National Aeronautics and Space Administration

NASA eClips™

Educator Guide

NASA LAUNCHPAD:

Satellite Orbits

Educational Product	
Educators & Students	Grades 9-10

EG-2010-06-009-LaRC

www.nasa.gov

SATELLITE ORBITS

National Standards:

National Science Education Standards (NSES)

Earth and Space Science
Structure of the Earth system

Physical Science
Motion and forces

Science and Technology
Understanding about science and technology

National Council of Teachers of Mathematics (NCTM)

Measurement
Understand measurable attributes of objects and the units, systems, and processes of measurement
Apply appropriate techniques, tools, and formulas to determine measurements

Representation
Create and use representations to organize, record and communicate mathematical ideas

Geometry
Specify locations and describe spatial relationships using coordinate geometry and other representational systems
Use visualization, spatial reasoning, and geometric modeling to solve problems

International Society for Technology in Education: National Educational Technology Standards (ISTE/NETS)

Creativity and Innovation
Apply existing knowledge to generate new ideas, products, or processes

NASA LAUNCHPAD

Grade Level:
9-10

Subjects:
Earth and Space Science, Algebra, Geometry

Teacher Preparation Time:
30 minutes

Lesson Duration:
Two 55-minute class meetings

Time Management:
Class time can be reduced if some work is completed at home.

educator guide

Lesson Overview:

Students first learn about the purpose, function, and orbits of satellites. Then, they plot positional data of several satellites to investigate different satellite orbits. Students use a globe and scaling to visualize the orbit and altitude of the International Space Station. Using real-time data, students record, plot, and analyze positional information of different satellites to categorize the satellites' orbits. This lesson follows the 5E model of learning.

Icons flag five areas of interest or opportunities for teachers.

- **TECHNOLOGY** highlights opportunities to use technology to enhance the lesson.
- **MODIFICATION** denotes opportunities to differentiate the lesson.
- **RESOURCES** relates this lesson to other NASA educator resources that may supplement or extend the lesson.
- **CONNECTIONS** identifies opportunities to relate the lesson to historical references and other topics or disciplines.
- **CHECK FOR UNDERSTANDING** suggests quick, formative assessment opportunities.

Materials List

EXPLORE
Per student
- Student Guide
- protractor
- straight edge
- colored pencils

Per group of 2 or 3
- globe Note: inflatable globes may be used

Per class
- enlarged diagram from page 5 of the Student Guide

EXPLAIN
Per group of 2 or 3
- globe (inflatable globes may be used)
- rubber band large enough to stretch around the globe
- ruler
- meter stick
- protractor
- piece of yarn long enough to wrap around the equator on the globe
- scotch tape

EXTEND
- computers with Internet access
- class world map

Essential Questions

- Why don't all satellites fly in the same orbit?
- How does a satellite arrive in an orbit and stay there?
- What drives scientific and technological advancement?

Instructional Objectives

Students will
- learn about the purpose, function, and orbits of satellites through readings and a video segment;
- describe at least four different shapes and types of satellite orbits and the purpose of each;
- plot data and become proficient in measuring angles using a protractor;
- use a globe and scaling to investigate the orbit and altitude of the International Space Station; and

5E Inquiry Lesson Development

ENGAGE (15 minutes)

1. Have the class complete a KHWL chart to organize what your students KNOW, HOW they know this information, and what they WANT TO KNOW about satellite orbits. Use these questions can help guide the discussion:
   a. What do you KNOW about satellite orbits? *(Answers will vary. Students may suggest ideas that are incorrect. Do not correct these ideas at this time. You will come back to this KHWL chart at the end of the lesson to correct any misconceptions and add more facts. One general student misconception is that an object in orbit needs thrust to maintain its orbit. This is incorrect. Once an object is in orbit it keeps going.)*
   b. Ask students to explain HOW they have learned the information stated about satellite orbits. *(Answers will vary. This is the time to help students consider the validity of their sources for information.)*
   c. What do you WANT TO KNOW about satellite orbits? *(Answers will vary. Encourage students to seek answers to their questions beyond this lesson.)*

(MODIFICATION) You may choose to have students complete the KHWL chart individually in a science notebook before sharing their thoughts with the class.

EXPLORE (25 minutes)

1. Prior to class, enlarge and post the drawing from page 4 of the Student Guide.
2. Divide the class into groups of two or three. Distribute the necessary materials for the Explore activity to each group.
3. Use a globe to demonstrate how a polar projection is generated.
   a. Have students place a globe on a table with the North Pole at the top.
   b. Direct them to look down on the globe, placing their eye directly above the North Pole at a distance so they can see the entire globe.
   c. Tell them that this view of a globe, when reproduced on a flat piece of paper, is called a polar projection because it is a view of Earth from a pole, in this case the North Pole. Tell them that polar projections can be generated from either the North or South Pole.
4. Demonstrate how to use the protractor to plot the satellites' location. Students align the 0° and 180° marks on the protractor with the Prime meridian and International Date Line. The circular hole or mark in the protractor that identifies the vertex of the angle and should be aligned with the North Pole. Point out to students that for the Eastern Hemisphere they will need to use the reverse scale to correctly plot the satellite's location. If the protractor is too small to reach the outer circle, demonstrate how to use a straight edge with the protractor to mark locations.

educatorguide

5. Assign each group four of the TDRS satellites below and have them plot each satellite's location on the drawing on page 4 of the Student Guide.
   a. TDRS-1 49.0°W (black)
   b. TDRS-3 275.0°W or 85°E (dark blue)
   c. TDRS-4 41.0°W (light blue)
   d. TDRS-5 174.0°W (purple)
   e. TDRS-6 47.0°W (green)
   f. TDRS-7 150.0°W (yellow)
   g. TDRS-8 171.5°W (orange)
   h. TDRS-9 170.0°W (red)
   i. TDRS-10 150.7°W (brown)

(TECHNOLOGY) Students can create their own diagram using geometry software.

(CONNECTIONS) NASA Space Communication and Navigation has developed an interactive demonstration that will allow you to show students how satellites relay information and communications. This interactive demonstration is available at http://www.nasa.gov/multimedia/3d_resources/spacecomm.html.

Note: This software must be downloaded and installed on a local computer. A detailed description of each screen in the program can be found at http://www.nasa.gov/multimedia/3d_resources/spacecomm_508.html.

(CONNECTIONS) As noted in the Student Guide, the diagram is not to scale. Challenge students to calculate the diameter of the circle representing the orbit if drawn to scale.

Diameter of Earth in diagram – 5.70 cm
Actual diameter of Earth – 12,740 km
Distance from Earth to satellite orbit – 35,800 km

$$\frac{5.70\ \text{cm}}{12{,}740\ \text{km}} = \frac{x\ \text{cm}}{38{,}500\ \text{km}}$$

x = 17.2 cm This represents the distance the orbit must be from the surface of earth in the diagram.
Diameter of orbit = (17.2 x2) + 5.70 = 40.1 cm or 15.8 inches

6. Have each group mark their satellites' locations on the enlarged diagram in the color indicated.
7. **(CHECKING FOR UNDERSTANDING)** Lead a class discussion around the data displayed in the diagram.
   a. What pattern do you notice about the satellite locations in the diagram? *(All but one of the satellites are in the Western Hemisphere.)*

b. Early TDRSS satellites were located in such a way that they were visible only from the White Sands ground terminal. This created a "zone of communications exclusion" over the Indian Ocean. What caused this "zone of communications exclusion?" *(Radio waves travel in straight lines, so the satellite must maintain a line of sight with the ground station to communicate with it. White Sands is in the Western Hemisphere and the Indian Ocean is in the Eastern Hemisphere. A satellite that has a line of sight to White Sands cannot "see" the Indian Ocean.)*

c. Which satellite was relocated over the Indian Ocean? Which ground station does it communicate with? How do you know? *(TDRS-3 is the only satellite in the Eastern Hemisphere. It communicates with the Guam Remote Ground Terminal.)*

EXPLAIN (25 minutes)

In the EXPLAIN activity, students study the orbit of the ISS.

1. Divide students into teams of three. Provide each group with the necessary materials.
2. Have students complete Part 1 of the activity and answer the questions in the Student Guide on pages 6 and 7.
3. **(CHECKING FOR UNDERSTANDING)** Have students share and explain their answers to the class.
4. Have students complete steps 1 and 2 of Part 2 on pages 7 and 8 of the Student Guide.

   (MODIFICATION) If individual student computers are not available, project the animation using an LCD projector. If no internet access is available, use figure 1 to explain the relationship between velocity and orbit.

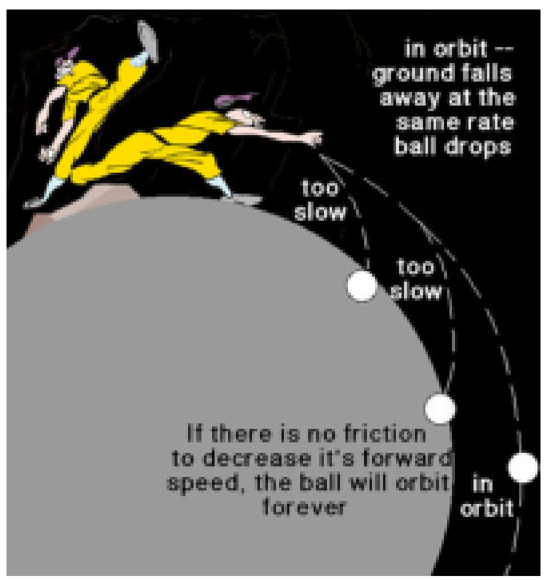


Figure 1. The relationship between velocity and orbit.
Image credit: Windows to the Universe, http://www.windows.ucar.edu

educatorguide

5. **(TECHNOLOGY)** Show the NASA eClipsTM video segment "Real World: Keeping the International Space Station in Orbit (5:38)" at http://www.nasa.gov/audience/foreducators/nasaeclips/search.html?terms="Station%20in%20Orbit"&category=0100 or http://www.youtube.com/user/NASAeClips#p/c/887C1C3BAAD53F17/0/NpHOlmNtFTQ

   (MODIFICATION ICON) The video may be streamed from either web site. The video may be downloaded from the nasa.gov web site; a captioned version is also available at the nasa.gov site

6. Have students answer question 3 on page 8 of the Student guide.
7. **(CHECKING FOR UNDERSTANDING)** Have students share and explain their answers to the class.

EXTEND (40 minutes)

1. **(TECHNOLOGY)(RESOURCE)** Direct students to the following web site: http://science.nasa.gov/realtime/
2. From this site, assign different groups to one of the following satellite tracking sites:
   a. Live 2D Satellite Tracking Maps – Students may choose to follow astronomy satellites, Earth observing satellites, weather satellites, and search and rescue satellites from this link.
   b. Human Space Flight's Tracking Map – Students may follow the space shuttle (if it is in flight) or the ISS from this site.
   c. Live 3D Tracking Display – Students can rotate this display to see nearly 900 satellites in orbit.
3. Ask students to choose one satellite to observe. They should record the latitude and longitude of the satellite every five minutes. Students should collect enough data points to determine the track of the satellite. It is suggested that students collect at least seven data points.
4. While they are tracking their satellite, the students should gather more information about the mission of the satellite as well as the altitude and inclination of the orbit. Have them compare this information to the background information about satellite orbits given on page 1 of the Student Guide.
5. Using a class map, have students plot the position of the satellite they have been following.
   (TECHNOLOGY) If available, use an Interactive Whiteboard to plot this data. Alternately, an image can be projected on a white board with an LCD projector for students to plot their data.
6. **(CHECKING FOR UNDERSTANDING)** Have students present the information they have gathered about the satellite they have tracked and relate this information to what they learned in the lesson using the satellite track to support their presentation.

EVALUATE (15 minutes)

1. Use questions, discussions, and work in the Student Guide to assess students' understanding.
2. Return to the KHWL chart to add more information that students have LEARNED throughout this lesson. Review the information under the KNOW column. With the help of the students, correct any misinformation placed there during the ENGAGE experience.
3. Ask students to summarize their learning by answering these journal questions:
   a. Why are different satellites in different orbits? *(The orbit of a satellite is dictated by the satellite's mission. Communications satellites such as TDRS are in high altitude, geosynchronous orbits so they can maintain constant communication with their associated ground stations. Satellites like the ISS that observe the Earth are in low altitude orbits so they can collect detailed data about regions of the Earth. The ISS is also inhabited so it must be low enough to be accessible by the space shuttle and other servicing space craft.)*
   b. What is inclination and what effect does it have on a satellite's orbit? *(Inclination is the angle of the satellite's orbit in relation to the equator. The inclination dictates how far north and south the satellite will travel as it orbits Earth.)*
   c. How did you use mathematics to support your investigations? *(Geometry is used to investigate the location of TDRS satellites and the orbit of the ISS. Algebra is used when scaling in the EXPLAIN activity.)*
   d. What drives scientific and technological advancement? *(Answers will vary but should include discussion about how new questions arise as we explore the universe and that the answers to these questions advance scientific knowledge. In order to find the answers we must develop new technology to enhance our ability to collect data.)*

educatorguide

SATELLITE ORBITS

Essential Questions

- Why don't all satellites fly in the same orbit?
- How does a satellite arrive in an orbit and stay there?
- What drives scientific and technological advancement?

Background

An **artificial satellite** is a manmade object that **orbits** Earth or some other body in space. Most artificial satellites orbit Earth. People use them to study the Universe as well as Earth. Satellites help forecast the weather, transfer telephone calls over the oceans, assist in the navigation of ships and aircraft, monitor crops and other resources, and support military activities. Artificial satellites have orbited the moon, the sun, asteroids, and the planets Venus, Mars, and Jupiter. These satellites mainly gather information about the bodies they orbit.

Satellite orbits have a variety of shapes. Some are circular and some are elliptical, or oval. Orbits also vary in altitude. Some circular orbits are just above the atmosphere at an altitude of about 250 kilometers, or 155 miles. Others are more than 32,000 kilometers, or 20,000 miles above Earth. The satellite's altitude affects its **orbital period**. The orbital period is how long it takes a satellite to complete one orbit. As the altitude increases, the orbital period lengthens and the slower the **velocity** of the satellite.

Most of the artificial satellites around Earth travel in high altitude, **geosynchronous** orbits; medium altitude orbits; **sun-synchronous polar orbits**; or low altitude orbits. Most of these orbits are circular.

A high altitude, geosynchronous orbit lies above the equator at an altitude of about 35,800 kilometers (22,300 miles). A satellite in this orbit travels around Earth's axis in exactly the same time, and in the same direction, as Earth rotates about its axis. As seen from Earth, a satellite in this type of orbit always appears at the same place in the sky overhead.

A medium altitude orbit has an altitude of about 20,000 kilometers (12,400 miles) and an orbital period of 12 hours. The orbit is outside Earth's atmosphere and is thus very stable. Radio signals sent from a satellite at medium altitude can be received over a large area of Earth's surface. This orbit is ideal for navigation satellites.

A sun-synchronous, polar orbit has a fairly low altitude and passes almost directly over the North and South Poles. The orbit's position is coordinated with Earth's movement around the sun in such a way that the satellite always crosses the equator at the same local time on Earth. In this orbit a satellite flies over all **latitudes**, so the instruments on board can gather information on almost the entire surface of Earth.

A low altitude orbit is just above Earth's atmosphere, where there is almost no air to cause drag on the spacecraft. Less energy is required to launch a satellite into this type of orbit than into any other orbit. Satellites that point toward deep space and provide scientific information generally operate in this type of orbit. The Hubble Space Telescope, for example, operates at an altitude of about 380 miles (610 kilometers), with an orbital period of 97 minutes.

studentguide

Vocabulary

artificial satellite - An **artificial satellite** is a manufactured object that continuously orbits Earth or some other body in space.

geosynchronous orbit - A **geosynchronous orbit** is a satellite orbit at approximately 35,800 kilometers above the Equator in which objects travel at the same speed as Earth. Objects in this orbit remain stationary in reference to Earth.

inclination - Inclination is the angle between a reference plane and another plane or axis of direction. For an artificial satellite, the reference plane is the Equator. The inclination of a satellite's orbit is the angle that the orbit crosses the Equator. If a satellite has a 0° inclination then it would be orbiting over the Equator. If a satellite has a 90° inclination, then its orbit is perpendicular to the Equator and it would pass over the poles.

latitude - **Latitude** is the number of degrees north or south of the Equator. The Equator is 0°N or S, and the North and South Poles are 90° N and 90° S respectively. To visualize this think of Earth as a circle divided into 360°.

longitude - **Longitude** is the number of degrees east or west of the Prime Meridian, the 0° E or W line going through Greenwich, England and the North and South Poles. The Prime Meridian divides the globe into eastern and western hemispheres. It runs between the Poles through the Pacific Ocean on the side of the globe opposite England. This line is called the International Date Line. Degrees longitude are 0° E or W at the Prime Meridian and 180° E or W at the International Date Line.

orbit - An **orbit** is the path of a celestial body or an artificial satellite as it revolves around another body.

orbital decay - **Orbital decay** is the reduction in altitude of a satellite's orbit caused by gravity and drag from the atmosphere.

orbital period - **Orbital period** is the time it takes a satellite to complete one orbit.

polar orbit - A **polar orbit** is an orbit in which the satellite passes over the North and South Poles on each orbit, and eventually passes over all points on Earth.

sun-synchronous polar orbit - **A sun-synchronous polar orbit** is a special kind of polar orbit. When traveling in this orbit, a satellite not only travels over the North and South Poles, but it passes over the same part of Earth at roughly the same time each day.

Tracking and Data Relay Satellite or TDRS - **TDRS** is a system of nine geosynchronous communications satellites. They are used to communicate from Earth to orbiting satellites, the space shuttle, and the International Space Station.

velocity - **Velocity** is the speed and the direction of travel of an object. An example of speed would be, "the wind was blowing at 40 miles per hour." Velocity would be expressed as "40 miles per hour from the SE."

EXPLORE

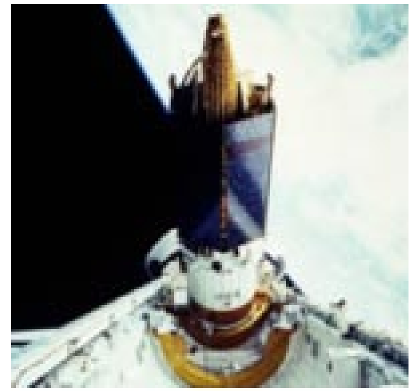


Figure 1. In April 1983, the first Tracking and Data Relay Satellite, TDRS-1, was launched from Space Shuttle Challenger's payload bay on mission STS-6.

Image Credit: NASA

An example of a communications satellite system is the **Tracking and Data Relay Satellite System**, or **TDRSS**. The first satellite in this system, TDRS-1, was deployed by Space Shuttle Challenger in April 1983.

It is 35,800 km, or 22,300 miles, above the Equator and it orbits Earth in a geosynchronous orbit. From this orbit, TDRS-1 beams communications from Earth to other orbiting spacecraft and back. TDRS-1 provided a link for the first wireless phone call between the North Pole and the South Pole and the first live webcast from the North Pole. It also was the first satellite to connect to the Internet.

Today there are nine TDRS satellites within the Tracking and Data Relay Satellite System. They provide nearly continuous tracking and high-bandwidth communications with many Earth-orbiting spacecraft, launch vehicles, long duration balloons, and a research station in Antarctica.

Over the last 27 years, the TDRSS network has brought stunning images from the Hubble Space Telescope to Earth. It has delivered pictures, television, voice and data from more than 100 space shuttle missions and the International Space Station. The TDRSS network has delivered large volumes of Earth observation data in support of Mission to Planet Earth and investigations into global climate change.

Resources

TDRS: 25 Years of Connecting Space to Earth

http://www.nasa.gov/topics/technology/features/TDRS_anniversary.html

TDRS Mission Page

http://esc.gsfc.nasa.gov/space-communications/tdrs/101.html

Gather the materials and follow the procedure listed below.

Materials

- protractor
- straight edge
- colored pencils
- globe (optional)

Procedure

The following diagram represents a view of Earth from directly above the North Pole and the orbit of the TDRS satellites. The line of **longitude** that runs from left to right represents the Prime Meridian at 0° longitude and the International Date Line at 180° longitude. The Prime Meridian begins to the left of the North Pole in the diagram and runs through Greenwich, England.   It then runs through the South Pole and becomes the

International Date Line. The International Date Line runs through the Pacific Ocean and through the North Pole, where it becomes the Prime Meridian. For further clarification, follow this path as you look at a globe from directly above the North Pole.

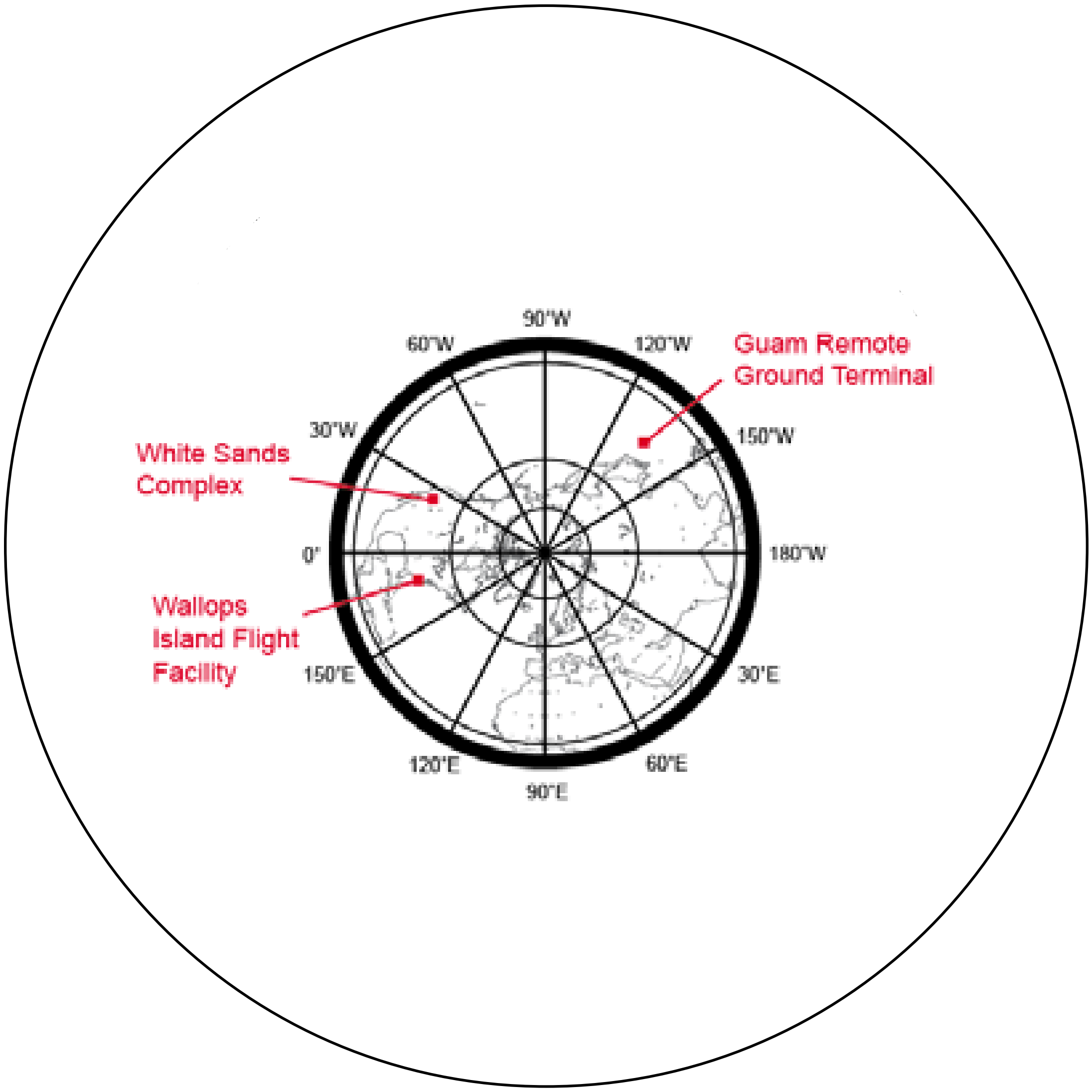


Figure 2. View of Earth from directly above the North Pole.
Note: Figure not to scale.

Using a protractor and the satellite information provided by your teacher, mark the locations of the satellites on the outer circle on the diagram, which represents the orbital path of the TDRS satellites. Align the 0° and 180° marks on the protractor with the line running through the diagram. The circular hole or mark on the protractor identifies the vertex of the angle and should be aligned with the North Pole. To accurately plot satellite locations in the Eastern Hemisphere use the reverse scale on the protractor. If your protractor is too small to reach the outer circle, use a straight edge to help you accurately plot the satellites' locations.

EXPLAIN

Background

The International Space Station, or ISS, is an orbiting research facility. A small crew lives on the ISS. More than 15 nations are working together to build this large Earth satellite. The completed station will have a mass of about 472,000 kilograms (1,040,000 pounds). It will measure 111 meters (356 feet) across and 88 meters (290 feet) long, with almost an acre of solar panels to provide electrical power to its state-of-the-art laboratories. The first part of the station launched in 1998 and the first full-time crew, one American astronaut and two Russian cosmonauts, occupied the station in 2000. It follows a low altitude orbit.

The ISS orbits Earth at an altitude of about 400 kilometers, or 250 miles. It orbits at an **inclination** of 51.6°. This orbit extends from 52 degrees north latitude to 52 degrees south latitude. In this orbit the ISS can make observations of most of the populated areas of the world.

Part 1

Working with your team, gather the materials and follow the procedure listed below.

Materials

- globe
- rubber band large enough to wrap around the globe
- ruler
- meter stick
- protractor
- piece of yarn long enough to wrap around the globe
- scotch tape

Procedure

1. Wrap a piece of yarn around the globe at the Equator. Tape the yarn to the globe.
2. Place a rubber band around the globe.
3. Imagine that the rubber band is a disk. Move it so that the plane of the disk passes directly through the Earth's center. This will divide the globe into two equal halves.
4. Move the rubber band so that it is at an angle of approximately 52° to the Equator. Use a protractor to help you create the correct angle. The rubber band now indicates the inclination of the orbit of the ISS. See Figure 3.

Figure 3. Drawing of the globe and rubber bands.

Use the globe with the rubber band and yarn around it to answer the following questions:

1. What is the most northern and southern latitude that the orbit passes over?

2. The ISS orbits about 400 km above Earth's surface. How high would the ISS be above the globe you are using? To find the answer you will have to figure out the scale of the globe and then determine how high the ISS would be if placed at its scale altitude. Use the yarn to measure the globe's circumference and use the circumference to calculate the globe's diameter.
(Hint: the Earth's diameter is 12,740 km.)

3. Once you have figured out how high the ISS would be in orbit around your globe, place your eye at that distance from the globe above the rubber band orbit. Estimate the percentage of the globe that is visible from the orbit based on what you can see of the globe.

4. Place your eye twice the distance from the globe as it was previously in question 3. Estimate the percent of the globe you see now. Continue to back away until you can see the entire globe. Measure this distance with a meter stick. Use this distance to calculate how far away, in kilometers, a spacecraft must be in order to see the entire globe at once.

5. The TDRS satellites in the Explore section orbit at an altitude of 35,800 km above the Equator. How high above your globe would these satellites be?

6. The rubber band only passes over a small percentage of earth's surface. How is it that astronauts on board the ISS can observe most of Earth's populated regions?

7. Why do you think that astronauts on board the ISS do not study the Arctic and Antarctic regions of Earth?

Part 2

1. Go to this web site http://spaceplace.nasa.gov/en/kids/orbits1.shtml and run the "Shoot a Cannonball into Orbit" animation. Use the animation to complete Table 1 on the following page.

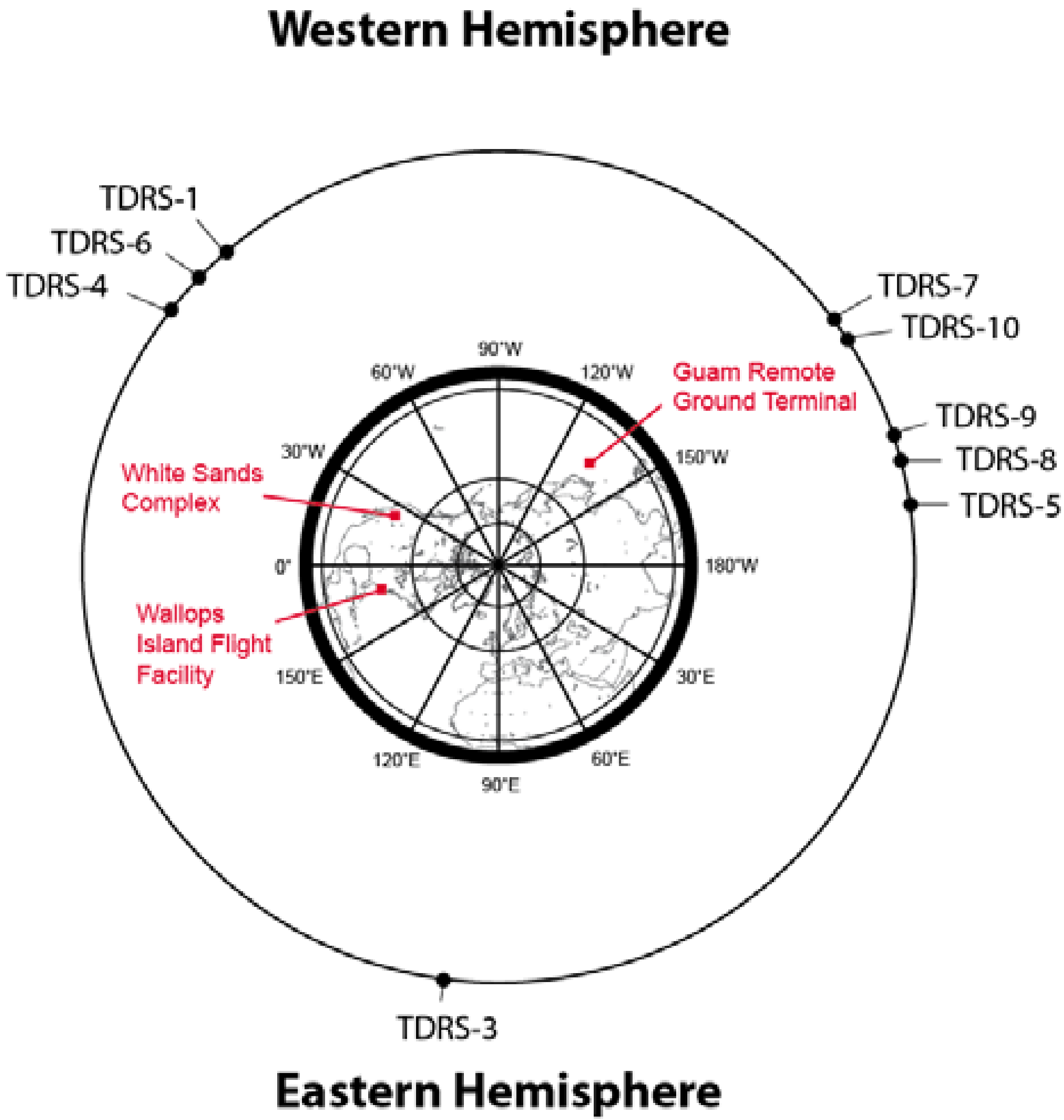
Table 1. Effect of Changing Amount of Gunpowder on Cannonball Orbit

Number of bags of Gunpowder	*Observations*
1	
2	
3	
4	
5	

2. What happens as the number of bags of gunpowder is increased?

A satellite remains in orbit because of a balance between the satellite's velocity and the gravitational force between the satellite and Earth. If the velocity of the satellite is too low, the force of gravity is strong enough to pull the satellite back to Earth. If the velocity of the satellite is too high, the satellite will overcome the force of gravity and fly off into space. Since the ISS is in a low altitude orbit, it experiences atmospheric drag from the air molecules at the top of the atmosphere. Because of this, the altitude of the ISS drops. This decrease in altitude is referred to as **orbital decay**.

3. The ISS must be boosted back into space periodically to keep it in orbit but the TDRS satellites do not. Why is this the case?


Western Hemisphere
TDRS-1
TDRS-6
TDRS-4
TDRS-7
TDRS-10
TDRS-9
TDRS-8
TDRS-5
TDRS-3
90°W
60°W
120°W
30°W
150°W
0°
180°W
150°E
30°E
120°E
60°E
90°E
Guam Remote Ground Terminal
White Sands Complex
Wallops Island Flight Facility
Eastern Hemisphere

EXPLAIN

Part 1

1. What is the most northern and southern latitude that the orbit passes over?
   52° north and south latitude.

2. The ISS orbits about 400 km above Earth's surface. How high would the ISS be above the globe you are using? To find the answer you will have to figure out the scale of the globe and then determine how high the ISS would be if placed at its scale altitude. Use the yarn to measure the globe's circumference and use the circumference to calculate the globe's diameter.
   (Hint: the Earth's diameter is 12,740 km.)
   For a 30.5 cm (12 inch) globe:
   circumference = 95.8 cm
   diameter = $95.8/\varpi$ = 30.5 cm

$$\frac{400 \text{ km}}{12{,}740 \text{ km}} = \frac{x \text{ cm}}{30.5 \text{ cm}}$$

$$x = 0.958 \text{ cm}$$

3. Once you have figured out how high the ISS would be in orbit around your globe, place your eye at that distance from the globe above the rubber band orbit. Estimate the percentage of the globe that is visible from the orbit based on what you can see of the globe.
   Answers will vary but should be no more than about 1%.

4. Place your eye twice the distance from the globe as it was previously in question 3. Estimate the percent of the globe you see now. Continue to back away until you can see the entire globe. Measure this distance with a meter stick. Use this distance to calculate how far away, in kilometers, a spacecraft must be in order to see the entire globe at once.
   Answers will vary but the distance and percent observed are roughly linear. In order to see the entire 30.5 cm globe, the observer's eye must be about 72 cm away. Therefore:

$$\frac{x \text{ km}}{12{,}740 \text{ km}} = \frac{72 \text{ cm}}{30.5 \text{ cm}}$$

$$x = 30{,}100 \text{ km (about 18,700 mi)}$$

5. The TDRS satellites in the Explore section orbit at an altitude of 35,800 km above the Equator. How high above your globe would these satellites be?

$$\frac{35{,}800 \text{ km}}{12{,}740 \text{ km}} = \frac{x \text{ cm}}{30.5 \text{ cm}}$$

$$x = 85.7 \text{ cm}$$

6. The rubber band only passes over a small percentage of earth's surface. How is it that astronauts on board the ISS can observe most of Earth's populated regions?
   As the ISS is orbit above Earth, Earth is rotating on its axis. This means that the ISS will fly over different areas of Earth.

7. Why do you think that astronauts on board the ISS do not study the Arctic and Antarctic regions of Earth?
Astronauts on board the ISS do not study these regions because the orbit of the ISS does not bring them over these regions to make observations.

Part 2

Table 1. Effect of Changing Amount of Gunpowder on Cannonball Orbit

Number of bags of Gunpowder	Observations
1	*The cannonball splashes down just before reaching the Equator.*
2	*The cannonball splashes down about 2/3 of the way down the coast of South America.*
3	*The cannonball goes into an almost circular orbit near the surface of Earth*
4	*The cannonball goes into a more elliptical orbit further away from the surface of earth. It also passes closer to the North pole than the South Pole.*
5	*The cannonball flies off into space.*

2. What happens as the number of bags of gunpowder is increased?
The cannonball goes faster and travels further. With a small amount of gunpowder, the cannonball falls back to Earth. With more gunpowder, the cannonball goes into orbit. With too much gunpowder the cannonball flies off into space.

3. The ISS must be boosted back into space periodically to keep it in orbit but the TDRS satellites do not. Why is this the case?
The ISS is in a low altitude orbit so its orbit is affected by the upper atmosphere. The TDRS satellites are in a high altitude, geosynchronous orbit so that once it is in orbit it will stay in the same orbit until acted on by an exterior force.

answerkey