Fly, fly away ... and bring back data

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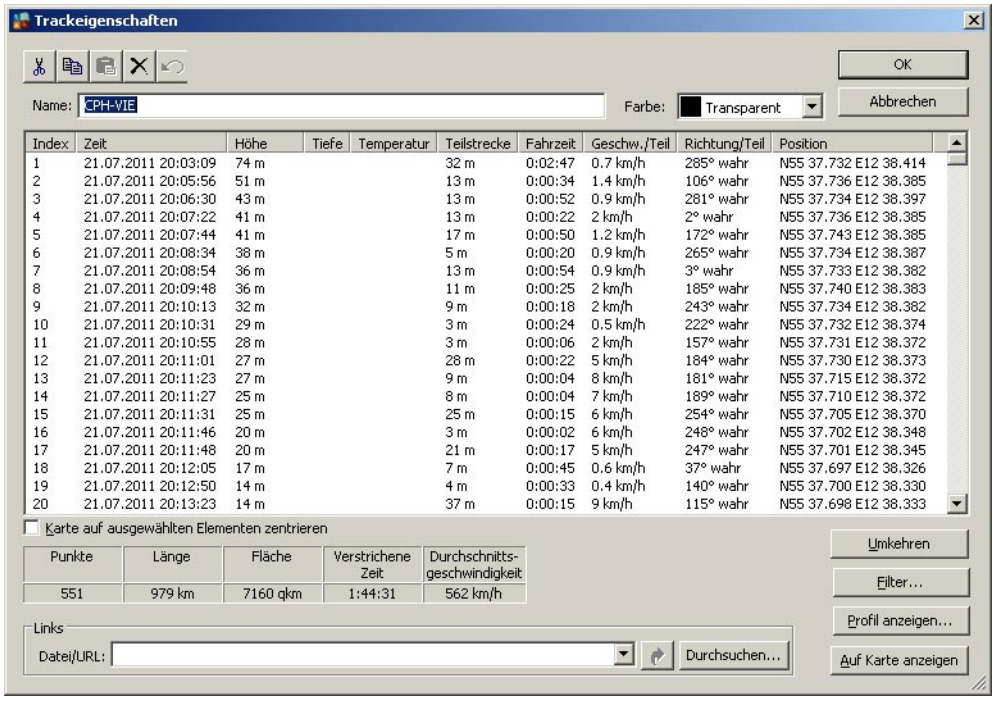
1 How was your flight? How fast, how high, how long?

During the flight of an airplane, passengers are often able to follow the path of the plane on screens in the cabin, which means that you know at any given time where the plane is. Also, other data is displayed, e.g. the altitude (height) and the speed of the plane. But even if such information is available during the flight, most passengers would not be able to answer questions like "what was the fastest speed", "how long did it take you from the gate to lift-off", "how steep did the plane climb", "how high did you get", "what was the total distance", or even "did you fly across Poland". And no wonder, there is a lot of information displayed, and you just don't stare at the screen all the time. But if you are interested in having all this data available for later analysis (or to answer all the questions on "how was the flight" from parents etc.), you can simply take a GPS device with you and set it up to record the data. Here we will show how this data can then be shown and analysed in Excel as well as in Google Earth.

2 Obtaining data

Data can be easily obtained by switching a GPS device to record the data. As this is done differently with different GPS models, we will not show this in detail here. One thing that you might want to pay attention to is that altitude measuring in GPS devices is sometimes done by measuring air pressure. As you (hopefully) sit in a pressured cabin, where the air pressure is (aside from take-off and landing) kept at a constant value corresponding to about 2000 m altitude, this would not get you useful data with respect to your real altitude. Most devices can be switched between "pressure" altitude measurement and "fixed" altitude (i.e. measured by satellite signal). Though "pressure" altitude gives you (once it is calibrated) more exact readings, which is useful for e.g. hiking or biking, here it would lead to false data.

Once you have obtained the data from a real flight (here as an example is a flight from Copenhagen airport [CPH] to Vienna airport [VIE]), it is time to see what can be done with it. In its raw form, the data does not look like much:



Index	Zeit	Höhe	Tiefe	Temperatur	Teilstrecke	Fahrzeit	Geschw./Teil	Richtung/Teil	Position
1	21.07.2011 20:03:09	74 m			32 m	0:02:47	0.7 km/h	285° wahr	N55 37.732 E12 38.414
2	21.07.2011 20:05:56	51 m			13 m	0:00:34	1.4 km/h	106° wahr	N55 37.736 E12 38.385
3	21.07.2011 20:06:30	43 m			13 m	0:00:52	0.9 km/h	281° wahr	N55 37.734 E12 38.397
4	21.07.2011 20:07:22	41 m			13 m	0:00:22	2 km/h	2° wahr	N55 37.736 E12 38.385
5	21.07.2011 20:07:44	41 m			17 m	0:00:50	1.2 km/h	172° wahr	N55 37.743 E12 38.385
6	21.07.2011 20:08:34	38 m			5 m	0:00:20	0.9 km/h	265° wahr	N55 37.734 E12 38.387
7	21.07.2011 20:08:54	36 m			13 m	0:00:54	0.9 km/h	3° wahr	N55 37.733 E12 38.382
8	21.07.2011 20:09:48	36 m			11 m	0:00:25	2 km/h	185° wahr	N55 37.740 E12 38.383
9	21.07.2011 20:10:13	32 m			9 m	0:00:18	2 km/h	243° wahr	N55 37.734 E12 38.382
10	21.07.2011 20:10:31	29 m			3 m	0:00:24	0.5 km/h	222° wahr	N55 37.732 E12 38.374
11	21.07.2011 20:10:55	28 m			3 m	0:00:06	2 km/h	157° wahr	N55 37.731 E12 38.372
12	21.07.2011 20:11:01	27 m			28 m	0:00:22	5 km/h	184° wahr	N55 37.730 E12 38.373
13	21.07.2011 20:11:23	27 m			9 m	0:00:04	8 km/h	181° wahr	N55 37.715 E12 38.372
14	21.07.2011 20:11:27	25 m			8 m	0:00:04	7 km/h	189° wahr	N55 37.710 E12 38.372
15	21.07.2011 20:11:31	25 m			25 m	0:00:15	6 km/h	254° wahr	N55 37.705 E12 38.370
16	21.07.2011 20:11:46	20 m			3 m	0:00:02	6 km/h	248° wahr	N55 37.702 E12 38.348
17	21.07.2011 20:11:48	20 m			21 m	0:00:17	5 km/h	247° wahr	N55 37.701 E12 38.345
18	21.07.2011 20:12:05	17 m			7 m	0:00:45	0.6 km/h	37° wahr	N55 37.697 E12 38.326
19	21.07.2011 20:12:50	14 m			4 m	0:00:33	0.4 km/h	140° wahr	N55 37.700 E12 38.330
20	21.07.2011 20:13:23	14 m			37 m	0:00:15	9 km/h	115° wahr	N55 37.698 E12 38.333

Punkte	Länge	Fläche	Verstrichene Zeit	Durchschnitts-geschwindigkeit
551	979 km	7160 qkm	1:44:31	562 km/h

Fig.1 Data obtained with GPS device on a flight from Copenhagen to Vienna

Although all the data that we need to answer the questions from above is there, it is not in a form that makes it easy to deal with it. Imagine your parents or friends asking you “how the flight was”, and you show them this table as an answer...

Quite often, real life data is in a form that is somewhat reasonable or practical for the people or instruments obtaining the data, but not in a form that makes it easy to understand or interpret the data. Also quite often, the data is numerical and/or graphical, so it requires mathematical skills to interpret, calculate, represent or handle the data in order to find out what you want to know.

3 Show me where I flew

One of the available data sets gives the position of the plane in what is called the WGS 84, which stands for *World Geodetic System* (dating from 1984). This is a standard coordinate frame for the earth surface, allowing each point on the earth surface (as well as in the air) to be described by a latitude and longitude information (as well as an altitude information). Theoretically you can type in this information e.g. into Google Maps or Google Earth and see exactly where you were. This would be tedious, though. Most GPS devices come with software allowing you to display the data of the whole flight on a map. Using again the example of a flight from Copenhagen to Vienna, it may look like this:

Fig.2 Flightpath shown in *Garmin MapSource*

Another possibility would be to feed the data into Google Earth. This allows for a lot of options, some of which we will show further down.

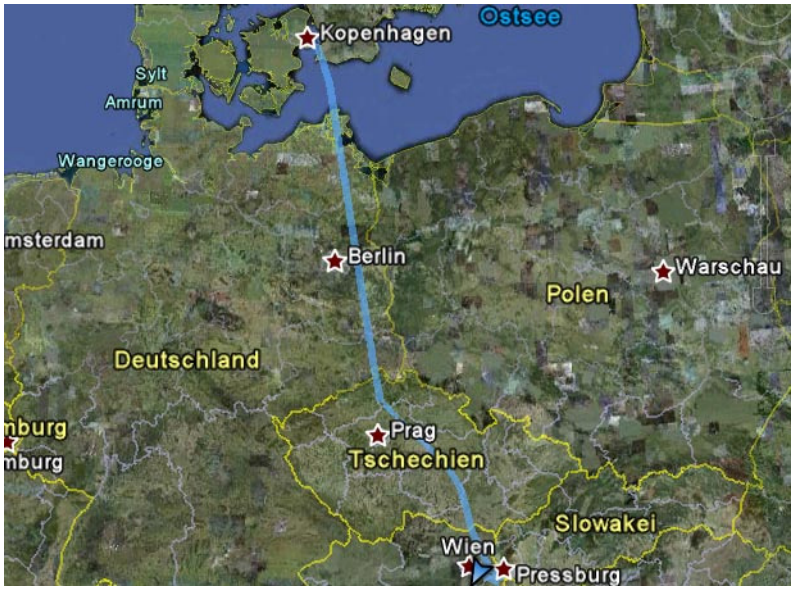


Fig.3 Flight path shown in *Google Earth*

This has the advantage of you being able to create a "tour" of your whole trip, i.e. watch the whole flight over the landscape in Google Earth:

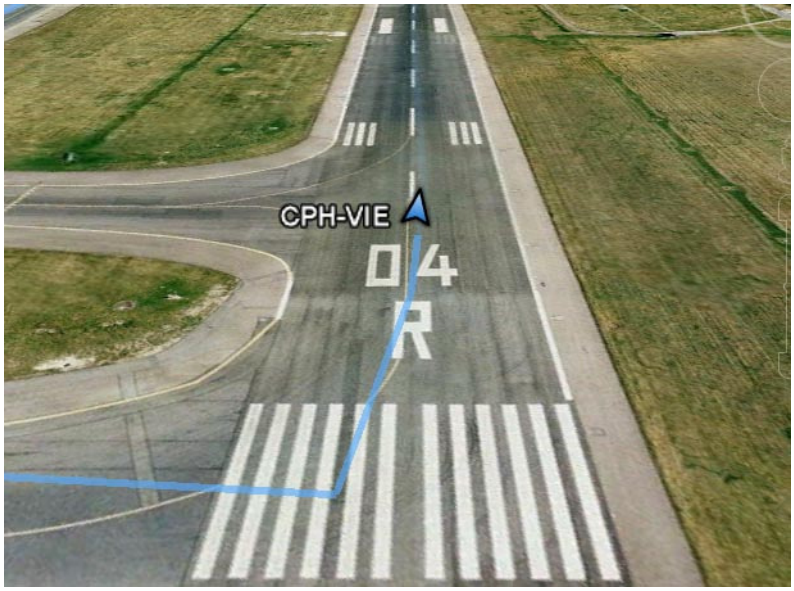


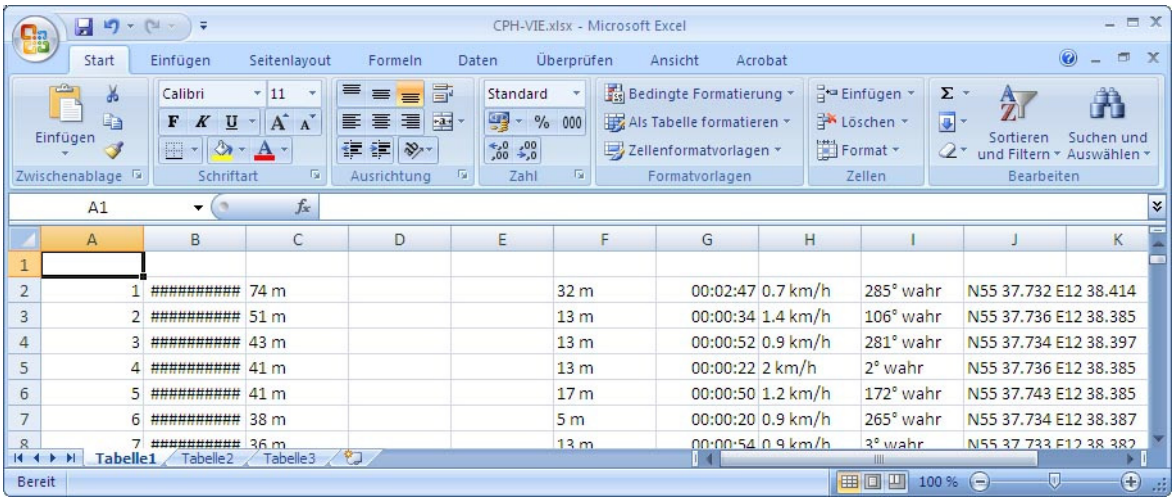
Fig.4 Takeoff in Copenhagen, shown in *Google Earth*

4 Now show me more!

We answered one of the original questions so far (no, we did not fly across Poland), but as to the maximum speed, climb, altitude etc. we have no answer yet. To obtain these answers, we copy the data into Excel. Before we do this, however, we make sure that we understand what the data actually means. GPS devices do usually not record continuously, but record measurements of position, speed, time, heading etc. at certain points in time. The flight path that we see above actually consists of several points where the position has been measured (about 550 points), and these points have then been connected with straight lines – mathematicians would call this a linear interpolation. This allows us to get a fairly good approximation of the flight path without having to obtain a huge amount of data. So the data we have available is a set of measurements, where each one of these measurements consists of an index (basically just a consecutive number), a timestamp (the date and time of the measurement), an altitude (how high you are), a distance (how far away you are from the last point of measurement), a time interval (how much time passed since the last point of measurement), a speed

(how fast you go), a heading (in which direction do you move), and a position in the above-mentioned WGS-84 system.

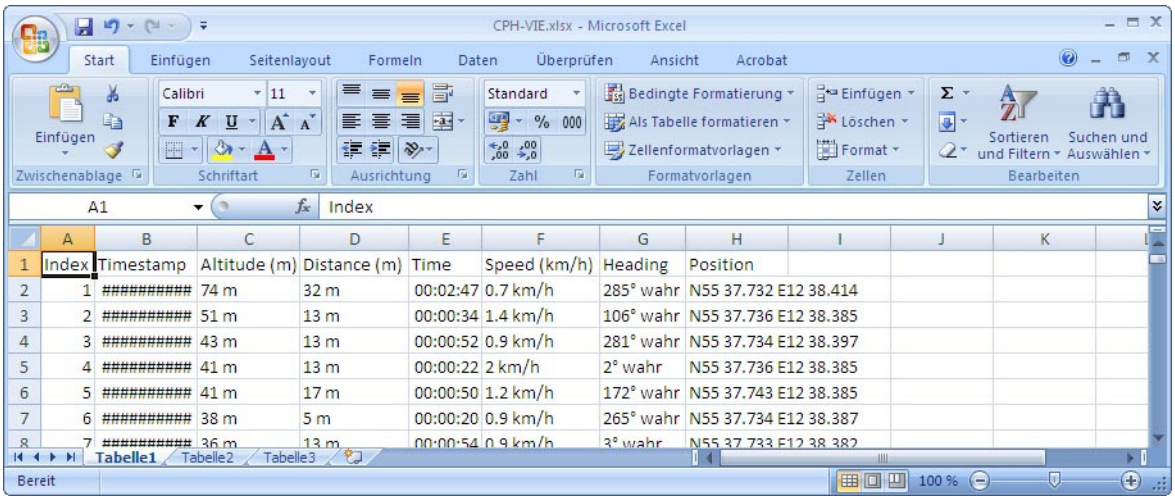
To get this data into Excel, we just mark the data in the GPS software, copy it, and then paste it into Excel:



	A	B	C	D	E	F	G	H	I	J	K
1											
2	1	##########	74 m			32 m	00:02:47	0.7 km/h	285° wahr	N55 37.732 E12 38.414	
3	2	##########	51 m			13 m	00:00:34	1.4 km/h	106° wahr	N55 37.736 E12 38.385	
4	3	##########	43 m			13 m	00:00:52	0.9 km/h	281° wahr	N55 37.734 E12 38.397	
5	4	##########	41 m			13 m	00:00:22	2 km/h	2° wahr	N55 37.736 E12 38.385	
6	5	##########	41 m			17 m	00:00:50	1.2 km/h	172° wahr	N55 37.743 E12 38.385	
7	6	##########	38 m			5 m	00:00:20	0.9 km/h	265° wahr	N55 37.734 E12 38.387	
8	7	##########	36 m			13 m	00:00:54	0.9 km/h	3° wahr	N55 37.733 E12 38.382	

Fig.5 Raw data in Excel

Now that does not look very useful. Let's start with naming the columns and give some meaning to the data:



	A	B	C	D	E	F	G	H	I	J	K
1	Index	Timestamp	Altitude (m)	Distance (m)	Time	Speed (km/h)	Heading	Position			
2	1	##########	74 m	32 m	00:02:47	0.7 km/h	285° wahr	N55 37.732 E12 38.414			
3	2	##########	51 m	13 m	00:00:34	1.4 km/h	106° wahr	N55 37.736 E12 38.385			
4	3	##########	43 m	13 m	00:00:52	0.9 km/h	281° wahr	N55 37.734 E12 38.397			
5	4	##########	41 m	13 m	00:00:22	2 km/h	2° wahr	N55 37.736 E12 38.385			
6	5	##########	41 m	17 m	00:00:50	1.2 km/h	172° wahr	N55 37.743 E12 38.385			
7	6	##########	38 m	5 m	00:00:20	0.9 km/h	265° wahr	N55 37.734 E12 38.387			
8	7	##########	36 m	13 m	00:00:54	0.9 km/h	3° wahr	N55 37.733 E12 38.382			

Fig.6 Raw data in Excel, with headings

This looks much better, only the second column, containing the time stamp, i.e. date and time of the measurement, looks strange. This is because Excel expects the time stamp to be in the format dd.mm.yyyy hh:mm (i.e. first the date, then the time in hours and minutes), while the GPS delivers the time stamp in the format dd.mm.yyyy hh:mm:ss (i.e. first the date, then the time in hours, minutes and seconds). Marking the time stamp column and correcting the format, we obtain:

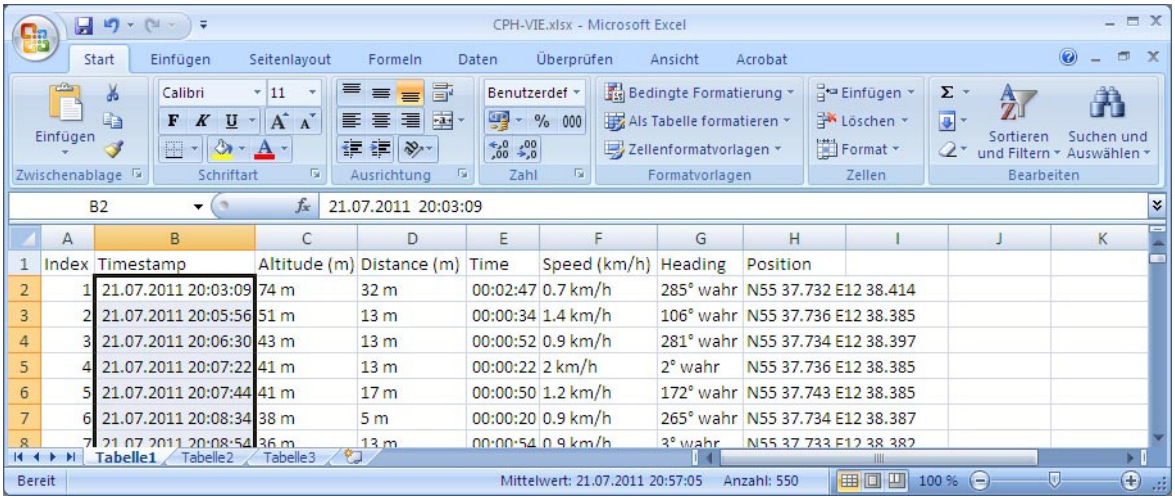


Fig.7 Raw data in Excel, with headings and corrected timestamps

To begin with some calculations and finally answer the questions that we had, we need to remove the units and make the cells contain only numbers (particularly Altitude, Distance, and Speed fields). We can do this by using search/ replace (search for all units and replace them with empty characters).

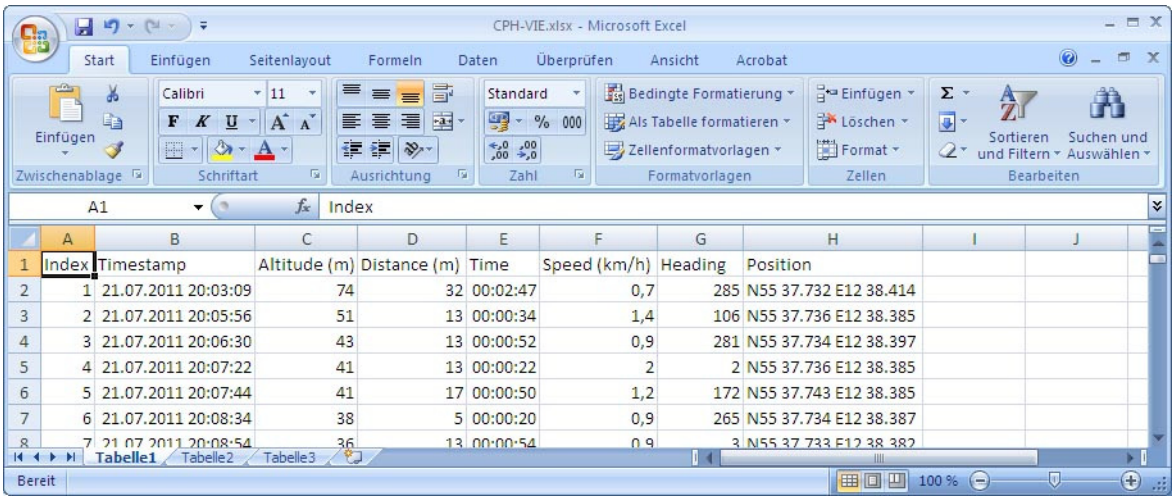


Fig.8 Raw data in Excel in numerical form

Finally we can start doing some calculations! To find out the total distance travelled, we just need to add the distances from the corresponding field, i.e. all distances in column D:

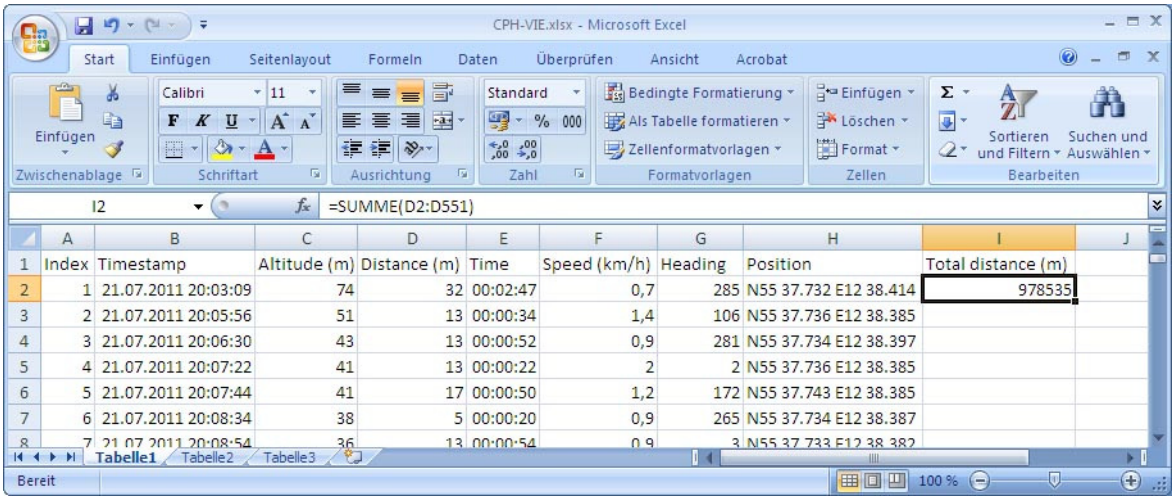


Fig.9 Total distance travelled

We travelled 978,535 m, which is about 978.5 km.

Tasks:

[1] Use Google Maps or an atlas to find out the linear distance ("as the crow flies") between Copenhagen and Vienna. Compare the two distance values. How much longer is the flight path?

[2] How long was the whole flight?

[3] What was the average speed? What was the maximum speed?

It would be nice to also have some graphical representations of the data. For that purpose, we would need the elapsed time and elapsed distance between the start and the current position. But that is easy to achieve: We can simply add up the values of the time column and the distance column, respectively:

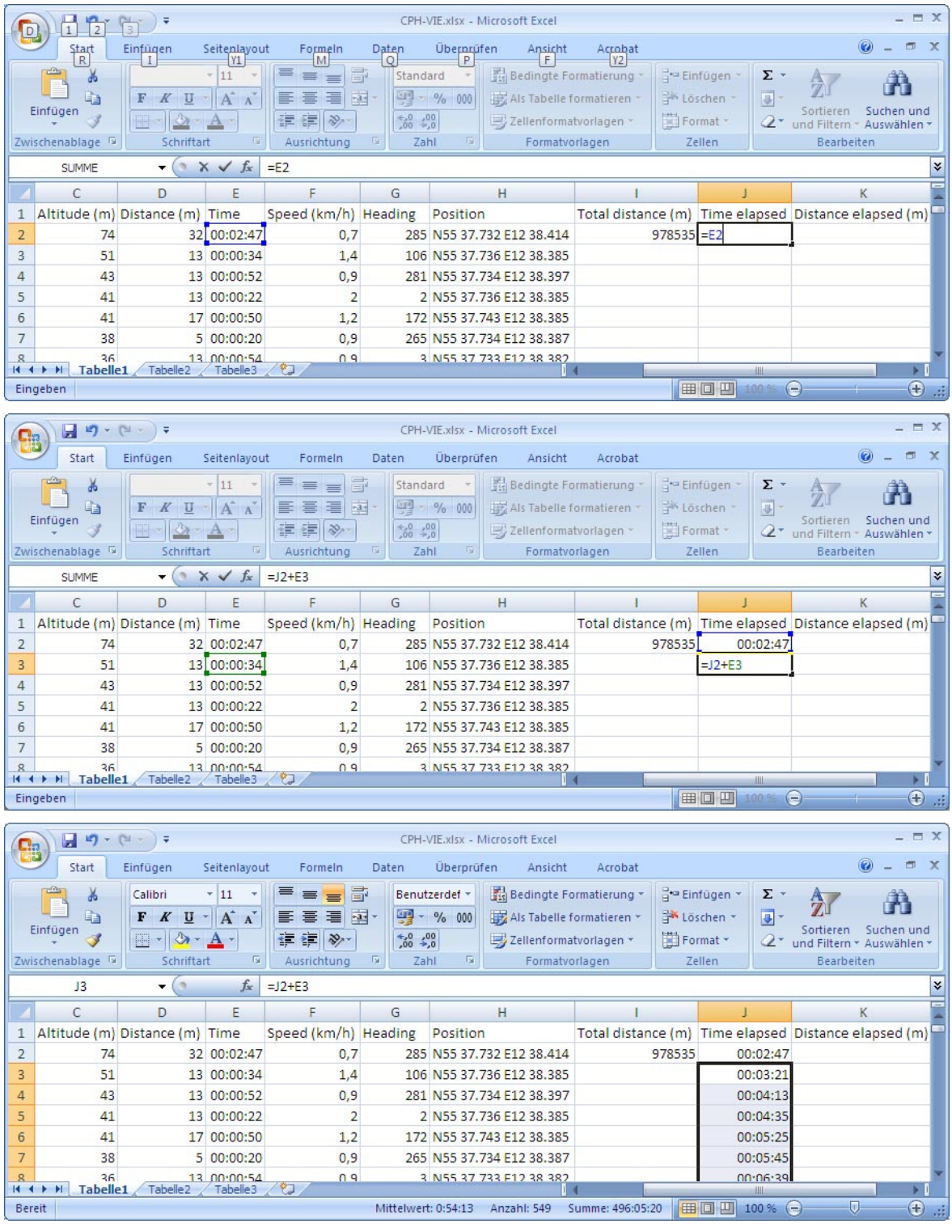


Fig.10 Obtaining elapsed time values

Now it is easy to construct a speed-time-diagram by using the diagram features in Excel. This results in:

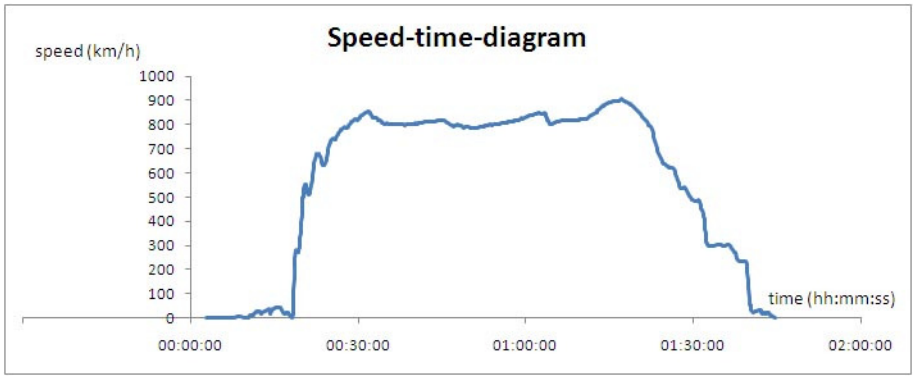


Fig.11 Speed-time-diagram

With the help of this diagram, it is now possible to answer further questions about the flight.

Tasks:

[4] At what time did the maximum speed occur?

[5] How long did it take the plane to taxi from the gate to the runway at take-off?

[6] How long did it take the plane to taxi from the runway to the gate at landing?

Much the same way we can obtain an altitude profile of the flight, i.e. an altitude-time diagram:

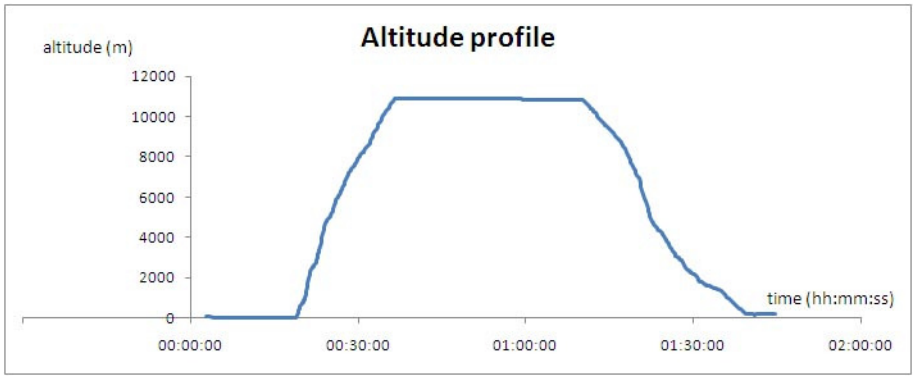


Fig.12 Altitude profile

Tasks:

[7] What was the maximum altitude?

[8] How steep did the plane climb from take-off to maximum altitude (i.e. how many meters per second did the plane climb)?

[9] Complete the *distance elapsed* column and construct a speed-distance diagram!

[10] Modelling: Try to find a function (it may also be a piecewise defined function) which approximates the altitude profile.

5 What else can I find out?

With the given data (more data sets can be found here), it is easily (and sometimes not so easily) possible to answer a whole lot of questions. You may think about why the speed of the plane seems to be highest shortly after leaving the maximum altitude, or at what time in the flight the highest acceleration occurred, or even on which runway the plane took off, and many other interesting things. Furthermore, pilots usually give the speed of the plane in knots, and the altitude in feet, so you could convert all the data into feet, knots etc. And last but not least, the whole thing is of course the most fun if you record the data of a flight where you were onboard yourself!

6 I don’t like flying …

No problem at all! A lot of the things that we just talked about can also be done when you record a car trip, a bike trip, or even a jogging trip.

Tasks:

[11] Record data from a bike or hiking trip with a GPS device (or a Smartphone) and analyse it.

[12] Give the data set to another student in your class and invent some questions about it yourselves, that your fellow student then has to answer.

References

[1] De Silva, D.A. *Flying an airplane*. In Andersen, J. et al. *Bringing Mathematics to Earth*, Prvokruh Publishing House, Prague, 2010

[2] WGS84 implementation manual (October 14, 2011)