# Use of GPS for Determining Free Flight Performance

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**Key words**: GPS, paraglider, performance curve.

## ABSTRACT

Time aloft and distance travelled in free flight with a paraglider is determined by three factors: weather conditions, pilot skill and paraglider performance. The latter factor can be accurately determined and represented in a performance curve using sensors (a variometer and a wind speed indicator or speed probe) calibrated by GPS receivers. A test flight was carried out with a paraglider which was launched to an altitude of 750m using a stationary winch. After release, a variometer and speed probe logged horizontal velocity and vertical velocity data respectively for different angles of attack of the paraglider airfoil. From this data a performance curve was constructed. The performance curve is very useful to paraglider pilots because it allows for the correct choice of airspeed to maximize time aloft and distance travelled in particular wind and lift/sink conditions.

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## 1. INTRODUCTION

Free flight (unpowered flight) with paragliders is a popular recreational activity. Time aloft (often many hours) and distance travelled (often tens of kilometres) is determined by weather conditions, pilot skill and paraglider performance. To accurately determine paraglider performance, GPS receivers were used to calibrate sensors carried by the pilot to measure horizontal velocity and vertical velocity. From this horizontal and vertical velocity data, a performance curve was constructed.

## 2. CALIBRATION OF THE SENSORS

In order to produce an accurate performance curve, both the sensor used to measure vertical velocity and the sensor used to measure horizontal velocity had to be calibrated.

### 2.1 Variometer

The sensor used to measure vertical velocity is a variometer (vario). It is contained in a small unit having dimensions of approximately 3 cm x 10 cm x 15 cm. The key component in a variometer is a sealed chamber; small changes in pressure inside this chamber caused by changes in altitude are converted into vertical (upward or downward) velocities. Variometers are calibrated at the factory but one should not expect the factory calibration to be much better than +/- 5%.

To calibrate the vario (a Brauniger IQ Competition vario; see Brauniger 2002), a Trimble 4000 series geodetic-quality receiver and antenna (see Trimble 2002) were used. GPS time-tagged data was logged at 1 second intervals for a vehicle driven on a road down a 200m high hill. The data was analyzed using the GRAFNAV software package. Simultaneously, time-tagged data was also logged at 1 second intervals on the vario. This data was analyzed using software provided by Brauniger. Direct comparison of the two data sets produced a scale factor correction to the vario of 1.03. This correction was later applied to the data gathered in the performance test.

### 2.2 Wind Speed Indicator

The sensor used to measure horizontal velocity is a wind speed indicator (speed probe). (Note that for the performance test results given in Section 4., horizontal velocity is horizontal velocity in the air mass rather than horizontal velocity relative to the ground, thus a speed probe is used instead of a GPS receiver. A GPS receiver could only be used for the performance test described later if the test took place when the horizontal wind velocity was zero. Zero-wind conditions rarely occur, especially if altitude is also a variable, as is the case in a performance test.) The Brauniger speed probe (see Brauniger 2002) consists of a small propellor and cowling (diameter approximately 2 cm) mounted on a 20 cm long arm. A shuttlecock on the end of the arm keeps the speed probe pointed into the wind when it is suspended below the pilot by a small data cable attached to the vario. The calibration of speed probes is known to be in error by as much as +/- 10% (Goldsmith 1998).

To calibrate the speed probe, a Garmin 12 hand-held GPS receiver (Garmin 2002) was used. GPS time-tagged data was logged at 1 second intervals for a vehicle driven 2.5 km on a nominally level road. This GPS data was analyzed using software provided by Garmin. Simultaneously, time-tagged data was also logged at 1 second intervals from the speed probe. In order to verify zero-wind conditions during the calibration, the 2.5 km road was driven in both directions. Direct comparison of the two data sets produced a scale factor correction to the speed probe of 1.08. This correction was later applied to the data gathered in the performance test.

## 3. PERFORMANCE TEST

The setup for the performance test is shown in Figure 1. On the left side of the figure the stationary winch is shown schematically as a rectangular box fixed to the ground. The winch is actually a front wheel drive vehicle with the driver’s side front wheel raised above the ground and replaced with a winch reel. The vehicle parking brake is set, the passenger side rear wheel is blocked, and a traction pad is placed beneath the passenger side front wheel; all of this forces power to be delivered to the winch reel when the vehicle’s automatic transmission is engaged and the foot brake is released. In idle, the winch exerts a force of about 100 pounds (450 Newtons) on the towline which is just sufficient to tighten the towline attached to the pilot.

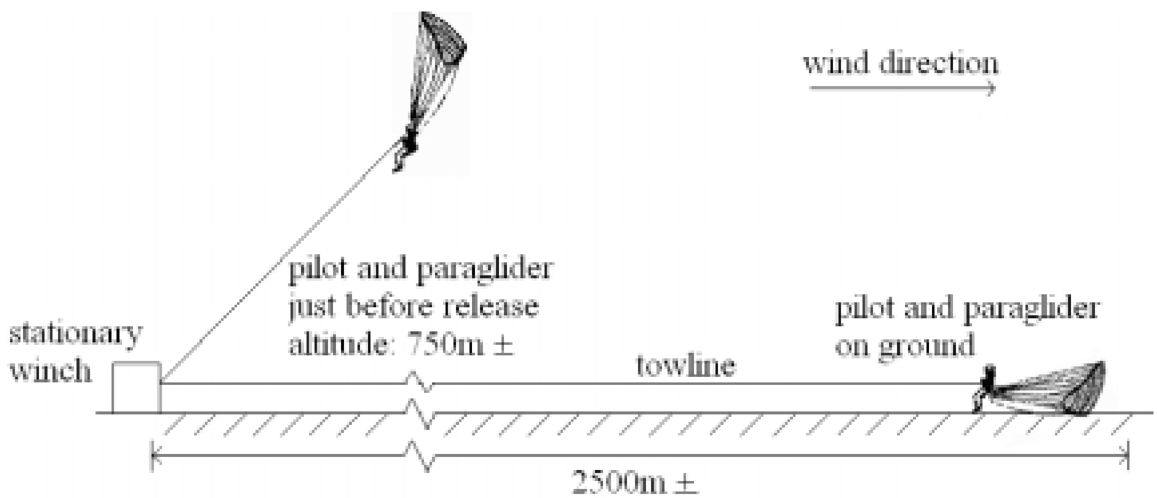


Figure 1 – Tow Launching with a Stationary Winch

To launch the pilot and paraglider, the engine is throttled up slowly and smoothly with a hand throttle. There are a number of safety features, the most important of which are:

(a) winch operator and pilot are in continuous cell phone contact (both cell phones have no-hands headsets) with the pilot instructing the winch operator to increase, hold or reduce the towline force;
(b) the towline has a weaklink at the pilot's end set at a predetermined breaking force, e.g. 250 pounds; and,
(c) the winch reel has a clutch which is set to slip and thus limit the towline force, e.g. to a maximum of 200 pounds.

After release by the pilot, a towline parachute deploys near the end of the line and the winch operator reels the entire length of line back onto the reel. Detailed information on tow launching equipment and procedures is given in Pagen and Bryden (1998).

Once the paraglider is in free flight, the performance test can begin. In the performance test the pilot varies the angle of attack of the paraglider airfoil. This is done by applying both left and right brake an equal amount with hand toggles connected to the trailing edge of the paraglider. Application of the brakes will increase the angle of attack, increase the downward vertical velocity (sink rate), and decrease the horizontal velocity. Angle of attack can also be varied by pushing on the speed bar with both feet. The speed bar is connected to risers and lines attached to the leading edge of the paraglider. Application of the speed bar will decrease the angle of attack, increase the sink rate, and increase the horizontal velocity.

A performance test was carrried out with a paraglider launched to an altitude of 750m and released into free flight as described in the previous paragraphs. Sink rate data was logged by the vario and horizontal velocity data was logged by the speed probe for the entire duration of the test. The data rate for both sensors was 1 measurement per second.

## 4. PERFORMANCE TEST RESULTS

The performance test results for the paraglider are shown in Figure 2 in the form of a performance curve. The performance curve is a plot of horizontal velocity versus vertical velocity (sink rate) for different angles of attack. For our test, we chose three key angles of attack as follows:

(a) 2/3 brake (the data point 28.4 km/hr, -1.72 m/sec);
(b) trim (no brake, no speed bar) (the data point 42.3 km/hr, -1.43 km/hr); and,
(c) full speed bar (the data point 48.8 km/hr, -2.19 m/sec).

Approximately 50 sink rates and 50 horizontal velocities were used to compute each data point; standard deviations were +/- 0.05 m/sec for sink rates and +/-0.2 km/hr for horizontal velocities.

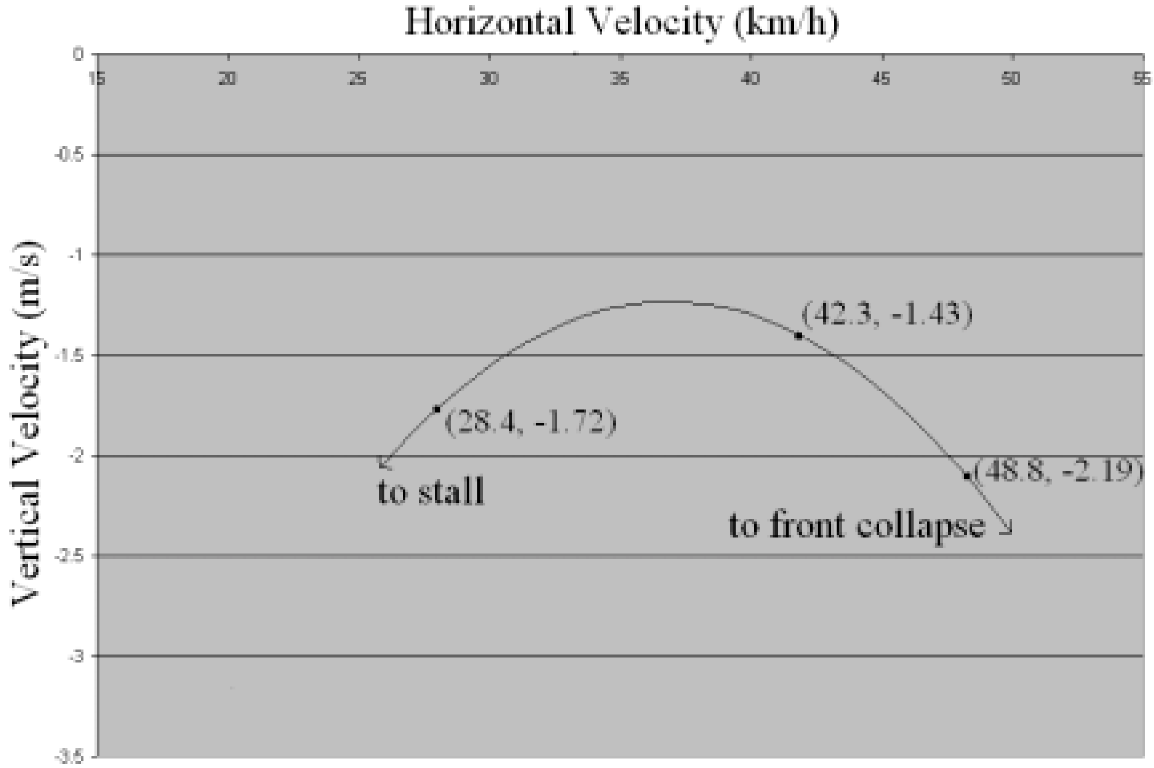


Figure 2 – Performance Curve for the Paraglider

The shape of the performance curve for any airfoil in free flight (unpowered flight) can be approximated by a parabola (Pagen 1990). With three data points, as in our test, a parabola fits exactly.The computed constants (a,b,c) of the parabola in Figure 2 are (-0.006 754, 0.4984, -10.43). From the analytical solution of the performance curve, other important information can easily be computed. Minimum sink occurs at the point the parabola attains a maximum value; this is at 1.24 m/sec sink with a horizontal velocity of 36.9 km/hr. Maximum glide occurs at the point where a straight line from the origin is tangent to the parabola; this is at 1.27 m/sec sink with a horizontal velocity of 39.3 km/hr which produces a best glide of 8.57 units horizontal motion to 1 unit vertical motion.

It is important to note that the performance test has to be carried out in atmospheric conditions which produce no lift or sink. One set of conditions which will produce no lift or sink are a snow-covered, flat-land site, high pressure weather system and an air temperature less than zero degree Celcius. These were the conditions which existed for the performance test results shown in Figure 2.

## 5. POSSIBLE FUTURE WORK

### 5.1 Following are some Areas in which the Authors Would Like to do Further Work:

(a) Determination of the best method to correct the test results to a standard air density, i.e. a standard atmospheric temperature, pressure and water vapour content.

(b) Determination of the performance curve using least squares adjustment with at least 6 data points ( 2/3 brake, 1/3 brake, estimated minimum sink, estimated maximum glide, 1/2 speed bar, full speed bar).
(c) Determination of the horizontal turn curvature (the inverse of horizontal turn radius; see Pagen 2001) versus vertical velocity relationship, and integration of the horizontal velocity versus vertical velocity relationship and the horizontal turn curvature versus vertical velocity relationship into a three-dimensional graph of the "performance surface" for a paraglider. This would give the turn performance of a paraglider (important in lift), in addition to the glide performance (important between areas of lift). The best sensor to determine horizontal turn curvature may be a small accelerometer. If so, we would connect the accelerometer to a PDA (personal digital assistant) to log time-tagged data and match it to the vario and speed probe data.

## 6. CONCLUSION

Paraglider performance in straight-line flight (glide) can be accurately determined and represented in a performance curve using sensors calibrated by GPS receivers. The performance curve is very useful to paraglider pilots because it allows for the correct choice of airspeed to maximize time aloft and distance travelled in particular wind and lift/sink conditions.

## ACKNOWLEDGEMENTS

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