WHAT PRICE PERFORMANCE?

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1. Introduction.

The title of this paper was deliberately taken from an excellent paper of Bruce H. Carmichael, Reference [1], published in 1954, more than 39 years ago. By this title, I want to demonstrate that my ideas and conclusions have been discussed over a long time, after Carmichael by many other authors. The References [2] to [4] are only a few examples. A successful sailplane and even more a successful contest class should have a good price-performance ratio. I think the 15 m classes were already not optimal in this sense, and I am afraid the decisions recently made in connection with the world class sailplane tend to an even lower price-performance ratio.

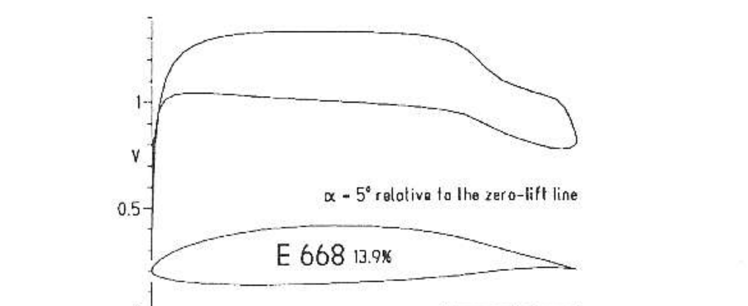

FIGURE 1. Airfoil E 668 for gliders with flaps, velocity distribution and drag polars.

Carmichael carefully estimated the performance and the weight of many sailplanes with spans between 12 and 27 m and aspect ratios between 10 and 30. He based his investigations on the NACA 6-series airfoils and the materials available by then. The performance was judged not only from the maximum L/D and the minimum sink rate but also from the average cross-country speed for three different thermals. He recommended a span between 15 and 18 m and a "normal" aspect ratio for an optimal price-performance ratio. However, he argued with the weight instead of the price, and his weight formula gave much higher weights for higher span than are now realized. With modern weight estimation he definitely would have recommended higher spans.

The present paper tries to repeat Carmichael's investigation based upon more recent data. The performance is evaluated similarly, only thermal mixes are used instead of single thermals. The costs are estimated for gliders built from composite materials. The maximum length of

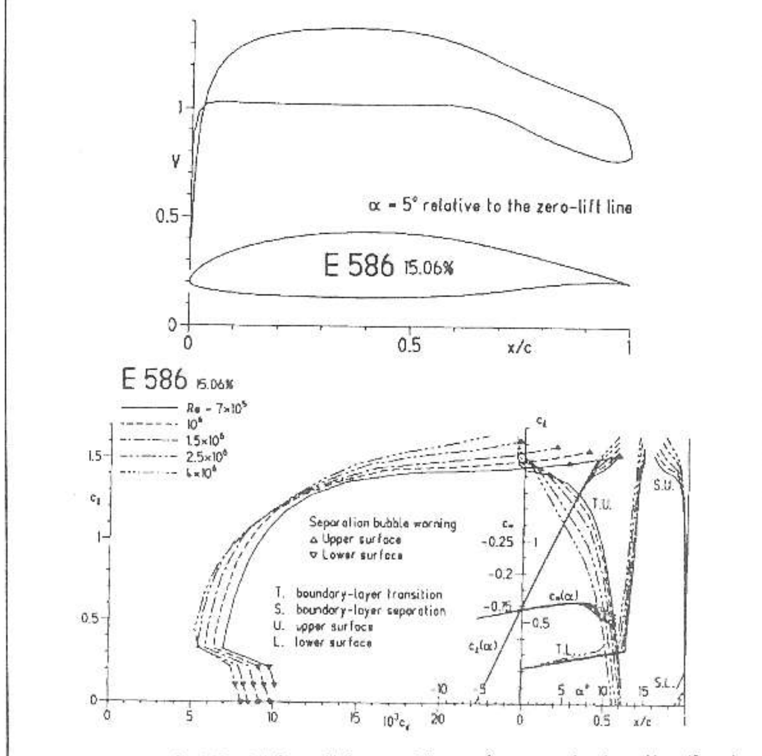

FIGURE 2. Airfoil E 586 for gliders without flaps, velocity distribution and drag polars.

the trailer box has been regarded. Several glider manufacturers have been asked for price estimations. I specially thank K. Holighaus and G. Waibel for their helpful cooperation.

2. The Estimation of the Performance.

2.1 The Airfoils

The performance has been evaluated for six spans from 12 to 27 m.

Three different airfoils have been used. For gliders with flaps only one airfoil E 668 with 13.9% thickness (see Reference [5]) was considered. For gliders without flaps, two different airfoils are considered. One of them, airfoil E 586, is designed for good average cross-country speeds in poor and medium thermal conditions. The other one, E 407, is better with respect to maximum L/D and cross-country speed in good conditions. Drag polars were computed by means of the code described in Reference [5], although for some of them wind tunnel test results are available. The differences between the different gliders are surely evaluated well this way. In Figures 1 to 3 the shape, a typical velocity distribution and the calculated drag polar are presented for the three airfoils. For airfoil E 668 only those parts of the polars for different flap settings are shown which contribute to the envelope.

2.2 The Speed Polars.

The computer code described in Reference [5] allows to calculate speed polars by adapting the Reynolds number to the lift coefficient cl and the wing chords. Three different chords have been analyzed and the average drag coefficient cd is calculated under consideration of the wing areas covered by these chords.

If the wings of modern sailplanes are considered it turns out that the mean aerodynamic chord in average varies very little with span, from the 15 m classes to the open class orchids. It is thus sufficient to select the same chords for all configurations to be analyzed.

The weights are roughly adapted to those of present day gliders. The following facts are to be regarded:

a) Increasing the span causes more weight increase for high span than for low span.

b) The same material is supposed for gliders with the same span. Very high spans are achieved only by means of materials stiffer than glass. This influences weights and prices.

c) Gliders without flaps are lighter for the same span and wing area than those with flaps. The latter need additional actuators for setting the flaps and for some superposing to the ailerons. They have some additional mass balance, additional wedges and gap sealings, and they mostly have thinner airfoils than gliders without flaps. It is thus justified to assume 5% less weight for gliders

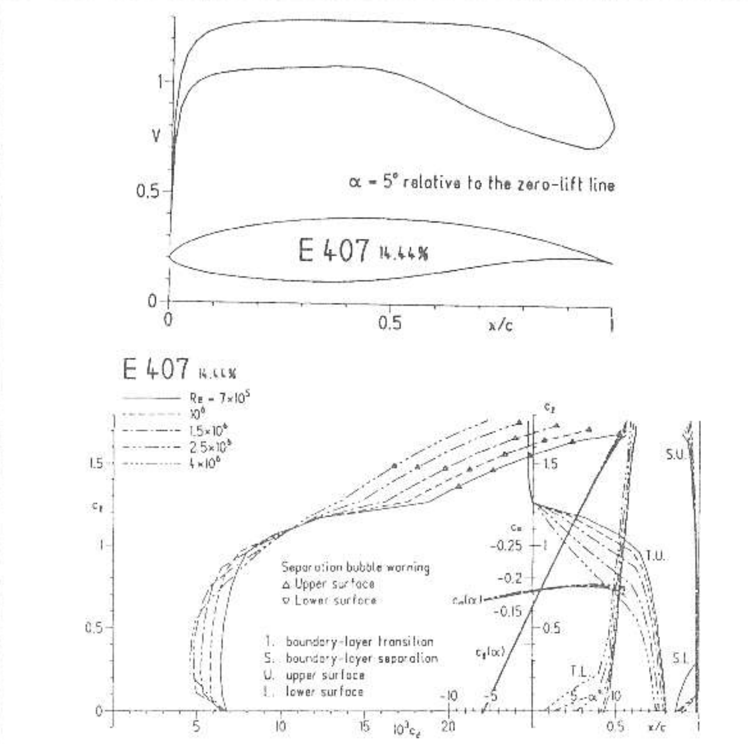

FIGURE 3. Airfoil E 407 for gliders without flaps, velocity distribution and drag polars.

Span s (m)	Wing Area A (m²)	Takeoff Mass W and Wing Loading W/A With Flaps W (kg)	W/A (kg/m²)	Without Flaps W (kg)	W/A (kg/m²)
12	8	320	40	304	38
15	10	350	35	332.5	33.25
18	12	390	32.5	370.5	30.88
21	14	440	31.4	418	29.86
24	16	500	31.25	475	29.89
27	18	570	31.66	541.5	30.08

TABLE 1.

without flaps.

The empirically selected data of all configurations analyzed in this paper are given in Table 1. They are of course open to discussion.

The coefficient of the induced drag was taken as

$$c_{d_i} = 1.05 \; c_l^2 / \pi \Lambda,$$

where C_l is the lift coefficient and Λ the aspect ratio. The factor 1.05 considers some lift dependent interference drag, but not a quadratic term of the profile drag which is carefully calculated for all cl and Reynolds numbers.

The parasitic drag was separately evaluated for the fuselage and the tail. The fuselage length was slightly increased with span. The tail volume coefficient was assumed to be 0.585 for all configurations. The horizontal tail profile drag was assumed to be cd=0.0045. The vertical tail was assumed to have the same area as the horizontal tail, with cd = 0.0055 because its sections are mostly thicker than those of the horizontal tail. The speed polars, including L/D-lines are shown in Figures 4 to 6. These diagrams show clearly that it is impossible to prevent a considerable performance improvement when only the span is increased and nothing else is changed. Of course, this is old hat. Why else is the span of the open class gliders continuously increasing? Why do all gliders of the 15 m classes exactly exploit the admitted span?

Another fact should also be mentioned. The performance improvement due to increasing span is higher at low spans than at high spans. Also this fact was clearly stated already by Carmichael, Reference [1]. It can be seen more distinctly from Figures 7 and 8 which show the maximum L/D and the minimum sink rate of all configurations versus the span. The slope of the lines for the minimum sink rate decreases more than that of the L/D-lines. This is due to wing loading which according to Table 1 increases when the span is above 24 m.

2.3 The Average Cross-Country Speeds.

The average cross-country speeds of all configurations have been calculated by means of the well known procedure, in particular that suggested by Horstmann,

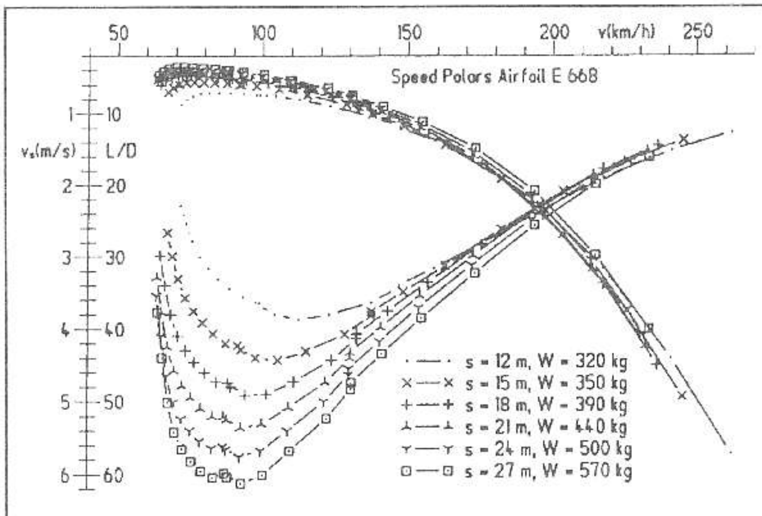

FIGURE 4. Speed polars of gliders with various spans and airfoil E 668.

Reference [5] assuming mixes of thermals representing poor, medium and good conditions; Figure 9 shows the medium conditions case.

Figure 10 shows the average cross-country speeds for the different airfoils for the three thermal mixes. These results are remarkable in several respects. The lines of the airfoils E 586 and E 407 are considerably below those of the airfoil E 668 with flaps. But still the 18 m configurations without flaps are equivalent to the 15 m configuration with flaps, except for the good conditions of mix 3. This is surprising because in the diagrams for the maximum L/D and the minimum sink rate the 18 m configurations without flaps were much better than the 15 m configuration with flaps. This is due to the better climb rate of the latter configuration.

The lines for the two airfoils without flaps

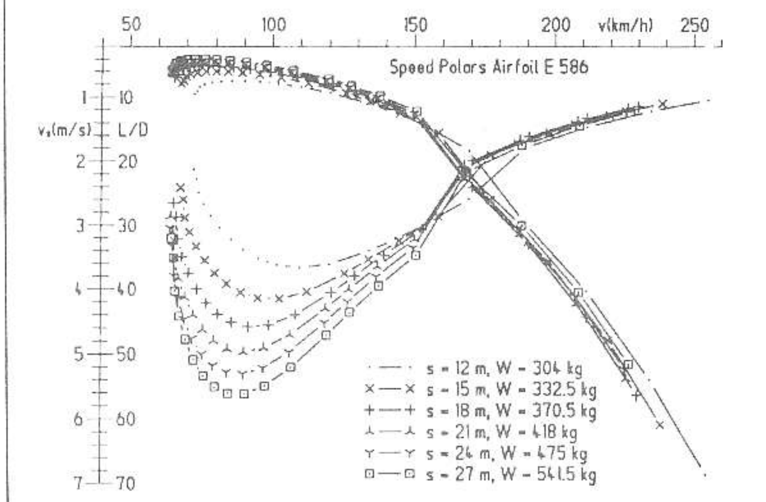

FIGURE 5. Speed polars of gliders with various spans and airfoil E 586.

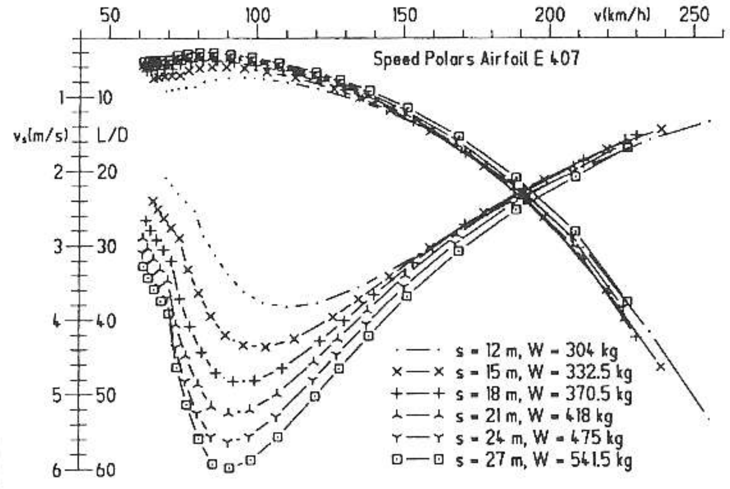

FIGURE 6. Speed polars of gliders with various spans and airfoil E 407.

show also some interesting features. Although airfoil E 407 has much better maximum L/D it has lower cross-country speeds for poor and medium thermal conditions. Only for mix 3 airfoil E 407 is slightly better than airfoil E 586.

3. The Prices of Gliders.

Discussing prices of gliders is like touching a hot iron. Different companies have different prices, different outfits, different payment conditions and so on. Therefore account was taken only of the man hours and material costs. But also these data have a large standard deviation. Only some rough estimations are possible. The most reliable data came from comparing typical differences between different configurations. The help of K. Holighaus and G. Waibel is very much appreciated.

The following aspects are probably most significant.

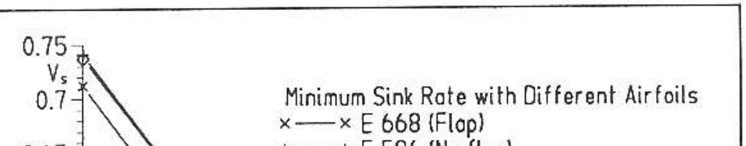

FIGURE 8. Minimum sink rate of gliders with various spans and airfoils.

a) Changing the span of a glider between 12 m and 17 m influences the costs relatively little. All fittings, the cockpit, the landing gear, the actuaters etc. must be produced for any span in the range. The differences in costs are due to some more or less material and to some man hours for putting the material in the molds. For example, increasing the span of the PHOEBUS from 15 to 17 m increased the production cost by less than 3%.

There are two limits to this situation, the wing weight and the length of the trailer box. Most people who were asked thought a box length of 9 m could be handled without problems. This allows stowing wings with 17 m span. Even boxes of 9.5 m for 18 m span can be discussed. The weight of such wings should not yet cause trouble during assembly. I often assembled my

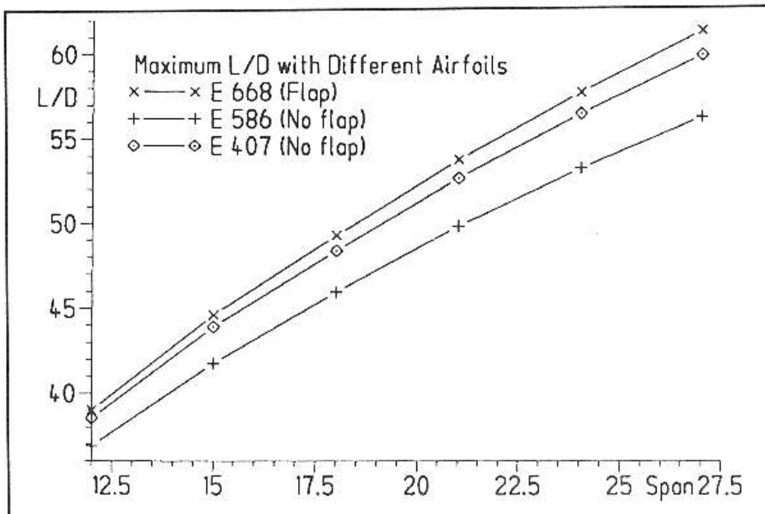

FIGURE 7. Maximum L/D of gliders with various spans and airfoils.

17 m PHOEBUS with 3 or even 2 people without problems. And this wing could be built much lighter today.

For this range of spans it was also assumed that the number of gliders to be produced is independent of the span. So far, gliders with less than 15 m span had much lower production rates. I am convinced that Standard Class rules with 17 m span would have made this span "normal."

b) If a 9 m trailer box is assumed then exceeding 17 m means having more than two pieces for the wing. For a sailplane without flaps it is possible to have just a small detachable piece beyond the end of the aileron. The costs of such a piece are low, surely not more than 5% of the total costs. For sailplanes with flaps such a detachable piece must have a piece of the aile-

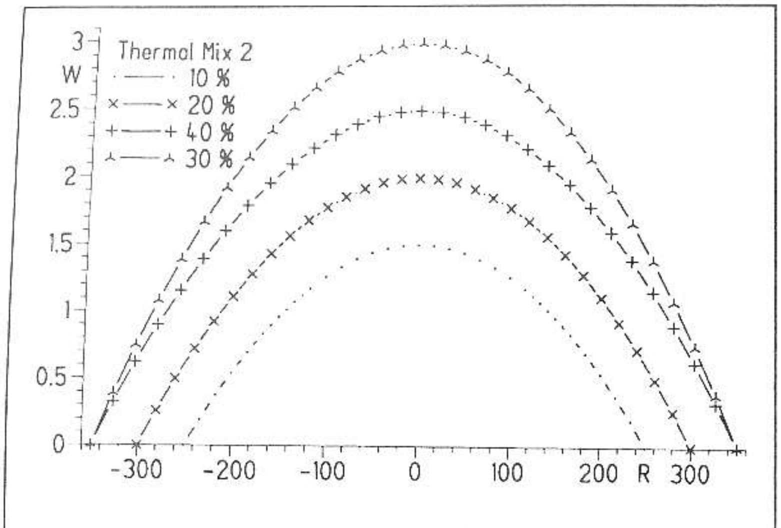

FIGURE 9. Thermal mix representing medium conditions.

ron. A wing tip without aileron would cause a discontinuity in the lift distribution if the ailerons are moved with the flaps. This is not desirable. The short aileron piece can be directly connected with the main aileron and does not need special actuators. The costs of such a wing tip were estimated to be about 10% of the total costs.

Wings with such tip pieces can have spans up to 18.5 m. The assembly of such wings should still be acceptable.

c) The costs of gliders with flaps are estimated to be 20% higher than those of gliders without flaps. This includes all actuatrs, mass balance, adaptation, superposition of ailerons and flaps, bearings, gap covers etc. It is justified to assume a fixed percentage independent of the span because gliders with higher span need also more effort for the flaps .

d) There is a span limit beyond which the additional wing pieces must have their own actuators for the aileron and perhaps flap piece. This is not separately considered. In this range of spans the bending moment at the wing root and at the separation locations increases non linearly with the span. More expensive materials must be applied. The production rates drop dramatically. Therefore the costs have been roughly oriented at the sales prices. The companies probably make little profit with these orchids.

Only that span is again important where another wing piece is necessary near the tip. This is indicated by another discontinuity in the lines.

The estimated costs are shown in Figure 11, and are shown relative to those of a 15 m Standard Class glider. The costs of an orchid with 27 m span should not be discussed too much. Also the curve for sailplanes with flaps is extended to such spans to cater for those pilots who really must have the highest performance glider regardless of costs, who will never buy a glider without flaps.

4. Conclusions.

There is not one performance for any glider. It is thus not possible to find one price-performance ratio. But the data so far given show several facts very clearly.

The most interesting spans are obviously between 17 and 18.5 m. Lower spans reduce the performance much more than the price. Higher spans make the prices unaffordable for many people.

The following conclusions are of course discussible, but surely not too far from reality and surely worthwhile to be discussed.

Gliders without flaps and with spans between 17 and 18.5 m can have nearly the same price as Standard Class gliders and are hence really affordable. Their L/D values can be in the upper

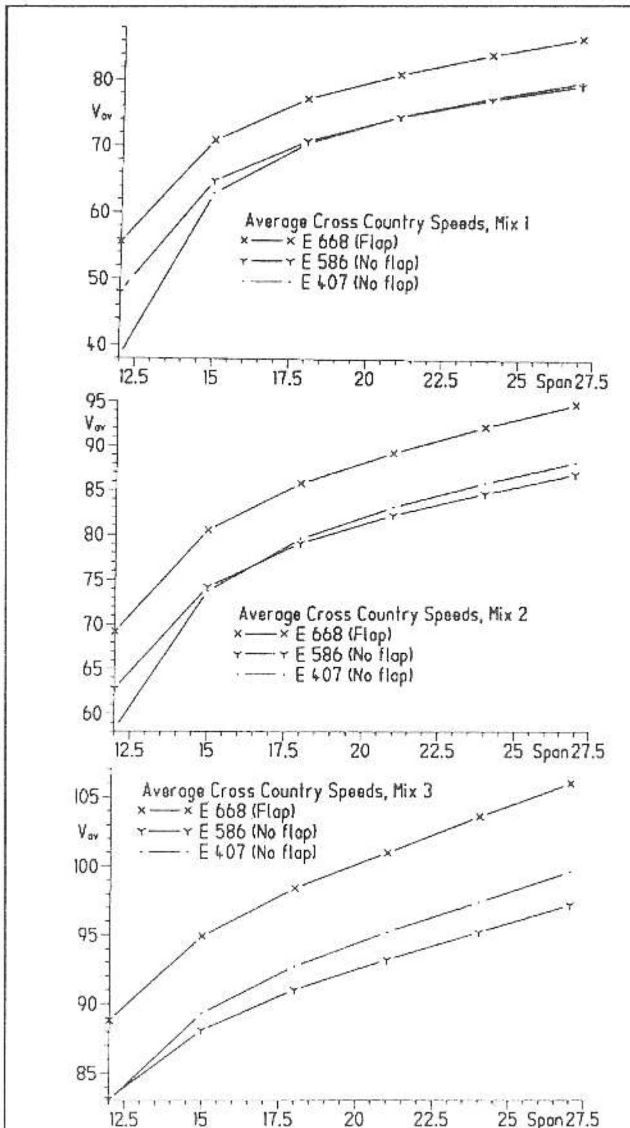

FIGURE 10. Average cross-country speeds of gliders with and without flaps.

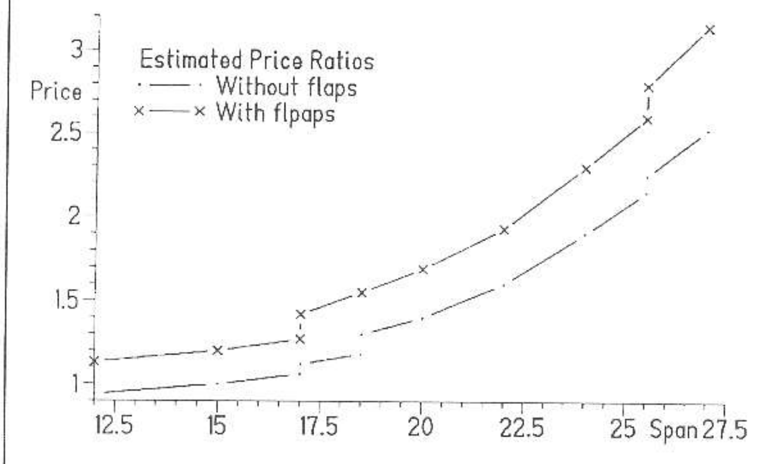

FIGURE 11. Costs of gliders related to a 15-m Standard Class glider.

half of the forties. The price-performance ratio of such gliders can probably not be achieved by any other configuration. If new contest classes are specified this configuration should be first choice.

Gliders with flaps and with spans between 17 and 18.5 m have also good price performance ratios. But they are around 20% more expensive than the corresponding gliders without flaps. They are thus not as affordable as those without flaps. If new contest classes are considered an 18 m open class is too close to the unlimited open class.

A world class glider with a span below 15 m can be introduced. But it must be realized that its price-performance ratio is much above the optimum. And it must be doubted if such a glider will promote our sport worldwide. This is only possible if a very high production rate is achieved. For the one glider type contests only a few of them are needed. Will the clubs worldwide buy this glider if much better ones are not much more expensive?

So far, the one-type contests, for example the 1-26 contests in the USA, were arranged after many of them were sold and the performance of them became poor in comparison to more recent gliders. Is it not the wrong way to promote a glider whose performance is relatively poor from the very beginning?

The world class has already now promoted the discussion of the contest classes. This seems to be an excellent opportunity to change the classes in the right direction.

5. References.

[1] Carmichael, B. H.: What Price Performance, Aerophysics Department, Mississippi State College (Now Mississippi State University).

[2] Irving, F. G.: Boundaries for World Class Sailplanes, *Technical Soaring* 13 (1989), P. 127-134.

[3] Horstmann, K.-H.: Neue Modellaufwindverteilungen und ihr Einflui3 auf die Auslegung von Segelflugzeugen. OSTIV-Congress 1976.

[4] Thomas, F., Eppler, R.: Aufwand und Nutzen von Klappen bei Segelflugzeugen. Aerokurier 1971, P. 846 - 849.

[5] Eppler, R.: Airfoil Design and Data. Springer-Verlag Berlin, Heidelberg, New York, Tokyo (1990).