Experiment # 3 Cessna 182 Airspeed Calibration using GPS
Data Card

Objectives

To determine the:

1. The true airspeed (TAS) of the aircraft at the test density altitude (in MPH).
2. Airspeed Calibration Chart for the test aircraft. Specifically find the static position error ΔV_{pc} as a function of instrument corrected airspeed.

Instrumentation

1. Airspeed indicator
2. Altimeter (set to 29.92" Hg)
3. Outside Air Temperature
4. Panel-mounted GPS with groundspeed readout

Stabilized Flight Techniques

1. Stabilize the aircraft at a selected pressure altitude (4500' nominal) on a magnetic heading of 180 degrees (South) at the first test indicated airspeed.
2. Record the Outside Air Temperature (OAT)
3. Allow at least 15 seconds for the GPS groundspeed to stabilize.
4. Record groundspeed readout on panel-mount GPS (note the units of the output)
5. Turn to a magnetic heading of 090 degrees (East) and repeat steps 3 through 4 at the same indicate airspeed (maintain constant pressure altitude).
6. Turn to a magnetic heading of 360 degrees (North) and repeat steps 3 through 4 at the same indicate airspeed (maintain constant pressure altitude).
7. Turn to a magnetic heading of 270 degrees (West) and repeat steps 3 through 4 at the same indicate airspeed (maintain constant pressure altitude).
8. Turn to heading of 180 and stabilize at a second test indicated airspeed, while maintaining the same pressure altitude.
9. Perform steps 2 through 8 for the second test indicated airspeed.
10. Repeat steps 2 through 8 for each successive test indicated airspeed

Analysis Methods

Follow the analysis procedures described in the accompanying paper by Greg Lewis of the NTPS.

Recall the definitions of the various airspeeds (instrument corrected, calibrated, equivalent and true).

Vic =Vi+ΔVic (assume ΔVic=0)

Vcal =Vic+ΔVpc where ΔVpc is the static position error you are to find

Ve =Vcal+ΔVc where ΔVc is the scale altitude correction

Vt =Ve/(sqrt(σ)) where s is the density ratio for the test condition

If the instrument correction is other then zero, the procedure you are following will calculate ΔVic + ΔVpc.

Magnetic Variation at Lafayette, IN: +3 degrees (3 deg W)						
Compass Deviation		Aircraft: Cessna 182P			N# N182PU	
For	360	30	60	90	120	150
Steer	001	029	061	091	121	151
For	180	210	240	270	300	330
Steer	181	210	241	269	301	332

GPS Airspeed Calibration Data Card						
Magnetic Variation:			Instrument System:			
Aircraft:	N#			Date:		
Test #	1	2	3	4	5	6
V_{IAS} Aim Indicated Airspeed (mph)	80	90	100	110	120	130
h_p Pressure Altitude of test (ft)						
T OAT at beginning of test (deg F)						
GPS Groundspeed on 180^0 leg						
GPS Groundspeed on 090^0 leg						
GPS Groundspeed on 360^0 leg						
GPS Groundspeed on 270^0 leg						

Results

Your results should be plotted as a function of indicated airspeed as was done in Figure 3 of the paper by Greg Lewis shown below.

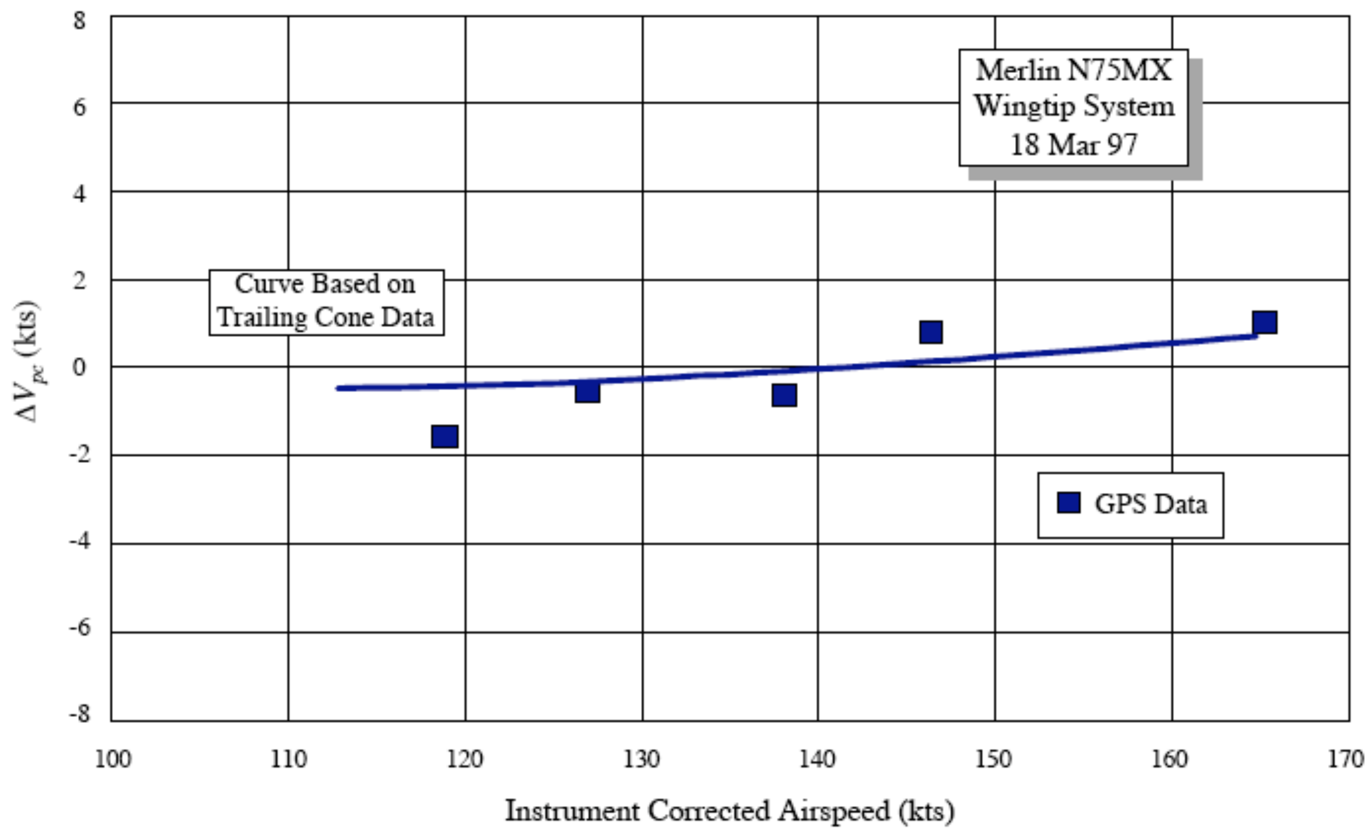

Figure 3 GPS Data

A Flight Test Technique Using GPS For Position Error Correction Testing

by

Gregory V. Lewis

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Many different flight test techniques (FTT's) have been espoused that use the precise ground speed available from Global Positioning System (GPS) units to determine position error corrections (PEC) in new or modified aircraft. Most of the proposed FTT's do not consistently give good results for various reasons. The purpose of this short paper is to describe an FTT that uses GPS for determining PEC which has been shown to consistently give good results.

There are several advantages of using GPS for determining PEC. No special aircraft equipment is needed such as fitting the aircraft with a trailing cone or bomb. Sufficiently precise hand held GPS units can be obtained for under $500. There is no need for a second, precisely calibrated, compatible, pace aircraft. A surveyed ground course is not required. Flying close to the ground is not necessary, allowing tests to be done safely at speeds just above stall speed. There is no requirement for RADAR tracking and the attendant lengthy (and costly) post flight data processing. The only drawback to date has been the unacceptable high data scatter seen when using the various FTT's that use GPS.

Before explaining the FTT proposed in this paper, previously used PEC FTT's using GPS will be described, along with some comments on their drawbacks and probable error sources:

1. The *National Test Pilot School* (*NTPS*) has taught the use of GPS in a flight test technique similar to the traditional ground course method[1]. For this technique, the pilot flies directly into the wind and records the GPS ground speed. Then the same point is flown in the opposite direction and the two ground speeds are averaged to obtain a true airspeed. The true airspeed is compared to the indicated airspeed corrected to true. The difference is ΔV_{pc}. Unlike the traditional ground course, the heading must be directly into and away from the wind since the unknown wind velocity will result in a unknown drift angle and contribute to an unknown component of ground speed over and above the true airspeed. The practical problem of determining the wind direction has been the major contributor to errors. Flying different directions until the ground track was equal to the aircraft heading has been the suggested method of ensuring that the tests were flown directly into and away from the wind. In practice, this has not been found to be sufficiently accurate.

2. The United States Air Force Test Pilot School has developed a method[2] similar to that used by *NTPS*. First the wind direction is determined as above. Then the aircraft is flown perpendicular to the wind in both directions. Noting both the ground speed and the drift angle (difference between aircraft heading and GPS ground track) gives true airspeed and wind velocity. The advantage of this method over the *NTPS* method is that it is less susceptible to small changes in wind velocity between test runs. The disadvantage is the same that affects the previous method: determining wind direction.

3. A third technique has been used by some flight test personnel in the Federal Aviation Administration (FAA). This method is most like the traditional ground course. A waypoint approximately 8,000 nm away is entered into the GPS unit. The aircraft is then stabilized on the test airspeed and flown directly towards the waypoint. As the distance to the waypoint changes to 8,000 nm, a stopwatch is started. At 7,998 nm the stopwatch is stopped. Reversing direction, time is again recorded for the same 2 nm. Calculating ground speed from the time and distance on each leg separately, the two ground speeds are averaged to negate the effect of wind. Drift is not a problem since by flying towards and away from such a remote waypoint, the aircraft's speed between the two distance rings result in nearly parallel lines, just as in the traditional ground course method. The major error source with this FTT is the error introduced by update rates on the display of distance. Most commercial hand held units update the distance at an interval of one to three seconds. The method has given good results at low speeds where the 1 to 3 second error is not excessive. But at higher speeds the error is proportionally higher due the shorter times to cross the two nm interval. This could be compensated for by flying progressively larger intervals, but this is a disadvantage both due to the time required to get good data points and to the likelihood of having the winds change over the larger distances, negating the basic principle on which the ground course data reduction is based.

4. A fourth method was described in an article in *KITPLANES*[3] magazine. In this method the same indicated airspeed is flown on three perpendicular ground tracks. Assuming the wind and true airspeeds are constant on all three legs, the wind velocity, wind direction, and true airspeed can be uniquely determined. The only disadvantage seen with this method is the need to fly orthogonal ground tracks. The article describing the method suggests flying low over perpendicular land marks, negating one of the benefits of GPS methods in general - not being constricted to low altitude or a specific geographic location.

The method proposed in this paper is a slight variation on method four above. Three orthogonal headings are flown at the same indicated airspeed and altitude. The ground speed is read about 15 seconds after the indicated airspeed is stable, allowing time for the computed ground speed to stabilize. From the three ground speeds the wind velocity, wind direction, and true airspeed can be uniquely determined (three equations and three unknowns) as shown in Figure 1.

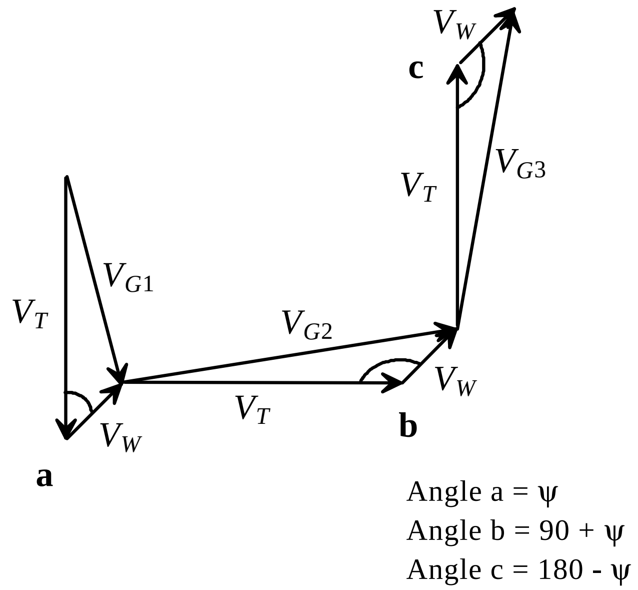

Figure 1 Ground Speed Components

The equations for solving for these variables are as follows:

a. Wind Direction $$\Psi = \tan^{-1}\left[\frac{-V_{G1}^2 + 2V_{G2}^2 - V_{G3}^2}{V_{G3}^2 - V_{G1}^2}\right]$$

b. Wind Velocity $$V_W = \tfrac{1}{2}\left[V_{G3}^2 + V_{G1}^2 \pm \sqrt{\left(V_{G3}^2 + V_{G1}^2\right)^2 - \left(\frac{-V_{G1}^2 + 2V_{G2}^2 - V_{G3}^2}{\sin\Psi}\right)^2}\right]^{\frac{1}{2}}$$

c. True Airspeed $$V_T = \sqrt{\frac{V_{G3}^2 + V_{G1}^2}{2} - V_W^2}$$

The choice of + or - in the wind velocity equation should be made so that the total quantity within the radical is positive. The resulting angle for the wind direction is the angle clockwise from north assuming the original heading was south. For other initial headings, the wind angle must be adjusted. A free Visual Basic® program for Microsoft Windows® is available from the *NTPS* internet web site (http://www.ntps.com) that will perform the above calculations.

To demonstrate the practicality of the method described, it was flight tested on a medium transport aircraft (Merlin III) fitted with a trailing cone and a Kiel tube during a training course with the Canadian Armed Forces at Cold Lake, Canada. Confidence in the trailing cone/Kiel tube data was very high as differential pressure gauges were used to measure the static and dynamic pressure errors directly. At the same time, ground speeds were recorded from a Garmin® 95 hand held GPS receiver. Data reduction was completed using the above equations to determine the true airspeed and then traditional ground course data reduction was used to find the PEC. The results from the two different methods are shown graphically in Figures 2 and 3. The standard deviation of the trailing cone data from the fitted curve shown in Figure 1 is 0.38 kts. The standard deviation of the GPS data from the same trailing cone curve is only slightly higher, 0.53 kts. The generally excellent correlation between the two methods validates the GPS method. Table 1 shows the consistency of the wind determination using GPS. The data was taken over a two hour period as other training objectives were being accomplished during the three flights. While knowing the wind direction and velocity isn't necessary to determine the PEC, a review of the wind data can help to determine if the points are reasonable and perhaps show which points may not be good. The fifth data point was eliminated as being unreasonable. The deviation of ΔV_{pc} from the smooth curve in Figure 2 for the fifth point was 16 times as large as the standard deviation for the other 5 points. That variance plus the unlikely winds for the point were used as justification for eliminating the data point.

Wind Speed (kts)	Wind Direction (degrees true)	Approximate Time of Day
17.4	283	9:30
15.5	286	9:40
13.5	285	10:15
12.5	286	10:25
1.1	120	10:50
11.3	252	11:00

Table 1 GPS Determined Winds

Extension to different aircraft and to higher speeds should not affect the validity of the GPS method. If the test aircraft is being flown at much higher speeds then the method could still be used, most efficiently perhaps by using a slower aircraft with GPS to do a wind survey in the test area. If the winds are accurately known, the test aircraft only has to do one pass per point noting ground speed and track or heading. Then combining the wind with the ground speed of the test aircraft, accurate true airspeed can be calculated.

References:

1. *Professional Course Flight Test Technique Demonstrations*, National Test Pilot School, Jan 1997.

2. AFFTC-TR-95-76, "Investigation of Using Global Positioning System for Air Data System Calibration of General Aviation Aircraft (Have Pacer II)", Captain William D. Bailey, Jan 1996.

3. "Is Your Speed True?", David Fox, *KITPLANES*, February, 1995

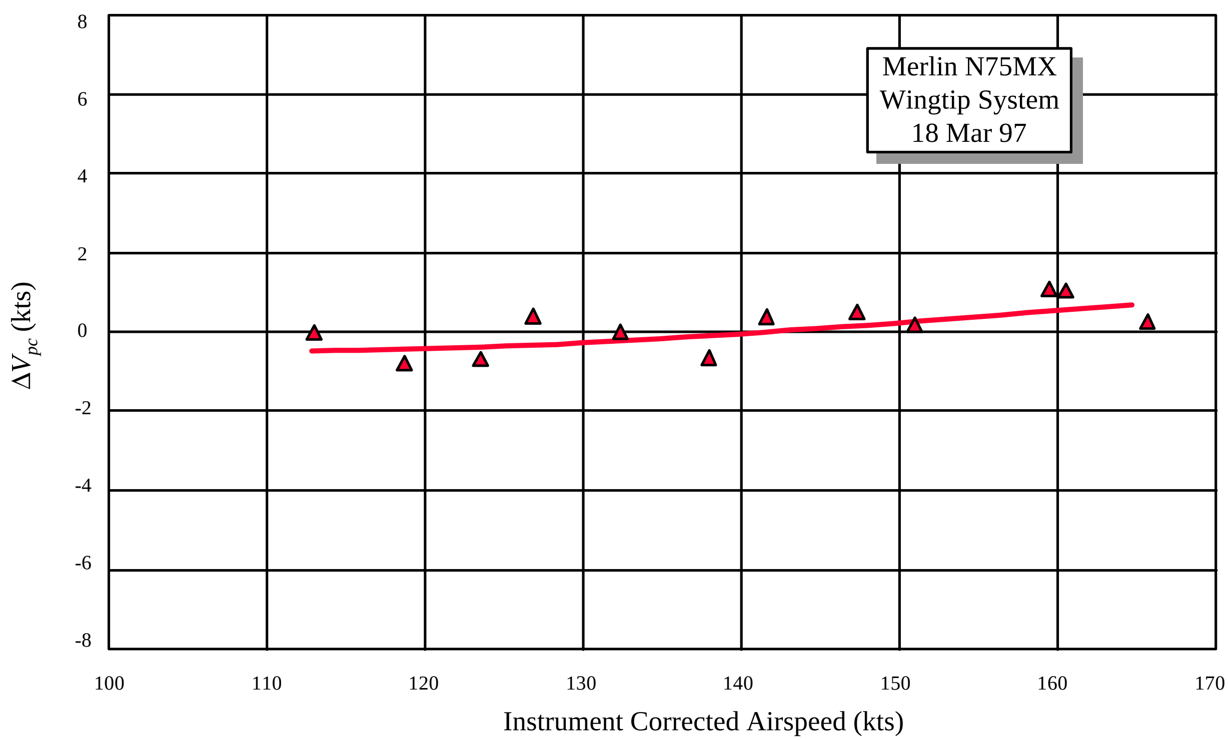

Figure 2 Trailing Cone Data

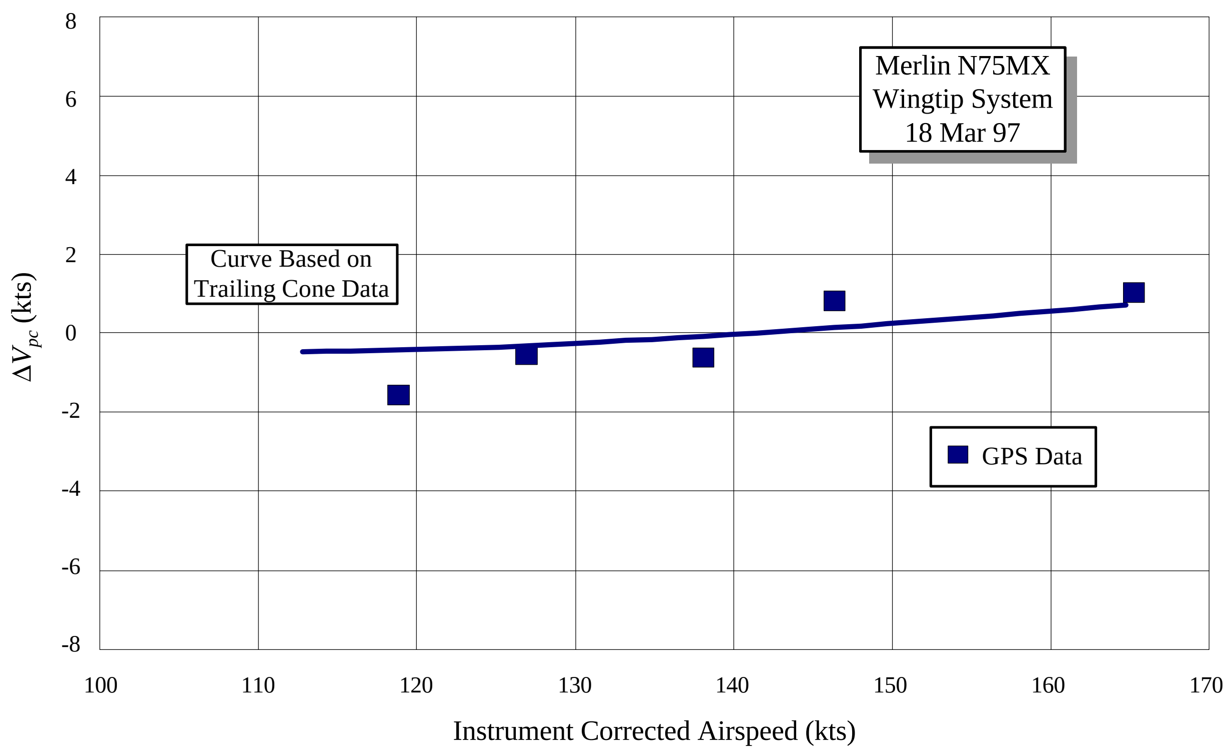

Figure 3 GPS Data