



# Hypersonics STEM Curriculum



## Flying in All Directions

Grade	Time	Subject Area	Key Concepts
5	50 min	Mathematics	Direction Axis

### Lesson Overview

In this lesson, students will use online resources to learn about the different ways to give directions: everyday, mathematical, and aeronautical. They will then use their knowledge to determine the degrees of freedom of three different objects.

### CCSS Standards

CCS.MATH.CONTENT.5.G.A.1 Use a pair of perpendicular number lines, called axes, to define a coordinate system, with the intersection of the lines (the origin) arranged to coincide with the 0 on each line and a given point in the plane located by using an ordered pair of numbers, called its coordinates. Understand that the first number indicates how far to travel from the origin in the direction of one axis, and the second number indicates how far to travel in the direction of the second axis, with the convention that the names of the two axes and the coordinates correspond (e.g., x-axis and x-coordinate, y-axis and y-coordinate).

### Learning Objectives

By the end of this lesson, students will be able to:

- Explain different ways to give directions (everyday, mathematical, aeronautical).
- Describe the possible motion of an object in terms of degrees of freedom.

### Essential/Overarching Question

How many degrees of freedom do we have?

### Key Vocabulary

**Speed** – the rate at which an object is moving. Speed is calculated by dividing the distance travelled by the time it took to travel that distance.

**Speed of Sound** – the rate at which sound moves through a medium. The speed of sound depends on both the density and the temperature of the medium. The speed of sound through air at 20° C (68° F) at sea level is 343 m/s (767 mph).

**Mach** – the ratio of the speed of an object to the speed of sound or how many times the speed of sound an object is moving. It is often followed by a number indicating the ratio; for example: Mach 1 is the speed of sound, Mach 2 is twice the speed of sound, Mach 5 is five times the speed of sound.

**Sonic** – speeds equal to the speed of sound (Mach 1).

**Subsonic** – speeds smaller than the speed of sound (less than Mach 1).

**Transonic** – speeds near (Mach 0.8-1.2) the speed of sound where drag is highest (e.g. sound barrier).

**Supersonic** – speeds greater than the speed of sound (Mach 1 and greater).

**Hypersonic** – speeds greater than five times the speed of sound (Mach 5 and greater).

**Fluid** – a substance with no fixed shape; a liquid, gas, or plasma. A substance that flows when an external force is applied to it.

**Flow** – the motion of a fluid (liquid, gas, or plasma) when it experiences unbalanced forces.

**Magnetic North** – the direction the north end of a compass will point in response to Earth's magnetic field.

**Geographic North Pole** – the direction of true north, latitude 90° North. At this point, all directions point south.

**Axis** – a fixed reference line for the measurement of coordinates or rotation.

**Origin** – the point or place where something begins, the starting point of measurements and calculations.

**Roll** – rotation around the front-to-back axis.

**Pitch** – rotation around the side-to-side axis.

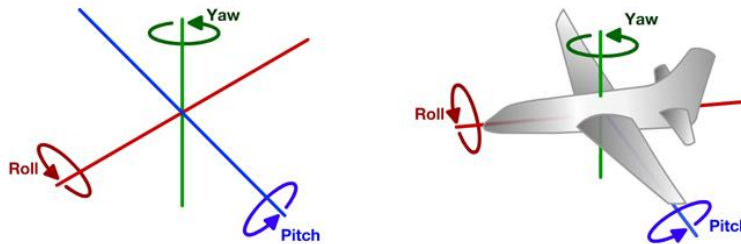
**Yaw** – rotation around a vertical axis.

**Degrees of Freedom** – the six mechanical ways a rigid body can change its position: forward/backwards, left/right, up/down, yaw, pitch, and roll. Also known as 6DOF and six degrees of movement.

### Science Concepts Overview

There are many different ways to give someone directions. We tend to be most familiar with everyday directions (left, right, forwards, backwards, up, down). In mathematics, we study direction in terms of coordinates about the three axes (x, y, z).

Another, but less familiar, way to give directions is with aeronautical directions. Aeronautical directions (roll, pitch, yaw) describe ways an object can move and rotate about its axes. Roll describes how much an aircraft will rotate about its front-to-back axis. Pitch describes the rotation along the side-to-side axis. And yaw is the rotation along the vertical axis.



<https://www.touringmachine.com/Articles/aircraft/6/>

Everyday and aeronautical directions come together for the six degrees of freedom. The six degrees of freedom, or 6DOF, or six degrees of movement describe the six mechanical ways a rigid body can change its position. The six degrees are forward/backwards, left/right, up/down, yaw, pitch, and roll. Not all objects can move in all six directions, for example, our ankles have only two degrees of freedom (yaw and pitch).

### Materials List

- Colored pencils, pens, or markers (assortment)
- Devices with access to the internet (one per student)
- Flying in All Directions handout (one per student)
- An assortment of object that can move or have a part that can move

### Lesson Preparation

Prior to the lesson, the instructor should gather the objects, make copies of the Flying in All Directions handout, and ensure that the devices that the students will be using to do the activity are charged and connected to the internet.

If possible, the instructor should provide students with either an electronic copy of the Flying in All Directions handout and/or links to the websites through whatever learning platform is used at their school. This will help students more easily and quickly get to the correct resources.

### Safety

There are no additional safety concerns beyond normal classroom procedures for this lesson.

### Procedure

#### **Engage (10 minutes)**

1. Start the class with a contest. Give the students one minute to write down as many words that they can think of that they use to give directions. Have students count their total list.

2. Next, have students share a word on their list. If other students also wrote down that word, they all cross it off their list. If no one else has that word on their list, they circle it. Once all words are crossed off or circled, have students count the unique (circled) directional words they have.
3. Individually or as a class, read the introduction to the Flying in All Directions handout.

**Explore/Explain (20 minutes)**

4. Students will explore different online resources to learn about three different types of directions: everyday, mathematical, and aeronautical.
5. As students explore the online resources, they are asked to:
  - Label the axis on the next page with the different directions. Use a different color to label each set of directions.
  - Label the key to show which color represents which set of directions.
6. Students will then explore an additional resource that explains how degrees of freedom are used to describe the multiple ways an object can move.
7. Students will be asked to share their understanding of degrees of freedom by answering the question:
  - If you were to describe degrees of freedom to your friend, what would you say?

**Elaborate (10 minutes)**

8. Each student will be asked to pick 3 different objects and evaluate how many degrees of freedom each object has. Students are given the following instructions:
  - Describe and sketch your object in the table below.
  - Play with your object to see the different ways your object can move.
  - On the sketch of your object, draw and label arrows that show the different ways/directions your object can move.
  - Fill in the box with how many degrees of freedom your object has based on the arrows you drew.

**Evaluate (10 minutes)**

9. Have students each pick one of their objects and share with the class how they determined the number of degrees of freedom their object has.

**STEM Career Connections**

- Pilots
- Aeronautical engineering
- System engineers
- Biologists
- Machinists
- Manufacturing
- Metrology

**Extensions**

Students could further *explore* magnetic north and how it affects travel by reading the articles listed below. Students could read all three articles or students could be divided into

groups of three and do a jigsaw activity. In a jigsaw activity, students are divided into groups and each student in the group reads a different article, summarizes it, and shares out their summary with their group. Students can also want the two videos listed below instead of reading an article.

- GISGeography. (2023, October 11). *Magnetic north vs geographic (true) north pole*. GIS Geography. <https://gisgeography.com/magnetic-north-vs-geographic-true-pole/>
- National Business Aviation Association. (2011, March 14). *How changes in magnetic north are impacting airports*. National Business Aviation Association. <https://nbaa.org/aircraft-operations/airports/how-changes-in-magnetic-north-are-impacting-airports/>
- Science and Technology Concepts Middle School. (2018, January 4). *How do birds navigate?*. Smithsonian Science Education Center. <https://ssec.si.edu/stemvisions-blog/how-do-birds-navigate>
- Epilotdad. (2021, October 23). *What do these numbers on runways mean?* [Video]. YouTube. <https://www.youtube.com/shorts/rB9aJS0jPFw>
- 2012change. (2011, January 7). *Magnetic pole shift affects airport* [Video]. YouTube. <https://www.youtube.com/watch?v=zCI2myemRfY>

## References & Resources

- 2012change. (2011, January 7). *Magnetic pole shift affects airport* [Video]. YouTube. <https://www.youtube.com/watch?v=zCI2myemRfY>
- API Metrology. (2019, June 28). *What Is 6 Degrees Of Freedom?* [Video]. YouTube. <https://www.youtube.com/watch?v=DdvBrKl3SHg>
- Chris Craft. (2016, January 25). *X Y Z* [Video]. YouTube. [https://www.youtube.com/watch?v=iijh3\\_ukuNg](https://www.youtube.com/watch?v=iijh3_ukuNg)
- Encyclopedia Britannica, Inc. (n.d.). *Direction*. BKIDS. <https://kids.britannica.com/students/article/directions/274015>
- Epilotdad. (2021, October 23). *What do these numbers on runways mean?* [Video]. YouTube. <https://www.youtube.com/shorts/rB9aJS0jPFw>
- flight-club. (2014, September 17). *Axes of movement* [Video]. YouTube. <https://www.youtube.com/watch?v=5IkPWZjUQlw>
- FuseSchool – Global Education (2016, November 3). *Axis & coordinates | Graphs | Maths | FuseSchool* [Video]. YouTube. <https://www.youtube.com/watch?v=Byw72mbDBT8>
- GISGeography. (2023, October 11). *Magnetic north vs geographic (true) north pole*. GIS Geography. <https://gisgeography.com/magnetic-north-vs-geographic-true-pole/>
- MooMooMath and Science. (2020, November 13). *What are cardinal directions and a compass rose?* [Video]. YouTube. <https://www.youtube.com/watch?v=lkfq37bMVBY>
- National Business Aviation Association. (2011, March 14). *How changes in magnetic north are impacting airports*. National Business Aviation Association. <https://nbaa.org/aircraft-operations/airports/how-changes-in-magnetic-north-are-impacting-airports/>
- National Geographic Education. (n.d.). *Direction*. National Geographic. <https://education.nationalgeographic.org/resource/direction/>

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Grade 5 | Mathematics

Pilot Ems. (2020, July 19). *Pitch, roll & yaw: Explained* [Video]. YouTube.

<https://www.youtube.com/watch?v=OE8ri97yrfQ>

Science and Technology Concepts Middle School. (2018, January 4). *How do birds navigate?*.

Smithsonian Science Education Center. <https://ssec.si.edu/stemvisions-blog/how-do-birds-navigate>

SciShow. (2019, July 8). *A surprisingly simple secret to supersonic flight* [Video]. YouTube.

<https://www.youtube.com/watch?v=kGefMLHJBKA>

Talented Tuber. (2017, April 11). *Difference between subsonic, supersonic and hypersonic speed* [Video]. YouTube. <https://www.youtube.com/watch?v=LBJ3tXCjzN0>

TestTube 101. (2015, November 11). *Flying at hypersonic speeds* [Video]. YouTube

<https://www.youtube.com/watch?v=vL1qAfS0gic>

Touring Machine Company (2007, November, 29). *Pitch, roll, and yaw*. Touring Machine Company. <https://www.touringmachine.com/Articles/aircraft/6/>

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## Flying in All Directions

### ✦ Introduction

We use directional vocabulary all the time. We use it to explain where something is. We use it to learn how to get to a new place. Airplanes and boats use it to navigate to their destination. Even animals have an innate sense of direction that allows them to migrate. Having good directions is important to get to your end point safely. The faster you go, the more important it is to have good directions. When traveling at **hypersonic** speeds (five times the speed of sound) it is especially important because a slight shift in directions could result in a large change in destination. We are going to learn about the different ways that you can talk about directions.



### ✦ Exploring Direction

- Explore the resources below to learn more about the different ways we can talk about direction: everyday, mathematical, and aeronautical.
- Get up and move your body in the different directions described in the resources.
- Label the axis on the next page with the different directions. Use a different color to label each set of directions.
- Label the key to show which color represents which set of directions.



### Everyday Directions: Left-Right-Forwards-Backwards-Up-Down

Encyclopedia Britannica, Inc. (n.d.). *Direction*. BKIDS.

<https://kids.britannica.com/students/article/directions/274015> (read at least The Language of Directions section)

National Geographic Education. (n.d.). *Direction*. National Geographic.

<https://education.nationalgeographic.org/resource/direction/>

### Mathematical Directions: x-y-z

FuseSchool – Global Education. (2016, November 3). *Axis & coordinates | Graphs | Maths | FuseSchool* [Video]. YouTube. <https://www.youtube.com/watch?v=Byw72mbDBT8>

Chris Craft. (2016, January 25). *X Y Z*. [Video]. YouTube.

[https://www.youtube.com/watch?v=iij3\\_uKuNg](https://www.youtube.com/watch?v=iij3_uKuNg)

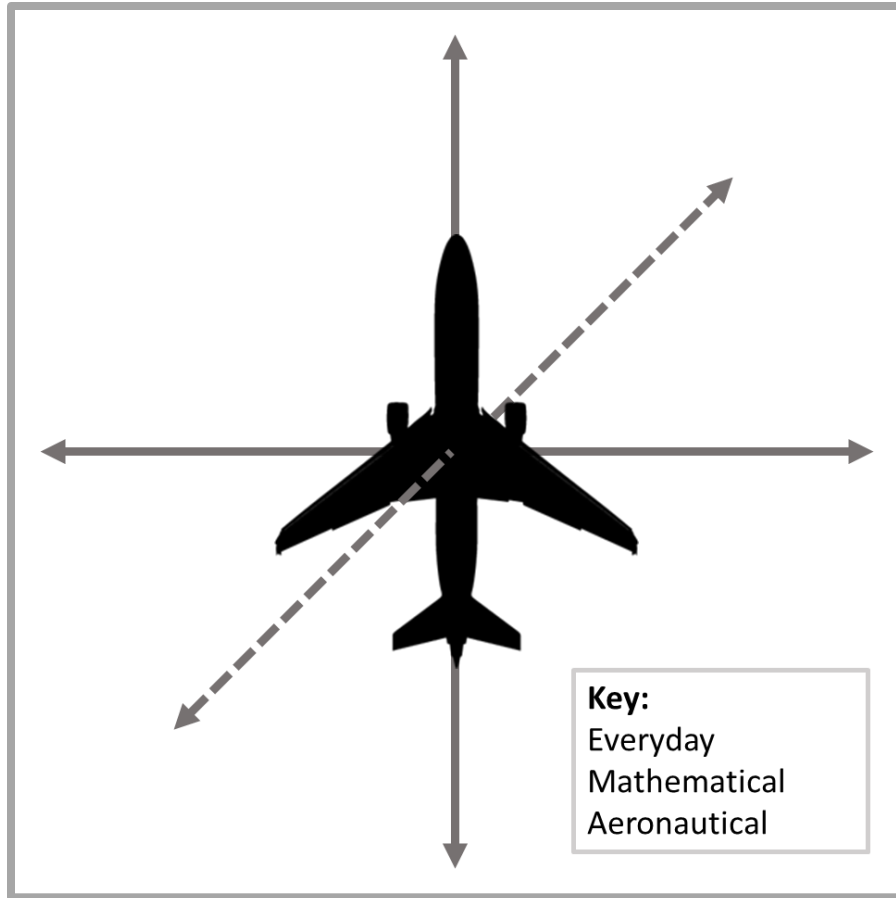
### Aeronautical Directions: Roll-Pitch-Yaw

flight-club. (2014, September 17). *Axes of movement* [Video]. YouTube.

<https://www.youtube.com/watch?v=5IkPWZjUQlw>

Pilot Ems. (2020, July 19). *Pitch, roll & yaw: Explained* [Video]. YouTube.

<https://www.youtube.com/watch?v=OE8ri97yrFQ>



✈ **Putting it Together: Degrees of Freedom**

- Watch the video below to learn about how degrees of freedom combines everyday and aeronautical directions.
- Get up and move your body in a way to demonstrate all six degrees of freedom.
- Answer the question below.

API Metrology. (2019, June 28). *What Is 6 Degrees Of Freedom?* [Video]. YouTube.

<https://www.youtube.com/watch?v=DdvBrKl3SHg>

*If you were to describe degrees of freedom to your friend, what would you say?*



### ★ Determining Degrees of Freedom

Pick three different objects. For each object:

- Describe and sketch your object in the table below.
- Play with your object to see the different ways your object can move.
- On the sketch of your object, draw and label arrows that show the different ways/directions your object can move.
- Fill in the box with how many degrees of freedom your object has based on the arrows you drew.

Object 1	
Description:	Sketch:
Degrees of Freedom:	
Object 2	
Description:	Sketch:
Degrees of Freedom:	
Object 3	
Description:	Sketch:
Degrees of Freedom:	