

# Climb Performance and Handicapping

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The promise of a Mueller-Vickland fly-off (or is it an LS-8 vs. 1-26 fly-off?) got me interested in the subject of glider handicapping. I'd always wanted to go through the exercise and see if I could come up with numbers similar to those Carl Herold's or the Deutscher Aero Club's.

It seemed to me that handicaps should reflect the climb performance of the glider in question. Especially in this case, because of the 1-26's oft-touted ability to core tight thermals at low airspeed. As far as I can tell (e.g. from Ref. 5), the Carl Herold (SSA) handicaps do not reflect this, but assume that all gliders climb at the same rate. On the other hand, I am given to understand that the DAeC indices (on which the OLC is based), do attempt to model this. I decided to try to incorporate thermaling ability in my handicap numbers, but doing this turned out to be much more involved than I first realized, and I thought it would be useful to put my notes together for *Skylines*.

These are the questions:

1. when flying a circle of given radius in still air, what is the combination of airspeed and bank angle that yields the lowest rate of sink? For handicapping, we'll assume that the pilot flies this "optimum schedule" of airspeed vs. bank.
  2. assuming the pilot is flying this "optimum schedule" in a thermal of given lift vs. radius profile, what is the optimum solution (airspeed, bank, radius) to maximize the rate of climb? This is what tells you how to fly in a thermal. Never mind that thermals seldom look exactly like the models we'll be using — this is just a handicapping exercise. That said, there is still some useful insight to be had.
- While we're at it, we'll consider these additional questions, although they don't have much to do with handicapping per se:
3. when flying a turn with given *bank angle*, what airspeed minimizes the rate of sink? This is probably never the right question to ask — the only reason to bring it up is to point this out.
  4. For completeness: when flying a circle of given *airspeed*, what bank angle minimizes the rate of sink? This one is easy: zero!

## Basic turn relationships

Steady turns are defined by radius  $r$ , airspeed  $V$ , and bank angle  $\phi$ . Given any two of these, the third can be computed. Specifically:

$$V = \sqrt{rg \tan \phi} \tag{1}$$

$$r = V^2 / g \tan \phi \tag{2}$$

$$\phi = \arctan(V^2 / rg) \tag{3}$$

In addition, the load factor  $n_z$  in a turn is  $1/\cos \phi$ , and the lift is  $n_z W$ . For a given turn, this lets us find the level flight airspeed at which the glider would have the same lift coefficient:

$$\bar{V} = V / \sqrt{\cos \phi} = V \sqrt{\cos \phi}$$

This says that if you fly a turn at airspeed  $V$  at bank angle  $\phi$ , you'll be operating at the same lift coefficient as you would in level flight at airspeed  $\bar{V}$ . So for example, if your level flight minimum airspeed is 30 kt, in a turn that same lift coefficient would be achieved at  $30 \text{ kt} / \sqrt{\cos \phi}$ .

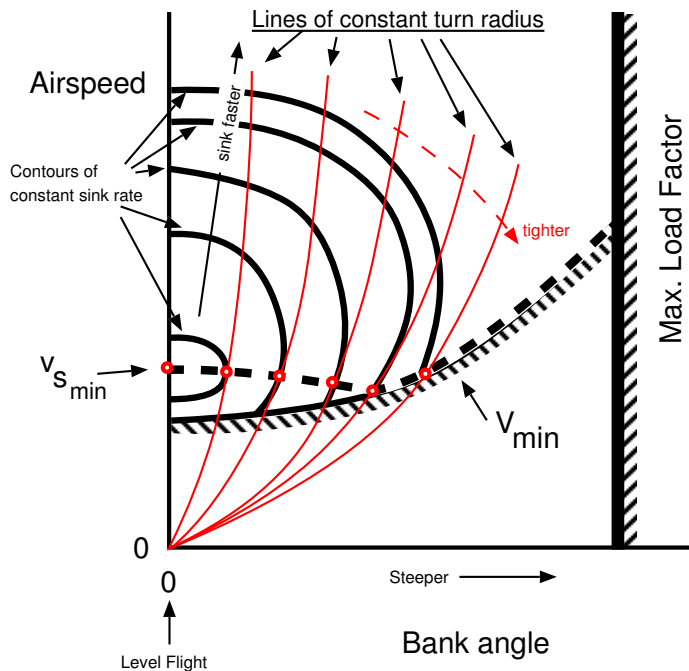


Figure 1: Typical turn polar (full airspeed-bank map)

## Sink rate in a turn from the Level Flight Polar

The bad news is, there seem to be no experimental data available for gliders in turning flight. This means that sink rates in turns have to be estimated from polars measured in straight-and-level flight.

Skipping the derivation, the approach I used was:

1. compute  $\bar{V} = V \sqrt{\cos \phi}$
2. look up the sink rate  $\bar{v}_s$  in the measured polar at airspeed  $\bar{V}$
3. compute the  $L/D = \bar{V} / \bar{v}_s$
4. the sink rate in the turn is then  $v_s = V / (L/D) \cos \phi$

There are some problems with this. It ignores the effects of control deflections and sideslip. The effects of yaw rate are neglected. Most important of all, it leaves out the influence of handling qualities. For example, some gliders just seem to "like" steep turns more than others. However, this is the best we can do given only the level-flight airspeed polar.

## The "Turn Polar"

The level-flight polar we're familiar with is a plot of sink rate vs. airspeed. In turns, we have an additional independent variable — bank angle. So the "polar" becomes a "map" of sink rate vs. airspeed and bank angle. Fig. 1 shows a cartoon of such a map. Along each of the  $v_s$ -contour lines (black), the sink rate is constant. This is sort of like a topographic chart, with the "bottom" of the hill being the level-flight  $V_{s \text{ min}}$  point. The red lines are lines of constant radius, based on equation 1. Note that these constant-radius lines are the same for every glider, regardless of performance. As we go to the right of the chart, these lines represent steeper and steeper turns.

Question #1 asks: along any one of these lines of constant radius, where is the point of minimum sink rate? Without going into the math, this occurs at the point where the constant-radius line is

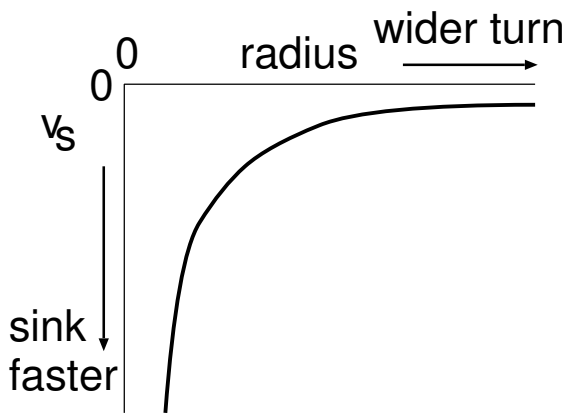


Figure 2: Typical turn polar (sink rate vs. radius)

exactly tangent to a constant- $v_s$  contour. The red circles in Fig 1 show these points, and the dashed line indicates the locus of the minimum sink points as the turn radius is varied.

Initially, for very shallow turns, the optimum solution may call for a *slower* airspeed than the level flight  $V_{s_{min}}$ . This happens when the tradeoff favors the increased drag of flying “behind the curve” over the effects of bank angle. As the turn is tightened up, the best airspeed decreases, until the minimum airspeed line is reached. This line might be due to stall, buffet, or simply lack of data in the measured polar. At this point, slowing down is no longer an option, and the best airspeed follows the  $V_{min}$  line.

As we’ll see, slowing down below level-flight  $V_{s_{min}}$  only makes sense in shallow turns, and there may be other reasons not to do this, for example handling qualities and concern over stalling. Some polars don’t even show a “backside” below  $V_{s_{min}}$ , either because there isn’t one or (more likely) they didn’t bother to measure it. Even in steeper turns, where the optimum would seem to be to fly at  $V_{min}$ , some gliders will do better at a slightly higher speed, for reasons mentioned above. Again, this is a handicapping exercise, and we have to base everything on the available performance data, i.e. the level-flight polar.

The dashed line gives us the optimum “schedule” of airspeed vs. bank as the turn is tightened up. If we plot the sink rate along this line as a function of turn radius, we end up with another version of the “turn polar”, shown in schematic form in Fig 2. This tells us the best sink rate we can achieve as a function of turn radius, assuming the pilot flies the optimum turn solution.

Note Fig. 2 predicts that for very steep turns, the sink rate really takes off. This is why some tow pilots like to come down in steep turns (though some discourage this, for other reasons).

While we’re at, let’s think about Question 3, which asks how to minimize the rate of sink for a given *bank angle* (not turn radius). By visualizing a vertical (constant bank angle) line in Fig 1, it’s not hard to see that, for a fixed bank angle, the airspeed that produces the minimum rate of sink generally leads to suboptimal airspeed/bank angle combination, i.e. one that is off the “optimum schedule” line. In other words, if you find the optimum airspeed/bank angle combination for a turn of given radius, the airspeed will *not* be the one that minimizes the rate of sink for that bank angle. That’s why Question 3 is the “wrong question”.

## Thermal Models

The simplest thermal models assume that thermals are perfectly circular, with strength varying as a function of distance from the center.

The results I’ll be showing here are based on the four Horstmann thermals [2, 7]. These are labeled “A1”, “A2”, “B1”, and “B2” according to their size (“A” = narrow, “B” = wide) and strength (“1” = weak, “2” = strong). These models were based on flight test measurements made in Central and Eastern Europe and may not be representative of the ones we get west of the Mississippi. For that, we could use the Carmichael models [1, 7] but let’s save that for another day.

The Horstmann model specifies the thermal velocity at a specified radius, and a linear velocity gradient with radius. When we add the climb velocity of the thermal to the sink rate of the glider, we get a chart of climb performance, for example Fig. 3. Fig 3 tells us what we already know: the climb in a thermal is optimized by flying at a particular radius, with the correct bank angle and airspeed. If we fly a wider turn, we lose because we end up in a weaker part of the thermal. If we fly too tight a turn, we *really* lose because of the detrimental effects of bank angle and airspeed. If the turn is too tight, we stop climbing altogether.

The best rate of climb indicated by Fig 3, along with the airspeed/bank angle combination required to achieve it, provide the answer to Question 2

## Getting down to cases

As promised, we’ll consider the SGS 1-26E and the LS-8A. For grins, we’ll also throw in the Schleicher K-8b (the “European 1-26”, or maybe the 1-26 is the “American K-8”, depending on your outlook).

Measured polars for the three gliders are shown in Fig. 4. The SGS 1-26E and LS-8A data were measured by Dick Johnson, Refs. 3 and 6, respectively. The 1-26E was measured at 620 lb. gross weight, and the LS-8A at 736 lb. I don’t have a lot of faith in this LS-8A polar because it doesn’t look much better than a Std. Cirrus, but it’s close enough for now. The K-8b data were measured by Hans Zacher [8]. The gross weight corresponded (I think) to empty plus a 90 kg pilot.

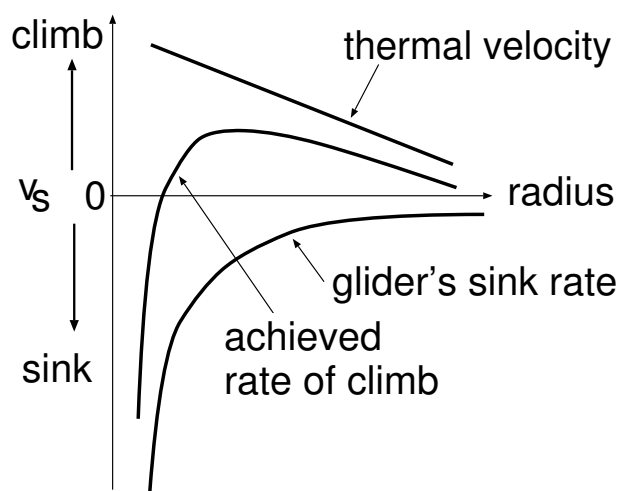


Figure 3: Climb performance in thermal

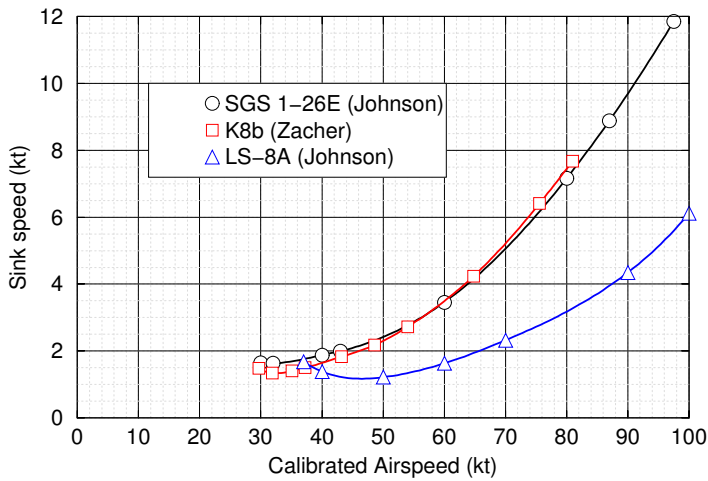


Figure 4: Polars for 1-26E, K-8b, and LS-8A

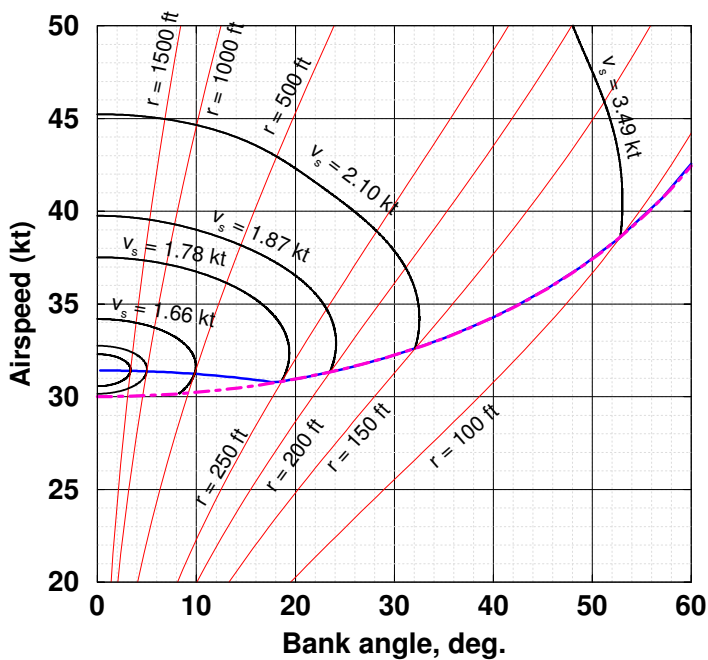


Figure 5: SGS 1-26E turn performance map

The symbols show the points I read from the published polars and used to fit cubic splines to the data. In the case of the LS-8A, I first had to draw a polar line through Johnson's data; he didn't do this himself, possibly because of the scatter. So bear in mind that the LS-8A polar is, to some extent, a product of my artistic interpretation.

In Fig. 4, the 1-26E and K-8b have very similar performance. The K-8b is a bit better at low airspeeds, the 1-26E slightly better at higher airspeeds. The LS-8A is much better than either of them (it ought to be!) and its advantage increases steadily with airspeed.

Figure 5 is the actual turn performance map for the SGS 1-26E based on the measured polar in Fig. 4. The red lines are lines of constant turn radius; the black lines are contours of constant sink rate, the blue line is the locus of optimum turn solutions, and the magenta line is the minimum airspeed. According to these results, up to about 18° bank, the optimum airspeed decreases slightly

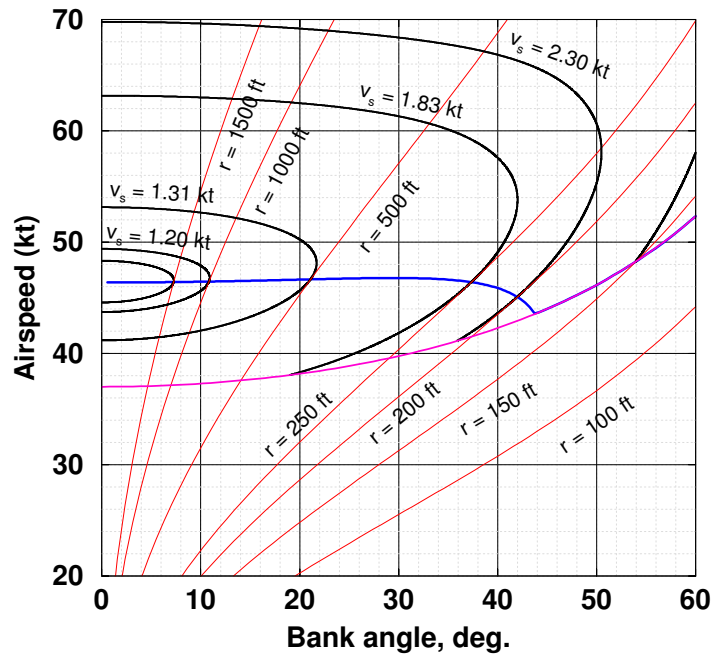


Figure 6: Turn performance map, LS-8A

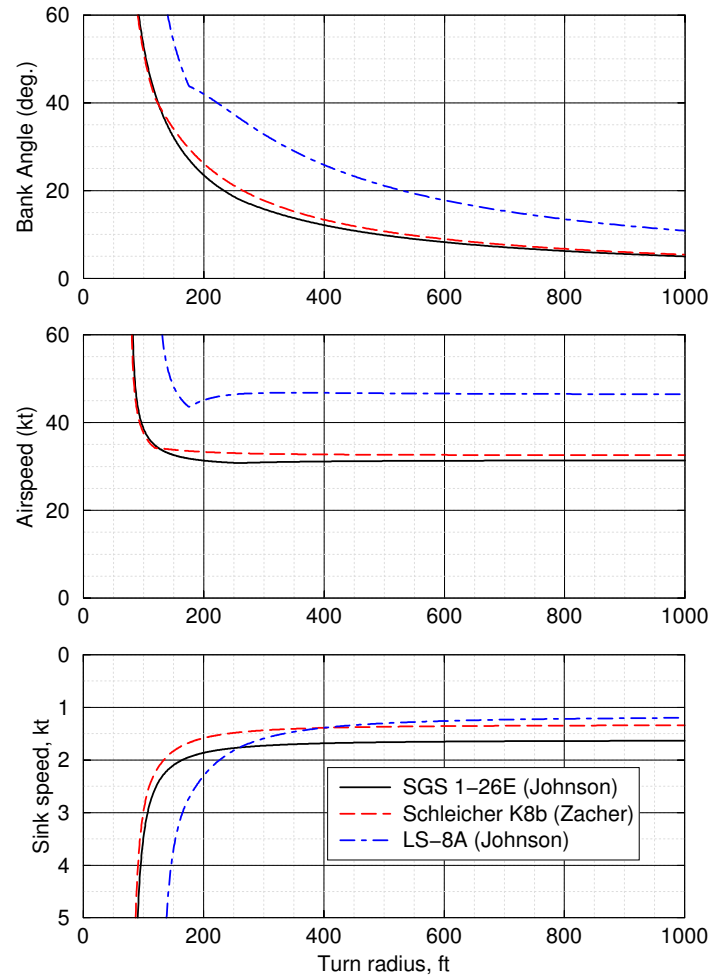


Figure 7: Turn Polars

Glider	Thermal	Optimum Climb Solution				MacCready Solution	
		V <sub>c</sub> (kt)	Bank (deg)	Airspeed (kt)	Radius (ft)	V <sub>g</sub> (kt)	V <sub>avg</sub> (kt)
1-26E (Johnson)	A1	2.1	37	34	132	52	23
	A2	5.7	39	34	126	64	38
	B1	1.5	24	31	200	50	19
	B2	4.9	26	32	185	61	35
K-8b (Zacher)	A1	2.3	38	34	130	50	25
	A2	6.0	40	34	123	63	38
	B1	1.8	26	33	204	49	22
	B2	5.2	28	33	188	61	36
LS-8A (Johnson)	A1	1.1	42	45	197	56	24
	A2	4.5	43	44	182	79	47
	B1	1.5	31	47	319	58	29
	B2	4.8	33	47	294	81	48

Table 1: Climb and cross-country performance of the three gliders in each of the four Horstmann thermals

from the level flight minimum sink speed of 32.5 kt. At around 27.5° bank the optimum airspeed is back up to 32.5 kt. Said another way, if the idealized pilot is flying in an idealized thermal at anything less than around 30° of bank, she shouldn't be flying faster than the level flight minimum sink speed. Beyond this bank angle, the optimum airspeed increases steadily; at 60° bank our idealized handicapping pilot will be flying at around 42 kt.

Take these numbers with a grain of salt. If you're a 1-26 pilot, you might well disagree with them, and of course you should use what works best. This analysis is just for handicapping, and is the best we can do with just the level-flight polar.

The map for the LS-8A is in Fig. 6. The picture is similar, except the optimum schedule calls for a nearly constant 46 kt<sup>1</sup> up through around 40° bank, at which point there's a kink in the schedule as it approaches the minimum airspeed line. The kink is more pronounced than the one we saw for the 1-26E, probably because of the relatively wide "bucket" in its polar. This in turn could just be an artifact of the way I shot the line through the published points.

Fig. 7 summarizes the "turn polars" for the three gliders. The typical tradeoff between a relatively high wing loading, high performance glider like the LS-8A and lighter, lower performance gliders like the 1-26E and K-8b is evident. In nearly-level flight (very high turn radius) the LS-8A descends the slowest, followed by the K-8b and then the 1-26E. As the turn is tightened up, the LS-8A starts to come down faster than the K-8b at  $r = 400$  ft, and faster than the 1-26E at around  $r = 260$  ft. For turns tighter than this, the LS-8A really starts to suffer in comparison to the lighter, slower gliders.

The K-8b descends slower than the 1-26E, but unlike the LS-8A, retains this advantage even in very tight turns.

The figure also shows that, for a given turn radius, the best climb solution for the LS-8A has it flying faster and steeper than the lighter gliders. The kink in the LS-8A airspeed and bank angle curves at around  $r = 175$  ft occurs at the place where the optimum schedule nears the minimum airspeed line in Fig. 6.

Figure 8 show the achieved rate of climb for the three gliders in each of the four thermals as a function of radius. Table 1 summarizes the best climb solutions from these figures, as well as the corresponding MacCready cross-country speeds based on the actual polars.

Some observations:

1. The K-8b, correctly flown, outclimbs both 1-26E and LS-8A,

<sup>1</sup>Johnson has minimum sink for this gross weight occurring at 40 kt, but it's hard to determine from the data

regardless of (Horstmann) thermal type.

2. In the narrow ("A") thermals, the K-8b and 1-26E both outclimb the LS-8A by 1–1.5 kt, despite having a higher  $V_{s_{min}}$  in level flight. This is because their approx. 10 kt. slower level flight minimum sink speed allows them to fly tighter turns in the stronger part of the thermal, without the performance penalty that comes with excessively steep bank.
3. In the wide ("B") thermals, the lighter gliders' advantage largely disappears, because the LS-8A can fly a wider turn and still stay reasonably well in the thermal while taking advantage of its lower minimum sink rate.
4. The lighter gliders actually climb faster in the narrow thermals than the wide thermals, because of the way the thermal velocity profiles are defined (the "narrow" thermals are stronger near their core than the "wide" thermals). It may be that the Horstmann model wasn't intended for such tight-radius turns.
5. The average cross-country speed is very much a function of thermal type and strength. Different gliders are impacted by this to different degrees, so handicaps based on one set of weather conditions may be wildly off in others.
6. The optimum solutions (Table 1) suggest that there's seldom a need to thermal in a turn much steeper than 40° bank, at least with these gliders flying in these standard thermal types.
7. For a given glider, the optimum thermaling airspeed does not vary much from thermal type to thermal type. The optimum bank angle seems to be mainly a function of the thermal width ("A" vs. "B") rather than strength.
8. The LS-8A has its best advantage over the 1-26E with the B1 thermals, where it's 53% faster. However, the DAeC indices for these gliders are 108 for the LS-8A and 63 for the 1-26E [4]<sup>2</sup> In other words, DMSt (and thus OLC) assume the LS-8A can *always* fly 71% faster (108 vs. 63) than the 1-26E. This is rather harsh to the LS-8A pilot, who as we see in the table might *never* be able to fly that much faster, at least not with the four Horstmann thermals. On a day dominated by weak/narrow (A1) thermals, a 1-26E, with a 71% handicap advantage, will *clobber* any LS-8A.

Regarding this last point, given that the 1-26E performs almost as well as the K-8b, the 1-26E index should probably be close to the K-8b DMSt index of 78. Setting it at 75 (for example) would put the LS-8A at 44% faster than the 1-26E. This is a little more consistent with the MacCready benchmarks in Table 1.

Over an OLC flight of 500 km actual distance, setting the index at 63 rather than 75 gives the 1-26E pilot an extra  $500 \cdot (1/.63 - 1/.75)$  — around 125 km!

### Implications for Handicapping

Given that, on some days, the 1-26E (when flown optimally) may enjoy a 1–1.5 kt climb advantage over the LS-8A, it would seem reasonable to try to capture this in the handicapping system. For example, the results in Table 1 suggest that on a weak day dominated by "A1" thermals, the K-8b actually beats the LS-8A in raw cross country speed! OK, by a knot ... but still.

On the other hand, handicapping gliders is a fundamentally uncertain undertaking. Handicapping cross-country speed alone ignores the fact that on some days the 1-26 (K-8, etc.) just won't

<sup>2</sup>The 1-26E index isn't in Ref. 4; I have the number from the 1-26 Association web site.

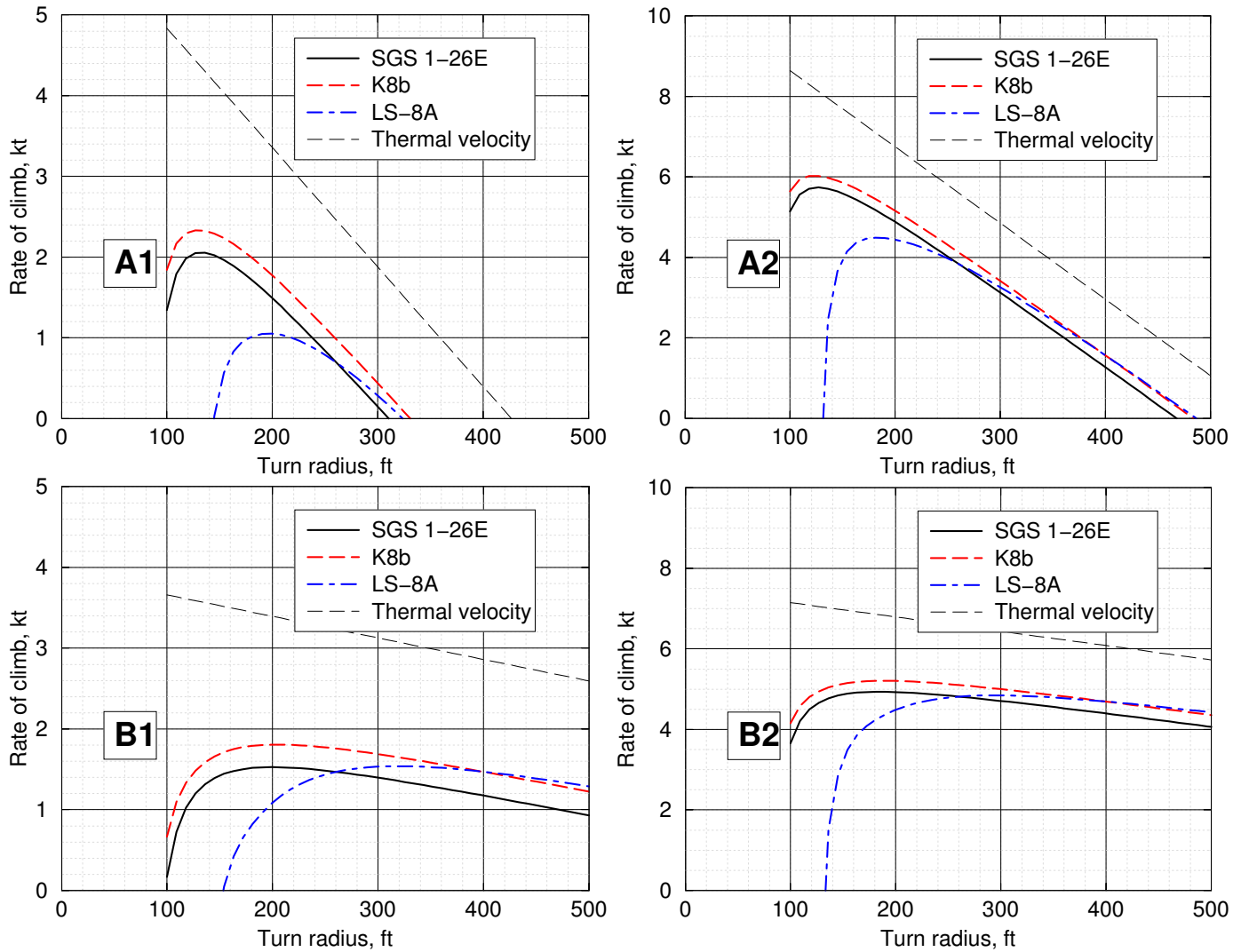


Figure 8: Climb performance comparison, Horstmann thermals A1 (narrow,weak), A2 (narrow, strong), B1 (wide, weak), and B2 (wide, strong)

make it to the next thermal, and doesn't have the same flexibility in choosing lift that the LS-8 does. And Fig. 8 suggests that there are going to be weak-lift situations where the LS-8 won't even be able to stay aloft while the lighter gliders might manage to get away. Although the calculations required to account for differences in climb performance aren't too difficult, making reasonable assumptions about the thermal strength and shape (to say nothing of possible streeting and wind) is probably impossible.

The good news is that nobody really expects handicapping to "work". No single handicapping system can be fair in all (or even most) conditions, but it doesn't matter because Sports Class is lots of fun and the good pilots seem to do well anyway.

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