Effect of Wind on the Average Groundspeed of an Aeroplane.

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1. Introduction

The flight manual of an aeroplane usually provides the true airspeed (TAS) of the aircraft in given conditions. This would be the speed to calculate the flight time t for a given roundtrip distance D if no wind is present.

Usually there is always some wind in every altitude, which makes the calculation of the groundspeed GS or a good guess of the average groundspeed $avGS$ neccessary for correct flight time calculations.

The intention of this document is to give an idea of the reduction of the average groundspeed compared to the true airspeed for small general avation aircrafts like the standard Cessna C172.

2. Method

In the long run every flight is a round trip. The usual recreational flight of a private pilot starts at his departure airport, has some landings at other airfields and finally returns to his home base. Compared to the flight time of such a round trip without any wind, if the lightest wind is present the duration of the flight will be longer.

To understand this look at the example given by my colleague Hermann Scherer: You are flying from A to B with a given TAS and you have a tailwind equal to your TAS. You will reach B in half the time compared to the flight time without the wind. But if you try to return from B to A it will take you forever! This is the extreme, but if there is any wind the round trip always will take longer than without wind.

To quantify this proposition we will look at an idealized circular trip in the horizontal plane: It consists of an isoceles triangle with a length of each side of 100 nautical miles (NM). So the total distance is D =300 NM. One direction is 270° true course (TC270), so the other two are TC030 and TC150, respectively.

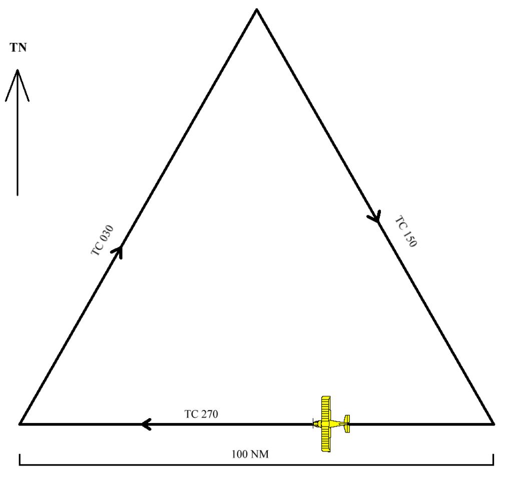

Figure 1: Isoceles Triangle as idealized round trip.

To test the influence of wind upon the flight time we will check first some representative examples. After drawing conclusions we will generalize the results and finally come to a closed calculation method.

2.1. Calculation of the Groundspeed

To get the groundspeed we have to calculate the following formulas [1] in the given sequence.

Take the wind vector $(W, V_W) = W/V$, where W is the wind direction and $V = V_W$ is the windspeed.
Calculate the wind angle (wa)

$$wa = W - TC$$

With the TAS of the aircraft the wind correction angle (WCA) is then given by

$$\sin(WCA) = \frac{V_W}{TAS} \cdot \sin(wa)$$

So, the groundspeed ($GS = V_G$) is

$$V_G = TAS \cdot \cos(WCA) - V_W \cdot \cos(wa)$$

2.2. Examples

Let us assume the following Parameters:

Distance of the round trip D = 300 NM
TAS = 100 knots = 100 NM/h = 100 kt

Without wind the flight time is therefore t_0 = 3.0 hours.

First we will assume wind from north with 10 knots

W/V = 360/10

The first leg of our flight has TC270
→ wa = 360° - 270° = +90°
→ sin(WCA) = 0.1
→ WCA = 5.7°
→ V_G = 99.5 kt
The second leg of our flight has TC030
→ wa = 360° - 030° = +330°
→ sin(WCA) = -0.05
→ WCA = -2.9°
→ V_G = 91.2 kt
The last leg has TC150
→ wa = 360° - 150° = +210°
→ sin(WCA) = -0.05
→ WCA = -2.9°
→ V_G = 108.5 kt

The total flight time with the different groundspeeds taken into account is therefore:

$$t = 100\ NM / 99.5\ kt + 100\ NM / 91.2\ kt + 100\ NM / 108.5\ kt = 3.0232\ h = 3^{h}01^{min}23^{sec}$$

The next step is to check different wind directions to see if this makes any difference. First we calculate the total time for a winddirection of 270° where we have a direct headwind on one leg:

$$t = 100\ NM / 90.0\ kt + 100\ NM / 104.6\ kt + 100\ NM / 104.6\ kt = 3.0232\ h = 3^{h}01^{min}23^{sec}$$

Then, we will check the further wind directions of 045°, 090°, 135°, 180°, 225°, and 315°. The results for the time differences Δ are summed up in the following table:

D = 300 NM, $\mathbf{t_0}$ = 3:00:00			
TAS			
100 kt			
$\mathbf{V_W}$	**W**	**t**	**Δ%**
10 kt	360°	03:01:23	0,8%
	045°	03:01:23	0,8%
	090°	03:01:23	0,8%
	135°	03:01:23	0,8%
	180°	03:01:23	0,8%
	225°	03:01:23	0,8%
	270°	03:01:23	0,8%
	315°	03:01:23	0,8%

We reckognize that the flight time of a round trip does not depend on the wind direction.

We further have to investigate the influence of the windspeed. Therefore we calculate the timeloss depending on windspeed and TAS by the means of a Qbasic™-Program. The following table lists the results (speed in knots):

TAS	Vw	Timeloss [%]		TAS	Vw	Timeloss [%]		TAS	Vw	Timeloss [%]
0	0	-100		10	0	0		20	0	0
				10	5	-19,7		20	5	-4,7
				10	10	-100		20	10	-19,7
								20	15	-47,9
								20	20	-100

TAS	Vw	Timeloss [%]
30	0	0
30	5	-2,1
30	10	-8,5
30	15	-19,7
30	20	-36,7
30	25	-61,4
30	30	-100

TAS	Vw	Timeloss [%]
40	0	0
40	5	-1,2
40	10	-4,7
40	15	-10,8
40	20	-19,7
40	25	-31,8
40	30	-47,9
40	35	-69,4
40	40	-100

TAS	Vw	Timeloss [%]
50	0	0
50	5	-0,8
50	10	-3
50	15	-6,9
50	20	-12,4
50	25	-19,7
50	30	-29,1
50	35	-40,9
50	40	-55,7
50	45	-74,5
50	50	-100

TAS	Vw	Timeloss [%]
60	0	0
60	5	-0,5
60	10	-2,1
60	15	-4,7
60	20	-8,5
60	25	-13,5
60	30	-19,7
60	35	-27,4
60	40	-36,7
60	45	-47,9
60	50	-61,4
60	55	-78,2
60	60	-100

TAS	Vw	Timeloss [%]
70	0	0
70	5	-0,4
70	10	-1,5
70	15	-3,5
70	20	-6,2
70	25	-9,8
70	30	-14,3
70	35	-19,7
70	40	-26,2
70	45	-33,8
70	50	-42,8
70	55	-53,4
70	60	-65,9

TAS	Vw	Timeloss [%]
80	0	0
80	5	-0,3
80	10	-1,2
80	15	-2,7
80	20	-4,7
80	25	-7,5
80	30	-10,8
80	35	-14,9
80	40	-19,7
80	45	-25,3
80	50	-31,8
80	55	-39,3
80	60	-47,9

TAS	Vw	Timeloss [%]
90	0	0
90	5	-0,2
90	10	-0,9
90	15	-2,1

TAS	Vw	Timeloss [%]
100	0	0
100	5	-0,2
100	10	-0,8
100	15	-1,7

TAS	Vw	Timeloss [%]
110	0	0
110	5	-0,2
110	10	-0,6
110	15	-1,4

TAS	Vw	Timeloss [%]
90	20	-3,7
90	25	-5,9
90	30	-8,5
90	35	-11,7
90	40	-15,4
90	45	-19,7
90	50	-24,7
90	55	-30,3
90	60	-36,7

TAS	Vw	Timeloss [%]
100	20	-3
100	25	-4,7
100	30	-6,9
100	35	-9,4
100	40	-12,4
100	45	-15,8
100	50	-19,7
100	55	-24,1
100	60	-29,1

TAS	Vw	Timeloss [%]
110	20	-2,5
110	25	-3,9
110	30	-5,7
110	35	-7,7
110	40	-10,2
110	45	-13
110	50	-16,1
110	55	-19,7
110	60	-23,7

TAS	Vw	Timeloss [%]
120	0	0
120	5	-0,1
120	10	-0,5
120	15	-1,2
120	20	-2,1
120	25	-3,3
120	30	-4,7
120	35	-6,5
120	40	-8,5
120	45	-10,8
120	50	-13,5
120	55	-16,4
120	60	-19,7

TAS	Vw	Timeloss [%]
130	0	0
130	5	-0,1
130	10	-0,4
130	15	-1
130	20	-1,8
130	25	-2,8
130	30	-4
130	35	-5,5
130	40	-7,2
130	45	-9,2
130	50	-11,4
130	55	-13,9
130	60	-16,7

TAS	Vw	Timeloss [%]
140	0	0
140	5	-0,1
140	10	-0,4
140	15	-0,9
140	20	-1,5
140	25	-2,4
140	30	-3,5
140	35	-4,7
140	40	-6,2
140	45	-7,9
140	50	-9,8
140	55	-11,9
140	60	-14,3

TAS	Vw	Timeloss [%]
150	0	0
150	5	-0,1
150	10	-0,3
150	15	-0,8
150	20	-1,3
150	25	-2,1
150	30	-3
150	35	-4,1

TAS	Vw	Timeloss [%]
160	0	0
160	5	-0,1
160	10	-0,3
160	15	-0,7
160	20	-1,2
160	25	-1,8
160	30	-2,7
160	35	-3,6

TAS	Vw	Timeloss [%]
170	0	0
170	5	-0,1
170	10	-0,3
170	15	-0,6
170	20	-1
170	25	-1,6
170	30	-2,3
170	35	-3,2

TAS	Vw	Timeloss [%]
150	40	-5,4
150	45	-6,9
150	50	-8,5
150	55	-10,4
150	60	-12,4

TAS	Vw	Timeloss [%]
160	40	-4,7
160	45	-6
160	50	-7,5
160	55	-9,1
160	60	-10,8

TAS	Vw	Timeloss [%]
170	40	-4,2
170	45	-5,3
170	50	-6,6
170	55	-8
170	60	-9,6

TAS	Vw	Timeloss [%]
180	0	0
180	5	-0,1
180	10	-0,2
180	15	-0,5
180	20	-0,9
180	25	-1,5
180	30	-2,1
180	35	-2,9
180	40	-3,7
180	45	-4,7
180	50	-5,9
180	55	-7,1
180	60	-8,5

TAS	Vw	Timeloss [%]
190	0	0
190	5	-0,1
190	10	-0,2
190	15	-0,5
190	20	-0,8
190	25	-1,3
190	30	-1,9
190	35	-2,6
190	40	-3,4
190	45	-4,3
190	50	-5,3
190	55	-6,4
190	60	-7,6

TAS	Vw	Timeloss [%]
200	0	0
200	5	0
200	10	-0,2
200	15	-0,4
200	20	-0,8
200	25	-1,2
200	30	-1,7
200	35	-2,3
200	40	-3
200	45	-3,8
200	50	-4,7
200	55	-5,8
200	60	-6,9

The results in graphical form:

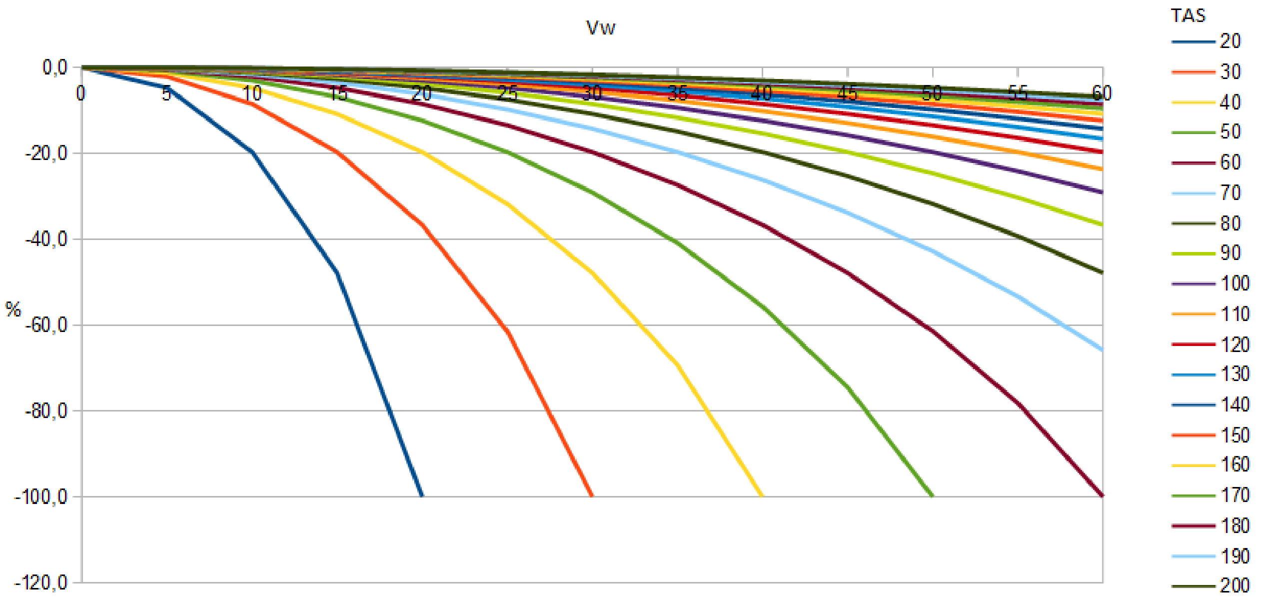

Figure 2: Timeloss due to reduced average groundspeed depending on the windspeed.

3. Evaluation

The flight time of a round trip does not depend on the wind direction. But it depends on the windspeed *V* in relation to the *TAS*.

We do have the following context:

$$\frac{t}{t_0} = \frac{D \cdot t}{D \cdot t_0} = \frac{\frac{D}{t_0}}{\frac{D}{t}} = \frac{TAS}{avGS} \rightarrow avGS = TAS \cdot \frac{t_0}{t}$$

The 'timeloss' Δ in percent was calculated using the following expression:

$$\Delta = \left(\frac{t_0}{t} - 1\right) \cdot 100 \rightarrow \frac{t_0}{t} = 1 + \frac{\Delta}{100}$$

Now we will find polynomial regressions for every timeloss curve ($\Delta_{TAS} = p(V_W)$). We assume for every curve the form $\Delta = p(V) = -a \cdot V^b$, where *V* is the windspeed and the parameters *a* and *b* are depending on *TAS*.

We find $a = 0.1656989833 \cdot \left(\frac{TAS}{10}\right)^{-1.5076543006}$ and $b = 2.6400513966 \cdot \left(\frac{TAS}{10}\right)^{-0.0945216878}$

therefore $\frac{t_0}{t} = 1 - \frac{a \cdot V^b}{100}$ and $avGS = TAS \cdot \frac{t}{t_0} = TAS \cdot \left(1 - \frac{a \cdot V^b}{100}\right)$.

In short form:

$$avGS = TAS - \frac{0.0533 \cdot V^{3.282 \cdot TAS^{-0.0945}}}{TAS^{0.5077}}$$

3.1. Example

Let us calculate an example. If we check the METARs along our route we get an idea of the ground wind which we have to expect. Let's say the average windspeed on the ground is 13 kt. To guess the windspeed aloft we simply double this value. So, we calculate with $V_W = 26$ kt. The speed of our aircraft is *TAS* = 100 kt. Our formula therefore gives us the average groundspeed to calculate the flight time of any trip under these wind conditions:

$$avGS = TAS - \frac{0.0533 \cdot V^{3.282 \cdot TAS^{-0.0945}}}{TAS^{0.5077}} = 100 - \frac{0.0533 \cdot 26^{3.282 \cdot 100^{-0.0945}}}{100^{0.5077}} = 94.8\ [kt]$$

The following Figure 3 shows the relation of TAS, windspeed and groundspeed in graphical form:

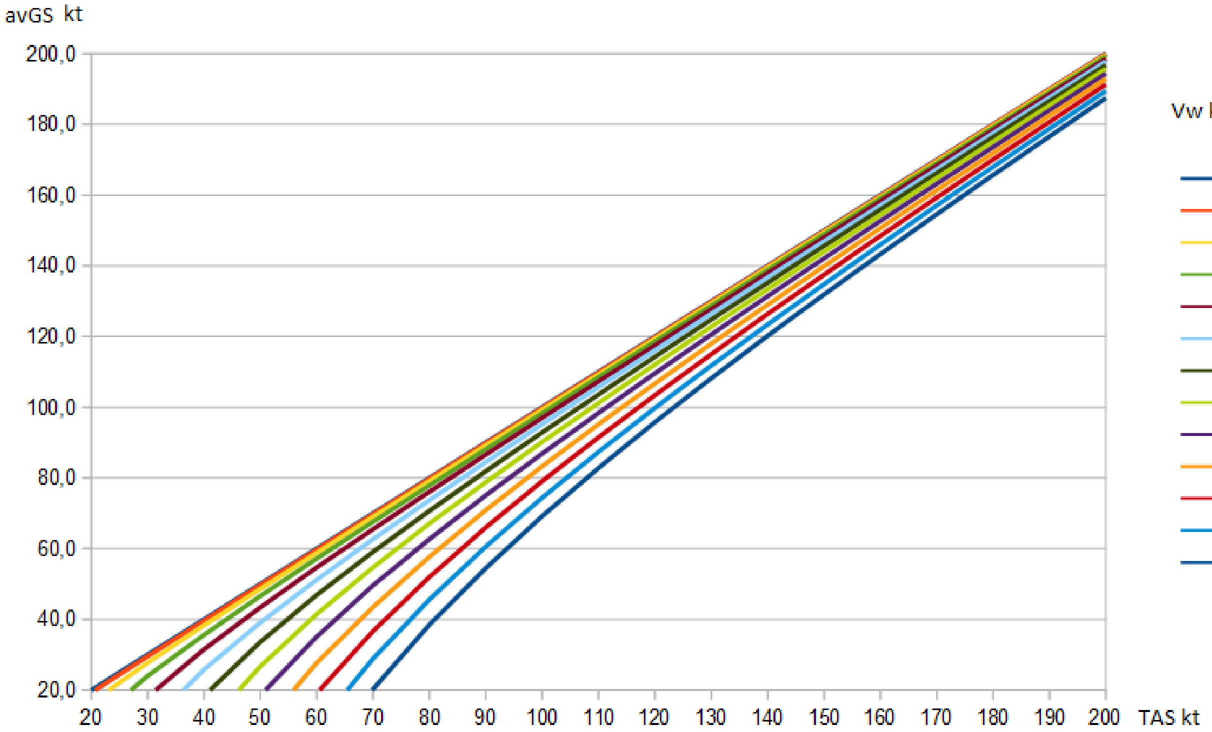

Figure 3: Average Groundspeed.

3.2. Reconstruction

Finally we will reconstruct the Figure 2 to check the correctness of the calculation.

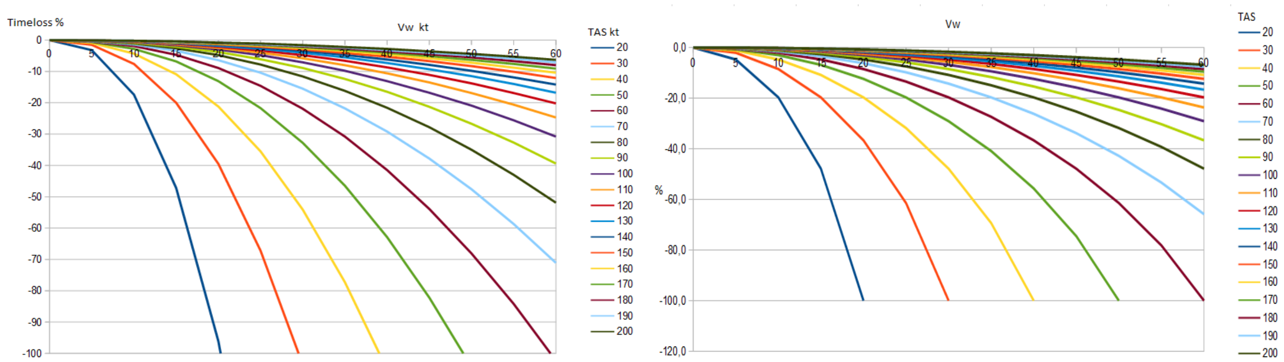

Figure 4: Timeloss recalculated (left) vs original calculation (right).

4. Conclusion

While the average groundspeed of a round trip is independent from the wind direction, it is possible to calculate it just by means of the TAS and the average windspeed aloft. The average groundspeed may be used for any flight distance. The value of the average groundspeed can be obtained either by graph or by calculating the formula.

5. Sources

[1] Rules of Thumb, p. 43Ff;
Wolf Scheuermann: Instrument Flight Procedures, v1.3.
Lufthansa Flight Training (LFT) GmbH,
Bremen 2015