ASI Calibration

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In another article we discussed the basic concepts behind the workings of an airspeed indicator (ASI), instrument error and the differences between indicated airspeed (IAS), calibrated airspeed (CAS), equivalent airspeed (EAS) and true airspeed (TAS). Now it is time to calibrate the ASI. Surprisingly enough, many airspeed indicators have significant instrument errors. For example, an A-36 that I regularly fly for a flight test course reads from 7–9 knots fast in the clean configuration! That sure makes you feel good, or think you have a much higher headwind.

There are several standard flight test methods for calibrating an ASI. Fundamentally, all the methods attempt to independently determine the true airspeed (TAS) and compare it to the true airspeed determined by correcting the indicated airspeed (IAS) for instrument, compressibility and density effects. The difference between the two values is the position error, i.e., the standard methods attempt to determine the position error. All the standard methods assume that the ASI has been bench calibrated to determine any instrument errors.

Our interest is somewhat different. Beech has determined the position error for us. It is in the POH (Pilot Operating Handbook) as a graph of IAS vs CAS, which indicates that the CAS is approximately $-1/2\%$ less than the IAS in the clean configuration, i.e., quite small. What we want to determine is the instrument error, or more conveniently the combined instrument and position error. Of course, we could pull the ASI and send it out for recalibration; but flight testing is more fun and relatively simple.

One of the classical ASI calibration techniques is to record the time taken to fly between two geographic features a precisely known distance apart while maintaining a constant altitude and a constant heading. The time to fly the reciprocal of the heading between the geographic features is also recorded. The ground speed in each direction is obtained by dividing the known distance by the time. Averaging the ground speeds in the two directions cancels any headwind component and yields the true airspeed.

Now that you have either a handheld or panel mounted GPS, it seems logical to simply fly reciprocal headings and directly average the resulting GPS ground speeds. Well, you are not wrong; but you are also not right! Why?

The answer lies in understanding what you are measuring. Figure 1 is a diagram of the flight path as the aircraft is flown on a heading from point A to point B in a wind of 35.36 kts, which is at a 45 degree angle to the heading. At this angle and velocity the component of the wind in the heading direction results in a tailwind (or headwind) of exactly 25 kts ($V_{\text{wind}} \times \cos 45°$). The crosswind component is also exactly 25 kts.

If you fly from point A to point B at a true airspeed of 100 kts and hold the *heading* corresponding to the direction from A to B constant and start your stopwatch just as the spar cap on the wing passes point A and stop it just as the spar cap passes point B, the time you record will correspond to a ground speed *in the direction from A to B* of exactly 125 kts. In this case you have a 25 kt tailwind. If you fly the reciprocal heading from B to A, you will record a time corresponding to a ground speed *in the direction from B to A* of

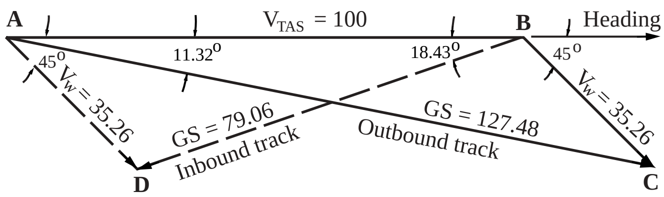

Figure 1. Schematic of the flight path.

exactly 75 kts. In this case you have a 25 kt headwind. Averaging the two ground speeds gives a true airspeed of 100 kts ($(125 + 75)/2 = 100$ kts), as expected.

However, while holding the heading from A to B the crosswind causes the aircraft to follow the ground track from A to C. The speed along the ground track is 127.48 kts. It is this speed that the GPS measures. Similarly, when holding the heading from B to A the aircraft ground track is from B to D, and the GPS shows a ground speed of 79.06 kts. If you average these ground speeds to obtain true airspeed you get ($(127.48 + 79.06)/2 = 103.27$ kts). This value for the TAS is in error by 3.27%!

The error depends on two factors—the wind fraction V_w/V, where V_w is the wind speed and V is the true airspeed, and the wind angle between the wind and the heading, which we will call theta (θ). (It also depends on how accurately the pilot holds the heading, but we'll ignore that.) Figure 2 shows the percentage error for various wind fractions and wind angles. Note that only angles between 0 and 90° are considered, because it does not matter whether the wind comes from the left or right. Examining Fig. 2 immediately shows that using GPS to calibrate the airspeed indicator can lead to serious errors. In an extreme case, with a wind fraction of one at ninety degrees to the heading, the error in the calculated true airspeed is more than 40%! However, Fig. 2 also shows that for small wind fractions, with

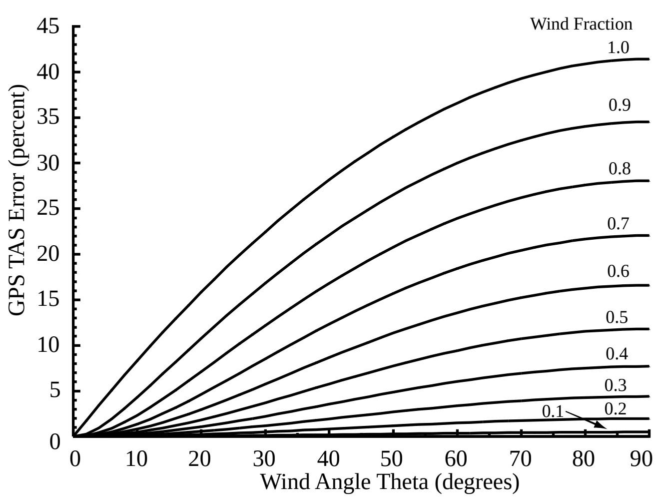

Figure 2. Error in determining the true airspeed using GPS.

the wind at small angles to the heading, the error is much reduced.

Figure 3 shows the lower left-hand corner of Fig. 2 with an expanded scale. The shaded box indicates those conditions under which the GPS calculated TAS error is less than one percent. Examining Fig. 3 immediately shows that for large wind fractions the upwind heading must essentially be directly into the wind. However, for wind fractions up to approximately 0.4 the GPS calculated TAS error is less than one percent if the upwind heading is within 15 degrees of the wind direction.

Finding Wind Direction

Although this technique will allow you to find the true airspeed, a much more accurate and simpler technique called the Horseshoe Heading Technique is available (see the companion article on this website).

However, how do we find the wind direction? First, Figure 3 shows that we want to do this with as small a wind fraction as possible. So, do it early on a calm morning or on a calm evening. It will take about an hour and a half to obtain the data necessary to calibrate the ASI. Here is a simple approximate technique for finding the wind direction within that magic 15 degrees. For various reasons you want to do this at low altitude, say 1000 feet AGL, and you want to do this at a pressure altitude, i.e., you want to set the Kohlsman window in the altimeter to 29.92. Be aware that on a day that is warmer than standard the pressure altitude is lower than MSL and on a cold day higher than MSL. So, on a warm day take care to insure that you are at least 1000 feet AGL. You will need at least one other individual to record data and act as a lookout, and two are better with one assigned only as a lookout. Your head will be inside the cockpit.

From a weather briefing you know the approximate wind velocity and direction within 3000 feet AGL. From observing the direction at takeoff you know the approximate wind direction and velocity at ground level. The wind direction at 1000 feet AGL is probably somewhere between these values.

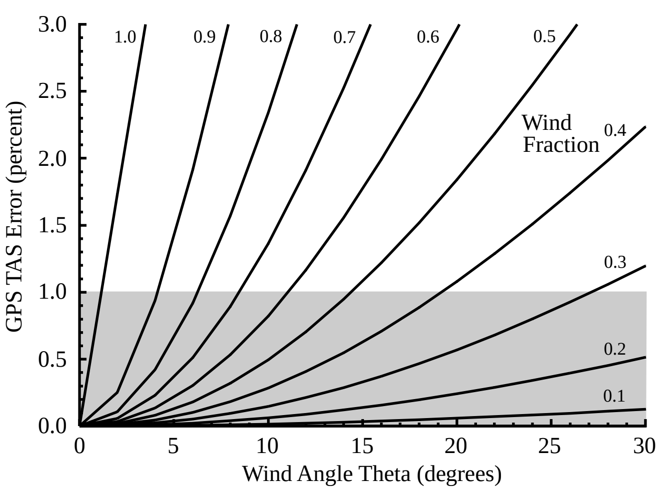

Figure 3. Acceptable wind angle and fraction for acceptable error.

Before takeoff, record the total fuel on board and the total weight of the aircraft. Keep a running estimate of the time and fuel flow during the flight.

With the altimeter set to field elevation, takeoff and climb to 1000 feet AGL and level off.

Reset the Kohlsman window to 29.92.

If a descent is indicated, don't; rather, climb to 1500 feet AGL pressure altitude.

Set the power (MP, RPM and mixture) and leave them set. Record the values.

Carefully align the DG with the magnetic compass while in wings level flight.

If you have an autopilot, use it for the test. Use the altitude hold if you have it.

With the GPS operational, turn to a heading that is into the wind and about 30 degrees right (or left) of the estimated wind direction.

Now, maintaining your altitude within ± 20 feet and the heading within ± 1 degree (I told you your head was going to be in the cockpit), allow the ground speed on the GPS to stabilize. This takes 2–3 minutes. Be patient.

Once the ground speed has stabilized, carefully record ground speed (GS), indicated airspeed (IAS) and outside air temperature (OAT), pressure altitude and the estimated fuel remaining. While determining the wind direction, the IAS, OAT and pressure altitude should remain constant.

Do this in 10 degree heading increments from 30 degees to the right (or left) to 30 degrees to the left (or right) of the estimated wind direction.

The minimum recorded GS represents the estimated wind direction. We now know the wind direction within ± 10 degrees. To increase the accuracy repeat the tests, starting 15 degrees to the right (or left) of the estimated wind direction using 5 degree increments. The results provide an estimated wind direction within ± 5 degrees.

Note that many GPS receivers incorporate a function that allows determining both the wind direction and velocity while in flight. You can use this function to estimate the wind direction and velocity instead of the above procedure. In using this function care must be taken to read the indicated airspeed (IAS) from the airspeed indicator and the heading from the directional gyro carefully to get reasonably accurate results. It is also important to allow the ground speed to stabilize. However, they do simplify the determination of the wind direction. If you use this method, you should confirm the results by determining the wind direction and velocity using at least three headings.

Getting the Data

We are now ready to do the ASI calibration runs.

Without changing the power settings, realign the aircraft on a heading directly into the estimated wind. Allow the airspeed to stablize. Record manifold pressure, RPM, ground speed (GS), indicated airspeed (IAS) and outside air temperature (OAT), pressure altitude and the estimated fuel remaining.

Execute a teardrop-course reversal and align the aircraft with the exact reciprocal of the upwind heading. Again, record manifold pressure, RPM, ground speed (GS), indicated airspeed (IAS) and outside air temperature (OAT), pressure altitude and the estimated fuel remaining.

The average of the the GPS ground speeds is the true airspeed derived from the GPS ground speeds, or $\mathrm{TAS}_{\mathrm{GPS}}$. Vary the power setting to obtain approximately 10 kt increments in airspeed and repeat the runs over the range of airspeeds desired, say 100–160 kts. Once the data is obtained, the rest of the work can be done on the ground.

Finding the Error

Using the chart in the POH correct the IAS to calibrated airspeed (CAS). Typically, this is a very small correction. Assuming that CAS equals equivalent airspeed (EAS), convert the EAS to TAS. This is true airspeed derived from the IAS, or $\mathrm{TAS}_{\mathrm{IAS}}$. Using the true airspeed derived from the GPS ground speeds as the 'truth data', the difference $\mathrm{TAS}_{\mathrm{GPS}} - \mathrm{TAS}_{\mathrm{IAS}}$ is the ASI instrument error. Considering the accuracy of the data and especially of the E6B, if the difference is less than about 2 kts, you can consider the ASI accurate. On the other hand, if it is more than say 4–5 kts you might want to send it out for calibration. Don't throw away the data, we may use it later.