Figure 1. Aerial view of the STS-2 Columbia launch from Pad 39A at the Kennedy Space Center, Florida.

Science Activity 1

Launching the ISS into Orbit

Objective

To investigate the speed required to launch the International Space Station (ISS) into a circularized orbit. To introduce the concept of lateral velocity, and investigate how changes in a spacecraft's lateral velocity affect its orbit.

NASA Challenge

You are a NASA Rocket Scientist, and you need to find a way to launch segments of the International Space Station (ISS) into orbit at just the right speed to keep the orbit from going too high or too low.

Materials

Globe (or large ball on a stable platform)

Large pencil eraser

String (about 4 feet long)

Stopwatch

Management

This activity can be conducted in a classroom or lecture hall environment, and can be performed individually or in teams.

National Science Content Standards:

Physical Science

Position and motions of objects

Motions and forces

Change, Constancy, and Measurement

Evidence, Models and Exploration

Mathematics Standards:

Communication

Geometry

Background

The international Space Station (ISS) orbits between 370-460 kilometers (230 – 286 miles) above the surface of the earth, at an average speed of approximately 7.7 kilometers per second (17,240 miles per hour). Each component of the ISS was launched from Earth using rockets to get them to precisely the right speed to maintain a circularizedorbit.

All orbits are elliptical, but most spacecraft orbiting the Earth travel in ‘circularized’ orbits, ellipses that are made as circular as possible, to maintain a more constant altitude above the surface.

Velocity means speed and direction. When a rocket lifts off the launch pad, at first it is traveling straight up, so all of its velocity is vertical. Then it begins to tilt so that some of its speed is pointed laterally (or to the side), so that it begins to travel around the Earth instead of continuing to travel away from it. This is called lateral velocity (depicted in Figure 2), and it is the key to reaching orbit.

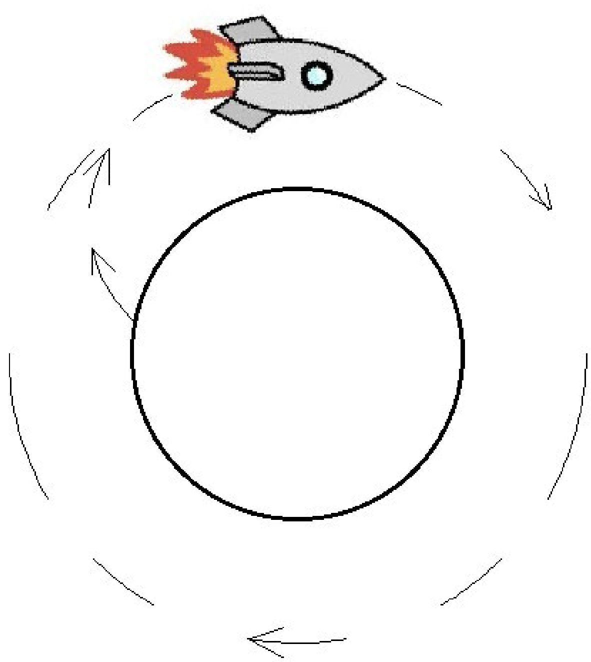

Figure 2. Looking from the top - a rocket orbiting around the Earth, showing initial vertical velocity during launch, and the transition to lateral velocity in orbit.

Setting up the Rocket Launch

1. Tie one end of the string around the eraser

2. Set the globe on the floor, or place the ball in a stable position close to the floor.

3. Hold the other end of the string approximately 4 feet above it. The eraser should rest against the side of the globe, at the equator, as depicted in Figures 3 and 4. You can tie the string up or have a friend hold it.

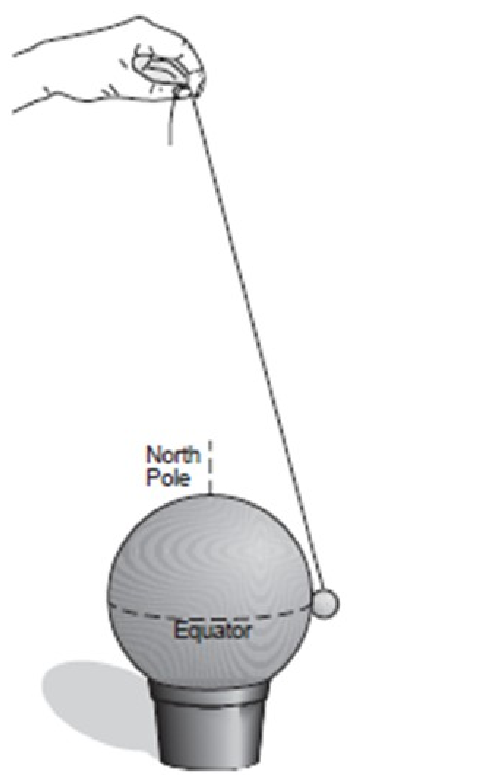

Figure 3. Looking from the side - method for holding the rocket (eraser) against the equator of the Earth(ball), using the string.

Test 1: Vertical Launch with Zero Lateral Velocity

1. Pull the eraser a few inches directly away from the side of the globe, but let the string hold the weight of the eraser.

2. Let it go and watch it fall right back to the surface of the globe, where it was before. This shows how gravity pulls us back to the surface of the Earth when we jump up in the air. This would also happen if a rocket kept going straight up (vertical velocity) during launch, and never turned to go around the Earth (lateral velocity).

Figure 4. The rocket (eraser) after Test 1, is at rest on the side of the Earth (ball).

Test 2: Launch with Low Lateral Velocity

1. Pull the eraser a few inches directly away from the the surface of the globe, while still letting the string hold the weight of the eraser.

2. Gently swing the eraser to the side, parallel with the Earth's equator, and let go. If you do this very gently, the eraser will travel partway around the Earth, and then fall back to the surface at a different point around the equator.

Test 3: Launch with Orbital Velocity

1. Keep trying until you find just the right speed where the eraser circles around the ball without touching the surface, as depicted in Figure 5. Try to make the orbit as circular as possible.

2. Once you have found the speed where the eraser comes back to the starting position at the same height where it started, you have reached orbit!

3. Use the stopwatch to measure the time it takes for the eraser to go around the globe in one orbit. Measure this a few times and take an average.

4. Compare your time with the other teams - did you all get the same answer? Why or why not?

Figure 5. The rocket (eraser) orbiting around the Earth (ball), with the string being held at a point about 4 feet above the ball.

Extension

Advanced studentscan use the following equation to calculate the lateral velocity that the International Space Station must maintain in order to remain in orbit at 402 km (250 miles) above the surface of the Earth.

v= GMr

v = velocity of the ISS, in meters/sec

GM = Gravitational Constant times Earth's mass

= 3.99×10^{14} meters^3/sec^2

r = Radius of ISS orbit (Radius of the Earth plus altitude of ISS orbit)

= 6,378 km + 402 km = 6.78×10^6 m

Discussion and Answers

1. This experiment is focused on the qualitative lesson, and giving the students a sense of what it means to be in orbit.
2. The orbital time measured by the students in Test 3 will vary according to the radius of the orbit, and the height at which the string is held (the angle the string makes with the ground). Therefore the specific orbital time (and therefore, orbital velocity) that they measure is not as important as the fact that they should all come up with the same number, within a margin of error taking these factors into account.
3. For the extension question, the calculation should result in an answer of 7.67 km/sec (17,160 miles/hour). The same calculation will not apply directly to the ball and eraser (i.e. the parameters G and M cannot be used for the experiment setup), because the experiment uses the tension in the string to simulate the effects of gravity on the eraser's orbit.

Assessment

- Have students compare their orbital times.
- Review students' time measurements and their conclusions with the class.