

# The glider polar ABC

Small article on how to set the polar in the instrument in a reasoned way, and how to interpret the indications of the instrument regarding the speed to be held in flight.

VERY VERY DRAFT VERSION  
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The instruments we use for gliding (OUDIE, XCSOAR, LX...) ask us to declare the polar of the glider in use, and the ballast on board. XCSOAR, for example, uses the dialog shown in Figure 1.

Plane Polar: D-KFGW 18M			
Name: Ventus 2cT (18m) by Sandro			
Polar V	100 km/h	120 km/h	150 km/h
Polar W	-0.71 m/s	-0.83 m/s	-1.35 m/s
Reference Mass	525 kg		
Dry Mass	430 kg		
List	Import	OK	Cancel

Figura 1: the dialog box used by XCSOAR to specify the glider polar.

These data are used to perform some important calculations, including the calculation of  $V_{opt}$ , the optimal speed to maintain in flight (to be clear,  $V_{opt}$  is the one indicated by Sohlfarth and takes into account both the movement of the air mass and the McReady value selected - forgive me for the clarification, but on the internet there are definitions that do not correspond). Basically, with the same thermals, with LS4 pilots do well to keep speeds a bit lower than ASH31 pilots.

Obviously - with the data provided in Figure 1 - the instrument does not know exactly the polar of the glider, but manages to calculate an approximation of it. We can say that we have provided the data to create a mathematical model of the polar of the glider we fly.

Unfortunately

- often, the mathematical model used by the instruments is grossly inaccurate. Example: we are flying an LS4, we have given the instrument correct data for the glider we are using (the data in Figure 1), but the instrument gives us wrong indications about the speed to fly and the Netto.
- Even when it is not completely wrong, the mathematical model is always imprecise, and it is worth understanding its limitations. Example: we are sitting in an LS4, the mathematical model used by the instrument is the appropriate one for the LS4, but due to the limitations of the model, certain indications are not correct, and can never be correct.

- Contrary to what some manuals would have us believe, specifying the parameters required by the instruments to calculate the polar (we are always talking about the parameters in Figure 1) is a delicate operation, which can easily introduce even large errors. Example: we introduce in the instrument some parameters that are reasonably correct for our LS4, but the mathematical model that comes out is extremely inaccurate.

In this article we focus first on how to set the polar of a glider in the instrument avoiding big mistakes. Then we analyze the differences between the true polar of a glider and its "representation" used by the software to calculate for example the speed to be held in flight. This is also meant to explain the intrinsic limits of the information provided.

Let's start with the first point: **often, the mathematical model used by the instruments is grossly inaccurate**. In my Ventus 2c 18m I use three instruments, two portable and one fixed, all of which are popular brands among gliders. According to instrument #1, the Ventus2 would have an max efficiency of 55 (more appropriate for an ASH25), instrument #2 compensates for the error, using a polar that has an efficiency of 45 (a bit pessimistic for an 18m) Instrument #3 is almost correct, though. Things are worse if you use a glider that is a bit more esoteric than the Ventus. I won't go into detail because it's not the point of this article, but errors of 7-8 points of efficiency are quite common. Actually, glider manufacturers - especially in the past - have often sinned by lack of transparency regarding the true polar of their machines, Johnson's tests confirm this in full.

Is it bad if the mathematical model used by the instrument to approximate the polar is very incorrect? To a large extent, yes: the instrument uses it to determine

1. The indication of the sohlfarth regarding the speed to be held during glides
2. The indication of the estimated arrival altitude at a given waypoint
3. The vario Netto

In fact, many pilots, even very good ones, do not use the instrument for purpose #1 nor #2 (TBD: maybe add a chapter underneath?). The Netto, on the other hand, is definitely important. In any case, if you're one of those who watches the instrument for these things, then it's worth reading on.

## Specifying the polar

How do we specify to the instrument which model to use? By far the most common system is the **three-point method**, which requires us to specify three points of the polar, i.e., the sink rate at three distinct speeds. As already mentioned, XCSOAR for this purpose offers us the box in Figure 1, where we see that the glider in question, when loaded at 525kg has a sink rate of 0.71 meters per second when flying at 100kmh (point 1), 0.83 m/s when flying at 120kmh (point 2) and 1.35 m/s when flying at 150kmh (point 3). From these values, XCSOAR deduces the parameters (A,B,C, see below for mathematical aspects) of the parabola that will use as a mathematical model. In this case the speed and sink values were provided by myself, but this is often not necessary: almost all instruments have a list of glider types from which we can select the one we use.

And here the problems continue, not only because the default values used by the instruments are often inaccurate, but also because manually specifying the three points is a delicate operation that can introduce macroscopic errors.

The first source of error is that the velocity and sink values are often approximated, and these approximations can be magnified in the extrapolation process; in particular XCSOAR makes things unnecessarily complicated, since it requires you to select these values from a list, making it impossible to provide accurate data; the trick I use is to directly edit the polar file XXX.xcp (this seems to work). The values shown in Figure 1 are the result of this "trick". Had I not used it, I would have had to declare a drop rate of 0.7 m/s (instead of 0.71) at 100kmh and 0.85 m/s (instead of 0.83) at 120kmh; these differences seem small, but since the model is obtained by extrapolation, these errors will likely be magnified on the "external" parts of the polar.

The second source of error is that if the points are poorly chosen, even if the values provided are correct and accurate, the resulting model will look very little like the polar of the glider. Such an example is shown in Figure 3, where the model (in purple) is not a good approximation of the polar (true, in blue), since below 110kmh the two curves diverge a lot. In this case I just chose the "wrong" reference points (125kmh, 140kmh, 170kmh or so), but the values I introduced were accurate. Obviously, by introducing approximations in the specification of the three points would make the model even more inaccurate.

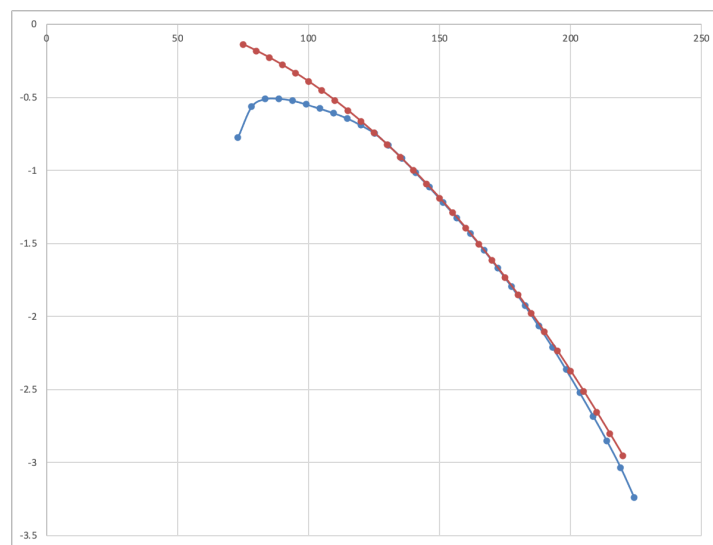


Figure 2: Polar of a Ventus 2 in blue. In red, a parabola specified correctly using the three-point method, but which turns out to be very inaccurate at speeds below 120kmh.

Tips for choosing the three points in order to get a decent model.

1. Choose the leftmost point (the most delicate) in close proximity to the glider's minimum drop point.
2. Choose the third point (the least delicate), in the region of your fast glides; say between 150 and 200 km/h.
3. At this point do some tests with the second point, looking for it in the region of maximum glider efficiency.

After specifying the three points, the best thing to do would be to check that the values you provide produce a reasonably faithful model, using one of the spreadsheets I discuss below.

If you follow these common sense rules, the resulting model should be "reasonable".

Unfortunately, "reasonable" doesn't mean it's always right, **in fact there are important areas (the low speeds) where the instrument indications are always inaccurate**. Let's see why.

### The polar and its mathematical approximation.

Let's start by trying to understand without going into too much technical detail how the instrument approximates the behavior of a glider. The polar of a sailplane is nothing more than a graph indicating the sink rate in still air at different speeds for a given wing loading. In general, the polar is a fairly complex curve, and to simplify calculations our glider's instruments (all of them) try to approximate it using a parabola. When the parabola overlaps well with the polar, we can say that the model is quite faithful. We have already seen a not very faithful model in Figure 2. Figure 3 - on the contrary - shows the case of a very good model (red) for the same polar (blue).

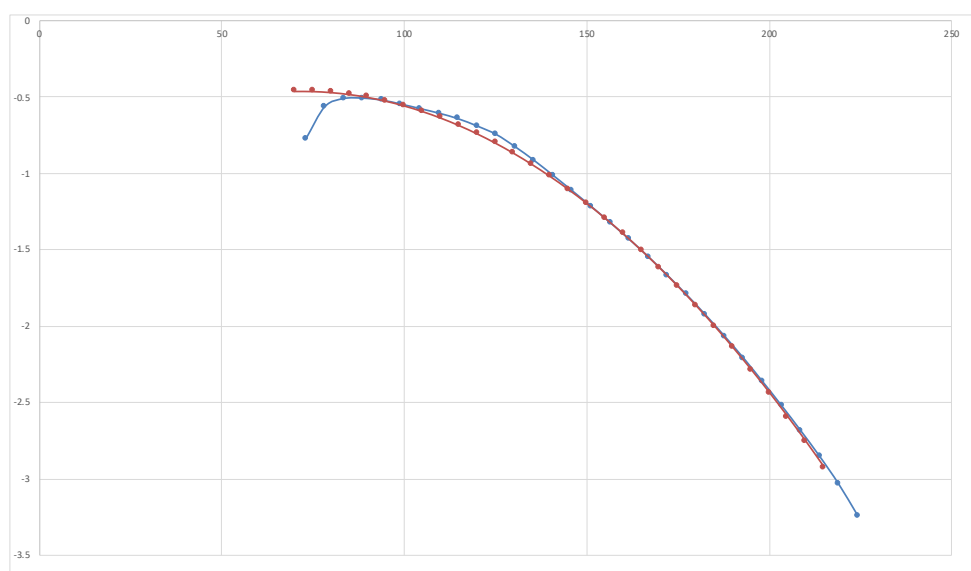


Figure 3: always the polar of a Ventus 2 (in blue) and a new parabola that approximates it (in red). In this case the approximation is very good (the red curve follows very well the blue one). Nevertheless, the model is inaccurate for speeds below the  $V_{min}$

Note, however, that for speeds below the minimum sink speed  $V_{min}$ , the model is vastly inaccurate. For instance, according to the "model" (red line) the  $V_{min}$  should be at 70kmh, while the true  $V_{min}$  (blue line) is about 90kmh. In other words: although in this case the instrument is using an exceptionally faithful model, the instrument "believes" that the  $V_{min}$  of our glider is 20kmh slower than the true  $V_{min}$ . This is a common problem: even if one of the three points we give as input is the  $V_{min}$ , it is not sure that the model "understands" that that is really the  $V_{min}$ . Simply put: we can't have it all, and the problem is fundamental in nature: a parabola is only *second* degree curve, and its ability to faithfully follow the polar is very limited. A third or fourth degree curve would certainly be able to be more faithful, but on the other hand it would also be more difficult to specify, needing 4 or 5 points, the

possibility of error would increase macroscopically, and it would also be more complex to manage at the software level. We'd therefore better accept with resignation the fact that the instrument is inaccurate at low speeds.

Specifically: When sohlfahrt suggests to fly at speeds lower than  $V_{min}$ , it is giving (almost) surely wrong indications. For example, in the presence of a decent climb it is normal that the instrument that has been set up with the parabola (red) in Figure 3 advises me to fly at ... 70kmh, or maybe even slower, and these are areas where the glider (blue) becomes very inefficient.

Tip #2 (theoretically useless, but you never know): learn the true  $V_{min}$  of the glider with ballast and when the instrument tells you to fly slower than  $V_{min}$ , don't do it. We are talking about glide flight, and we are considering only the part related to energy maximization, without taking into account turbulence or proximity to the ridge, which require a separate discussion. The typical situation is the delphin flight. Theoretically, in the presence of strong lift it might be useful to slow down to a speed lower than  $V_{min}$ . On the other hand, there are several reasons not to do so: (a) as we said, the instrument in this area usually gives wrong indications, (b) generally, glider efficiency deteriorates very quickly below  $V_{min}$ : we find ourselves flying in areas where the wing does not work well anyway (c) going slower means giving up kinetic energy, which then has to be recovered. Of course there are also pilots adopting – to my horror - ballistic trajectories, for which these considerations are not valid, but this article is not for them....

One last example, this time referring to an exceptionally good model. In Figure 4, the true polar (in green) should be that of a Ventus 2b 15m, for a weight of 450 kg, and the parabola in red, is the model in use. We note a minimum sink rate of about 100kmh, corresponding to the highest point of the curve, and a sink rate of about -1.1 m/s at a speed of 150kmh. The curves in this figure overlap almost completely, and we can definitely say that the model is extremely accurate.  $V_{min}$  is also modeled almost correctly. The fact remains that since the polar is not a parabola, the fidelity of the model has limitations. In particular you can see for speeds below  $V_{min}$ , the model is still extremely inaccurate. Let's deal with it.

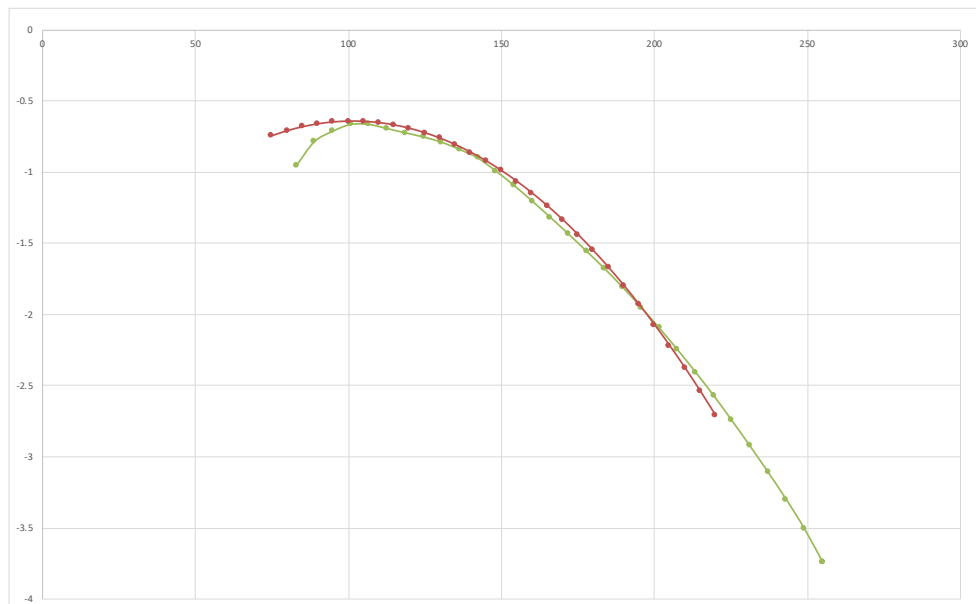


Figure 4: Polar (in green) and Parabola that approximates it (in red). The approximation in this case is exceptionally good. Nevertheless, the inaccuracy below 100kmh remains.

**Let's compare the polar to the parabola.** It is certainly also interesting to analyze if the model in use is accurate, to do this you can compare the (presumed) polar of the glider (possible sources are [1], [2]), with the parabola in use in our instrument, to do this, I have prepared a small spreadsheet (see reference [4]), which allows precisely to specify and compare up to four curves, two polars to be specified point to point (which can be copied from [1] or [2]), and two parabolas that can be specified using the three point method or directly with parameters A, B, C. The spreadsheets in [2] and [4] also allow one to "play" with the polar, experiment with various values for the three points, and extract parameters A, B, C.

In addition, some of these spreadsheets allow to analyze what the real performance of a glider is, for example in the presence of wind against or descent. Spreadsheet [1], [3] and mine [4] allow you to do that, and to "play" with various values of MC, wind and descent to figure out what the key speeds of a glider are. And maybe you rediscover things that have been somewhat forgotten. For example, the true efficiency of the glider in descent. A moderate descent of -1 m/s is enough to bring down the efficiency of an 18 m glider from 50:1 to less than 20:1, if the descent is -3 m/s - a common value in the mountains - it goes to about 10:1. We are flying a very fast paraglider.

**A couple of notes on the mathematical model and parameters A, B, C.** We said that the mathematical model used by the instruments is a parabola, which has as standard formula

$$y = - (A * x^2 + B * x + C)$$

where y is the speed of fall in m/s and x is the speed with respect to the air, expressed in hundreds of kilometers per hour (these are the units of measure used by my SeeYou). The model is then univocally determined by the four parameters A, B, C and P, where A, B, C determine the parabola, and P is the reference weight, in kg. Some instruments - for example SeeYou - allow you to specify the polar also using precisely these parameters (Figure 5), but usually - as mentioned above - you use the more intuitive three-point method. The three points, after all, uniquely determine the polar.

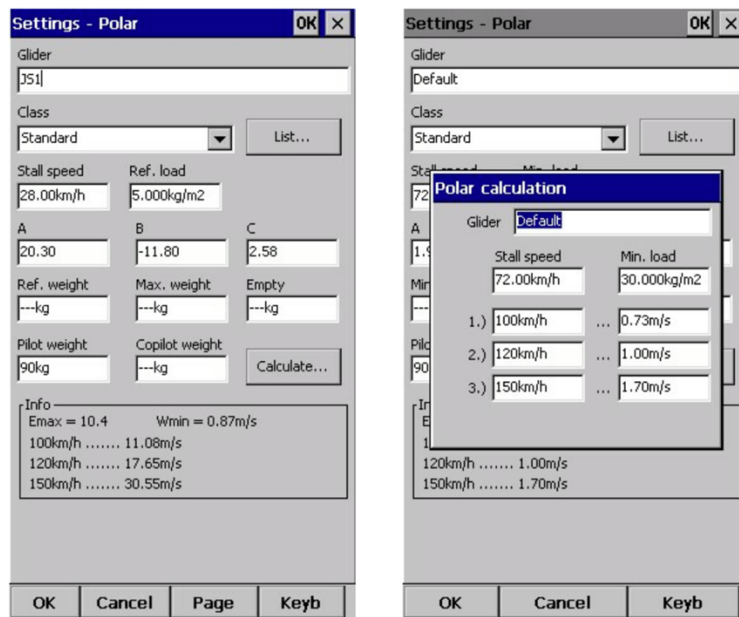


Figure 5: The polar specification in SeeYou

## REFERENCES (the links below are not verified not endorsed in any way, use at your own risks)

[1] Jim Rennie's spreadsheet for comparing glider polar diverts and calculating speed-to-fly in different conditions. Found on the internet at

<http://www.gliding.cz/souteze/2012/ppjsk/doc/polars-.xls>

Local copy (downloaded on 2/5/2021) at [https://setalle.github.io/glider-polars/other\\_spreadsheets/index.html](https://setalle.github.io/glider-polars/other_spreadsheets/index.html) (file polars.xls)

[2] A list of measured polars that appears to be very complete and accurate, found at

<http://www.lkka.cz/sport/docs/PolaryCZIL.xls>

Local copy (downloaded 2/5/2021) at [https://setalle.github.io/glider-polars/other\\_spreadsheets/index.html](https://setalle.github.io/glider-polars/other_spreadsheets/index.html) (file PolaryCZIL.xls)

[3] Remde Polar analysis spreadsheet, can be downloaded at [http://www.cumulus-soaring.com/files/Remde\\_Polar\\_Analysis.xlsx](http://www.cumulus-soaring.com/files/Remde_Polar_Analysis.xlsx). Mr. Remde maintains a very accurate page, with various explanations at: <https://www.cumulus-soaring.com/store/links/polar-data>

Local copy (downloaded on 2/5/2021) at [https://setalle.github.io/glider-polars/other\\_spreadsheets/index.html](https://setalle.github.io/glider-polars/other_spreadsheets/index.html) (file Remde\_Polar\_Analysis.xlsx)

[4] My spreadsheet <https://setalle.github.io/glider-polars/polarspreadsheet/index.html>