**STEM ACTIVITY 7**
TEACHER NOTES

# NAVIGATION

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## EQUIPMENT REQUIRED PER PAIR OF STUDENTS:

- A4 sheet of paper
- 30 cm ruler
- Protractor and ping pong ball
- Thread or thin string
- Scissors and sticky tape
- Access to a fan or hair dryer (if available)
- Clamp stand and boss
- Two drawing pins or map pins
- Thick cardboard or corkboard
- Navigation Chart printed onto card or paper (Select "print to same size as original" when printing).

## PREPARATION REQUIRED

You may need to download the accompanying video: *Operation Black Buck*.

**PHYSICS CURRICULUM LINKS:** SPEED, VELOCITY

## HEALTH AND SAFETY

STUDENTS WILL BE USING DRAWING PINS TO LINK WIND AND AIRSPEED ARROWS TO THEIR NAVIGATION CHART. INSTRUCT THEM TO PLACE CHART AND ARROWS ON CORKBOARD OR THICK CARDBOARD BEFORE PUSHING PINS THROUGH.

## STEM ACTIVITY: WIND SPEED AND AIRSPEED

**In this activity students build an anemometer and explore how wind speed , ground speed and airspeed are linked.**

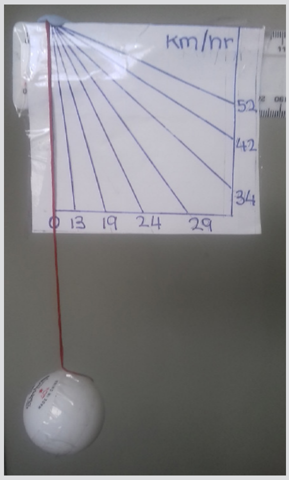
Introduce the activity by playing the accompanying video: *Operation Black Buck*. Explain that working out how much fuel is required for a mission requires an understanding of wind speed. Wind is caused by pressure differences in the atmosphere. Air flows from region of high pressure to a region of low pressure and the rate at which air flows over the ground can be measured using an instrument called an anemometer.

Students should follow the STEM instructions to build an anemometer calibrated in kilometres per hour (km/hr). Explain that the ping pong ball design illustrated on their instructions is drawn to scale (half-sized). They should use a protractor and ruler to make a full sized version. Their completed dial should be 10cm x 9cm and they should attach it along with a ping pong ball on a string to the end of a 30cm ruler. They will need to zero the anemometer and check that the string can swing freely before clamping the ruler into position. The string in front of the dial should line up with zero when there is no wind (see figure 1).

To measure low wind speeds they will need to pair up. One of them should take readings while the other provides a gentle breeze by blowing steadily on the ball. If they have access to a fan or hairdryer they can also investigate higher wind speeds. Comparison of their readings to the Beaufort scale will allow them to link their results to the type of terminology they may have heard in weather forecasts (see figure 2).

For the next part of the activity they should investigate how ground speed, airspeed and wind speed are linked. Explain that speed can only be measured relative to something else. They will be familiar with measuring speed relative to the ground. If they walk 5 km in 1 hr their ground speed will be 5 km/hr. Pilots are also interested in their speed relative to the air (as this is what governs the size of aerodynamic forces such as lift).
On a still day, ground speed and airspeed are the same. If it is a windy day, the ground speed depends on wind speed and direction.

**FIGURE 1:** PING PONG BALL ANEMOMETER




A simple instrument for measuring the speed of air. When there is no wind the anemometer should read zero.

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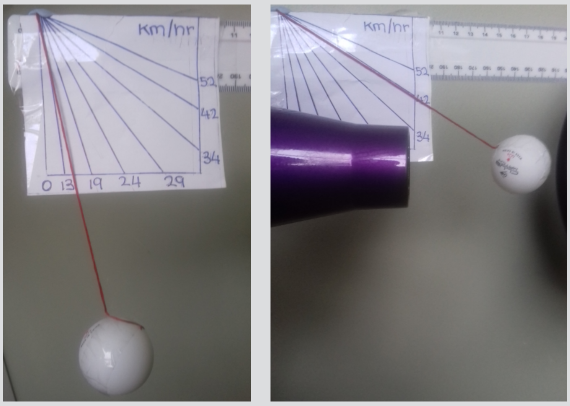
### FIGURE 2: DESCRIBING WIND SPEEDS

A gentle breeze created by blowing on the ping ball and a strong breeze created using a hairdryer. The Beaufort scale is provided on the student instructions.




| Wind speed | Beaufort number | Description |
|---|---|---|
| 0-1 km/h | 0 | Calm |
| 2-5 km/h | 1 | Light air |
| 6-11 km/h | 2 | Light breeze |
| 12-19 km/h | 3 | Gentle breeze |
| 20-29 km/h | 4 | Moderate breeze |
| 30-39 km/h | 5 | Fresh breeze |
| 40-50 km/h | 6 | Strong breeze |
| 51-61 km/h | 7 | Near gale |
| 62-74 km/h | 8 | Gale |
| 75-87 km/h | 9 | Strong gale |
| 88-101 km/h | 10 | Storm |
| 102-117 km/h | 11 | Violent storm |
| >117 km/h | 12 | Hurricane |

For the second part of the activity students will need their Navigation Chart. They should plot a course by drawing a line between point A (Ascension Island) and point F (the Falklands). Explain that the length of the arrows illustrated on their chart represent the speeds (1 cm represents 50 km/hr). The average wind speed at high altitudes can be much larger than those on the ground. They should record the wind speed by working out what a 2 cm long arrow represents.

Students will be considering a (hypothetical) one-way mission to the Falklands in which both wind and airspeed remain constant throughout the 6,300 km journey. Emphasise that this is much simplified model. How much fuel they need depends on their flight time (ie 6,300 km divided by the ground speed). After cutting out both arrows from the Navigation Chart they should push a pin through point A to connect the airspeed arrow to the chart and another pin through point B to connect the wind arrow to airspeed arrow. Pointing both arrows at the Falklands will simulate a tailwind. Pointing the wind arrow in the opposite direction will simulate a headwind. To determine ground speeds they will need to measure the distance between the tail of the airspeed arrow and tip of the wind arrow. A tailwind increases ground speed and a headwind decreases ground speed (see figure 3). They will require less fuel if there is a tailwind.

If there is time, they can try the crosswind challenge described on their STEM instructions. Pointing the wind arrow east will simulate a westerly wind (blowing from the west). Pointing it west will simulate an easterly wind. They will need to orientate the airspeed arrow so that wind arrow touches the line for both scenarios. An easterly wind increases ground speed and a westerly decreases ground speed (see figure 4). They will require less fuel if there is an easterly wind.

### FIGURE 3: GROUND SPEED AND FLIGHT TIME

| | | |
|---|---|---|
| **Course** | **220** | **degrees** |

| | |
|---|---|
| **Airspeed** | **750 km/hr** |

| | | |
|---|---|---|
| **Wind speed** | **100** | **km/hr** |

| | |
|---|---|
| **Distance** | **6300 km** |

| With tailwind | | |
|---|---|---|
| **Ground speed** | **850** | **km/hr** |
| **Flight time** | **7.4** | **hrs** |

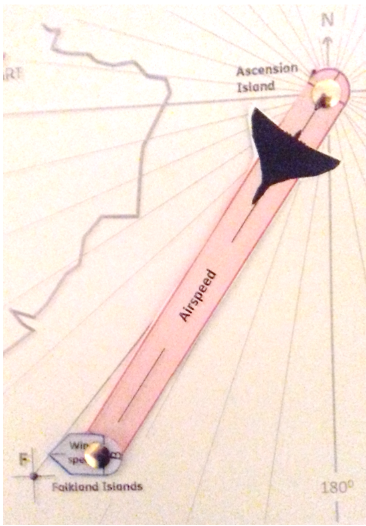
| With headwind | | |
|---|---|---|
| **Ground speed** | **650** | **km/hr** |
| **Flight time** | **9.7** | **hrs** |

### FIGURE 4: CROSSWIND CHALLENGE

| With westerly crosswind | | |
|---|---|---|
| **Heading** | **225** | **degrees** |
| **Ground speed** | **700** | **km/hr** |
| **Flight time** | **9.0** | **hrs** |

| With easterly crosswind | | |
|---|---|---|
| **Ground speed** | **215** | **degrees** |
| **Ground speed** | **800** | **km/hr** |
| **Flight time** | **7.9** | **hrs** |

Heading and ground speed data for easterly and westerly winds.
The photo shows arrow positions for an easterly wind.

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## ABOUT AIRSPEED ANEMOMETERS

**Depending on student's age and ability you may want to include more discussion about measuring air flow in different frames of reference and airspeed indicators.**

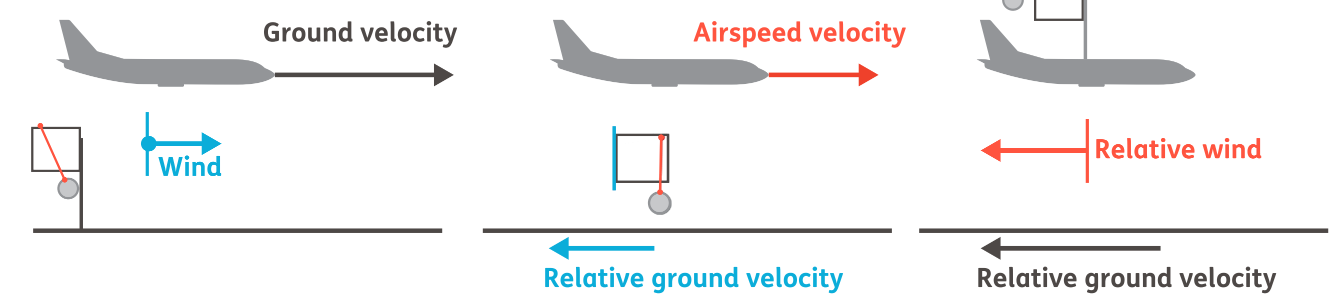
Anemometers measure relative air flow. An anemometer on the ground measures the speed at which the air moves relative to the ground (the wind speed). An anemometer mounted to the outside of moving aircraft measures the relative wind (see figure 5).

Two types of anemometer are illustrated in figure 6. A moving cup design was used in early aircraft to measure airspeed and is still used today in ground weather stations to measure wind speed. A high air flow rate corresponds to more revolutions per second. A Pitot tube (pronounced "pea-toe" ) is a pressure based sensor. A high air flow rate corresponds to a bigger displacement of a diaphragm mounted in the tube. Pitot tubes are more aerodynamic and less prone to mechanical failure than spinning cups and are the type of anemometer used in modern airspeed indicators.

Air pressure depends on air density. At high altitudes the airspeed indicated by a Pitot tube calibrated at sea level will be lower than the true airspeed. Navigators need altitude as well as airspeed indicators in order to be able to work out how fast they really are moving relative to the air (as a rule of thumb they usually add 2% to the indicated airspeed for every 300 m of altitude).

### FIGURE 5: REFERENCE FRAMES

Speeds measured in different reference frames.



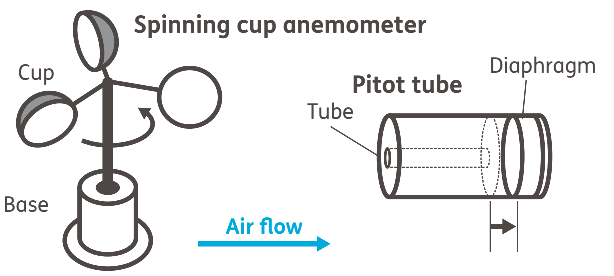

In the **ground reference frame,** the aircraft moves at the ground speed. The size of the speed is indicated by the length of the ground velocity arrow. An anemometer on the ground will measure the wind speed.

In the **air reference frame** the aircraft moves at the airspeed. If the anemometer moves with the air the reading will be zero.

In the **aircraft reference frame** there will be a relative wind equal in size to the airspeed velocity, but in the opposite direction. If the anemometer moves with the aircraft it measures airspeed.

### FIGURE 6: ANEMOMETER DESIGN

Operation of a spinning cup and Pitot tube anemometers.




### CUP CAKE ANEMOMETER

Students can make their own anemometer using cake cups, lollipop sticks, a pencil, blu-tack and a plastic cup.

## FURTHER INFORMATION

In aeronautics, the term speed is used to refer to both vector and scalar quantities. Emphasise that in physics they should refer to a speed written next to an arrow as a velocity. If students want to find out more about airspeed and ground speed they can visit the NASA website **bit.ly/RAF-Velocity**