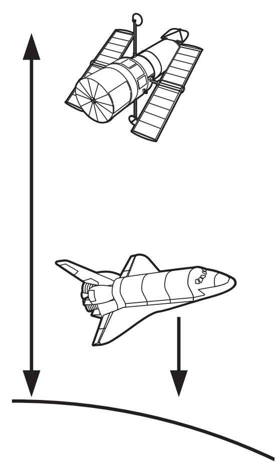
   What is the ratio of the vertical dive distance to the KC-135's parabola top?



3. **Space Shuttle**

   During the STS-78 mission, the Space Shuttle orbited at 220 km. To capture the Hubble Space Telescope for servicing on other missions, the Shuttle had to orbit at 595 km.

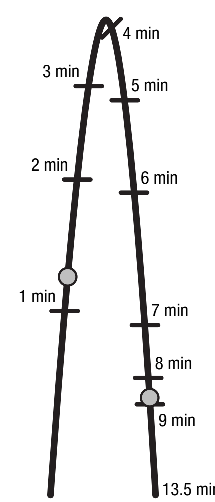
   Using the STS-78 orbital altitude as a basis, at what percentage of this altitude is the Shuttle when it services the Hubble?



4. **Sounding Rocket**

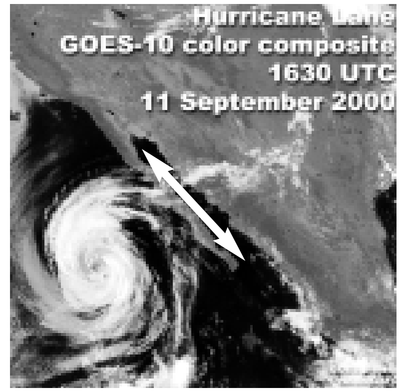
   This sounding rocket's flight path has a roughly parabolic shape with a peak of 208.5 km. The payloads experience "weightless" conditions from 1.2 minutes into the flight until 9 minutes into the flight, when a parachute is released.

   During what percentage of the total flight time is the experiment in weightless conditions?



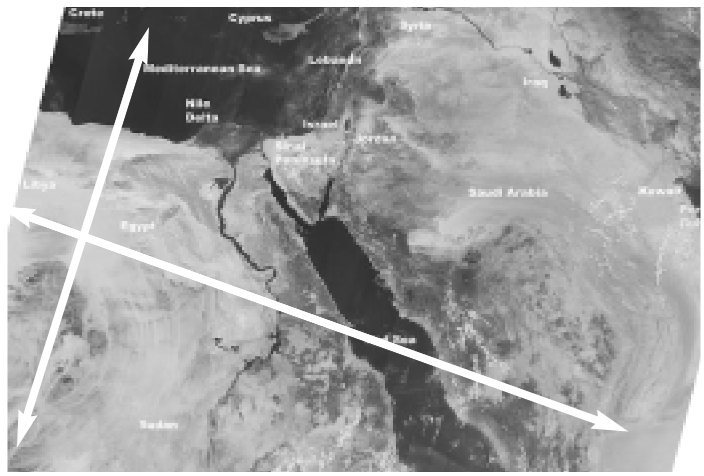
Worksheet 1: Math Challenge Problems

Earth Science



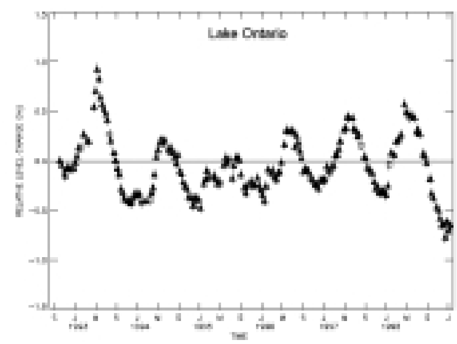
1. **GOES**

   The Baja Peninsula is about 1,130 km in length. What is the scale on the Weather Monitoring card?



2. **Terra Satellite**

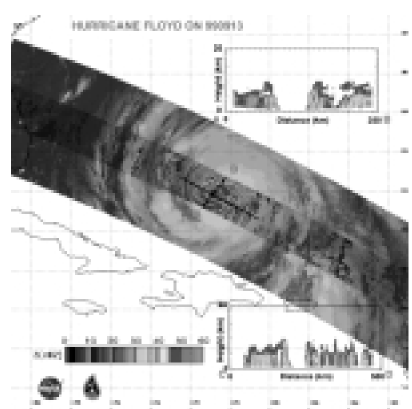
   This composite picture of the Middle East was generated using data from 16 orbital passes between August 16 and 30, 2000. The total width of the picture covers 2,700 km from east to west and 1,750 km from north to south. What is the scale of this picture?



3. **TOPEX/Poseidon**

   TOPEX/Poseidon has measured variations in Lake Ontario’s surface water levels for a number of years.

   Using the axis labels and data plotted, calculate the approximate vertical scale of this plot.



4. **TRMM**

   The TRMM Precipitation Radar provides data across a swath 220 km wide.

   What scale would be needed to fit a precipitation data plot across 10 cm?

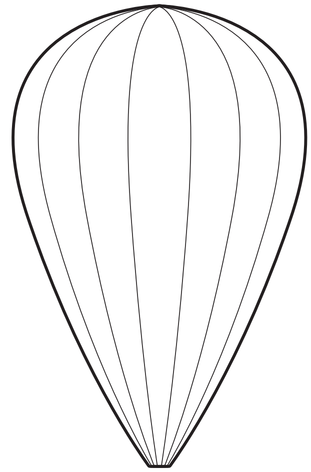
Worksheet 1: Math Challenge Problems

Space Science

1. **BOOMERanG**

   A standard-sized party balloon is 23 cm in diameter. An Ultra-Long Duration Balloon is 130 m in diameter.

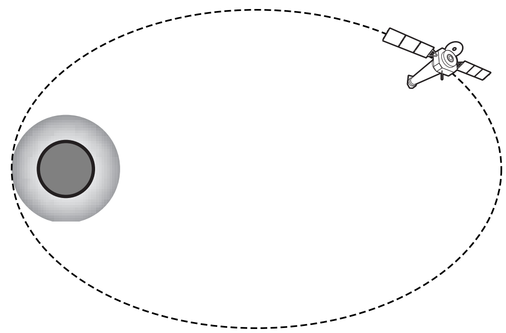
   How many times bigger in diameter is an Ultra-Long Duration Balloon? Express your answer with no more than 3 significant digits.



2. **Chandra Space Observatory**

   Chandra's orbit is highly elliptical compared to other satellites. The orbit's perigee (closest point to Earth) is 16,313 km. Its apogee (farthest point from Earth) is 146,341 km.

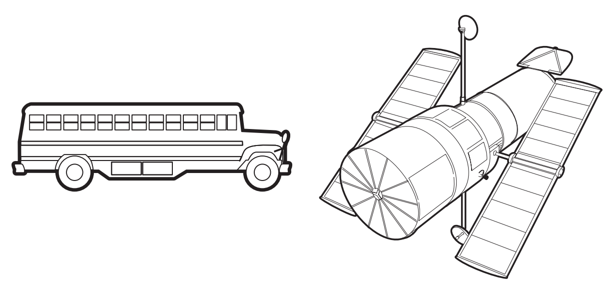
   How many times farther from Earth's center is Chandra at apogee compared to perigee?



3. **Hubble Space Telescope**

   The Hubble Space Telescope is 13.2 m in length. A school bus is 10.5 m in length.

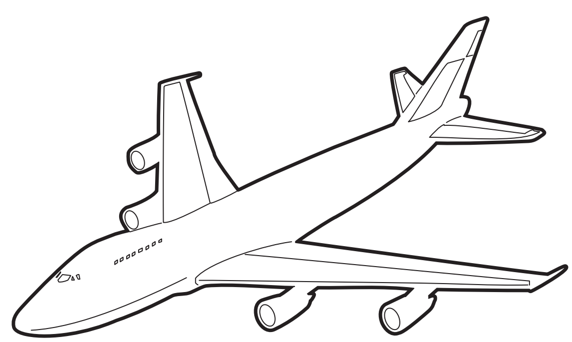
   What percentage of the Hubble's length is the school bus's length?



4. **SOFIA**

   Most of the mass of Earth's atmosphere is within 50 km of Earth's surface. SOFIA flies at 12.5 km.

   What percentage of this 50-km distance is SOFIA's cruising altitude?



Math Challenge Aerospace Technology Enterprise Answer Key

1. **Blended Wing Body**

1.5 m represents:	88 m	3.4 m represents:	88 m	5.2 m represents:	88 m
1 m represents:	88 m / 1.5	1 m represents:	88 m / 3.4	1 m represents:	88 m / 5.2
1 m represents:	58.7 m	1 m represents:	25.9 m	1 m represents:	16.9 m
Scale factor:	1:58.7	Scale factor:	1:25.9	Scale factor:	1:16.9

2. **F-15 ACTIVE**

Using aircraft wingspan:

2.5 cm represents 13 m; 1 cm represents 13 m / 2.5.
1 cm represents 5.2 m for a scale of 0.2 cm/m.

Using aircraft length:

3.6 cm represents 19.4 m; 1 cm represents 19.4 m / 3.6.
1 cm represents 5.4 m for a scale of 0.2 cm/m.

3. **Helios Prototype**

Use Pathfinder Plus' record altitude as the basis for answering the question.

Altitude difference = $HP_{ALT} - PP_{ALT}$ = 30.5 km - 24.5 km = 6.0 km

As a percentage of PP record:

% altitude difference = (altitude difference/PP_{ALT}) * 100 =
(6.0 km / 24.5 km) * 100 = 24.5%

4. **X-37**

Percentage of cargo bay length = (length X37 / length cargo bay) * 100

This can be represented as:

$$X\%\ CB_L = (X37_L / CB_L) * 100$$
$$= (8.3\text{ m} / 18.28\text{ m}) * 100$$
$$= 45\%$$

Math Challenge Biological and Physical Research and Human Exploration and Development of Space Enterprises Answer Key

1. **International Space Station**

Ratio of the ISS width to field width = 88 m / 48.8 m = 1.8

The ISS will be about 1.8 football fields wide when completely assembled.

2. **KC-135**

KC-135 Parabola Top d_{PT} = 11 km
Vertical Dive Distance $d_{dive} = d_{PT} - d_{PB}$ = 11 km - 8 km = 3 km
Ratio Dive to Parabola Top = d_{dive} / d_{PT}
= 3 km / 11 km
= 3 / 11

3. **Space Shuttle**

STS-78 altitude a_{78} = 220 km
Hubble servicing altitude a_{HST} = 595 km
a_{HST} = x% of a_{78}
$(a_{HST} / a_{78}) * 100 = x$
(595 km / 220 km) * 100 = 270%

4. **Sounding Rocket**

Total microgravity time: t_{mg} = 9 min - 1.2 min = 7.8 min
% of total flight time: $(t_{mg} / t_{tot}) * 100$ = (7.8 min / 13.5 min) * 100 = 58%

Math Challenge Earth Science Enterprise Answer Key

1. **GOES**

2 cm represents 1,130 km.
1 cm represents 1,130 km / 2.
1 cm represents 565 km, for a scale of 0.002 cm/km.

2. **Terra**

8.2 cm represents 2,700 km.
1 cm represents 2,700 km / 8.2.
1 cm represents 329.3 km, for a scale of 0.003 cm/km.

3. **TOPEX/Poseidon**

Measurement on plot (-1 to +1 m) represents 2 m.
2.5 cm represents 2 m.
1 cm represents 2 m / 2.5.
1 cm represents 0.8 m, for a scale of 1.25 cm / m.

4. **TRMM**

A length of 220 km needs to be scaled to fit on a 10-cm axis. For this, 10 cm represents 220 km.

1 cm represents 220 km / 10.
1 cm represents 22 km, for a scale of 0.04 cm/km.

Math Challenge Space Science Enterprise Answer Key

1. **BOOMERanG**

$$
\begin{aligned}
\text{Diameter comparison} &= ULDB_d / PB_d \\
&= 130 \text{ m} / 0.23 \text{ m} \\
&= 565.2
\end{aligned}
$$

An Ultra-Long Duration Balloon is about 565 times bigger than a party balloon's diameter.

2. **Chandra**

146,341 km / 16,313 km = 8.97

Chandra is 9 times farther away from Earth's center at apogee than at perigee.

3. **HST**

$$
\begin{aligned}
\text{x\% of Hubble's length} &= B_L / H_L * 100 \\
&= 10.5 \text{ m} / 13.2 \text{ m} * 100 \\
&= 79.5\%
\end{aligned}
$$

4. **SOFIA**

$$
\begin{aligned}
\text{x\% of 50-km distance} &= S_{ALT} / 50 \text{ km} * 100 \\
&= (12.5 \text{ km} / 50 \text{ km}) * 100 \\
&= 25\%
\end{aligned}
$$

Worksheet 2: Continental U.S. Map Model

You have learned that the atmosphere is divided into several distinct layers and is so large that it is difficult, if not impossible, to imagine. In this assessment, you will construct a scale model of the layers of the atmosphere and some of the aircraft, spacecraft, and satellites that are located there. You will compare it to another large structure, the United States, with which you are more familiar. Before beginning, make sure you have colored pencils, a drawing compass, and a metric ruler.

Altitude from Earth:	Actual Distance	Scale Model Distance
A. Troposphere top at equator	12 km	
B. Stratosphere top	50 km	
C. Mesophere top	80 km	
D. Thermosphere top	500 km	
E. Helios Prototype	31 km	
F. KC-135 Parabolic Peak	11 km	
G. International Space Station	400 km	
H. Terra Satellite	705 km	
I. Hubble Space Telescope	600 km	
J. TOPEX/Poseidon	1,336 km	

Worksheet 2: Continental U.S. Map Model

1. The approximate altitude of each atmospheric layer top from Earth is given in the table on the previous page. Convert each altitude using a scale of 1 mm = 5 km. Place the scale model altitude in the appropriate space in the table.

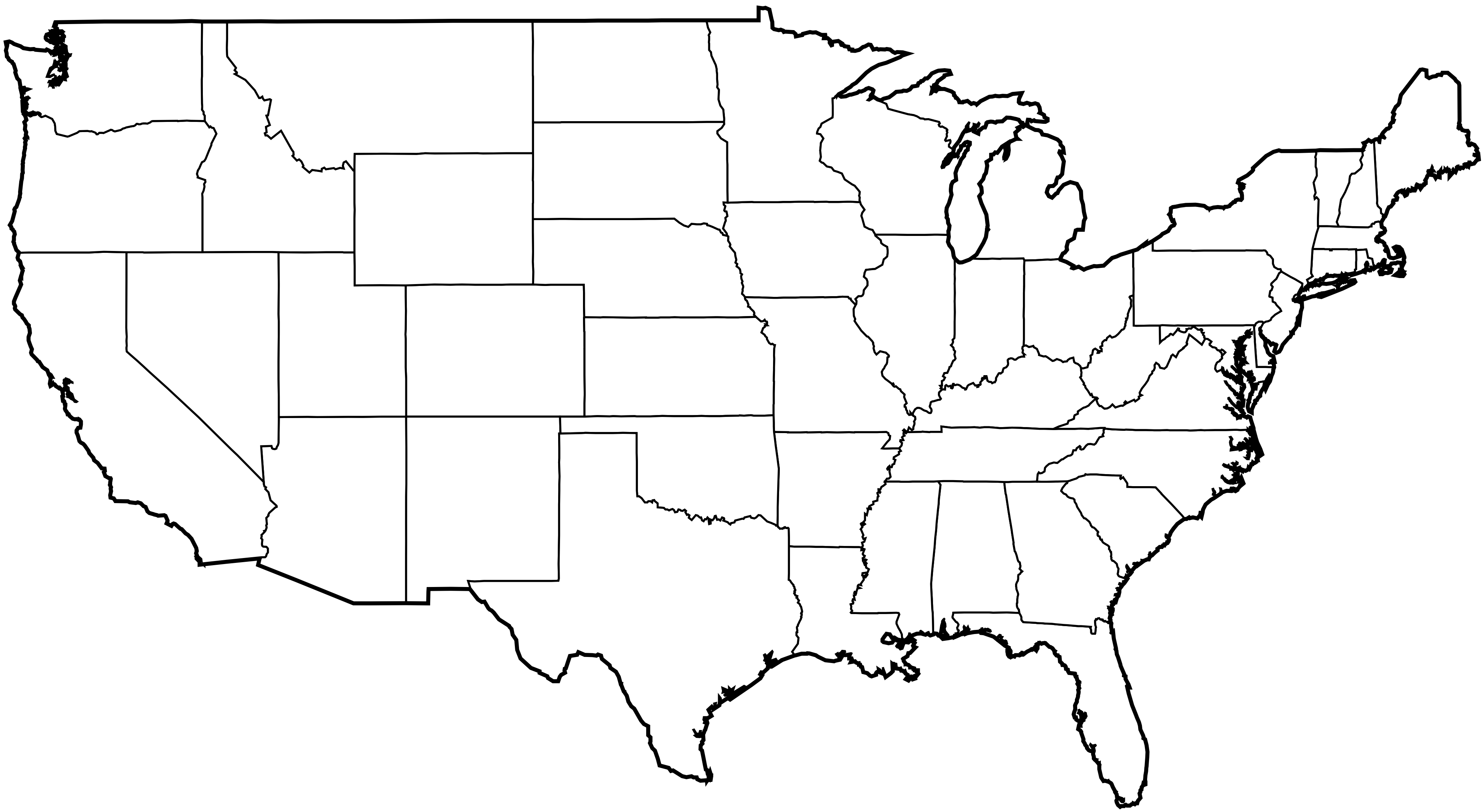
2. As accurately as possible, place a dot that identifies the location of your school on the map of the United States. This dot will represent the Earth's surface at Sea Level in the scale model. Label it Earth.

3. Using a metric ruler, a compass, and the scaled altitudes from the table, draw the upper boundary for each layer. Label (or color in) each layer.

4. Mark and label the altitudes at which the various aircraft, spacecraft, and satellites operate. Use the altitudes from the table on the previous page.

5. Using the same scale, indicate what the scaled altitudes are for these items:
   a. Chandra Space Observatory (139,970 km) = ________
   b. Global Positioning Satellites (20,200 km) = ________
   c. Tracking and Data Relay Satellite (35,700 km) = ________
   d. Moon (384,430 km) = ________

Map of the Continental United States



Worksheet 2 Answer Key

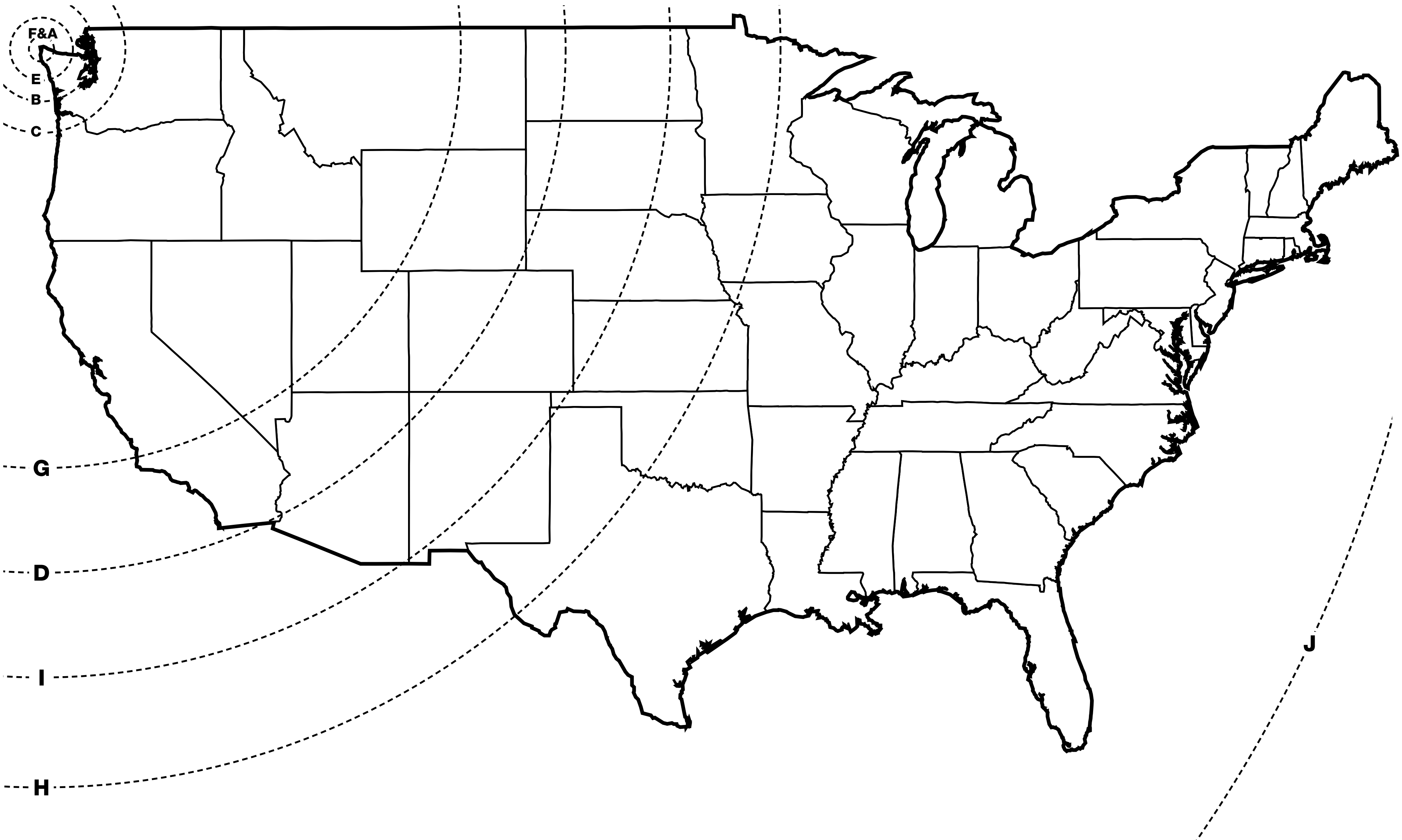
Altitude from Earth:	Actual Distance	Scale Model Distance
A. Troposphere top at equator	12 km	2.4 mm
B. Stratosphere top	50 km	10 mm
C. Mesosphere top	80 km	16 mm
D. Thermosphere top	500 km	100 mm
E. Helios Prototype	30 km	6 mm
F. KC-135 Parabolic Peak	11 km	2.2 mm
G. International Space Station	400 km	80 mm
H. Terra Satellite	705 km	141 mm
I. Hubble Space Telescope	600 km	120 mm
J. Topex/Poseidon	1,336 km	267.2 mm

2-4. To personalize this question for your school's location, you will need to use a compass and ruler to correctly measure where the above answers fit on the map starting from your school's location. The sample included begins in Washington State. See next page.

5. Using the same scale, indicate what the scaled altitudes are for these items:
   a. Chandra Space Observatory (139,970 km) = 27,994 mm or 28 m
   b. Global Positioning Satellites (20,200 km) = 4,040 mm or 4 m
   c. Tracking and Data Relay Satellite (35,700 km) = 7,140 mm or 7.1 m
   d. Moon (384,430 km) = 76,886 mm or 76.9 m

NOTE: With the very large numbers, it is suggested that students find the scale altitudes and then convert millimeters to meters. This will aid in their understanding of the vastness of the altitudes of these objects in comparison to the layers of the atmosphere.

Map of the Continental United States Answer Key



Worksheet 3: Models, Scales, and Distance

1. Calculate the diameter of a model of Earth when using a scale of 1 cm = 200 km. Note: Earth's actual diameter is 12,742 km.

2. A model airplane was built on a 1:24 scale. If the length from front to back is 30.5 cm, what is the length of the life-size counterpart of the real plane?

3. The range of the Mesosphere is 2.5 times that of the Troposphere's range, which is 12 km. What is the range of the Mesosphere?

4. The International Space Station orbits at a maximum altitude of 463 km. Over the course of 80 days, the ISS's orbital altitude decreases 33.3%. The ISS is then reboosted back to its maximum altitude over 10 days. What is the ISS's altitude when reboost begins?

5. The F-15 ACTIVE aircraft can fly a maximum altitude of 18 km. The BOOMERanG research balloon circumnavigated the Antarctic Circle at an altitude 205.6% higher. What was BOOMERanG's flight altitude?

6. The International Space Station is 108 meters long end-to-end. That's the equivalent to the length of a football field, including the end zones. If you wanted to make a scale model of the International Space Station that you could bring to school for a science project and that fits on a desk (about 60 cm), what would be a reasonable scale to use? Explain your answer.

7. What other types of objects are commonly built to scale? What models do you use everyday? What scale is used? How could you find the scale?

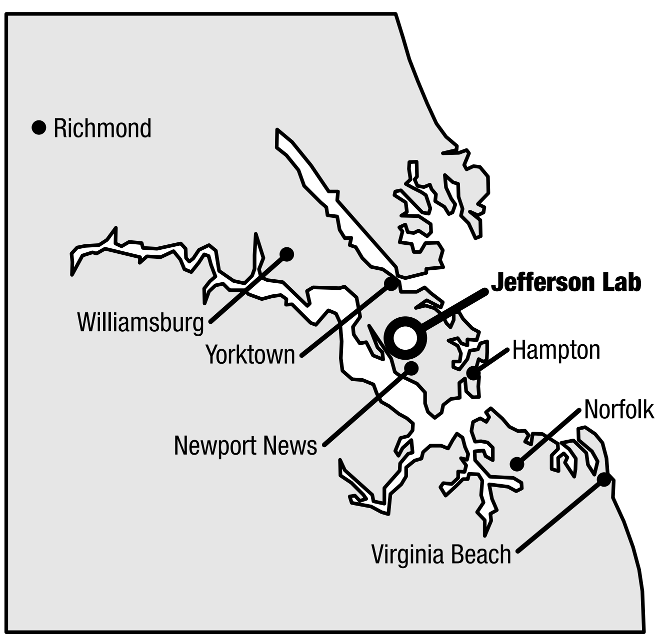
8. A model may represent a system. A model may be an object, a drawing, or a mathematical equation. Give an example of each kind of model.

9. What are some reasons to make models?

10. How is a model different from the object which it represents?

11. What is a scale?

12. Using this map, answer the following question. If the actual distance from Williamsburg to Yorktown is 161 km, give the map scale: 1 cm = _______.



Worksheet 3 Answer Key

1. *Scale: 1 cm = 200 km. (Scaled distance = 12,742 km / 200 km/cm = 63.7 cm)*

2. *Scale is 1/24 (24 * 30.5 cm = 732 cm)*

3. *2.5 * 12 km = 30 km*

4. *The ISS's altitude (463 km) decreases 33.3%. So, 463 km * 0.333 = 154.179 km. 463 - 154.179 = 308.8, which rounds to 309 km. At the time of reboost, the ISS's orbital altitude is about 309 km.*

5. *F-15 ACTIVE's flight altitude is 18 km. 18 km * 2.056 = 37.008, which can be rounded to 37 km. So, 205.6% higher = 18 km + 37 km = 55 km*

6. *Answers may vary but should allow a model small enough to be transported to school and fit on a desk of about 60 cm long. Any scale where the model will be less than 60 cm is valid. Here is one example that works, where:*

   60 cm represents 108 m.
   1 cm represents 108 m / 60.
   1 cm represents 1.8 m, or 1 m = 0.55 cm.

7. *Answers may vary, but examples are model planes, trains, automobiles, and doll houses. Scale is sometimes given, or you can select a full-size dimension and compare it with same dimension on the model and calculate the ratio between them.*

8. *Answers may vary, but examples include:*
   Object = model of Earth, an atom, a cell
   Drawing = house plans, maps
   Diagram = circulatory system, electrical circuits
   Mathematical equation = formula for area, volume.

9. *Models are made to help in our understanding of objects that are microscopic, are extremely large, or are too far away or too dangerous to study directly.*

10. *Models are either smaller or larger than the original object. They are a simpler version of the real object. They may have some features in common, but they are less complex and are often not made of the same materials.*

11. *A scale is the ratio between the dimensions of a model and the dimensions of the object that the model represents.*

12. *Max distance from Williamsburg to Yorktown is 1.5 cm, which represents 161 km. Set up a ratio:*

    1.3 cm / 161 km = 1.0 cm/x
    Solve for x = 123.8 km.

HOW HIGH IS IT WEB SITES

RESEARCH AIRCRAFT/ROCKETS/SPACECRAFT

Blended Wing Body
http://oea.larc.nasa.gov/PAIS/BWB.html
BOOMERanG
http://www.wff.nasa.gov/pages/scientificballoons.html
http://www.physics.ucsb.edu/~boomerang/
F-15 ACTIVE
http://www.dfrc.nasa.gov/PAO/PAIS/HTML/FS-048-DFRC.html
Helios Prototype
http://www.dfrc.nasa.gov/PAO/PAIS/HTML/FS-068-DFRC.html
KC -135
http://microgravity/kjenks/kc-135.htm
SOFIA
http://sofia.arc.nasa.gov/
http://www.ipac.caltech.edu/Outreach/Edu/
Sounding Rockets
http://rscience.gsfc.nasa.gov/

EARTH ORBITING SATELLITES

Chandra Observatory
http://chandra.nasa.gov
http://chandra.harvard.edu/photo/0052/index.html
Geostationary Operational Environmental Satellite (GOES)
http://goes2.gsfc.nasa.gov/
http://rsd.gsfc.nasa.gov/goes/text/hotstuff.html
Global Positioning System (GPS)
http://leonardo.jpl.nasa.gov/msl/Programs/gps.html
Hubble Space Telescope (HST)
http://www.stsci.edu
http://oposite.stsci.edu/pubinfo/latest.html
Landsat
http://landsat.gsfc.nasa.gov/
Terra
http://terra.nasa.gov/
http://visibleearth.nasa.gov/Sensors/Terra/
TOPEX/Poseidon
http://topex-www.jpl.nasa.gov/
http://www.jpl.nasa.gov/elnino/
Tracking and Data Relay Satellite System (TDRSS)
http://nmsp.gsfc.nasa.gov/tdrss/tdrsshome.html

Tropical Rainfall Measuring Mission
http://trmm.gsfc.nasa.gov/
http://trmm.gsfc.nasa.gov/Ed_Resources.html

CREWED SPACECRAFT

International Space Station
http://spaceflight.nasa.gov/station/
Space Shuttle
http://spaceflight.nasa.gov/shuttle/
X-37
http://www.msfc.nasa.gov/news/background/facts/x37.htm

MOON

http://www.tsgc.utexas.edu/everything/moon/

NASA ENTERPRISES

Aerospace Technology
http://www.aerospace.nasa.gov/
Biological and Physical Research
http://spaceresearch.nasa.gov/
Earth Sciences
http://www.earth.nasa.gov/
Human Exploration and Development of Space
http://spaceflight.nasa.gov
Space Science
http://spacescience.nasa.gov/osshome.htm
http://teachspacescience.stsci.edu/

NASA EDUCATION

NASA Education Programs
http://education.nasa.gov/
NASA Spacelink
http://spacelink.nasa.gov/index.html

DOWNLOADABLE MATERIALS FOR THE HOW HIGH IS IT EDUCATOR'S GUIDE

The Educator's Guide, gamecards, and overhead sets can be downloaded.

The National Center for Microgravity Research on Fluids and Combustion K–12 Education Program, For the Classroom (by the guide's authors)
http://www.ncmr.org/education/k12/classroom.html
NASA Spacelink (Search for How High Is It.)
http://spacelink.nasa.gov/products

NASA RESOURCES FOR EDUCATORS

NASA's Central Operation of Resources for Educators (CORE) was established for the national and international distribution of NASA-produced educational materials in audiovisual format. Educators can obtain a catalog and an order form by one of the following methods:

- NASA CORE
  Lorain County Joint Vocational School
  15181 State Route 58
  Oberlin, OH 44074-9799
- Toll-free Ordering Line: 1-866-776-CORE
- Toll-free FAX Line: 1-866-775-1460
- E-mail: *nasaco@leeca.org*
- Home Page: *http://education.nasa.gov/core*

Educator Resource Center Network (ERCN)
To make additional information available to the education community, NASA has created the NASA Educator Resource Center (ERC) network. Educators may preview, copy, or receive NASA materials at these sites. Phone calls are welcome if you are unable to visit the ERC that serves your geographic area. A list of the centers and the regions they serve includes:

AK, HI, ID, MT, NV, OR, UT, WA, WY, Northern CA
NASA Educator Resource Center
Mail Stop 253-2
NASA Ames Research Center
Moffett Field, CA 94035-1000
Phone: (650) 604-3574

CT, DE, DC, ME, MD, MA, NH, NJ, NY, PA, RI, VT
NASA Educator Resource Laboratory
Mail Code 130.3
NASA Goddard Space Flight Center
Greenbelt, MD 20771-0001
Phone: (301) 286-8570

CO, KS, NE, NM, ND, OK, SD, TX
Space Center Houston
NASA Educator Resource Center for
NASA Johnson Space Center
1601 NASA Road One
Houston, TX 77058
Phone: (281) 244-2129

FL, GA, PR, VI
NASA Educator Resource Center
Mail Code ERC
NASA Kennedy Space Center
Kennedy Space Center, FL 32899
Phone: (321) 867-4090

VA and MD's Eastern Shores
NASA Educator Resource Center
Visitor Center Building J-17
GSFC/Wallops Flight Facility
Wallops Island, VA 23337
Phone: (757) 824-2298

KY, NC, SC, VA, WV
Virginia Air & Space Center
Educator Resource Center for
NASA Langley Research Center
600 Settlers Landing Road
Hampton, VA 23669-4033
Phone: (757) 727-0900 x 757

IL, IN, MI, MN, OH, WI
NASA Educator Resource Center
Mail Stop 8-1
NASA Glenn Research Center
21000 Brookpark Road
Cleveland, OH 44135
Phone: (216) 433-2017

AL, AR, IA, LA, MO, TN
U.S. Space and Rocket Center
NASA Educator Resource Center for
NASA Marshall Space Flight Center
One Tranquility Base
Huntsville, AL 35807
Phone: (256) 544-5812

MS
NASA Educator Resource Center
Building 1200
NASA Stennis Space Center
Stennis Space Center, MS 39529-6000
Phone: (228) 688-3220

AZ and Southern CA
NASA Educator Resource Center for
NASA Dryden Flight Research Center
45108 N. 3rd Street East
Lancaster, CA 93535
Phone: (661) 948-7347

CA
NASA JPL Educator Resource Center
Village at Indian Hill
1460 East Holt Avenue, Suite 20
NASA Jet Propulsion Laboratory
Pomona, CA 91767
Phone: (909) 397-4420

Regional Educator Resource Centers offer more educators access to NASA educational materials. NASA has formed partnerships with universities, museums, and other educational institutions to serve as regional ERCs in many states. A complete list of regional ERCs is available through CORE, or electronically via NASA Spacelink at *http://spacelink.nasa.gov/ercn/*

NASA's Education Home Page serves as a cyber-gateway to information regarding educational programs and services offered by NASA for the American education community. This high-level directory of information provides specific details and points of contact for all of NASA's educational efforts, Field Center offices, and points of presence within each state. Visit this resource at the following address: *http://education.nasa.gov*

NASA Spacelink is one of NASA's electronic resources specifically developed for the educational community. Spacelink serves as an electronic library to NASA's educational and scientific resources, with hundreds of subject areas arranged in a manner familiar to educators. Using Spacelink Search, educators and students can easily find information among NASA's thousands of Internet resources. Special events, missions, and intriguing NASA Web sites are featured in Spacelink's "Hot Topics" and "Cool Picks" areas. Spacelink may be accessed at: *http://spacelink.nasa.gov*

NASA Spacelink is the official home to electronic versions of NASA's Educational Products. A complete listing of NASA's Educational Products can be found at the following address: *http://spacelink.nasa.gov/products*

NASA Television (NTV) features Space Station and Shuttle mission coverage, live special events, interactive educational live shows, electronic field trips, aviation and space news, and historical NASA footage. Programming has a 3-hour block—Video (News) File, NASA Gallery, and Education File—beginning at noon Eastern and repeated five more times throughout the day. Live feeds preempt regularly scheduled programming.

Check the Internet for program listings at:
http://www.nasa.gov/ntv

NTV Weekday Programming Schedules
(Eastern Times)

Video File	NASA Gallery	Education File
12–1 p.m.	1–2 p.m.	2–3 p.m.
3–4 p.m.	4–5 p.m.	5–6 p.m.
6–7 p.m.	7–8 p.m.	8–9 p.m.
9–10 p.m.	10–11 p.m.	11–12 p.m.
12–1 a.m.	1–2 a.m.	2–3 a.m.

For more information on NTV, contact:
NASA TV
NASA Headquarters
Code P-2
Washington, DC 20546-0001
Phone: (202) 358-3572

How to Access Information on NASA's Education Program, Materials, and Services EP-2000-09-345-HQ

This brochure serves as a guide to accessing a variety of NASA materials and services for educators. Copies are available through the ERC network, or electronically via NASA Spacelink.

How High Is it?

An Educator's Guide with Activities
Focused on Scale Models of Distances

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   College/University: _______ Undergraduate _______ Graduate

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2. What is your home 5- or 9-digit zip code? __ __ __ __ __ — __ __ __ __

3. This is a valuable educator guide.
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