Budapest University of Technology and Economics
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Summary of my diploma thesis

A Computational Fluid Dynamics Study of Keel Sections with Trim Tabs

Budapest
2009

The foils chosen for the study

As the first step of my study, I generated several keel sections, with both conventional and Heyman trim tabs. The generation steps were the following:

- I took one side of a symmetrical NACA 4 digit section and rotated it around the trailing edge so that the joint is located 30% or 40% of the chord length before the trailing edge and has a diameter of 30mm (chord was 1000mm).
- I drew the Heyman-concept section (blue) of which the rotated profile is the suction side
- I drew two conventional trim tab sections with the joint being at 15% and 25% respectively before the trailing edge, the trailinges edge coinciding with the trailing edge of the Heyman section, so that the angle between keel centerline and boat centerline also stayed the same.

These sections can be seen in Fig. 1.

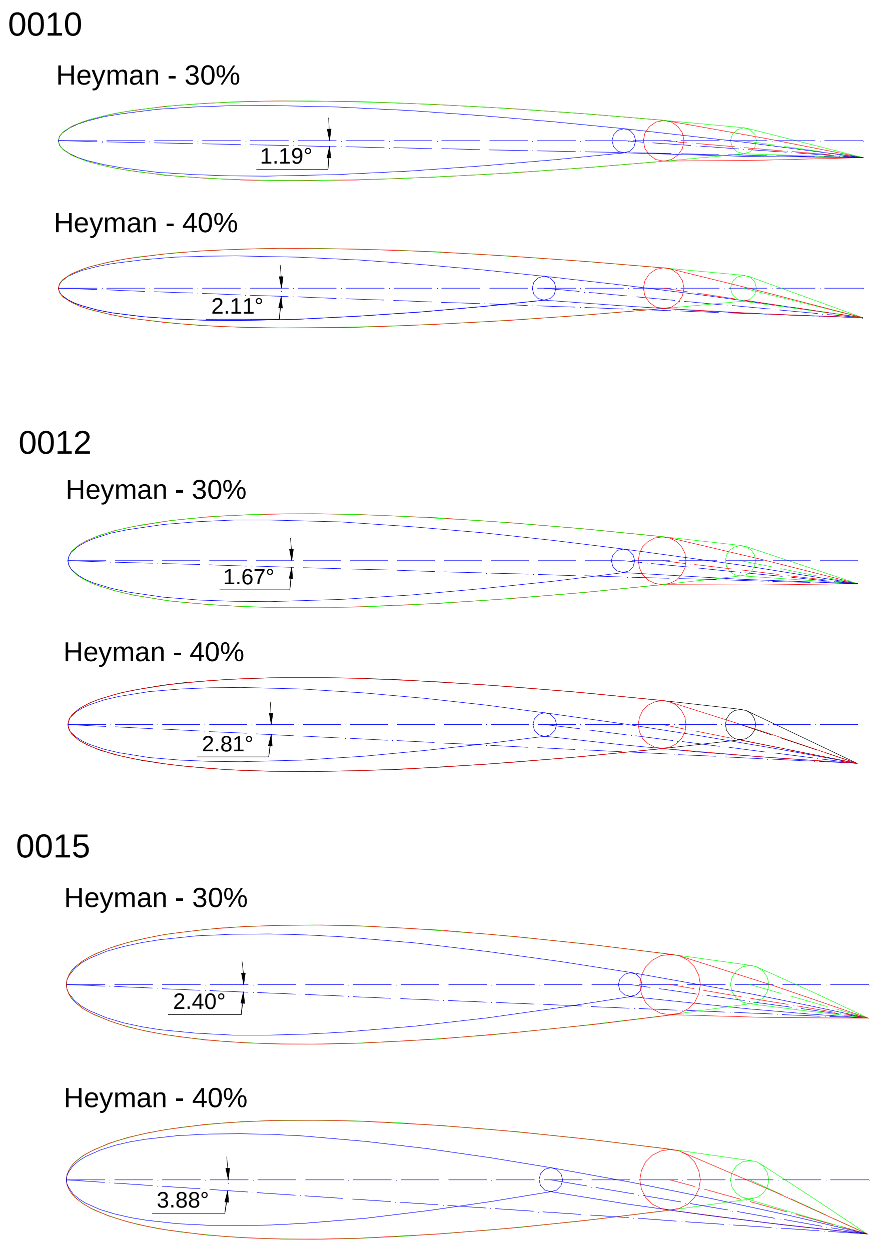

Fig. 1.

From the sections above, I finally chose one family of foils for the study: the third family from above, that means NACA 0012, Heyman trim tab at 30%. According to this, the studied foils were:

- NACA 0012 family:
  - Original symmetrical section (benchmark)
  - Conventional trim tab section with joint at 15%
  - Conventional trim tab section with joint at 25%
  - Heyman section with joint at 30%

CFD Meshing, Boundary Conditions, Turbulence Model, Wall Treatment

I did a CFD simulation with Low-Re wall treatment for a better computation of the boundary layer and thus the drag. The mesh near the foil can be seen in Fig. 2.

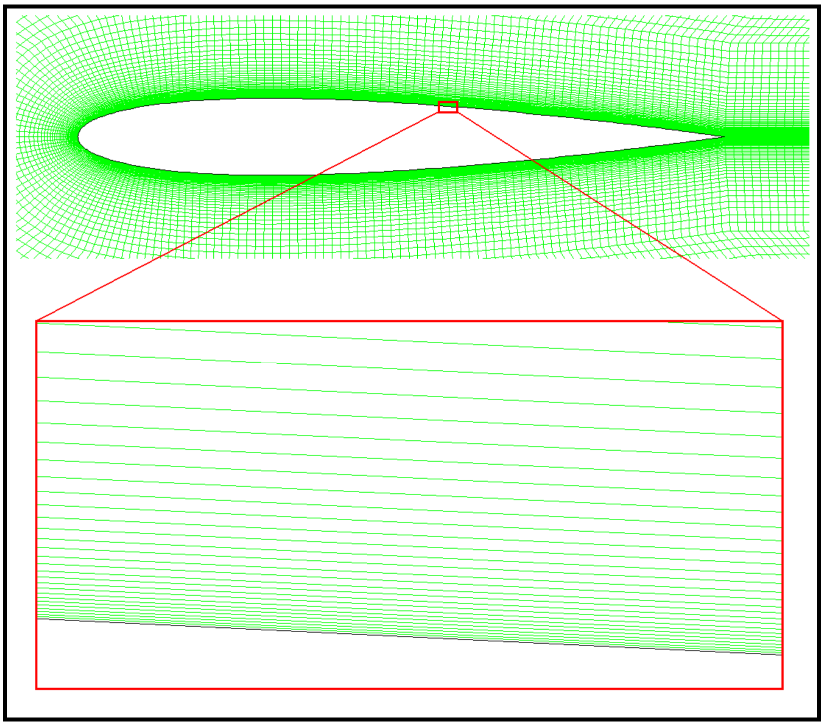

Fig. 2.

The complete mesh with the far-field can be seen in Fig. 3.

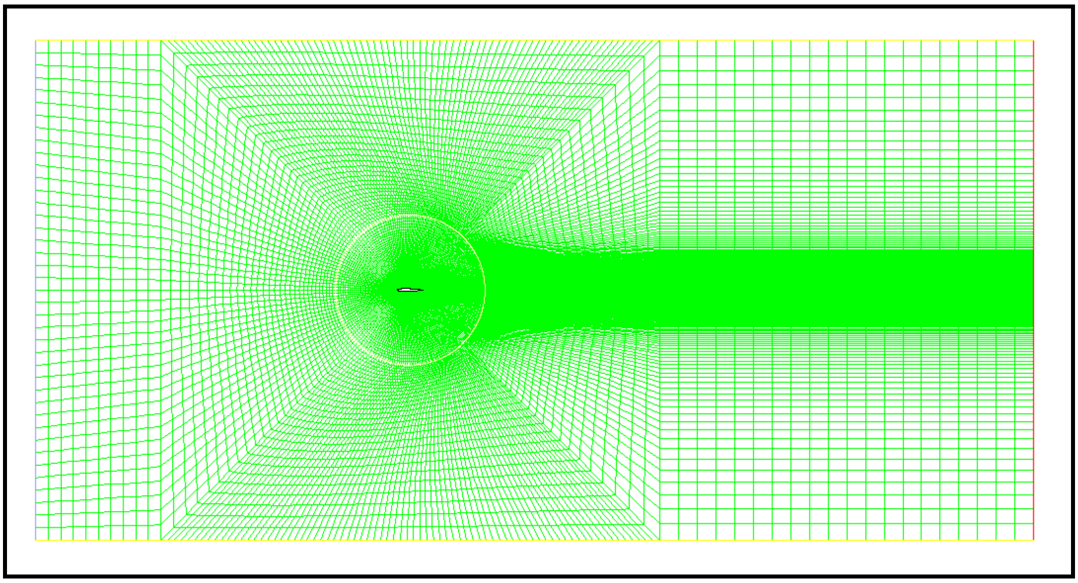

Fig. 3.

The mesh consists of 54.000 quadliteral cells.
Far-field dimensions are 40 and 20 times the chord length, respectively.

The boundary conditions were set as follows:

- Velocity Inlet at the inlet (blue, to the left), with a speed of 5 m/s upwind and 8 m/s downwind
- Pressure Outlet at the outlet (red, to the right) with a pressure of 101325 Pa
- Symmetry at the top and bottom of the far-field (yellow)
- No-slip, smooth wall at the surface of the foil

I chose the SST-k-ω turbulence model with an intensity of 0,1% and a length scale of 1m.

Validation

The results of the simulation of the symmetrical NACA 0012 section compared to experimental results can be seen in Fig. 4.

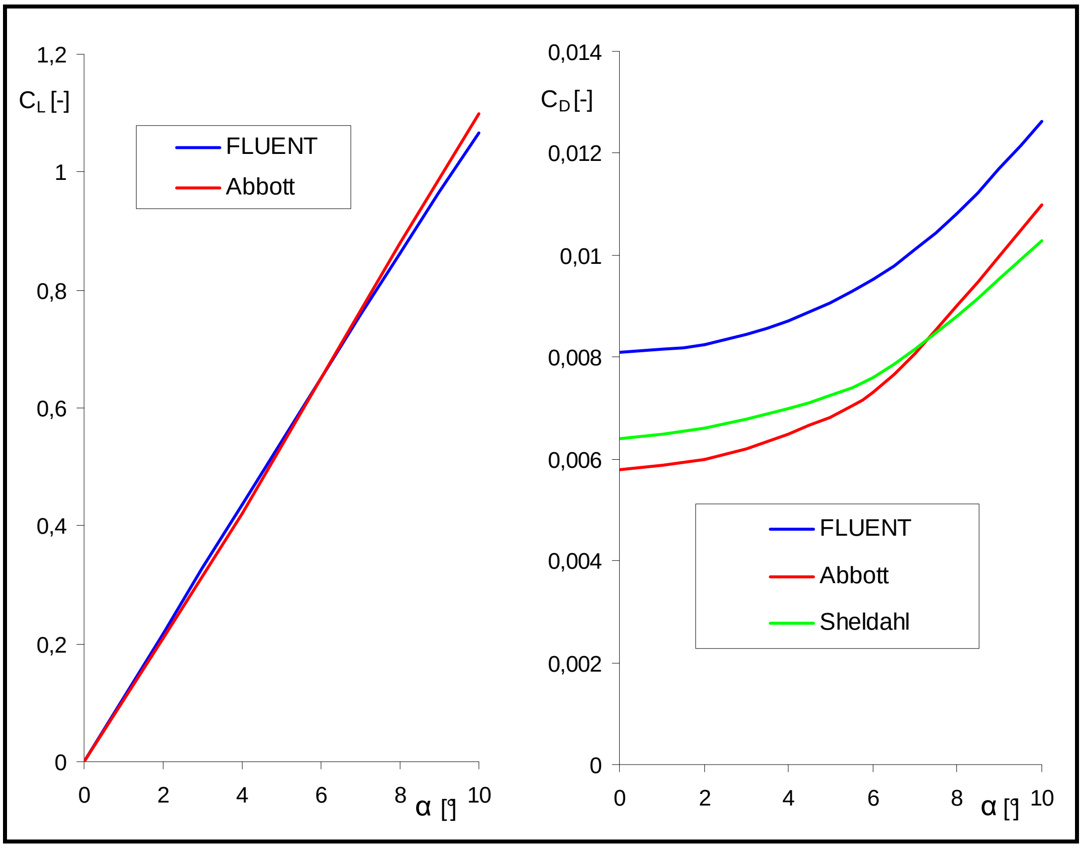

Fig. 4.

We can see an almost perfect agreement in the C_L values. However, as the drag values show a serious overprediction of about 30% in average. The cause of this is the coarse mesh. Studies show that as the mesh gets more and more refined, the drag values start to converge to the experimental data values. However, I didn't have the opportunity to run the simulations on finer meshes – it simply would have taken too much of time and computer resources. This means that my results can't be interpreted as an exact prediction of the performance of the different foils – they will be pretty good for comparison, though, since the overprediction of the drag is probably around the same with all foils.

Characteristics of the different foils

Let's take a look at the lift vs. AOA and the drag vs. AOA charts of the sections (Fig. 5.). (blue: symmetrical section; red: Heyman-section; green: conventional trim tab section with joint at 25%, black: conventional trim tab section with joint at 15%)

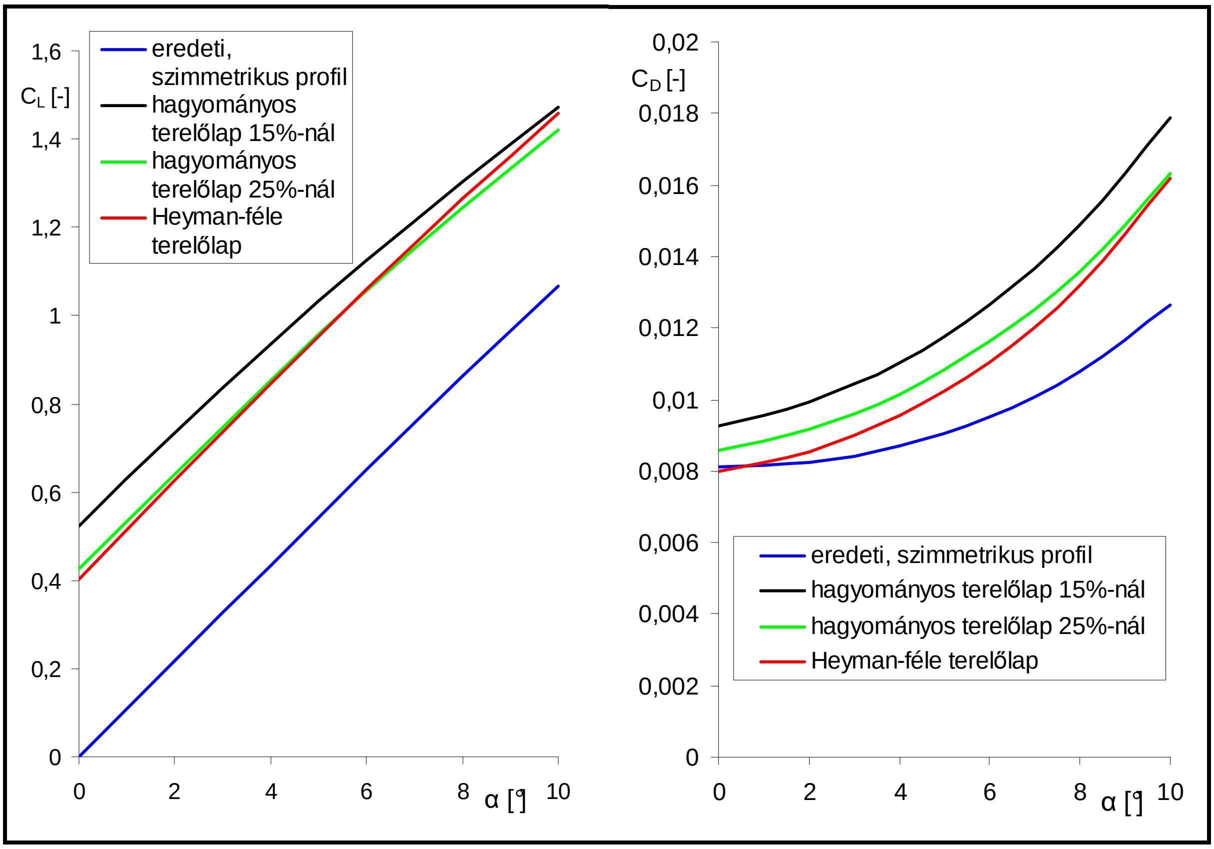

Fig. 5.

As we can see, of course all trim tab sections have a higher lift than the symmetrical section. The 15% section has the highest lift, particularly at low AOA, because of its highest "curvature".
However, the 15% section also has the highest drag values in the complete range of the studies AOA-s. The 25% section follows, and the Heyman section is the third. However, at very small AOA, the Heyman section happens to have a smaller drag than the symmetrical foil! Also, the slope of the trim tab foil drag curves are steeper than that of the symmetrical section.

Let's see what this means regarding the L/D values (Fig. 6.).

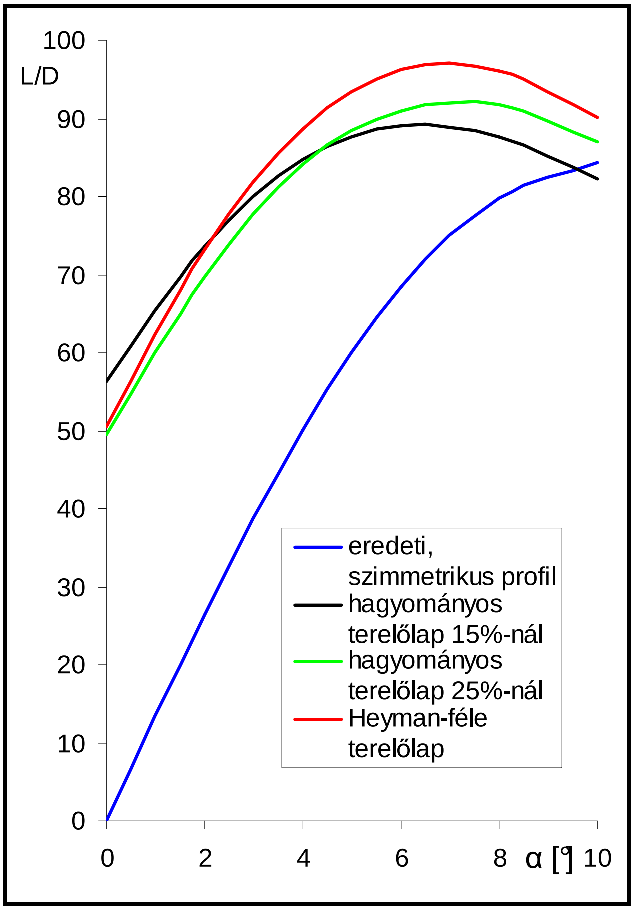

Fig. 6.

As we can see, the L/D ratios of all three trim tab foils are superior to that of the symmetrical foil over the whole range of AOA-s. However, the answer to the question which trim tab foil has the highest ratio depend very much on the AOA: the 15% foil seems to be best at low AOA-s, but above around 2°, the Heyman section seems to be better than all the others.

However, these charts show the values of the section, that means just the 2D case, as if the wing would be infinite long or would have two walls at its tips, thus eliminating induced drag.

But since real keels are 3D finite length wings, we also should try and say something about the 3D performance of these sections. Of course, it would have been best to do a 3D simulation, too, but this would have been too time-consuming. Therefore, I only computed the expected characteristics of the sections using the following formulae:

$$C_{L\_3D} = \frac{C_{L\_2D}}{1 + \frac{2}{AR_e}}$$

C_{L_3D} – 3D lift coefficient [-]
C_{L_2D} – 3D lift coefficient [-]
AR_e – Effective aspect ratio of the keel [-]

$$C_{DI} = k \cdot \frac{{C_{L\_3D}}^2}{\pi \cdot AR_e}$$

C_{DI} – Induced drag coefficient [-]
k – Coefficient for the sideview of the keel (1 if elliptic, 1.05…1.15 if not) [-]
C_{L_3D} – 3D lift coefficient [-]
AR_e – az effektív karcsúsági tényező [-]

$$C_{D\_3D} = C_{D\_2D} + C_{DI}$$

C_{D_3D} – 3D drag coefficient [-]
C_{D_2D} – 2D drag coefficient [-]
C_{DI} – Induced drag coefficient [-]

I did the computation for two cases: a racing yacht (effective keel aspect ratio 8) and a family touring yacht (effective keel aspect ratio 8).
The results for the racing yacht can be seen in Fig. 7.

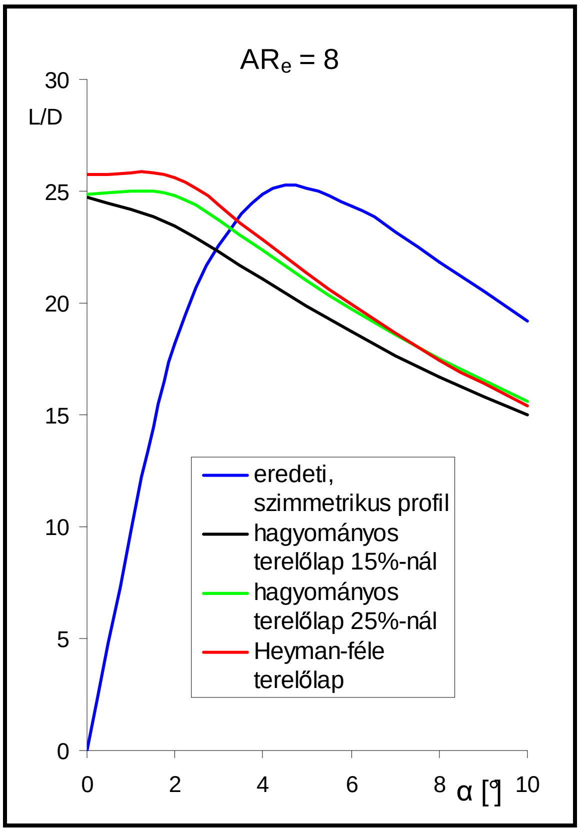

Fig. 7.

We can see that the big advantage of the trim tab foils over the symmetrical foil we saw in the 2D study has disappeared here for AOA-s higher than 4°. This is because the higher lift produced by the trim tab foils also means a higher induced drag, of course. But since a racing yacht usually has a leeway angle smaller than 4°, using a trim tab foil would pay off in this case. Between the trim tab foils, the Heyman foil shows the best L/D ratio.

Now let's see the family touring yacht with the low-aspect-ratio keel (Fig. 8.).

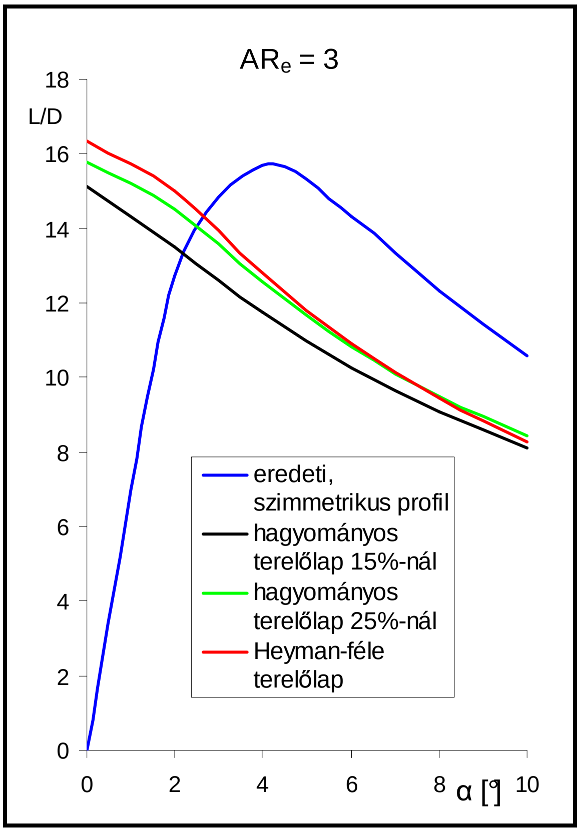

Fig. 8.

Basically, this chart is almost the same than that of the racing yacht. Of course, the lower aspect ratio means higher induced drag, and thus smaller L/D values. The other difference is that the intersection points of the symmetrical section curve with the trim tab section curves has moved slightly towards smaller AOA-a.

These results mean that in the case of a touring yacht with a smaller aspect ratio keel and a leeway angle of around 5-7°, the symmetrical section would be the better choice, since in the AOA range of interest, it has higher L/D values than the trim tab keels.

Conclusions

Trim tab keel produce more lift, but unfortunately also more drag than symmetrical keels. The choice between them can only be made looking at the L/D curves. I have concluded that at low leeway angles, trim tab keels perform better. However, as the AOA increases, the L/D ratio of the trim tab keels gets lower, and above a certain AOA it comes below the L/D of the symmetrical keel. Above this AOA, the symmetrical keel pays off better.

Between the trim tab keels, the Heyman-concept keel had the highest L/D ratios over the complete range of AOA-s of interest, so this concept is worth some more detailed studies in the future.