The Aerodynamics of a DLG Unravelled

A practical analysis of this popular form of R/C soaring.

Theo Volkers

Co-author (along with Tjarko van Empel) Theo Volkers demonstrating textbook DLG form. (image: Trudi Volkers)

We have been enthusiastic discus launch glider (DLG) pilots for several years. It started with a classic, the Highlight, then a second-hand Twister II, a home-built one, then the first stream NXT and then two more. The flight performance of the DLG models has increased dramatically in recent years and we are very curious where it is now. On the one hand just out of interest and on the other hand to build a second model with such flying performance, or even better.

We have measured the latest model and analysed its aerodynamics, to find out what flight performances we can expect. It fits well with our background. Theo has worked as an aerodynamic specialist and Tjarko is good in mechanics. We try to bring theory and practice together in this story and hope to unravel the secret of a good DLG. We start with some joint test flights.

Photo 1: The two recently purchased DLGs

We get a launch height of 35 to 45 m (we are better at math than at throwing). Figure 2 shows what that means for flight times on an evening with very little wind. From 45 m height over two minutes is feasible . Now it comes down to whether we are on the right track. Are these good flight times at these heights or is there more to it?

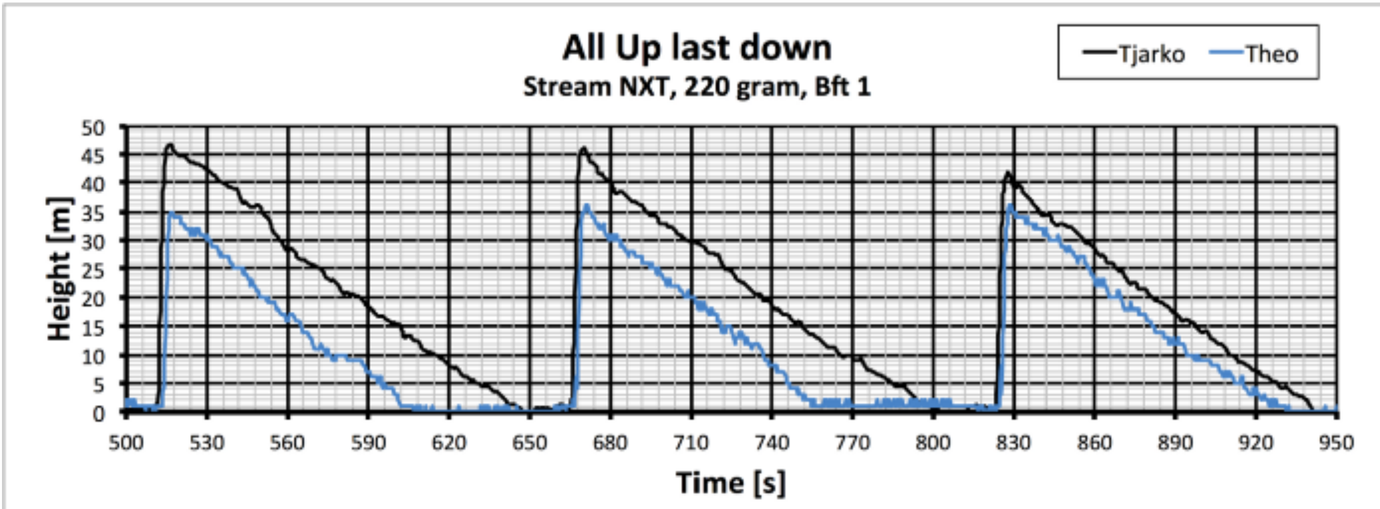

Figure 2 : Comparison of measurement results during an evening with very little wind

To answer this question, we try to calculate the performance. For this we need to know exactly the dimensions of the model and the airfoils. This is also interesting for the DLG self-builder. This new model uses a better airfoil than for instance the previously popular Zone V1?

Measuring airfoils : To find out the airfoils, we make moulds of the airfoil in three places on the old NXT from Theo. We take the airfoil at the root, 34 cm from the wingspan (mid) and 10 cm from the tip. We want to keep the wing intact, so the moulds have to separate properly from the wing. First I stick thin transparent tape on the wing. Then a thin layer of wax is applied. On photo 3 you can see the 4 mm plywood templates that I saw on approximately 1 mm accurate with the airfoil. The moulds are then placed on the wing at the bottom with polyester filler. With a piece of balsa that is in the span direction and glued to the plywood, I ensure that the templates remain exactly perpendicular. When the filler is a bit hard after 30 minutes, the wing is turned over and it is on the three templates. I make guide strips with some leftovers of balsa. The top moulds can now be used as guillotine knives, with another layer of polyester filler. On the front and back, the plywood templates are about 2 cm cold on top of each other. This is useful later when measuring as a zero reference. When the polyester is really hard after about five hours, the exciting moment comes. Is it coming loose? And do we have a beautiful mould? It went well in one go!

To measure the airfoil shape very precisely, I use the milling column on my lathe. This has a digital readout with 0.01 mm resolution. I file a screwdriver a bit thinner and serves as a measuring head. With the X slide, the airfoil is placed in chord direction with 0.1 mm precision and then measured vertically every 5 mm. At the nose every 0.5 and 1 mm. The drill column is a bit stiff as a measuring device, but with too much measuring force the tip pushes into the filler. With some practice I get 0.02 mm repro. At each position I repeat the measurement three times to avoid outliers. The measurements are processed in Excel. The airfoil now appears for the first time. You can see an impression of that measurement in photos 3 and 4 .

Photo 3: Imprint of the tip airfoil. **Photo 4**: Measuring on the milling column, with 0.01 mm resolution

After the measurement, the coordinates are corrected for the 35 µm thickness of the protective adhesive tape on the wing. Close to the nose some points are corrected by hand. You measure there on an inclined sloping piece, which is not always good. To make a comparison, the coordinates are normalized to chord length 1, see Figure 5. The Y-axis has been scaled up, airfoil shown thicker, to better see the differences .

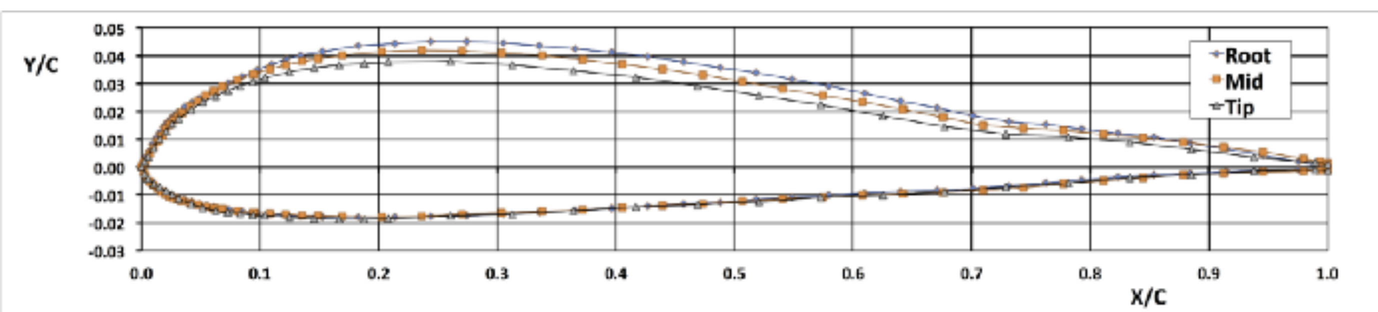

Figure 5: The measured airfoils

The airfoil has a thickness of 6.3% at the root, 6.0% at the mid and 5.6% at the tip. The lower side of the airfoil is at the three measured spanwise locations exactly the same. The first 2% of the nose on the upper side of the airfoil is quite straight. We ask ourselves if this is for a reason or is it a construction deviation? It is on all three moulds. Our new models don't seem to have that straight. In the back you can clearly see the flap hinge line. The flap is here at 0 mm deflection. This is the start position. We use 2 mm deflection down for cruising flight and 5 mm to 8 mm for thermal flight. This equates to a flap deflection of 2.3 degrees on cruising flight and 5.7 degrees to 9.2 degrees on thermal flight. At 2.3 degrees flap deflection, the airfoil has the most streamlined shape.

Calculating section properties: The airfoil coordinates are input in the program XFOIL of Mark Drela. Theo interpolates the measured coordinates to 121 points with the "PANE" option. In this way you realize a point distribution over the chord that is optimal for that program. The result of the point distribution and the aforementioned flap deflections results can be seen in Figure 6.

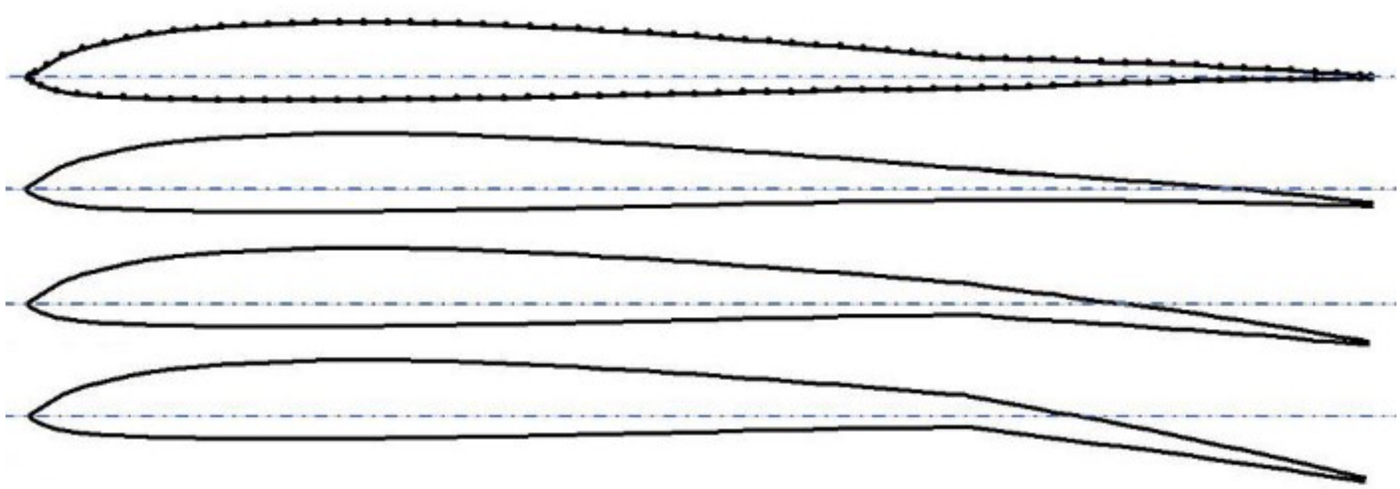

Figure 6: The geometry of the airfoil at 34 cm wingspan with flaps 0, 2, 5 and 8 mm

In XFOIL, the option is used to vary the Reynolds number by the lift coefficient. You then only need to enter the Reynolds number corresponding to lift coefficient = 1. For the other lift coefficients, the program then calculates the corresponding flight speed and Reynolds number. This Reynolds number is very important for calculating the airfoil properties for model aircraft in general. It stands for the so-called scale effect. You calculate it by multiplying the flight speed with the chord and the air density and then dividing it by the dynamic viscosity of the air. Model builders often use the following approximation formula : Re = 70 x Velocity[m/s] x chord[mm]). You see in Figure 7 that the airfoil of the tip with 96 mm chord has a significantly greater drag coefficient than the root with 164 mm chord. While that tip airfoil is still 0.8% thinner than the root airfoil. This is an example of the said scale effect. In this article, the applied airfoil properties are calculated for a wide range of Reynolds. This varies from a little below the Re = 25,000 for the tip airfoil at the lowest flight speed up to almost Re = 200,000 for the root airfoil at the maximum flight speed.

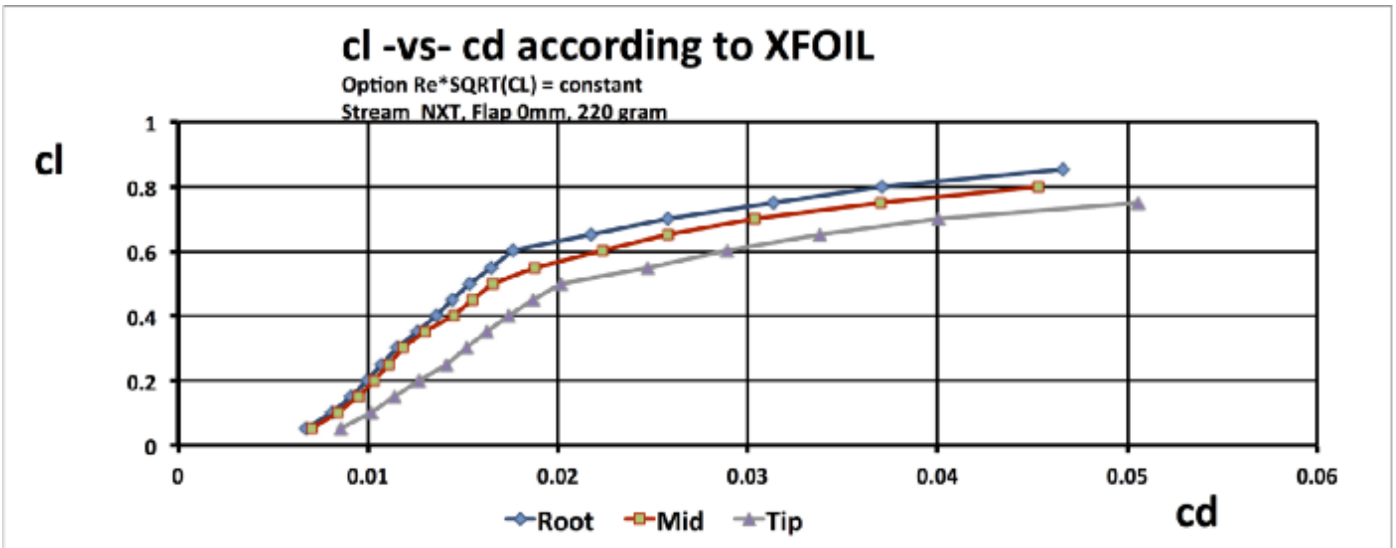

Figure 7. Example calculated airfoil properties for flap deflection of 0 mm

The calculations were made for the three measured airfoils and for each of them also all four flap positions. The influence of the root, mid and tip airfoils are included for 25% , 50% and 25% respectively. The implicit assumption is that the lift coefficient across the wing span is constant. This is a reasonable assumption because the plan shape of the wing has no washout, is substantially elliptical and the flap hinge line is at a constant percentage of the chord over substantially the entire span constant.

Air drag build-up whole model: Now you need a calculation of the parasitic drag of the fuselage + tail surfaces + protrusions + gaps and a calculation of the induced drag. Figure 8 shows the individual drag contributions and the total drag. All drag contributions are expressed here in CD value, non-dimensionalised with dynamic pressure and wing area. In this way the relative contributions are easy to compare.

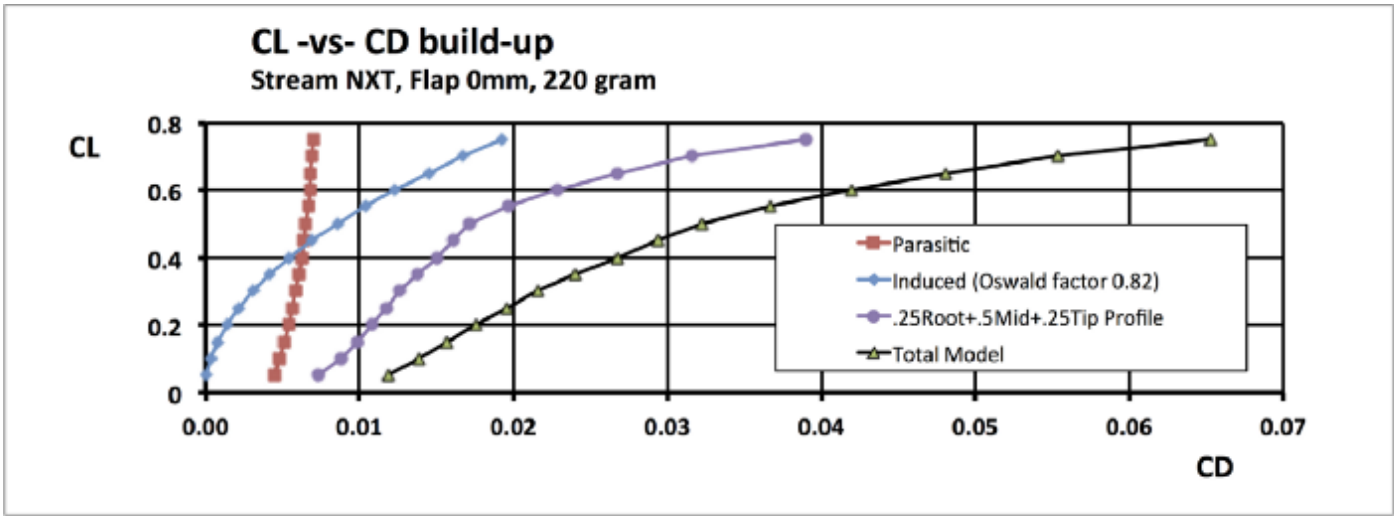

Figure 8: The main drag coefficients, non-dimensionalised with dynamic pressure and wing area.

The drag of the fuselage is defined by a Reynolds number-dependent coefficient of friction for the turbulent boundary layer. This may give a slight overestimation of the fuselage resistance because the boundary layer on the nose will be laminar. The contributions of the tail surfaces were determined with XFOIL calculations on a NACA 006 airfoil. Thereafter, the said contributions have been multiplied by their respective area and divided by the wing area. The result is shown in Figure 9. From 4 to 20 m/s, the Reynolds number increases so much that the drag coefficient almost halves. The air drag does not increase by a factor of 25, but only by a factor of 12.5. For the protrusions such as the control horns and the throwing pin, a constant Cd value of 0.1 has been assumed, estimated using the information from the book "Fluid Dynamic Drag" by Hörner. The drag of the parts is non-dimensionalised with dynamic pressure and wing area, as a comparison of the contribution to total drag. The contributions are: control horns + throw pin (= 0.00010), aileron gap (= 0.00005), stubwing under stabiliser + interference (= 0.00012) and the wing / fuselage interference (= 0.00043). The negligible contribution of the aileron gap surprised us. According to Hörner, it is 0.004 * (gap length * gap width) / wing area. This is because the gap is deeper than it is wide. A vortex inside the gap acts as a kind of "roller bearing" and guides the flow across the gap.

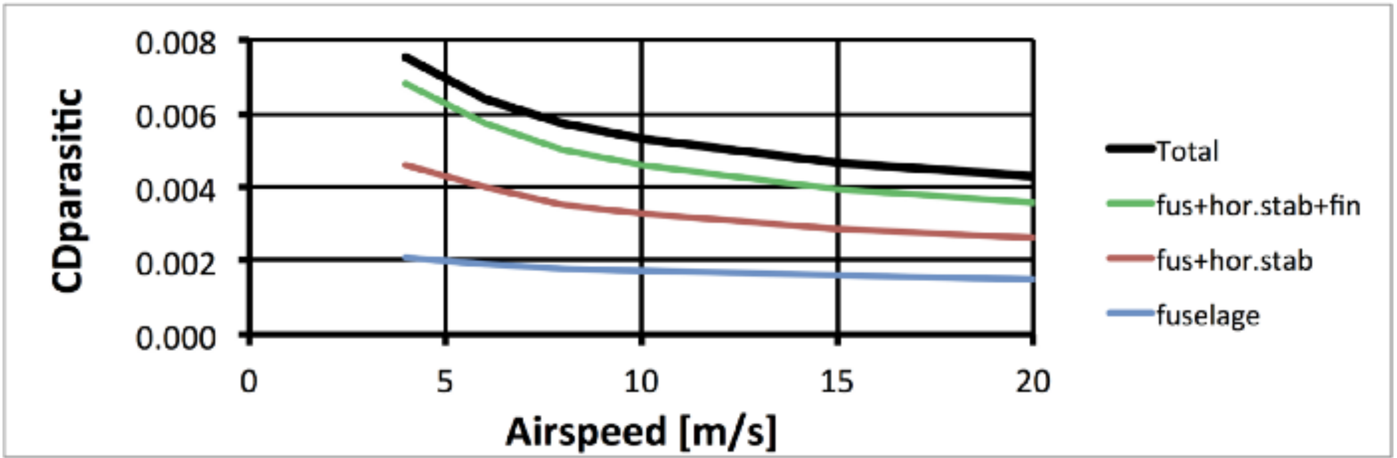

Figure 9: Build-up of the Parasitic drag.

Performance calculations: Using the data described above one can calculate the sink speed as a function of the airspeed. This is shown in Figures 10 through 12.

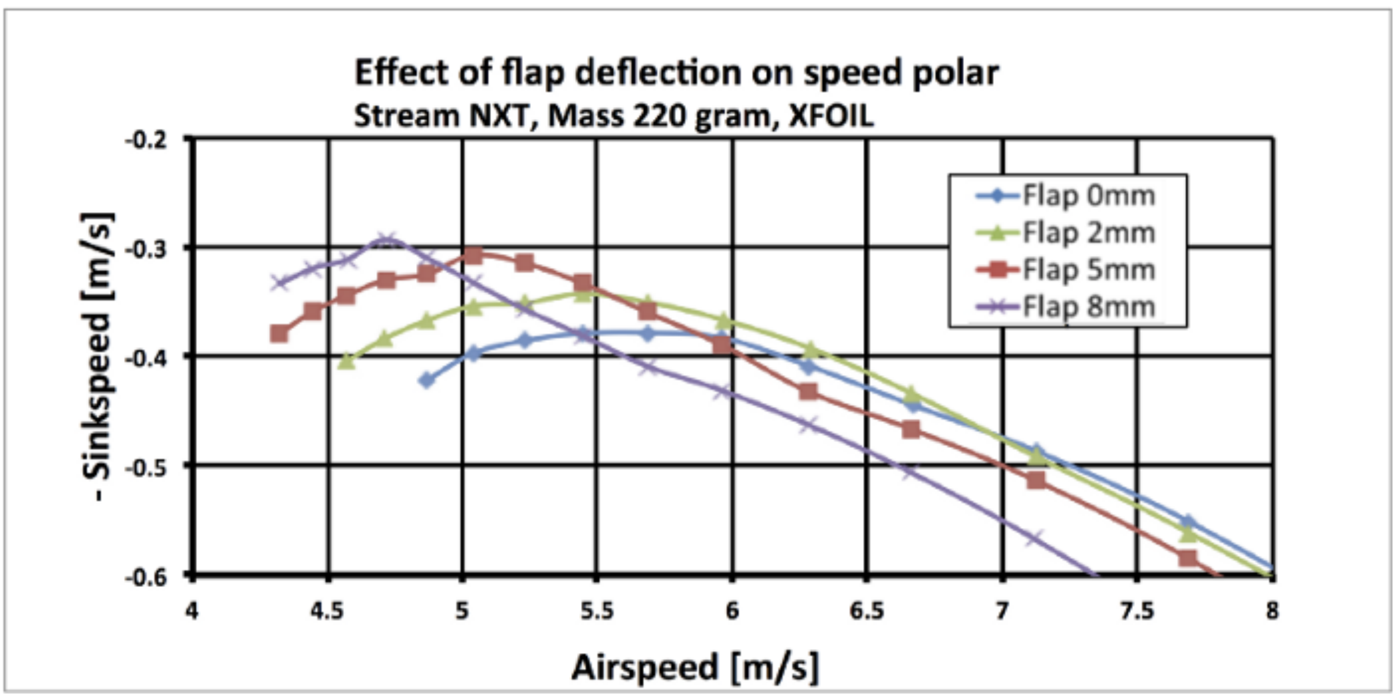

Figure 10: Effect of flap deflection on the speed polar.

You can read a number of important properties. Successively, you will find something about minimum sink speed and selecting the correct flap deflection. Then you will find something about the glide angle and what to do in downwind and headwind. Finally you find information about the reason for adding ballast.

Minimum sink speed and selection of the correct flap angle: In Figure 10 you can see that the calculated minimum sink speed of approximately 0.30 m/s is found with a flap deflection of 8 mm at a flying speed of 4.7 m/s. With flap at 0 mm, the launch position, it is 0.38 m/s, more than 25% worse. The measured sink speed at the beginning of this article was between 0.33 and 0.38 m/s, slightly higher, but it was also not perfectly still air. We fly in quiet conditions usually with flap at 5 mm. While turning in the thermals we give some elevator deflection with the result that the flap deflection is also increased, to about 8 mm. The optimal flight speed is now even lower so you can fly smaller turns. The flap deflection of 2 mm is indicated by the manufacturer for cruise flight. In Figure 10 you can see that it is indeed a good choice for finding areas with thermals faster. At slightly increased air speeds between 5.5 m/s and 7.0 m/s, this gives the least loss of height. If you want to move more quickly to another area, then flap deflection of 0 mm is even better. This result teaches us a lot about selecting the correct flap deflection.

Glide angle and what to do in sinking areas and headwind: The tangent line from the origin to the polar (red dotted line) in Figure 11 gives the point with the best glide angle. This is the same as Figure 10, but now on a slightly different scale. At between 5 and 6 m/s air speed, the glide angle is optimal with a flap deflection of 5 mm. If you have to cross a sink area, you should increase the airspeed significantly to, for instance, 8 m/s and select flap of 0 mm. That shows the blue stripe-dot line in Figure 11. The same applies in case of headwind, even then you have the best glide angle at increased air speed and corresponding flap position. The blue dash-dot line shows this for a 3.3 m/s headwind.

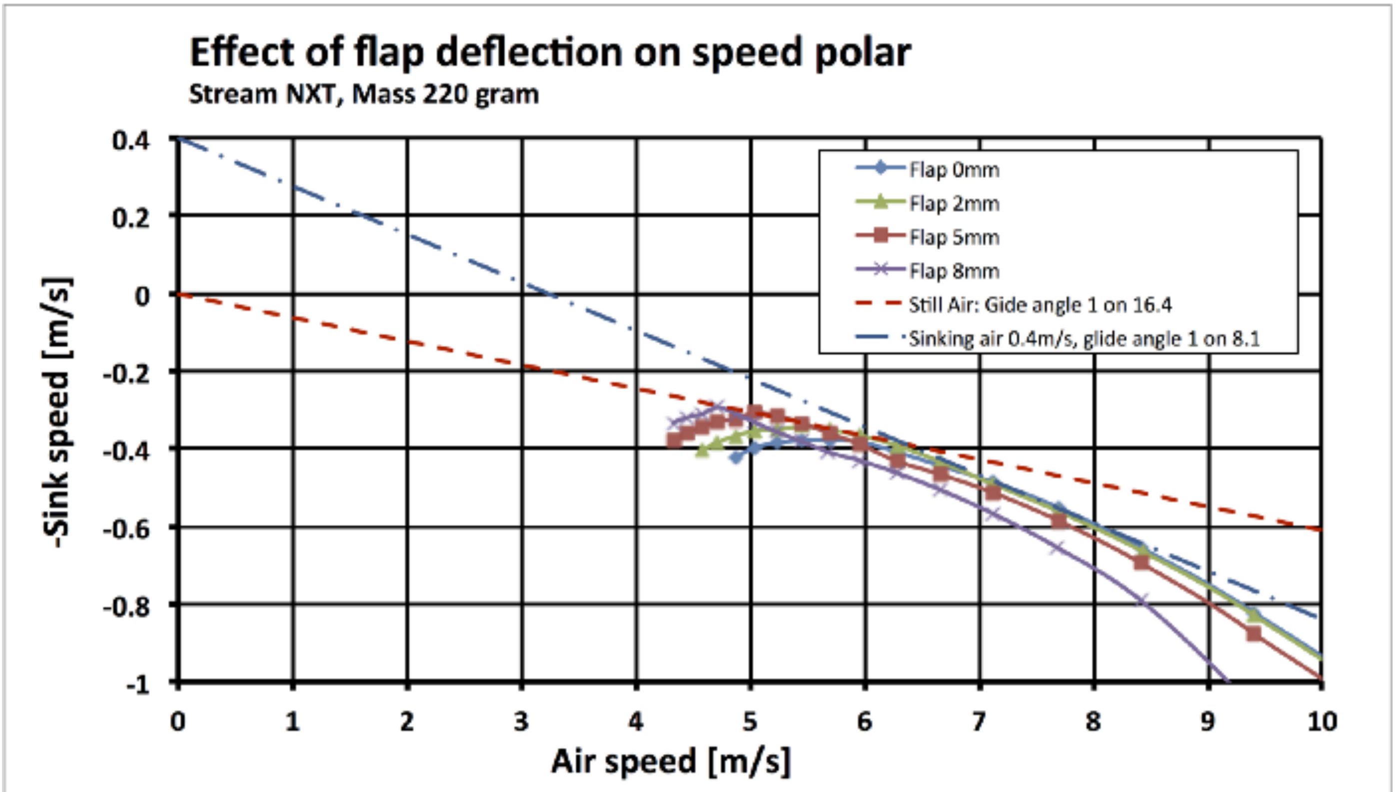

Figure 11: Effect of Flap deflection on speed polar with glide angle indication

The why of adding ballast: In Figure 12 you can see what to do if there is a headwind of 5 m/s. This is almost at the end of the Beaufort 3 scale. You will then add ballast to penetrate into the wind better. The red dotted line indicates a better glide angle than the blue. By adding 40 g ballast the sink speed at best glide is than reduced from approx . 0.82 m/s to approx . 0.72 m/s. You can then fly back with a glide angle of 1 to 6.1 instead of 1 to 5.4. You can then fly approximately 13% further in a thermal downwind. Perhaps that is an extra circuit in the thermal. You have to weigh that against the slightly lower climb rate in the thermals, because the minimum sink rate increases a bit.

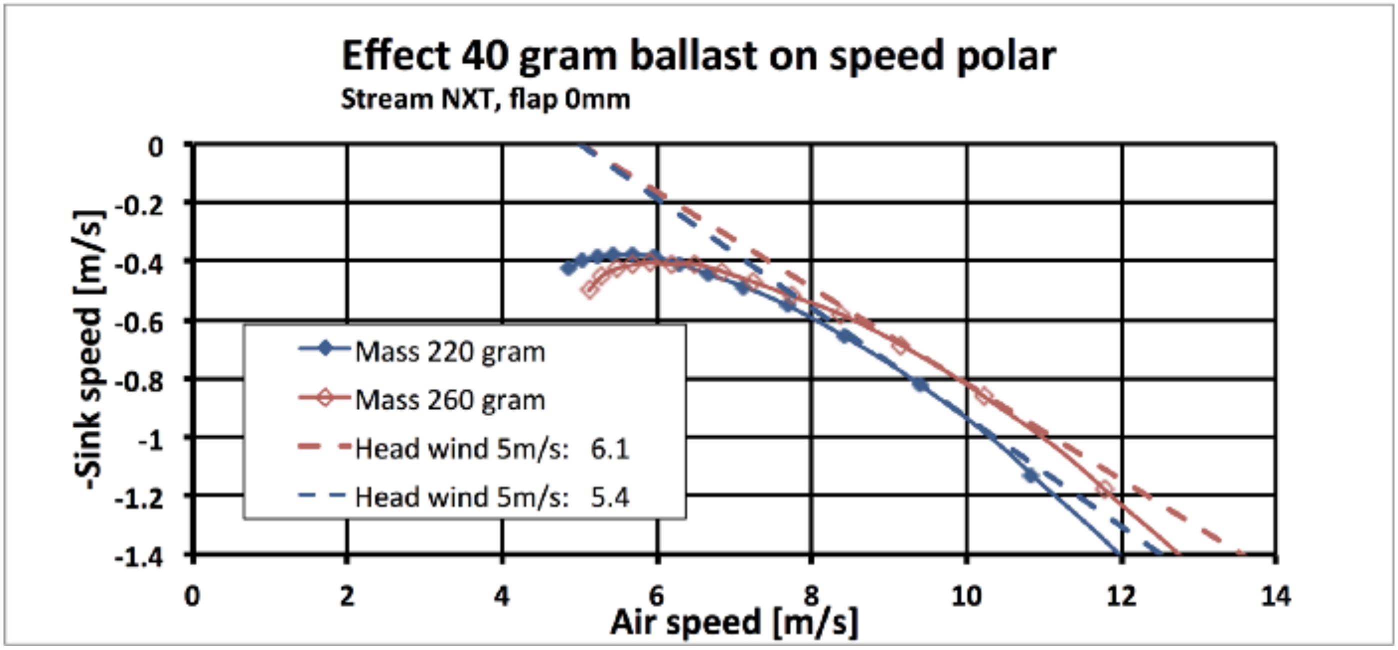

Figure 12: Influence of 40 grams of ballast on the glide angle.

There are a number of other aspects of ballast. The stall speed and sink speed increase with the square root of the mass ratio. So in this case with √(260/240) = 1.04, so with 4%. The response and sensitivity to sudden changes in wind speed and wind direction (gusts and thermals) decreases. And usually you throw the model a little bit higher.

Accuracy: To get an idea of the accuracy of these calculations and measurements, we have done a number of analyses:

- Measurement errors in sink speed of Figure 2: The air is not 'still' — air can always have some movement in it. And how accurate are the altimeters? Tjarko uses JETI equipment with 0.1 s and 0.1 m resolution. Theo uses an FD-A altimeter with 0.25 s and 1 m resolution. Measurements in still air (as far as possible) give values around 0.25 to 0.30 m/s.
- Measurement errors in the geometry of the airfoils. In particular, the "0" position of the flap may not be entirely correct. The flap is set to zero at the root (flush with the fixed mid-section above the fuselage). Due to the extensive use of the model, small geometry deviations have arisen. We estimate this error to be -0.2 mm and have therefore

neglected it. However, we dared not measure on our new models, so as not to damage them.

- Approaches in XFOIL: The default value for stability of the boundary layer (N = 9) is used. The program calculates the location of the transition point from laminar to turbulent boundary layer itself. Roughness of wing surface combined with the very low Reynolds number can greatly affect the airfoil properties, especially on the drag coefficient. The rudder gap has also been "sealed up" in the calculations. I have seen that the contest participants do not seal the rudder gap with a tape, so I assume that the effect is not too bad in practice.
- In this article, the trim drag has been neglected. If the horizontal tail plane provides a positive lift, the wing does not need to provide as much lift at the speed at which you fly. This leads to a small decrease in the induced drag of the wing . The trimming resistance can be both positive and negative and depends on which centre of gravity you have chosen. A simplified consideration of the forces- and moment balance shows that at minimum sink rate, the lift on the horizontal tail plane is slightly positive at 5 mm flap deflection. In this case, this leads to a negative trim drag of about 1% and thus to a favourable effect of 1% on the sink speed. All this with a centre of gravity of 70 mm from the nose. For a centre of gravity location of 65 mm, this consideration has a favourable effect on the minimum sink speed of only 0.2% This is perhaps an important reason why competition pilots always look for the most rear location of the centre of gravity.
- Deviation from the airfoil shape: At the first two millimetres of the leading edge the measurement process is not accurate. It seems that our new models have a somewhat more rounded nose than that we measured on than the older models. Here the airfoil has been recalculated with XFOIL, now with a slightly modified nose. Rounding the nose has no effect at low lift coefficient. However at higher lift coefficients an improvement has been found which results in a

reduction of the sink speed by a maximum of approximately 1.4%.

- The estimate of the parasitic drag is based on measurement data from the literature and is not always entirely applicable at these low Reynolds numbers. In particular, the drag contribution of the throwing peg is difficult to determine. It's slightly streamlined, but is relatively thick (~ 30%) at a Reynolds number between 3,000 and 24,000. It is also located close to the tip, where the flow direction can vary greatly. Its contribution to the total, however, is of the order of 1% of the minimum drag of the overall model (important for the launch height) and in the order of 0.2% on the minimum sink speed.

If you could add these inaccuracies, this would lead to a possible improvement of the minimum sink speed in the order of 0.01 m/s. Thus from 0.30 m/s into 0.29 m/s for a flap deflection of 8 mm.

Using the Zone V1 airfoils: Figures 13 and 14 show a comparison that is interesting for self-builders. In the XFOIL calculations, the measured airfoil coordinates are replaced by the Zone V1 airfoils often used by self-builders. These are optimized for Reynolds numbers 52000, 40000 and 25000. The airfoils for the root, mid and tip respectively are thinner by 0.17%, 0.70% and 0.63% than the NXT airfoils.

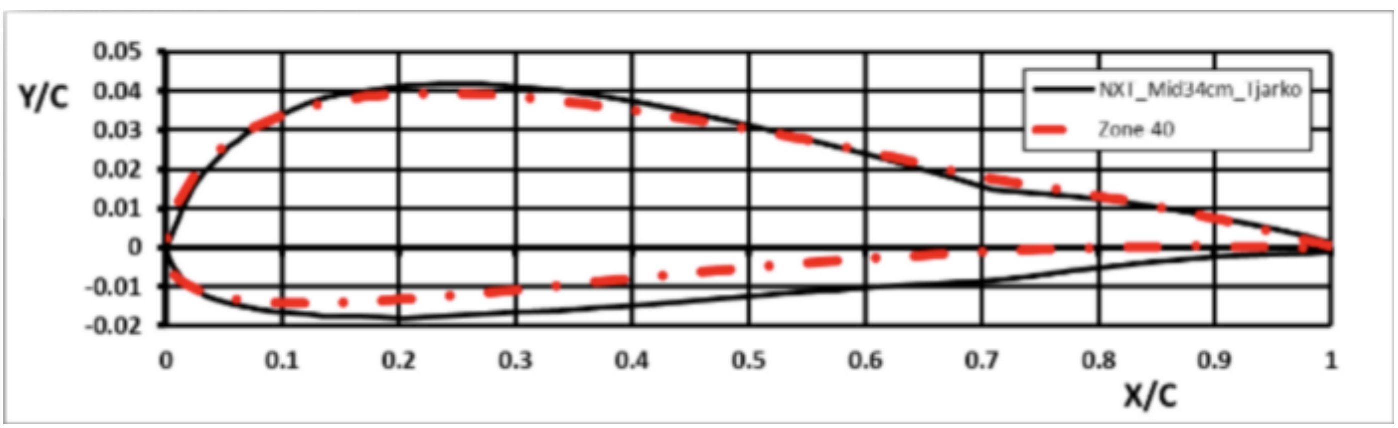

Figure 13: Comparison geometry measured NXT airfoil at 34 cm from the root with the V1 Zone — 40 airfoil.

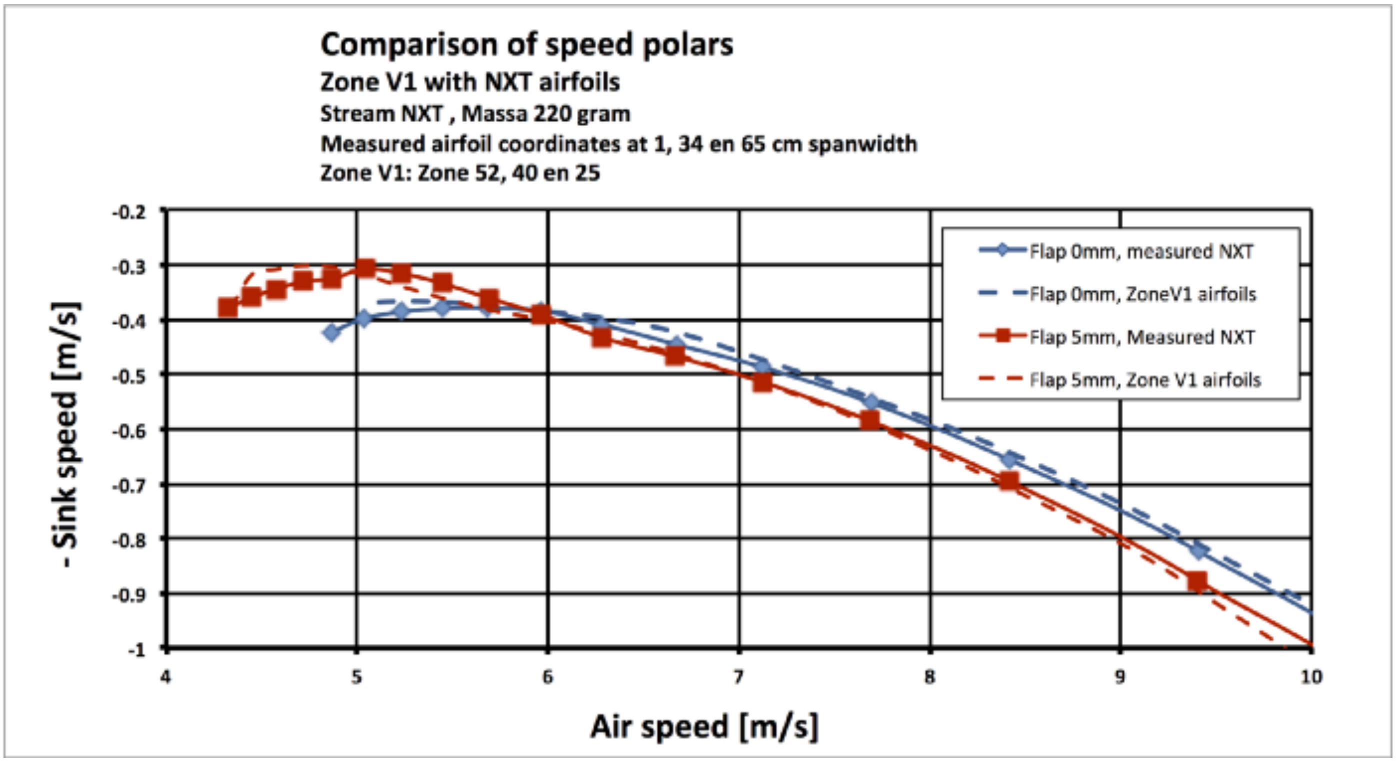

Figure 14 : Comparison of speed polars.

Although the airfoils are quite different, the performance together hardly deviate from each other. However, the XFOIL calculations for the Zone V1 airfoils stopped at a slightly lower maximum lift coefficient. This indicates a possible different stalling behaviour.

Subjective impressions: From the measurement of the airfoils and the total aerodynamic analysis we have got a good idea of the NXT. The wing plays the leading role in overall performance, with airfoil drag being the largest contributor to overall drag. Yet it is not the determining factor of this model, the difference with the well-known Zone V1 airfoils is minimal. So what makes the performance difference in the generations of DLGs we fly with? We are seeing an ever-decreasing flight weight from say 300 grams to 220 grams. Better materials are used and there is nowhere a gram can be wasted. This is particularly important in conditions with low wind speeds. But with some wind we will soon add 20 to 40 grams of ballast in the NXT. The wings are getting slimmer, this gives less drag when launching and gives a better glide angle. Yet there is perhaps an aspect that we cannot figure out: the calculation of the flight stability. This may determine a big difference between the model equipped with the Zone airfoils and the NXT airfoils. The Stream has a very good natural behaviour compared to my other DLGs and in turbulent weather it is able to turn its laps while maintaining height. Whereas my earlier DLG in turbulent conditions just steps down, the NXT is able to climb neatly back after a gust to almost its original altitude. It may be hidden in the polar in Figure 14, where the curve of the NXT airfoils continues a little further at low speeds. But it could also be due to the beautiful long and very light tail boom.

Conclusion: This type of analysis has given us a good idea where we stand with the tuning and flying with our DLGs. The calculation results help us to understand which flap position to choose in the various flight conditions. The sink speed that we are able to achieve corresponds to what seems possible via calculations and it therefore mainly comes down to improving the launch heights. Of course, all of this says nothing about the art of finding the areas with favourable air again and again. You can only learn that by flying a lot and challenging each other to do better than the other.

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