# The speed and orbit time of a satellite, ISS style!

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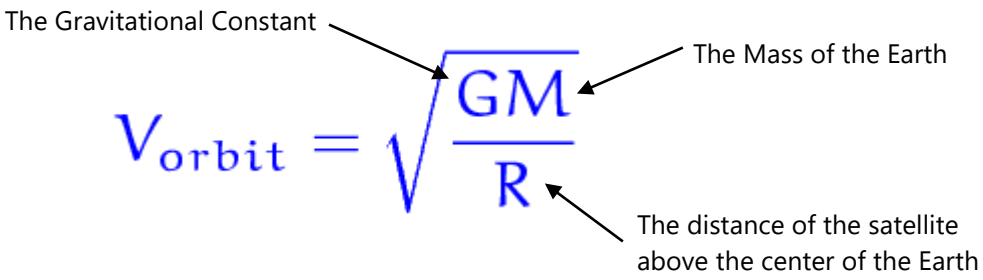
| **Subject/Grade Level:** | Space and the Solar System / Middle School (Grades 6-8) |
| **Lesson Objective(s):** | To understand orbital motions of satellites using the International Space Station. |
| **Materials**: | • Scientific calculator |
| **NGSS Essential Standards and Clarifying Objectives:** | **NGSS Essential Standards and Clarifying Objectives:**<br>*MS-ESS1-2:* Develop and use a model to describe the role of gravity in the motions within galaxies and the solar system.<br>**Science and Engineering Practices:**<br>● Developing and Using Models Modeling in G6–8 builds on K–5 experiences and progresses to developing, using, and revising models to describe, test, and predict more abstract phenomena and design systems. Develop and use a model to describe phenomena.<br>**Disciplinary Core Ideas:**<br>● *ESS1.A:* The Universe and Its Stars Earth and its solar system are part of the Milky Way galaxy, which is one of many galaxies in the universe.<br>● *ESS1.B:* Earth and the Solar System The solar system consists of the sun and a collection of objects, including planets, their moons, and asteroids that are held in orbit around the sun by its gravitational pull on them. The solar system appears to have formed from a disk of dust and gas, drawn together by gravity.<br>**Crosscutting Concepts**<br>● Systems and System Models<br>✓ Models can be used to represent systems and their interactions.<br>● Connections to Nature of Science<br>✓ Scientific Knowledge Assumes an Order and Consistency in Natural Systems Science assumes that objects and events in natural systems occur in consistent patterns that are understandable through measurement and observation. |
| **Differentiation strategies to meet diverse learner needs:** | • Think-pair-share, for students that learn best when engaging with classmates.<br>• Multisensory learning, to accommodate students that are auditory learners and visual learners, as well as encourage students to engage their senses in the learning process.<br>• Awareness of social and cultural backgrounds of students to reinforce the real-life application of what they are learning. |
| **Student Worksheet** | Worksheet for the speed of a satellite. Advanced exercise for the period of the ISS. |
| **Skills Needed** | Students need to be able to use a Scientific Calculator using exponential values, Pi and square root functions. |

**ENGAGEMENT**:

**What affects the speed of a satellite?**

NOTE: While the equation below has to do with the *velocity* of an object in orbit (like the ISS), velocity has to do with both the *speed* and the *direction* of an object (making it a *vector quantity,* namely one that has quantity AND direction). For the purposes of these calculations, we will only focus on one of these, the **speed** of the satellite.

The equation shows the speed (V) of a satellite, based on 3 numbers:




**Questions**

1. What factor determines the speed of a satellite like the ISS?

   *The ISS orbit speed is dependent on how far the ISS is from the Earth. The Gravitational Constant and the Mass of the Earth are both constants, so only R, the distance of the satellite above the center of the Earth, affects the speed of a satellite.*

2. If the ISS was further away from the Earth, would its velocity be higher or lower?
   *It would be lower. If R increases, V decreases*.

**EXPLORATION**

Hand out the Worksheet exercise for the speed of a satellite.

**How fast is the ISS travelling? The equation for the speed of a satellite.**

1. To calculate the speed (velocity) of the ISS orbiting around the Earth, we need to treat it like a satellite.
2. The formula is:
   Square root of ((Gravitational constant x Mass of Earth) ÷ Radius of the ISS from the center of the Earth).
   Units must be in metric, specifically in meter, kilogram, second.

$$V_{orbit} = \sqrt{\frac{GM}{R}}$$

V = Velocity (Speed) of the ISS in meters per second
G = Gravitational Constant: $6.67 \times 10^{-11}$ $m^3$ $kg^{-1}$ $s^{-2}$
M = Mass of the Earth (M): $5.97 \times 10^{24}$ kg
R = Radius of the Earth in meters + Orbit Height of the satellite in meters.
Radius of the Earth is $6.37 \times 10^6$ m. The Orbit Height of the ISS is 254 miles.

The results from the calculations will vary slightly, dependent on how numbers are rounded.

**Task 1: Convert to metric units**

(a) Convert the ISS Orbit Height of 254 miles into meters. (Multiply miles by 1609).
(b) How should you express the Orbit Height to match the units for the radius of the Earth? (Hint: how would you show the Orbit Height as a decimal which when multiplied by $10^6$ equals the number you got for the Orbit Height in part (a).
**Ans: 408686 meters or $0.409 \times 10^6$**

**Task 2: Calculate the velocity of the ISS**

(a) Add the Orbit Height to the Radius of the Earth.
**Ans: 6,779,000 or $6.78 \times 10^6$ meters**

(b) Calculate the speed/velocity of the ISS using a scientific calculator.
**Ans: 7,663 m/s**

(c) What is the speed of the ISS in miles per second? In miles per hour?
**Ans: 4.76 miles per second. Approx. 17,145 miles per hour.**

**EXPLANATION**

- Orbits:

- ✓ Circular vs. Elliptical orbits: The ISS moves in an approximately circular orbital path (relative to other satellites/ planets), whereas the planets (including Earth) move in elliptical orbits around the sun.
- ✓ Note that the mass of the ISS does not matter in these calculations.

- Satellite orbits can degrade. The ISS is at an altitude where there are some air molecules which 'drag' the ISS closer to the Earth. To solve this, the ISS Above has rockets which give it a little "kick" and serve to boost it back up to the correct distance from the Earth.

## EVALUATION

Students can calculate the speed of a satellite at various heights from the Earth's surface. Have students check each other's work to make sure they all understand how they can calculate the speed of an object in orbit.

**Calculate orbital speed of satellites at different heights above the Earth**

Have students copy the table below:

| **Height** | **Height in meters (calculate this)** | **Speed in meters/second (calculate this)** | **Speed in miles/second (calculate this)** |
|---|---|---|---|
| 254 miles (ISS) | Already calculated | Already calculated | Already calculated |
| 50 miles* | | | |
| 20000 miles** | | | |

*The speed should be faster than the ISS

**The speed should be slower than the ISS. This is the approximate height of geostationary satellites (such as communications and sat-nav satellites).

**EXTENSION MATERIAL for Mathematically Adept Students**

Have students calculate the orbit time of a satellite (see Student Worksheet for Lesson 2).

**How long does it take for the ISS to complete an orbit of the Earth?**

**The Equation for orbit time of a satellite is significantly more complex to calculate.**

The formula is:

Square root of ((4 x $\pi^2$) x (Radius of the ISS orbit)$^3$) ÷ (Gravitational Constant x Mass of the Earth)).

Units must be metric, specifically in meter, kilogram, second.

$$T = \sqrt{\frac{4\pi^2 R^3}{GM}}$$

**Task 1: Calculate the orbit time for the ISS**

From the prior exercise, students can use the values they already have to calculate the period of the orbit. Note that this is approximate as the orbit is not completely circular, but slightly elliptical.

In what units is the answer? It's in seconds.

Ans: Approx. 5,558 seconds

**Task 2: What is the orbit time in minutes**

Divide the orbit time in seconds by 60.

Ans: Approx. 92 minutes.

**CONCLUSION:** The ISS travels at 5 miles per second and orbits the Earth in 92 minutes.

# Student Worksheet 1
# – The speed of the ISS

**How fast is the ISS travelling? The equation for the speed of an orbiting body.**

Space Station Speed

The ISS is just a very large satellite and satellites behave like any other orbiting body (for example, the Earth around the Sun).

The formula is:
Velocity (speed) = Square root of ((Gravitational constant x Mass of Earth) ÷ Radius of the ISS from the center of the Earth).
Units must be in metric, specifically in meter, kilogram, second.

$$V_{orbit} = \sqrt{\frac{GM}{R}}$$

V = Velocity (Speed) of the ISS

G = Gravitational Constant: $6.67 \times 10^{-11}$ $m^3$ $kg^{-1}$ $s^{-2}$

M = Mass of the Earth (M): $5.97 \times 10^{24}$ kg

R = Radius of the Earth in meters + Orbit Height of the ISS in meters.
Radius of the Earth is $6.37 \times 10^6$ m. The Orbit Height of the ISS is 254 miles.

**Task 1: Convert to metric units**

(a) Convert the ISS Orbit Height of 254 miles into meters. (Multiply miles by 1609.)

(b) Use the answer from (a) above and express it in the form of 0.nnn x $10^6$. You are doing this to make is easier to add the Orbital Height of the ISS to the Radius of the Earth to get the value for R that you need for the equation.

**Task 2: Calculate the velocity of the ISS**

(d) Add the Orbit Height to the Radius of the Earth.

(e) Calculate the speed/velocity of the ISS using a scientific calculator. What units is this result in?

(f) What is the speed of the ISS in miles per second? In miles per hour?

Check your answers with your teacher.

# Student Worksheet 2 – The orbit period of the ISS

**How long does it take for the ISS to complete an orbit of the Earth?**

The Equation for orbit time of a satellite is significantly more complex to calculate.

The formula is:

T (the orbit period) = Square root of ((4 x $\pi^2$) X (Radius of the ISS)$^3$) ÷ (Gravitational Constant x Mass of the Earth)).

Units must be metric, specifically in meter, kilogram, second.

$$T = \sqrt{\frac{4\pi^2 R^3}{GM}}$$

**Task 1: Calculate the orbit time for the ISS**

From the prior exercise, use the values you already have (R, G and M) to calculate the period of the orbit. Note that this is approximate as the orbit is not completely circular, but slightly elliptical.

What is the orbit time of the ISS?

In what units is the answer?

**Task 2: What is the orbit time in minutes**

Divide your answer to part (a) by 60.

Check your answers with your teacher.