National Aeronautics and Space Administration

STEM LEARNING:

Advanced Air Mobility: Flight Control Math 4 (Pythagorean Theorem) Student Guide

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UAVS AND WEATHER

NASA is leading the nation to quickly open a new era in air travel called Advanced Air Mobility, or AAM. The vision of AAM is that of a safe, automated, and affordable air transportation system for passengers and cargo in both urban and rural locations.

Figure1. https://pixabay.com/photos/palm-trees-wind-windy-weather-4293013/ (Note: Image altered to include drone. Credit: Pixabay/NASA)

Compared to commercial airliners, the aircraft that fly in this new airspace are small. Many of these aircraft are Unmanned Aerial Vehicles, or UAVs, meaning they are self-flying or autonomous. Because of their size, UAVs can be greatly affected by weather conditions. Precipitation can impact the effectiveness of the propellers used to power them. They can also be adversely affected by cold weather; onboard batteries that power UAVs become less efficient in colder temperatures. As a result, the UAV's flight time decreases as it gets colder.

If there is more than a light wind, the speed of a UAV will be affected by the push of the wind. The wind sometimes blows from directly behind the UAV; this is known as a tailwind and it increases the speed of the UAV without changing its flight direction. In contrast, when the wind blows from directly in front of the UAV, this is known as a headwind. This slows the UAV down without changing its flight direction.

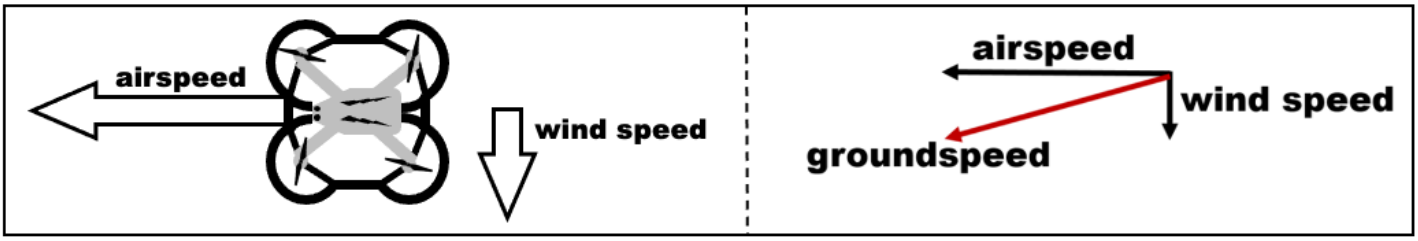


Figure 2. When there is a crosswind, the airspeed and wind speed combine to determine the groundspeed.

If the wind blows from a direction perpendicular to the UAV's motion, it is known as a crosswind. The UAV moves through the air at a certain speed called the airspeed. With a crosswind, the air moves at a constant speed, called the wind speed, in a direction perpendicular to the airspeed. The main effect of the crosswind is to push the flightpath in the direction of the wind. The airspeed combined with the wind speed is known as the groundspeed. The groundspeed describes the actual movement of the UAV.

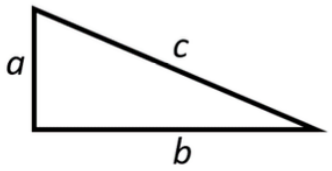
CALCULATING SPEED WITH HEADWINDS OR TAILWINDS

Tailwinds blow from behind the UAV. To calculate the groundspeed, the airspeed and the tailwind are added together. Headwinds blow from in front of the UAV, so the groundspeed is calculated by subtracting the headwind from the airspeed.

groundspeed = airspeed + tailwind **OR** *groundspeed = airspeed – headwind*

USING THE PYTHAGOREAN THEOREM WITH CROSSWINDS

According to the Pythagorean Theorem, if two sides of a right triangle are known, the other side can be calculated. Mathematically, it's expressed as:



$$a^2 + b^2 = c^2$$

Sides (a) and (b) are the shorter sides of the triangle and meet at a 90 degree angle, while (c) is the hypotenuse.

In this activity, sides (a) and (b) will represent the wind speed and the airspeed. Because of the commutative law, it doesn't matter whether side (a) or side (b) represents the airspeed or the wind speed. Side (c) represents the groundspeed.

Example: A small drone flies north with a speed of $15\frac{km}{hr}$ and there is a crosswind from the east that has a speed of $5\frac{km}{hr}$. What is the groundspeed of the drone?

$$c^2 = a^2 + b^2 = 15^2 + 5^2 = 225 + 25 = 250$$

$$\sqrt{c^2} = c = \sqrt{250} = 15.8\ \frac{km}{hr}$$

STUDENT ACTIVITY

PART 1: SOLVING FOR GROUNDSPEED

A company uses package delivery drones to deliver its products to customers. These drones fly with an airspeed of $60\frac{km}{hr}$ when carrying a package and $80\frac{km}{hr}$ when not carrying a package.

1. A drone is carrying a package to be delivered to a customer. As it flies, it encounters a headwind of $8\frac{km}{hr}$. Calculate the groundspeed for the drone.

2. After dropping off the package, the drone flies back in the opposite direction. Now it is not carrying a package and the wind is blowing from directly behind it. Calculate the groundspeed for the drone.

3. If the drone carries a package and encounters a crosswind of $9\frac{km}{hr}$, what is the groundspeed?

4. Complete the following chart:

Airspeed $\frac{km}{hr}$	**Wind Type and Speed** $\frac{km}{hr}$	**Groundspeed** $\frac{km}{hr}$
30	Headwind of 7	
75	Crosswind of 12	
50	Crosswind of 15	
45	Tailwind of 5	
90	Crosswind of 9	
40	Crosswind of 12	

5. An air taxi is trying to fly to a spot that is directly east of the vertiport from which it takes off. There is a wind blowing from the north toward the south. When programming the drone's flightpath (the airspeed and its direction), which of the three paths shown below (A, B, or C) should the programmers use? Explain why you chose the answer you did.

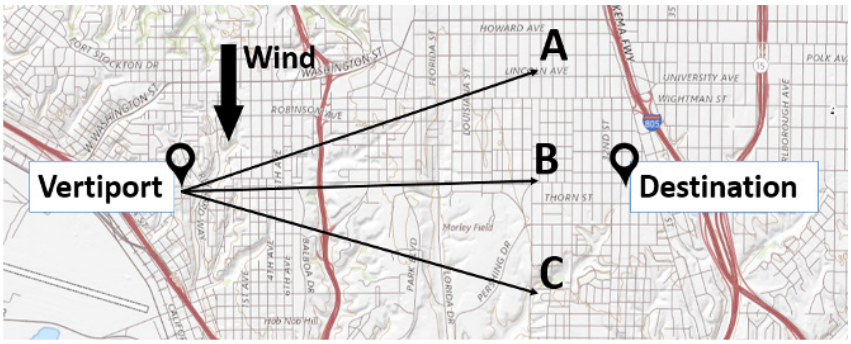


Figure 3. The three possible paths for the drone's flight. Credit: USGS

PART 2: SOLVING FOR AIRSPEED OR WIND SPEED

1. An engineer looks at the data from an air taxi and notices that it achieves a groundspeed of 53 $\frac{km}{hr}$ when flying northward through a headwind, and 68 $\frac{km}{hr}$ when it is flying southward. What is the airspeed of the taxi? Show your work.

2. What is the wind speed in question 1? Show your work.

3. Another air taxi has an airspeed of 50$\frac{km}{hr}$, but it is flying with a crosswind. The pilot measures the air taxi's groundspeed at 50.8 $\frac{km}{hr}$. Use the Pythagorean Theorem to calculate the wind speed.

4. Complete the following chart:

Airspeed $\frac{km}{hr}$	**Crosswind Speed** $\frac{km}{hr}$	**Groundspeed** $\frac{km}{hr}$
	15	25.00
	5	40.31
35		36.40
45		46.84
	4	18.44

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