USING GPS TO DETERMINE PITOT-STATIC ERRORS

Gregory Lewis
National Test Pilot School
Mojave, CA
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Introduction

This flight test technique (FTT) is another way to do the traditional ground course FTT for pitot-statics testing found in any flight test handbook (ref. 1, for example). The procedures detailed below are a variation of methods previously documented (ref. 2 and 3) in 1995 and 1997. This particular variation was laid out in an unpublished paper by Doug Gray (ref. 4) in 1998. The procedures detailed in this paper have been used in civil certification projects and have also been given to the FAA Small Aircraft Directorate for inclusion in FAA Advisory Circular 23-8B (ref 5). Lastly, as an historical note, the same concept (obviously without GPS and computer spreadsheets) was used by NACA in 1927 to measure the true airspeed of a dirigible airship, the U.S.S. Los Angeles (ref. 6).

The advantage of this method over the traditional ground course FTT is that it doesn't have to be flown near the ground, thus it can be done at very slow speeds as long as the aircraft can be held stable at constant speed, altitude and heading. This method can also be done at higher speeds with accuracy similar to low speed points.

Basic Concept

To do this method, at least three legs are flown at the same airspeed and altitude. Using a handheld GPS, note ground speed and ground track on each leg. Assuming the aircraft's true airspeed and the wind speed and direction are constant on each of the three legs, then three equations in three unknowns can be solved giving wind speed, wind direction, and true airspeed. The solution can be understood by realizing that the ground speed vector (magnitude and direction) is the vector sum of the wind and the true airspeed. This is graphically shown in Figure 1. If three ground track vectors are placed with the heads at the same point, then a circle drawn through the tails of the three vectors will have a radius equal to the true airspeed and the difference between the center of the circle and the three heads will be the wind speed and direction.

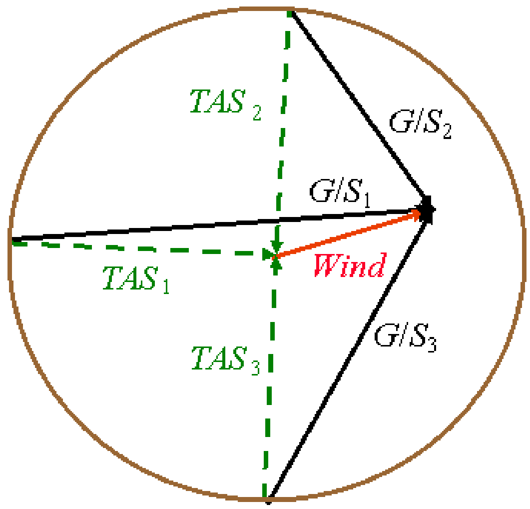

Figure 1. Vector Analysis

The solution of the equations is easily accomplished using a computer spreadsheet. The general solution has been shown by Doug Gray in his paper (ref. 3). A downloadable Excel solution, "GPS_PEC.xlw" is available on the National Test Pilot School's website: www.ntps.edu/downloads.htm.

Pitot-Static Error Determination

The GPS-derived true airspeed is then used to determine the pitot-static error by comparing it to the indicated speed, corrected to true, using the following relationship:

$$V_i + \Delta V_{ic} + \Delta V_{pec} + \Delta V_c = V_{true} * \sqrt{\sigma}$$

where:

V_i is the indicated speed on each of the three legs
ΔV_{ic} is the calibration instrument correction for the airspeed indicator
ΔV_{pec} is our unknown position error correction
ΔV_c is the scale altitude correction factor (insignificant below 5,000 ft and 250 kts)
V_{true} is the true airspeed determined from the three GPS legs
σ is the test day density ratio

A spreadsheet in the above mentioned Microsoft Excel workbook (GPS_PEC.xlw) will do the above calculations. Altitude error, ΔH_{pec}, is calculated assuming all of the error is in the static port, exactly as is done in the traditional ground course method.

Inflight Procedures

To fly the FTT:

1. Perform a stable trim shot at the desired airspeed and configuration. Pick an altitude and geographic location where you would expect steady wind.
2. Once stable, note everything that would affect true airspeed (indicated airspeed, pressure altitude, and outside air temperature).
3. After allowing sufficient settling time (perhaps 10 seconds after the aircraft is stable, no change in ground speed or track), record the GPS ground speed and track.
4. Turn 60^0 to 120^0 and repeat step 3 at the same airspeed and altitude. Small changes in altitude are much preferred over any change in airspeed. A one knot speed error will produce one knot or more error in true airspeed, but a 100 ft error in altitude will have a relatively insignificant error on true airspeed. A constant ground track is important.
5. Turn again and repeat at the same airspeed and altitude. Three legs are required to complete one data point (one speed/configuration). If four legs are done at the same conditions then the data can be averaged taking four legs, three at a time, four different ways.

GPS Receiver Equipment

There is no technical requirement to use a specially certified or differential GPS. The indication of accuracy of the derived true airspeed can come from the repeatability of the derived wind vector. If several points are flown at different speeds (each "point" being at least three legs at the same speed) and give the same derived wind speed and direction, then a high degree of confidence can be placed in the results. If on the other hand, regardless of how sophisticated the GPS equipment is, if the derived wind vector is not consistent, then the data can not be relied upon. If the wind is inconsistent the reason could be one of several things – a variable wind or temperature, failure to hold airspeed and/or heading constant during the data gathering process, changing airspeed between legs of a point, or even poor GPS satellite coverage. Figure 2 shows examples of calculations of GPS-derived true airspeeds on a certification program and the calculated wind stayed very nearly constant over the approximate 30 minute data gathering period. The average wind speed varied less than one kt (18.1 to 18.8 kts) and the direction changed a maximum of three degrees. The pitot-static errors derived from those calculations are shown in Figure 3 and compare favorably to other data gathered from a traditional ground course in the same aircraft. Lastly, Figure 4 shows data from a different certification project comparing GPS results to those obtained with a wing mounted boom. Both Figures 3 and 4 illustrate the type of accuracy possible using the GPS FTT. The data shown in both of these figures were taken using a handheld Garmin 92 GPS unit.

	Point 1		Point 2		Point 3		Point 4	
	Vg	Track	Vg	Track	Vg	Track	Vg	Track
	116	236	75	221	43	204	58	204
	131	135	92	117	64	109	77	115
	153	46	111	41	79	40	95	42
	134	316	90	315	61	318	75	316
Vtrue	**134.0**		**91.5**		**60.7**		**75.6**	

	Vg 1		Vg 2		Vg 3		Vwind		Vtrue	
	(kts)	(deg)	(kts)	(deg)	(kts)	(deg)	(mph)	(deg)	(mph)	
1	116	236	131	135	153	46	18.9	219	134.2	
	131	135	153	46	134	316	19.4	221	133.7	
	153	46	134	316	116	236	18.7	223	134.3	
	134	316	116	236	131	135	18.1	221	133.6	
							18.8	**221**	**134.0**	**Average**
									0.4	**Std Dev**

	Vg 1		Vg 2		Vg 3		Vwind		Vtrue	
	(kts)	(deg)	(kts)	(deg)	(kts)	(deg)	(mph)	(deg)	(mph)	
2	75	221	92	117	111	41	18.4	209	93.1	
	92	117	111	41	90	315	20.9	219	90.1	
	111	41	90	315	75	221	18.2	229	93.0	
	90	315	75	221	92	117	14.9	220	89.9	
							18.1	**219**	**91.5**	**Average**
									1.8	**Std Dev**

	Vg 1		Vg 2		Vg 3		Vwind		Vtrue	
	(kts)	(deg)	(kts)	(deg)	(kts)	(deg)	(mph)	(deg)	(mph)	
3	43	204	64	109	79	40	18.2	217	60.8	
	64	109	79	40	61	318	18.4	218	60.6	
	79	40	61	318	43	204	18.2	219	60.8	
	61	318	43	204	64	109	17.9	218	60.6	
							18.2	**218**	**60.7**	**Average**
									0.2	**Std Dev**

	Vg 1		Vg 2		Vg 3		Vwind		Vtrue	
	(kts)	(deg)	(kts)	(deg)	(kts)	(deg)	(mph)	(deg)	(mph)	
4	58	204	77	115	95	42	18.7	213	76.5	
	77	115	95	42	75	316	20.1	218	75.0	
	95	42	75	316	58	204	18.9	222	76.1	
	75	316	58	204	77	115	17.2	219	74.8	
							18.7	**218**	**75.6**	**Average**
									0.9	**Std Dev**

Figure 2. Example GPS-Derived Wind and True Airspeed

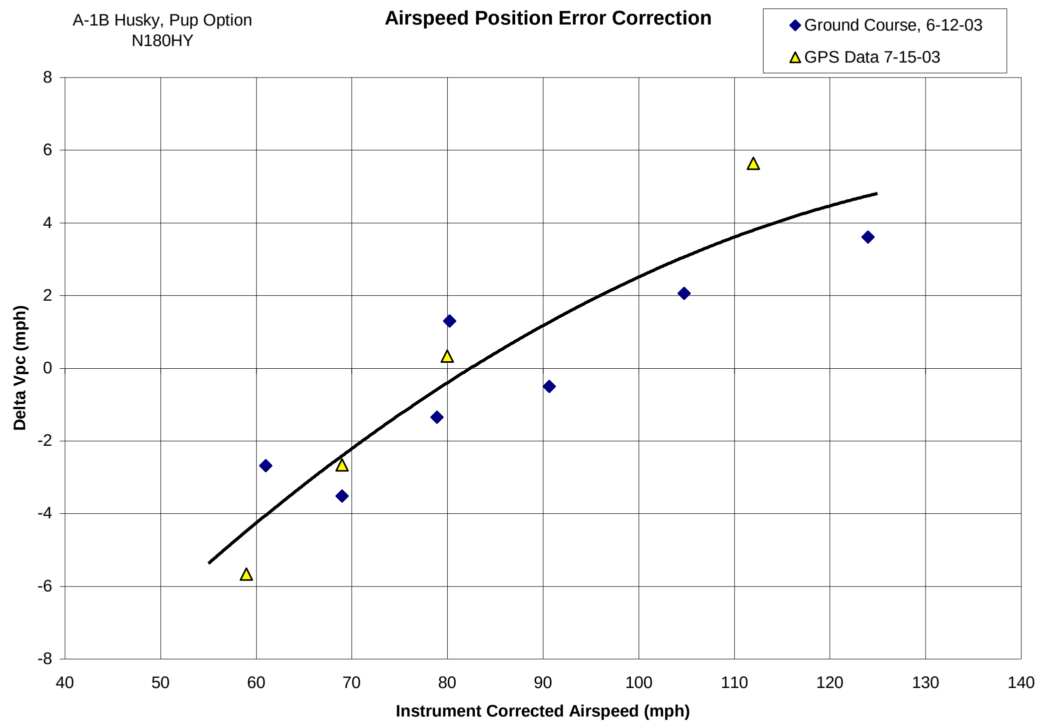

Figure 3. Example PEC Data

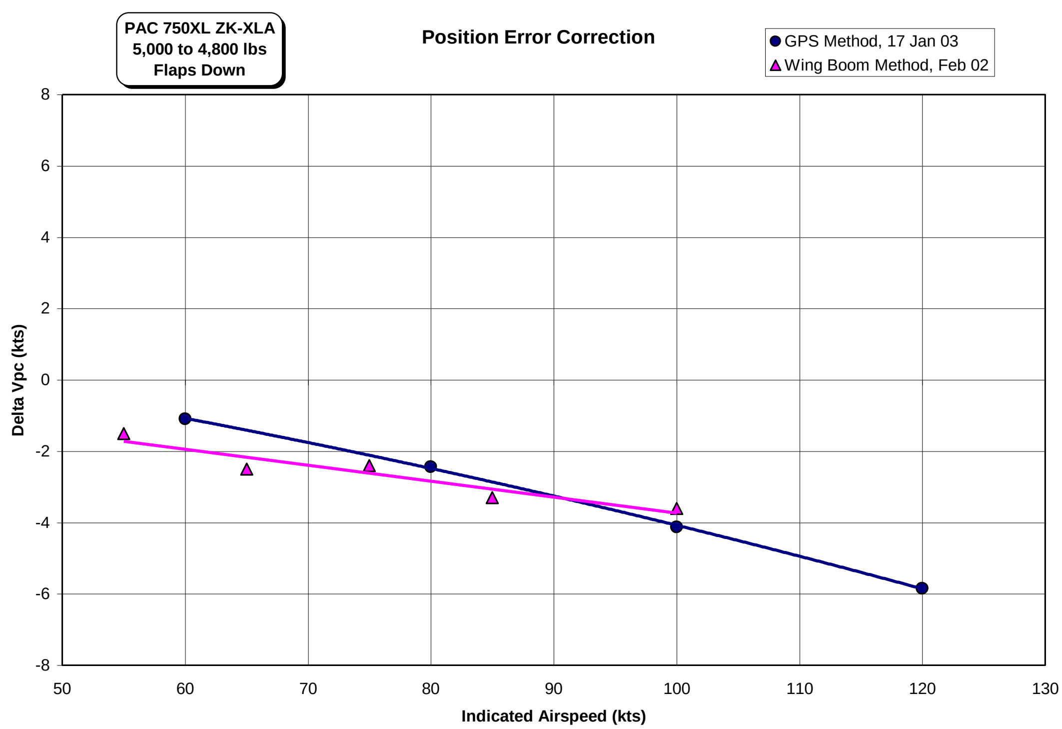

Figure 4 Second Example of PEC Data

References

1. National Test Pilot School Professional Course Series Textbooks, Vol. II, Aerodynamics for Flight Testers; Chapter 7, Pitot-Statics, Mojave, California, 1999.
2. "Is Your Speed True?" David Fox, *KITPLANES*, February, 1995.
3. "A Flight Test Technique Using GPS for Position Error Correction Testing", Gregory Lewis, *COCKPIT*, Society of Experimental Test Pilots Quarterly Publication, Jan-Feb-Mar, 1997.
4. "Using GPS to Accurately Establish True Airspeed", David Gray, unpublished paper available at www.ntps.edu/downloads.htm, June 1998.
5. Draft FAA Advisory Circular 23-8B, Flight Test Guide for Certification of Part 23 Airplanes.
6. NACA Report 318, 1927. Speed and Deceleration Trails of the U.S.S. Los Angeles.