How does trigonometry help pilots stay on course when tech tools are not working?

The following article will tell you how trigonometry helps pilots stay on course more specifically in terms of the wind correction angle.

When pilots fly the wind doesn't let them navigate in a straight line. A cross wind will push the aircraft away from its intended path line, forcing the plane to re-adjust in order to stay on course. Pilots are trained to master finding what angle they have to re adjust in some cases using analog tools but most often in their head or on paper especially when GPS systems fail which can be quite frequent depending on the route that's being taken. (Pilot Institute) The angle which they have to move to stay on course is called the Wind Correction Angle which is often seen as WCA. With some trigonometric calculations pilots are able to precisely calculate the WCA to stay on the intended path. GPS systems can often fail in cases when they are flying over certain countries which are in political tensions may send signals to interfere with the GPS's or in other cases when going through heavy storms the signal might become interrupted. (Simonds)

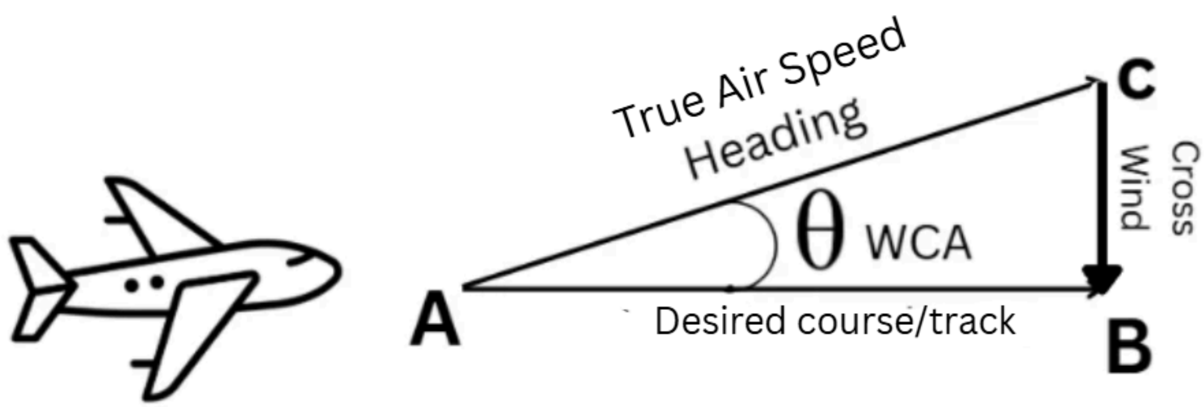

Figure 1: Self made canva design illustrating the basic values which will be needed in order to obtain the result. The values illustrated are the True Air Speed (TAS), the WCA or the wind correction angle (θ), where it needs to be headed (AC),

How does it form a right triangle

Aircraft motion and wind are examples of velocity vectors. A vector is a quantity that has both magnitude (speed) and direction. The aircraft has a velocity in its forward direction, while the wind has a velocity pushing sideways. These velocities act at the same time and combine to form a triangle. This allows trigonometry to be used to calculate the correction angle. Because the wind pushes perpendicular to the aircraft's path, the velocities form a right-angled triangle. The aircraft's true air speed forms the hypotenuse, and the wind speed forms the opposite side. This makes sine the appropriate trigonometric function to use.

Identifying the function that can be applied

In figure 1 we can clearly see how the different aspects and components create a right triangle, therefore trigonometric functions can be applied to solve for the wind correction angle. More specifically using the inverse sine function. (Nelaturu)

The inverse sine function

The inverse sine function is a core rule of trigonometric functions and in right angle triangles as you can see from figure 1 that's what's being dealt with. The inverse sine rule connects the opposite side and the hypotenuse to the missing angle which is the WCA in this scenario. ("Inverse Trig Functions")

Identifying the variables

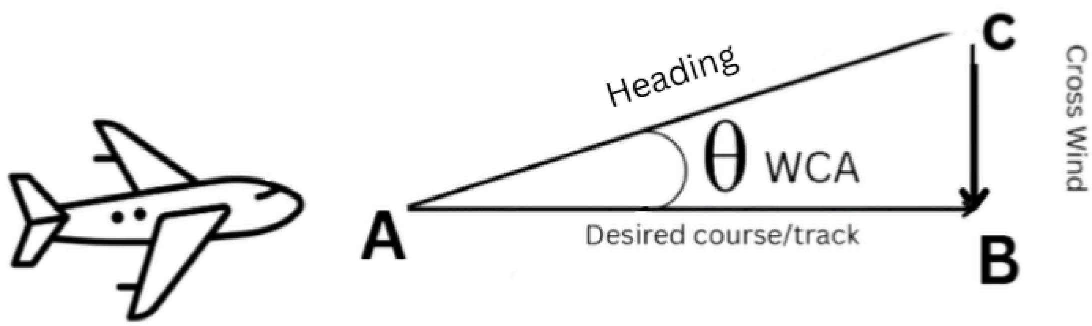

Figure 2: Self made canva design illustrating all the values needed to solve for the WCA. Desired course/track (AB), Wind correction angle (WCA), True air speed (TAS), and crosswind speed (W).
To apply the inverse sine function to my problem the variables presented in figure 2 must be defined.

In this model, the plane's motion and the wind are represented as velocity vectors forming a right-angled triangle.

The variables used are:

True Air Speed (TAS) the speed of the aircraft relative to the air (km/h or knots). This is the hypotenuse of the triangle.

Crosswind Speed (W) the sideways component of the wind that pushes the aircraft off course. In this simplified model, the wind blows at 90° to the aircraft's path, so the crosswind speed is equal to the total wind speed. This forms the opposite side of the triangle.

Wind Correction Angle (WCA) the angle the pilot must turn into the wind to stay on course.

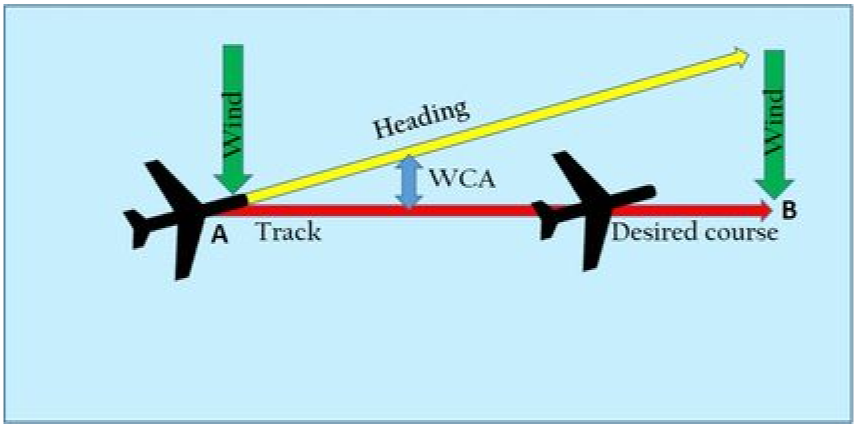

Figure 3: A diagram showing the impact of wind and how important it is that the WCA is used. This diagram is from (Singh)

Choosing the realistic values to apply to the situation

As seen in figure 3 values for the variables will have to be chosen. Now, to evaluate how effective this application of trigonometry is as a reliable backup system for pilots in the event of GPS failure when flying over countries with motives to send interfering signals such as Lebanon.

The following scenario will include the Boeing 737. The plane would take off in Egypt and land in Georgia flying right over Lebanon which some airlines do. A main risk is GPS spoofing which is a cybercrime which interferes with the signals. When going over Lebanon the pilots won't be able to rely on any digital tools so they will have to use different analog tools and trigonometric functions. (*Safe Airspace - Conflict Zone and Risk Database*) (*Calculate Distance, Bearing and More Between Latitude/Longitude Points*).

When flying over the area the aircraft will be going at 450 knots as that's around the average ground speed of a Boeing 737 at cruising altitude according to (Franklin)

Before the pilot starts the calculation he will use the E6B to determine the wind speed and direction which will be 107 knots ("Prevailing Winds") and the true air speed will be 450knots. I chose these values as they are a reasonable midpoint between perfect conditions to fly and extreme cases. But closer to the perfect side as extreme cases are really rare. For the purpose of the right triangle model we will assume the crosswinds component is at 107 knots which is equal to the total wind speed. ("Prevailing Winds")

Developing a mathematical equation

$$sin(\theta) = \frac{Opposite}{Hypotenuse}$$

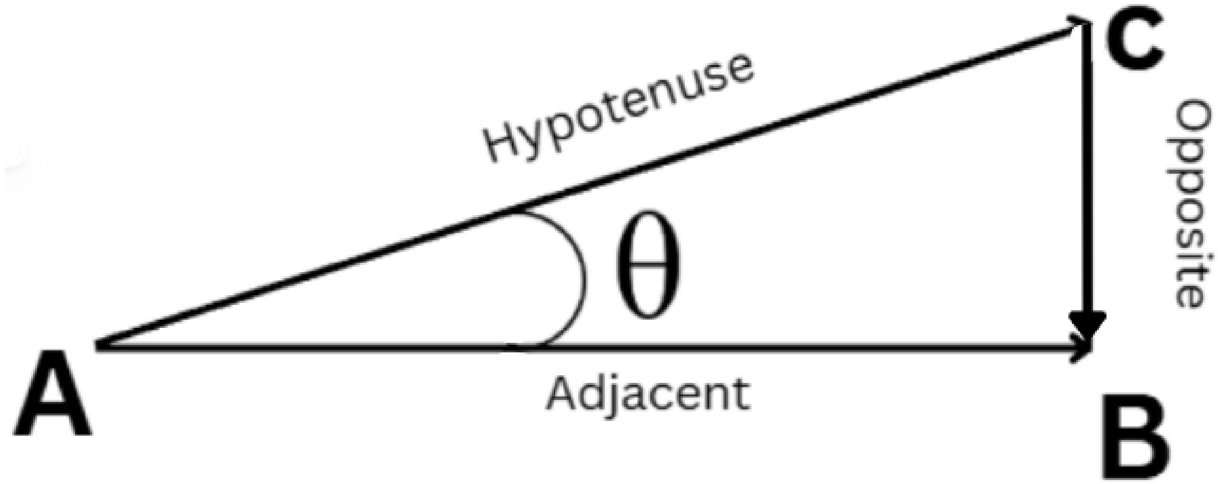

Figure 4: A self made diagram made with canva illustrating a right angle triangle with HYP, OPP, ADJ sides labeled, and their use in the sine formula

$$sin(WCA) = \frac{Crosswind\ speed}{True\ air\ speed}$$

<u>Re-arranging the formula in order for it to be applied to the situation</u>

$$WCA = Sin^{-1} \frac{Crosswind\ speed}{True\ air\ speed}$$

<u>Solving for the wind correction angle</u>

$$WCA = Sin^{-1} \frac{Crosswind\ speed}{True\ air\ speed}$$

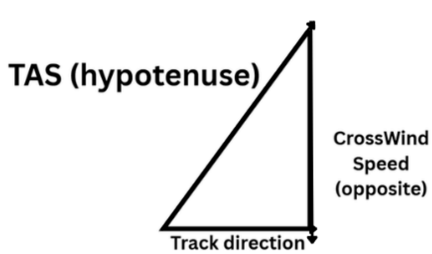

Figure 5: Self-made diagram created using Canva illustrating where the values are positioned in this example.

Solving for crosswind

$Crosswind\ =\ 107kt$ this is known aircraft property

Solving for the True Air Speed

$TAS\ =\ 450kt$ this is known aircraft property

Solving for the wind correction angle

$$sin\ = \frac{opposite}{hypotenuse}$$

$$sin(WCA)\ = \frac{Crosswind}{TAS}$$

$$sin(WCA)\ = \frac{107}{450} =\ 0.2378$$

$$WCA\ = sin^{-1}(0.2378) \approx 13.8°$$

Verification

$$sin^{-1}(x)\ =\ \theta$$

$$sin(\theta)\ =\ x$$

$$WCA\ = sin^{-1}(0.2378) \approx 13.8°$$

$$sin(13.8°)\ \approx\ 0.2378$$

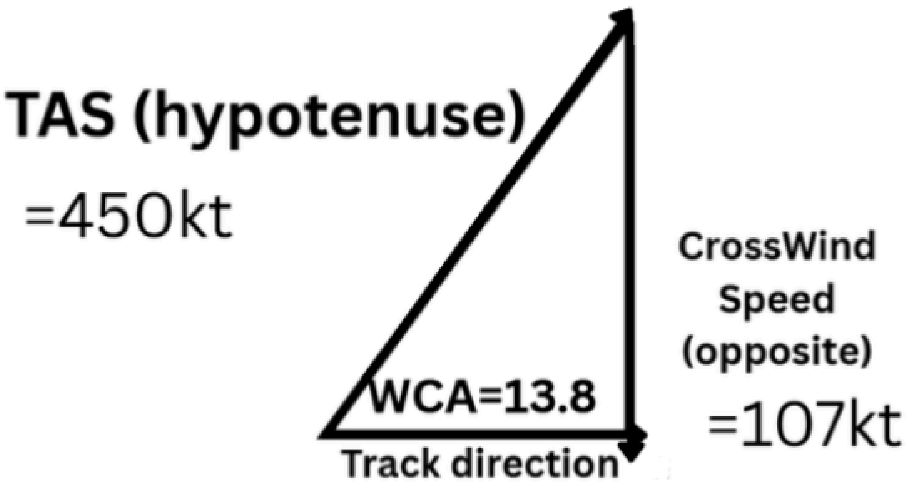

Figure 6: a self made canva diagram illustrating the triangle with the WCA solved

This means the pilot must turn approximately 13.8° into the wind to counteract the sideways drift caused by the crosswind. By applying this wind correction angle, the aircraft will remain aligned with its intended ground track.

Conclusion

Therefore it is observed in figure 6 or in the calculations above that the angle of which the pilot of the aircraft has to adjust to is 13.8 degrees into the cross wind. This value guides the pilot with a new correct heading of 25.8° to stay on track and follow the intended course in order to arrive at the destination safely without any detours. To make sure the value is correct the pilot is also able and often recommended to cross check the value through pre flight planning. The pilot should take notes on what the forecast will be to make sure his values are not too far away from the calculated value. (“Cross-Checking Process”)

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