



Not So Lost in Space



Unit Topic:	Navigation
Grade Level:	7 th grade (with suggestions to scale for grades 6 to 8)
Lesson No.	10 of 10
Lesson Subject(s):	Space Navigation

Lesson Abstract —

The final frontier of navigation that we will tackle is navigating satellites in orbit around the Earth and on their way to other planets in the solar system. The background section provides an overview of orbits and spacecraft trajectories from Earth to other planets. Then we describe how spacecraft are tracked from the ground using the Deep Space Network (DSN). Measurements from the DSN are the primary means for navigating unmanned vehicles in space. Onboard the spacecraft there might also be optical sensors and an inertial measurement unit (IMU). Accompanying activities allow students the opportunity to explore how ground-based tracking and onboard measurements are performed.

The associated activities are:

- [Activity 1: A Round About Way to Mars](#)
- [Activity 2: Satellite Tracker](#)

Lesson Opening Topics / Motivation —

Ask students if anyone knows the name of the first artificial satellite launched into orbit around the Earth. (Answer: On October 4, 1957, the Soviet Union launched Sputnik I.) How many satellites would you guess are currently orbiting the Earth? (Answer: about 3,000)

Ask students if they know the names of current space exploration missions that go beyond the Earth. (Answer: The Galileo spacecraft recently ended a 14-year mission to the planet Jupiter and its moons by crashing into the planet on Sept 21, 2003. The 2003 Mars Exploration Rovers are currently enroute to Mars, expecting to arrive in January 2004. You can find detailed information on NASA (National Aeronautics and Space Administration) missions at: <http://www.jpl.nasa.gov/missions/>)

How do these spacecraft get from Earth to other planets? Is it like driving a car or flying an airplane? How do they know where they are along the way and when to make adjustments?

In this lesson, we explore how space agencies like NASA keep track of where these interplanetary travelers are and how to get them to their destinations.

Lesson Desired Student Outcomes —

Students will understand the basic concept of an orbit around the Earth or sun and the types of measurements that are made from Earth to track interplanetary spacecraft.

Science: Students should be able to:

- Predict (hypothesize).
- Understand satellites and their usefulness in space exploration.

Math: Students should be able to:

- Use and understand scaling.
- Use geometry in creating circles and ellipses.
- Collect and analyze data.

Colorado State Standards Met

<http://www.mcrel.org/compendium/search.asp>

- Science Standard 1, 5
- Math Standard 1, 3, 4, 5

Lesson Background & Concepts for Teachers —

Overview

The following topics will be discussed:

- Planetary orbits
- Trajectories from Earth to Mars
- Deep Space Network

Planetary Orbits

The motion of planets or spacecraft around the sun is governed primarily by the gravitational attraction between the *central body* (the sun or planet) and the *secondary body* (the planet or spacecraft). The same is true for a satellite traveling around the Earth or other planet, where the Earth is now the central body and the satellite is the secondary body. The *trajectory*, or path, of a planet or spacecraft is referred to as an *orbit*. In the early 1600s, Johannes Kepler described the orbits of planets in his famous “Three Laws:”

1. The orbit of each planet is an ellipse with the sun at the focus.
2. The line joining the planet to the sun sweeps out equal areas in equal times.
3. The square of the period of a planet is proportional to the cube of its mean distance to the sun.

Kepler’s laws were based on empirical evidence: observations of the planet Mars made by Tycho Brahe. At the time, Kepler hoped that he would be able to describe planetary motion by circles, but the experimental evidence proved otherwise, and he was forced to resort to a little-known

geometrical shape — the ellipse. It is interesting to note that Kepler did not understand the physics of why planets followed these paths; but rather just described mathematically what he found in the data. Roughly half a century later, Sir Isaac Newton filled in the gap, explaining the physics of the motion with his famous laws of motion and gravitation. Orbits of planets about the sun and satellites about the Earth are typically described by six Keplerian elements (Figure 1).

They can be divided into parameters that describe the size and shape of the orbit:

- a - The semimajor axis (a) is the longest axis of the ellipse going through the two foci.
- e - The eccentricity (e) describes the elongation of the ellipse. The distance between the two foci can be computed as $2ae$.

And the orientation of the orbit plane:

- Ω – The right ascension of the ascending node (Ω) describes where the orbit crosses the equatorial plane relative to a reference direction known as the vernal equinox.
- i – The inclination of the orbit (i) describes how the orbit plane is tipped relative to the equatorial plane.
- ω – The argument of perigee (ω) describes where the point of closest approach to the planet lies within the orbit plane. It is an angle measured in the plane of the orbit from the ascending node to the point of closest approach.
- υ – The last parameter describes where the planet or spacecraft is within its orbit, measured from the perigee and given the unusual name of “true anomaly” (υ).

When an orbit is not circular, it has only one point that is closest to the central body and one point that is farthest from the central body. The closest point is known as the **periapse** and the farthest point is known as the **apoapse**. If the central body is the Earth, these points are also referred to as the **perigee** and **apogee**, respectively. Similarly, if the central body is the sun, the names change to **perihelion** and **aphelion**.

Very clear and accessible information on orbits and definitions can be found at: <http://www.jpl.nasa.gov/basics/>.

Planets in the solar system all travel in orbits with the sun at the focus. Most planets are in almost circular orbits with both foci at the sun. The orbits of Mercury and Pluto are both somewhat elliptical with eccentricities of 0.2 and 0.5, respectively. The eccentricity of Pluto’s orbit causes it to sometimes travel inside the nearly circular adjacent orbit of Neptune.

According to Kepler’s laws, if you know the semimajor axis of the orbit, you can find the orbit period (i.e., how long it takes to travel around the central body). The period of an orbit is given by:

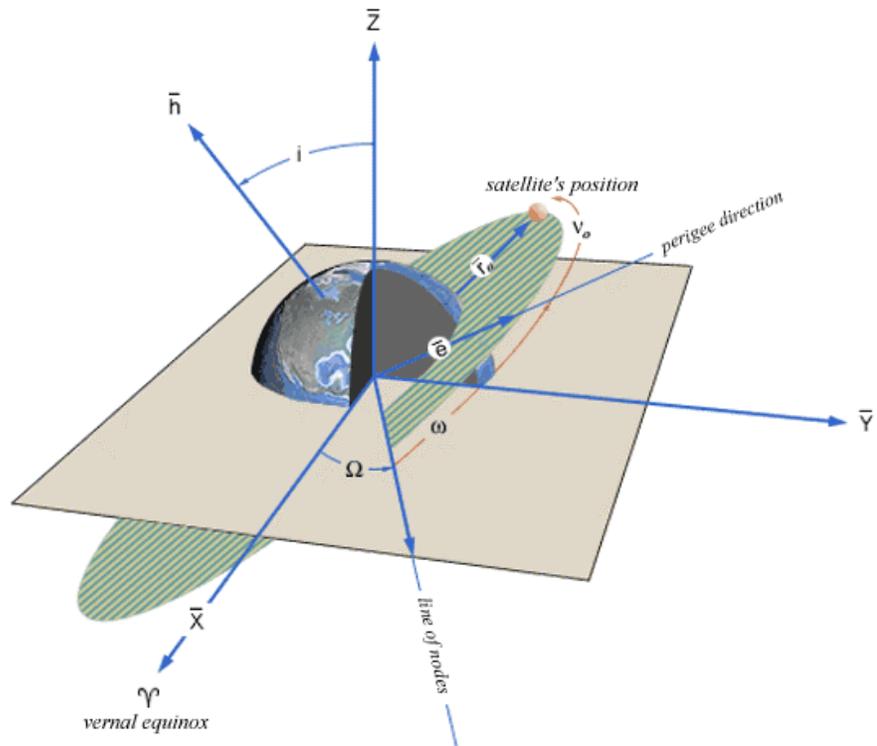
$$P = 2 \pi \text{SQRT}(a^3 / m)$$

Where a is the semimajor axis of the orbit and m is the gravitational constant for the central body. For Earth it is: $m_E = 398600 \text{ km}^3/\text{s}^2$. From this, you can see that the larger the orbit, the longer the period. For a circular orbit you can also compute the speed at which the object travels as follows:

$$s = \text{SQRT}(m / a)$$

This shows that **the smaller the semimajor axis** (i.e., the smaller the orbit), **the faster the speed** at which the satellite must travel. For example, the International Space Station in orbit around the Earth has a semimajor axis of about 6756 km. So, using the equation for the period given above, we find that its period is about 5,526 seconds or 92 .1 minutes. Using the speed equation, we can

calculate its speed as 7.68 km/s. In comparison, a TV broadcasting satellite, in a geosynchronous orbit around the Earth, has an orbital period of 24 hours!



- a - defines the size of the orbit
- e - defines the shape of the orbit
- i - defines the orientation of the orbit with respect to the Earth's equator.
- ω - defines where the low point, perigee, of the orbit is with respect to the Earth's surface.
- Ω - defines the location of the ascending and descending orbit locations with respect to the Earth's equatorial plane.
- v - defines where the satellite is within the orbit with respect to perigee.

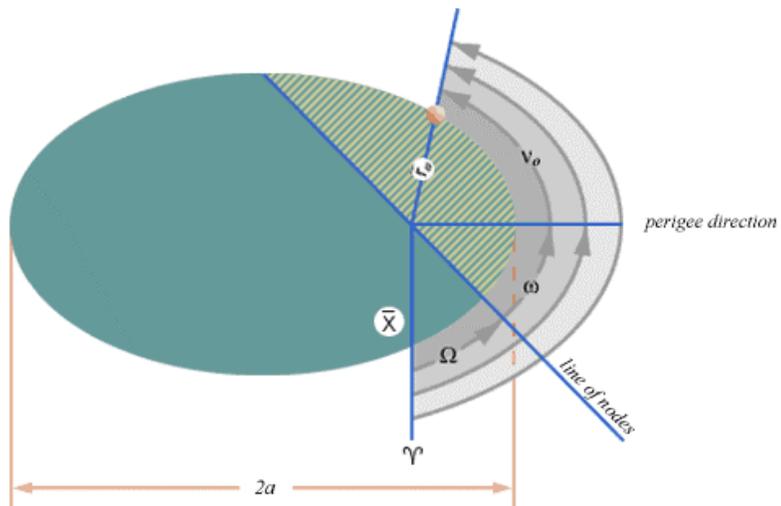


Figure 1. Planetary orbits.

Image source: <http://spaceflight.nasa.gov/realddata/elements/graphs.html>

To get from one orbit to another, a spacecraft must transfer to an elliptical path that connects its current orbit to the desired orbit. A simple way to do this is the Hohmann transfer. To execute a Hohmann transfer, a spacecraft fires thrusters tangentially along the direction of travel for a short burst. This initial “delta-v” changes the energy of the orbit to put it on an elliptical path. The periapse of the new orbit is at the starting orbit, and the apoapse of the orbit is at the target orbit. After half an orbital period, the satellite is at the right altitude for its new orbit, but it must again increase its speed to stay in the new higher orbit. A second delta-v is performed to circularize the orbit at the higher altitude. The Hohmann transfer is efficient for fairly small orbital changes. More complex maneuvers using gravity-assist fly-bys are also used to provide more efficient transfers to distant planets.

Source for orbit definitions: <http://www.jpl.nasa.gov/basics/>.

Measurements

Unmanned satellites and spacecraft are generally tracked by ground stations to determine their orbits. NORAD (the North American Aerospace Defense Command) currently tracks all objects larger than 30 cm in orbit around the Earth. NASA’s Deep Space Network (DSN) is used to track interplanetary craft. Commercial satellites are tracked by private ground stations, and some satellites (like the GPS satellites) have their own dedicated tracking networks. A tracking station receives transmissions from the satellite and may also send out a ranging signal that is reflected or echoed by the satellite.

Three basic types of ground-based measurements are used to determine an orbit: range, Doppler, and angles.

Angle measurements are the most straightforward and generally the least accurate type of measurement. A ground station antenna connected to a receiver is scanned to find the highest signal power from the satellite. The antenna sweeps horizontally across in *azimuth* and vertically in *elevation*. When it locks on to the signal, the *azimuth* and *elevation* angles of the antenna indicate the direction to the satellite. By making a sequence of angle measurements over time, the orbit of the satellite can be estimated.

Range measurements can be made by timing the arrival of marked pulses or symbols in the communications link. The ground station transmits a signal to the satellite or spacecraft and the spacecraft receives and retransmits this signal. This is known as a *transponder*. The ground station measures the roundtrip time of the signal, divides by 2, and multiplies by the speed of light to find the range to the satellite. More precise measurements can also be made by using more than one ground station on the Earth. Differences between ranges measured at the different stations allow delays in the transponder to be determined and permit much more precise ranging measurements.

Doppler measurements represent the rate of change of range to the satellite. They are a measure of frequency shift of a transmission. Assume that a transmitter at rest emits a signal or tone of a certain frequency that we will call the base frequency. When a transmitter approaches a receiver, the receiver hears or senses a higher frequency than the base frequency. At the “point of closest approach,” that is, when the transmitter and receiver are as close as possible, the received frequency is equal to the base frequency. As the transmitter moves away from the receiver, the received frequency is lower than the base frequency. The figure below illustrates the Doppler shift as a function of time as a satellite in a low Earth orbit moves overhead a ground station. The closer to directly overhead the satellite moves, the more dramatic the Doppler shift will be. Scientists can use a sequence of Doppler measurements to determine the orbit of a satellite or spacecraft.

Today, orbit determination programs use all available measurement types to form the best estimate of a satellite's trajectory. The accuracy of the estimates depends on the type of orbit and the quality and quantity of observations from the ground.

Sightings

Many near-Earth satellites can be seen using a backyard telescope. A few are also visible to the naked eye. A good example is the International Space Station (ISS). The ISS is a very large structure, 3,300 sq. ft. in area, in an almost circular low-Earth orbit, about 250km above the surface of the Earth. The inclination of the orbit is 51.5 deg. Because of its large size and reflective surfaces, and under good viewing conditions (on a clear night when the sun's rays hit it just right), you can see the station pass across the sky with your naked eye (no telescope).

To observe a satellite (or planet or comet), you will need to know what time and where it will rise and set in the sky for your location on Earth. You will also need to know the quality of the "viewing conditions;" that is, how well it will be illuminated by the sun. A great website maintained by NASA provides observing information for a variety of satellites including the ISS. Instructions on using the website are given in Activity 2.

Lesson Vocabulary List —

Central Body – A massive object (like the sun or a planet) that attracts a satellite or planet.

Orbit – The closed path a satellite or planet takes around a central body.

Keplerian Elements – Six parameters that describe the size, shape, and orientation of an orbit.

Trajectory – The path taken by a spacecraft.

Range – The straight-line distance from an observer to the object observed.

Elevation – The angle measured at an observer's location between the direction to an object and the horizon.

Azimuth – The angle measured at an observer's location in the horizontal plane between an object and the direction to North.

Doppler – The frequency shift of a signal due to motion of the transmitter and receiver.

Activity Attachments —

[Activity 1: A Roundabout Way to Mars](#) – Students will use a cardboard and strings to explore Earth and Mars orbits around the sun and a transfer orbit from one to the other.

[Activity 2: Satellite Tracker](#) – Using information from an online resource, students will graph the motion of the space station at their location and create a 3D display of its path through the sky.

Lesson Closure and Follow-up —

Ask students about the difference between driving a car and guiding a satellite from one orbit to another. Does a planet like Venus that is in an orbit close to the sun, travel faster or slower than a planet like Jupiter that orbits farther from the Sun? (Answer: Closer-in planets travel faster. They need the extra velocity to counteract the higher gravitational attraction.) From your location, which way does the space station move across the sky? (Answer: From most areas of the

continental US, the passes will be W to E, sometimes SW to NE or other variations. They last for a few minutes and sometimes reach fairly high elevations.) How would it look from the North Pole? (Answer: The satellite would only appear at very low elevations and skirt across near the horizon.)

Lesson Extension Activities —

- The NASA JPL website has a lot of video clips of the Mars missions and other missions (<http://www.jpl.nasa.gov/missions/>)
- For students interested in hands-on construction of a satellite, JPL's website has a build-your-own DSN station activity.
- Look up the orbital period and radius of each of the planets. Graph the period as a function of the radius.

Lesson Assessment and Evaluation —

Pre-Lesson Assessment

- Question/Answer
 - Ask students if anyone knows the name of the first artificial satellite launched into orbit around the Earth. (Answer On October 4, 1957, the Soviet Union launched Sputnik I.)
 - How many satellites would you guess are currently orbiting the Earth? (Answer: about 3,000)

Post-Introduction Assessment

- Voting: Ask a true/false question and have students vote by holding thumbs up for true and thumbs down for false. Count the number of true and false, and write the number on the board. Give the right answer.
 - True or False: Unmanned satellites and spacecraft are generally tracked by ground stations to determine their orbits. (Answer: True)

Post-Lesson Assessment

- Bingo: Provide each student with a sheet of paper containing a list of the lesson vocabulary terms. Have each student walk around the room and find a student who can define one vocabulary term. Students must find a different student for each term. When a student has all terms completed, s/he shouts "Bingo!" Continue until two or three students bingo.

Lesson References —

<http://www.jpl.nasa.gov/basics/> - This JPL site has a great tutorial on orbits (definitions) and spaceflight.

<http://spaceflight.nasa.gov/realdata/elements/> - You can get information on the ISS and Shuttle at this NASA site.

<http://athena.cornell.edu/> - This website is dedicated to the Athena rovers headed for MARS. Lots of information and kids activities.

<http://education.jpl.nasa.gov/> - This site has activities for K-12 in classroom and at home. They also list research opportunities that schools can get involved in.

Fundamentals of Astrodynamics, by R. Bate, D. Mueller and J. White, Dover Publications, Inc., 1971.

Lesson 10: Activity 1 – A Roundabout Way to Mars

This activity is planned for 28 students working in teams of two.

Activity Materials List —

For each team:

- Cardboard – about the size of a sheet of paper.
- A few sheets of white paper
- Thread
- 4 Pens or pencils in different colors
- 6 Pushpins

Activity Cost Estimate —

Minimal or none, depending on office-type supplies that are available (under \$5 total).

Activity Equipment and Tools List —

- Rulers
- Scissors

Activity Attachments —

None

Activity Time Estimate —

30 minutes

Background

Space travel is one of the most exciting, high tech, and challenging fields in engineering. In 1961, Soviet cosmonaut Yuri Gagarin was the first human in space. In 1969, American astronaut Neil Armstrong was the first to walk on the moon. Aerospace technology has developed enormously since then, and aerospace engineers continue to seek safe and efficient ways to travel in space.

When imagining space travel, one should think of it not as a direct linear path from point A to point B, but more like a transfer between circular orbits. It is *possible* to travel in a straight line from A to B; but in the vicinity of a planet or star, the gravity of the planet or star causes the natural motion of objects to follow an elliptical (or hyperbolic) path. A huge amount of fuel would be needed to overcome gravity and follow a straight path. Instead, orbital transfers are designed to take advantage of gravitational motion by scheduling velocity changes, known as delta-v maneuvers at precise times and places in the orbit.

Orbit transfers are the main focus of this activity, specifically Hohmann transfers. An Hohmann transfer is a fuel efficient way to transfer from one circular orbit to another circular orbit that is in the same plane (inclination), but a different altitude. This transfer occurs when the launch and arrival points are lined up on opposite sides of the Sun. With the planets in this position, the travel trajectory between them is an ellipse. If the trajectory was from Earth to Mars — like the

one of this activity — the ellipse has its perihelion (closest point in to the sun) at the orbit of Earth and its aphelion (furthest point from the sun) at the orbit of Mars.

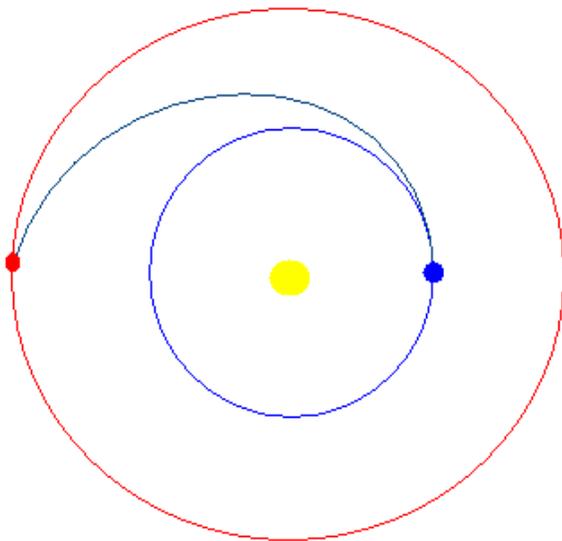


Figure 1: Hohmann transfer from Earth to Mars.

Activity Procedure —

Before the Lesson

- Gather materials

With the Students

1. Open with a discussion question and a prediction to get students' minds on the activity. First, ask the students how they would go from the Earth to Mars. Brainstorm and encourage wild ideas. Write ideas on the board. Next, ask them if they know how far apart the Earth and Mars are from the sun. Encourage guesses. Tell them they will learn in this activity.
2. To draw orbits, we have to scale the actual orbital distance to the size of a paper. The average distance from the sun to the Earth is 149,600,000 km and from the sun to Mars is 227,940,000 km. Have the students select a scale (such as: 1 cm = 10,000,000 km) that allows both orbits to be drawn on the paper. Find the orbit radius for the Earth (RE) and Mars (RM) on your scale.
3. Ask for a vote from students on the following true or false question: the easiest way to travel between two planets is a direct line. Get a show of hands from students and write the numbers on the board. (Answer: False, it is *possible* to travel in a straight line from A to B; but in the vicinity of a planet or star, the gravity of the planet or star causes the natural motion of objects to follow an elliptical (or hyperbolic) path. A huge amount of fuel would be needed to overcome gravity and follow a straight path. Instead, orbital transfers are designed to take advantage of gravitational motion by scheduling velocity changes, known as

delta-v maneuvers at precise times and places in the orbit. See lesson background information for more detail.)

4. Give the materials to the students.
5. Tell the students to place a piece of paper on the cardboard and use 4 tacks to hold down the corners. Put one pushpin in the center to represent the Sun. It can be labeled accordingly.
6. Cut a piece of thread for the Earth orbit that is 2 times the radius (RE) plus a little extra. Tie the two ends together. The extra length of thread allows for the knot and the extra distance taken up by the pushpin. Do the same for Mars (2 x RM).
7. Using the two thread loops and two different colored pens or pencils, draw each orbit around the “Sun” (see figure 3). This is accomplished by putting the loop around the pushpin on one end and the pencil or pen on the other. Make sure the string is pulled tightly all the way around the orbit.
8. Now set up the transfer orbit from the Earth to Mars. To do this, you will need to put another tack at the focus of the elliptical transfer orbit (see Figure 4). This focus is located at a distance from the Sun equal to the difference between the Mars orbit radius and the Earth orbit radius (RM-RE)
9. Use the Mars thread to trace the transfer orbit. Loop the thread around both tacks and the pen so that the string is in the shape of a triangle as you draw the orbit. Use a different colored pen or pencil to trace the ellipse created by the third string. The orbit should touch the Earth orbit on one side and the Mars orbit on the opposite side.
10. Run the post-assessment activity as directed in the Activity Assessment & Evaluation section below.

Math Skills Reinforced —

- Scaling
- Geometry of circles and ellipses



Figure 2. Activity materials

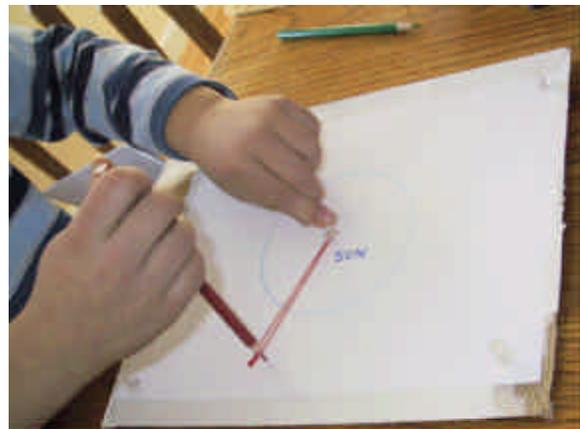


Figure 3. Drawing the Mars orbit.

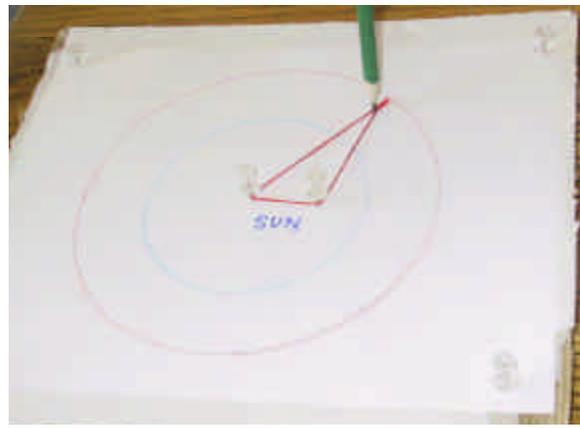


Figure 4. Drawing the transfer orbit.

Activity Troubleshooting Tips —

When tracing the orbits, the students should have enough tension on the string to trace an even, smooth orbit; however, the pushpins might come loose if pulled on too hard. Have one student hold the pushpins down while the second student traces the orbits.

Activity Desired Student Outcomes —

- Students should learn how to use scaling factors.
- Students should become familiar words like *orbits*, *perihelion* and *aphelion*
- Students should become familiar with space traveling and understand Hohmann transfers

Activity Assessment & Evaluation —

Pre-Activity Assessment

- Prediction/Discussion:
 - Ask the students how they would go from the Earth to the Mars.
 - Ask them if they know how far apart the Earth and Mars are from the sun.
(Answer: The average distance from the sun to the Earth is 149,600,000 km and from the sun to Mars is 227,940,000 km.)

Activity Embedded Assessment

- Voting: Ask for a vote from students on the following question. Get a show of hands from students and write the numbers on the board.
 - True or false, the easiest way to travel between two planets is a direct line.
(Answer: False, it is *possible* to travel in a straight line from A to B; but in the vicinity of a planet or star, the gravity of the planet or star causes the natural motion of objects to follow an elliptical (or hyperbolic) path. A huge amount of fuel would be needed to overcome gravity and follow a straight path. Instead, orbital transfers are designed to take advantage of gravitational motion by scheduling velocity changes, known as delta-v maneuvers at precise times and places in the orbit.)

Post-Activity Assessment

- Inside/Outside Circle: Have the students stand in two circles such that each student has a partner. Three people may work together if necessary. The outside circle faces in and the inside circle faces out. Ask the students a question. Both members of each pair think about the question and discuss their answers. If they cannot agree on an answer, they can consult with another pair. Call for responses from the inside or outside circle or the class as a whole.
- Define: Ask the students what an orbit, perihelion and aphelion mean.

Orbit: The path of a celestial body or an artificial satellite as it revolves around another body.

Perihelion: The point nearest the sun in the orbit of a planet or other object.

Aphelion: The point on the orbit of an object that is farthest from the sun.

Suggestions to Scale Activity for Grades 6 to 8 —

- 6th, 7th Grade: Do activity as is.
- 8th Grade: Do activity as it. For greater challenge, have students draw additional orbits from the sun to other planets.

Activity References —

http://liftoff.msfc.nasa.gov/academy/rocket_sci/satellites/hohmann.html

http://en2.wikipedia.org/wiki/Hohmann_transfer_orbit

Lesson 10: Activity 2 – Satellite Tracker

This activity is planned for a class of 28 students working in teams of three.

Activity Materials List —

- String
- Foam Balls (2-3” in diameter)
- Tape
- Masking tape

Activity Equipment and Tools List —

- Yard Sticks and or Tape Measures
- Protractor (the bigger the better)
- Scissors

Activity Time Estimate —

60 minutes

Activity Cost Estimate —

\$10 total



Background

The International Space Station (ISS) is a very large satellite that orbits the Earth. It is 3,300 sq. ft. in area, and moves in an almost circular low-Earth orbit, about 250km above the surface of the Earth. In this activity, you will learn how to predict and track the ISS' path using special computer software, the paths of spacecraft and satellites can be calculated and accurately predicted.

*Skywatch*¹ and *STSPPlus*² are two programs that can do this. To create these programs, you need a college degree in Aerospace Engineering, but, fortunately for us, you just need access to a computer to use these programs.

First, we must review three key terms that we will be using:

Azimuth – the number of degrees measured clockwise from the northern horizon. An object at 90 degree azimuth is due east. An object at 270 degree azimuth is due west.

Elevation – the height of an object, measured in degrees above the horizon. An object directly overhead is at a 90 degree elevation. An object on the horizon is at 0 degrees elevation.

Range – the distance from where you are located to a spacecraft or satellite.

¹ <http://spaceflight.nasa.gov/realdata/sightings>

² <http://www.dransom.com/stsplus.html>

Activity Procedure —

Before the Lesson

1. Gather the materials and equipment needed.
2. Run the Skywatch¹ program and pick a day within the next week or so for the students to find and track the ISS. See Troubleshooting Tips for more details.
3. Mark a point in the center of the room that will represent your city. Using masking tape, mark a line pointing north from the city point.

With the Students

1. Introduce the students to the Skywatch¹ website.
 - Click on *Start Java Applet*.
 - Enter your city (or closest city) under Observer Location.
 - Notice how Skywatch automatically adjusts to your latitude, longitude, and altitude.
2. Click on *Next Sighting* to track the next observable path of the ISS.
 - You may have to click *Next Sighting* more than once if it is more than 1 week away.
3. Find the day, or night, of interest and have the students print out the predicted points of travel by hitting the *Print* button.
4. Assign each group a different point to model.
5. One group at a time can model the ISS around the city point.
6. Each group should cut a length of string corresponding to the range scaled down by 10 and in inches. For example, if the range was 749 miles, the string would be cut to 74.9 inches long.
7. Have one student in the group hold one end of the string to the city point while a second student holds the other end along the ground facing north. *The second student should always have the string pulled tight.*
8. The first student should direct the second student to move clockwise around the city and stop when the azimuth is met. For example, if the azimuth is 180°, the second student will have moved in a half circle and be directly south of the city point.
9. Next, using a protractor located at the city point, the first student should instruct the second student to raise the string until the elevation is met.
10. While the second student carefully holds the azimuth and elevation, a third student should measure and record the height and location of the end of the string. This can be done by taping a piece of paper on the ground under the end of the string, marking an X beneath the end, and writing down how high it was next to the X.
11. Finally, when all the groups have marked their Xs and heights, the teacher or designated students should hang a foam ball over each X according to its height. In the end, you should have a 3-D model of the ISS path.

Math Skills Reinforced —

- Scaling

¹ <http://spaceflight.nasa.gov/realdata/sightings>

- Geometry of circles and ellipses

Activity Troubleshooting Tips —

- Make sure the day of interest has a maximum elevation of significance. Any max elevation less than 60° will result in a less than impressive looking model.
- Too many data points?
 - Click on *Variables* and raise the **Table Step Size** to 30 or 40 seconds then recalculate your day of interest.
- You feel the model is too low to the ground?
 - Simply add 5ft. to every height to shift the model towards the ceiling.

Activity Desired Student Outcomes —

- Students should learn key navigational terms like *azimuth*, *elevation*, and *range*.
- Students should become familiar with 3-D models.
- Students should become familiar with reading from data tables.

Activity Assessment & Evaluation —

Pre-Activity Assessment

- Question/Answer: Ask the students how they would find out when and where the next path of the ISS or any other satellite would be. (Answer: Online using a computer program called *Skywatch* or *STSPlus*.)

Activity Embedded Assessment

- Brainstorming: In small groups, have the students engage in open discussion. Remind students that no idea or suggestion is “silly.” All ideas should be respectfully heard. Ask the students:
 - How could a satellite track be traced without computer software? (Possible answers: Extremely hard to track them, manually, with other satellites sending data to a central office.)
 - Why do mission managers and engineers want to track satellites? (Possible answers: to predict when they will fall to Earth; to make sure they remain in their correct orbits.)

Post-Activity Assessment

- Define: Ask the students what azimuth, elevation, and range mean.
 - Azimuth* – the number of degrees measured clockwise from the north horizon.
 - Elevation* – the height, in degrees, above the horizon.
 - Range* – the distance from where you are located to a spacecraft or satellite.

Suggestions to Scale Activity for Grades 6 to 8 —

- 6th, 7th and 8th Grade: Do activity as is.

Activity References —

- *Skywatch* program website: <http://spaceflight.nasa.gov/realdata/sightings>
- *STSPplus* program website: <http://www.dransom.com/stsplus.html>
- Picture source:
<http://spaceflight.nasa.gov/gallery/images/station/assembly/html/s100e5958.html>