The Application of High Lift Devices to Competition Gliders

By Nicholas Goodhart

Presented at the 12th OSTIV Congress, Alpine, USA (1970)

In recent years designers of advanced competition gliders have sought to increase performance by using high lift devices. Outstanding examples have been the use of Fowler flaps in the South African BJ series and in the Polish Zefir 4; there are also many examples of the use of trailing edge flaps to give some degree of variable camber (e. g. Diamant, BS-1, HP-14). Two new designs, the AN-66C in Switzerland and the Sigma in United Kingdom, are incorporating a new type of flap designed to increase wing area and camber but without the slot implicit in the Fowler flap.
The aim of this paper is to examine the theoretical benefits to be obtained from high lift devices with particular reference to the development of the Sigma high performance glider.

The concept of using high lift devices

It is generally accepted that competition gliders will normally operate by climbing in circling flight in thermals and making distance in straight gliding flight between thermals. The aim of the designer is to achieve the highest possible average cross-country speed in the presence of an adequate supply of thermals.
In general, the characteristics a glider needs to climb fastest in thermals are:

- low wing loading
- high lift coefficient
- low drag coefficient
- large span.

In order to cruise fast between thermals and with a good glide ratio the requirements are:

- high wing loading
- low lift coefficient
- low drag coefficient
- medium span.

It is clear from these two lists that compromise is inevitable in the design of a glider and it is the existence of this need to compromise that accounts for the wide variation of glider designs.
There is no known method of adding and subtracting weight in flight thus the only method of varying wing loading is to vary wing area. Wing sections which have low drag coefficients in the cruising range of lift coefficients tend to be unwilling to generate high lift coefficients for circling flight and, if they are induced to do so by camber changing, they tend to develop high drag coefficients. Variable span is no doubt feasible (but mechanically discouraging) and anyway it does not offer, on its own, as much benefit as variable chord.
It therefore appears that the most rewarding line of development towards meeting the conflicting climb/cruise requirements is variable area (chordwise extension) and variable camber. There is a whole spectrum of possible area changes and aerofoil sections from which the designer must make his choice, his first problem is therefore to find a method of comparing the merit of the various possibilities.

The standard thermal

The key factor in defining the merit of particular wing sections and area changes is the exact definition of the thermal in which the climb is carried out. In practice thermals vary widely from day to day and country to country and in any case there is very little information even of a statistical nature to enable any particular thermal to be specified as representative of a particular area.
Under these circumstances it is necessary to fall back on judgment and take note of how current gliders actually perform in the conditions for which the new design is to be optimised.
There are arguments which suggest that the cross-section of the useful part of a thermal shows a relationship between vertival velocity (u knots) and radius (r feet) which is of the form

$$u = U\left(1 - \frac{r^2}{R^2}\right)$$

where U is the vertical velocity at the centre (r=0) and R is the radius at which the vertical velocity falls to zero. This thermal model is probably non-representative over the outer one-third of radius but experience shows that this part is not used by practical gliders when U and R are in a reasonable range. Experience in UK shows that representative values of U and R are in the region of 4.6 knots and 650 feet. These values will give achieved climbs for current high performance gliders in the range of 2.2–2.5 knots with achieved cross-country speeds approaching 35 knots.
This rather wide weak thermal is certainly not representative of other parts of the world, particularly areas well away from the sea and subject to strong insolation, thus the conclusions drawn below with regard to optimisation of glider parameters certainly cannot be read across to other countries.

Valuing high lift devices

Having defined the thermal it is now advantageous to define a method of valuing the various possible area and camber changes.
The benefits of area and camber change can be taken up either by holding circling performance constant and improving cruising performance or by holding cruising performance constant and improving circling performance or, as is likely to occur in practice, by improving both to some degree. This latter possibility leads to lengthy calculations of the complete performance of an almost unlimited spectrum of possible designs. However an adequate indication of the value of the various possibilities can be obtained by considering a fixed cruising configuration with all the benefit of variable area and camber taken up in improved circling performance. This approach cannot be stretched too far but at least gives a first order indication.
Variable area by chord extension and increased lift coefficient by camber change both have the same aim. In each case C_L max based on the original chord is increased and each has the inevitable penalty that C_D also increases. Thus, whether the improvement of C_L max is obtained by area change or camber change or a combination of both, the total value is defined by stating the C_L/C_D relationship of the new section based on the

FIGURE 1

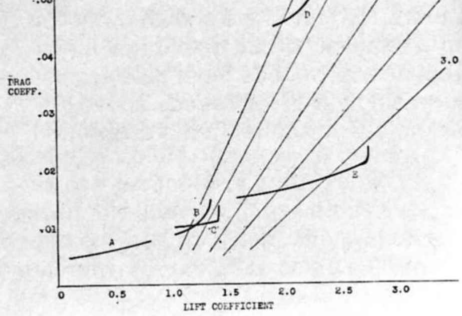

Table I

Span	68.9 ft	21.0 m
Wing area	131.1 ft²	12.2 m²
Aspect ratio	36.2	36.2
Weight	1500 lb	682 kg
Wing loading flap in	11.44 lb/ft²	56.0 kg/m²
Wing loading flap out	8.47 lb/ft²	41.5 kg/m²
Horizontal tail area	12.1 ft²	1.12 m²
Vertical tail area	15.6 ft²	1.45 m²
CD horizontal tail	0.0065	
CD vertical tail	0.0060	
Misc. drag	3.0 lb at 100 f.p.s.	
K cruise	1.04	
K climb	1.06	
Flap extension factor	1.35	
Climbing C_L	1.60	

Table II

STRAIGHT FLIGHT PERFORMANCE

SPEED KNOTS	SINK KNOTS	GLIDE RATIO	WING CD	----DRAG CONTRIBUTIONS IN LBS---- IND:	WING	TAIL	MISC	TOTAL
53.0	1.257	42.1	0.0120	16.4	15.0	1.8	2.4	35.6
55.3	1.194	46.4	0.0094	15.1	12.8	1.9	2.6	32.4
58.0	1.221	47.5	0.0086	13.7	12.9	2.1	2.9	31.6
61.2	1.252	48.9	0.0078	12.3	12.9	2.2	3.2	30.7
64.9	1.317	49.3	0.0072	11.0	13.4	2.5	3.6	30.5
69.4	1.445	48.0	0.0069	9.6	14.8	2.8	4.1	31.2
74.9	1.599	46.9	0.0063	8.2	15.8	3.2	4.8	32.0
82.1	1.870	43.9	0.0060	6.9	17.9	3.7	5.8	34.2
91.8	2.357	38.9	0.0057	5.5	21.4	4.5	7.2	38.5
106.0	3.287	32.2	0.0054	4.1	27.0	5.8	9.6	46.5
129.8	5.643	23.0	0.0053	2.7	39.8	8.3	14.4	65.2
183.5	15.265	12.0	0.0053	1.4	78.9	15.6	28.8	124.8

Table III

TURNING PERFORMANCE IN CLIMB CONFIGURATION BASED ON A LEVEL FLIGHT SPEED(KTS) OF 39.5 AND SINK(KTS) OF 1.154

RADIUS(FT)	SINK(KTS)	BANK(DEGS)	SPEED(KTS)
355	1.302	22.9	41.1
339	1.318	24.1	41.3
324	1.336	25.2	41.5
311	1.355	26.4	41.7
299	1.375	27.5	41.9
288	1.397	28.7	42.2
278	1.419	29.8	42.4
269	1.444	30.9	42.6
260	1.470	32.1	42.9
252	1.498	33.2	43.2
245	1.527	34.4	43.5
238	1.558	35.5	43.8
231	1.592	36.7	44.1
225	1.627	37.8	44.4
220	1.665	39.0	44.8
214	1.706	40.1	45.2
209	1.749	41.3	45.5
205	1.795	42.4	46.0
201	1.844	43.5	46.4
196	1.897	44.7	46.8
193	1.953	45.8	47.3
189	2.014	47.0	47.8
186	2.079	48.1	48.3
182	2.148	49.3	48.9
179	2.224	50.4	49.5
176	2.304	51.6	50.1
174	2.392	52.7	50.7
171	2.487	53.9	51.4
169	2.589	55.0	52.1
166	2.701	56.2	52.9
164	2.823	57.3	53.7

Table IV

THERMAL U KNOTS	R FEET	X-C SPEED KNOTS	CRUISE SPEED KNOTS	ACH: CLIMB KNOTS	BANK ANGLE DEGS.	CIRCLE SPEED KNOTS
12	1000	82.2	130	9.77	37	44.1
12	700	80.4	124	9.18	42	46.0
12	500	77.5	124	8.27	47	47.8
12	400	74.3	118	7.37	50	49.5
12	300	67.0	110	5.62	55	52.1
10	1000	76.1	118	7.88	36	43.8
10	700	74.2	118	7.36	40	45.2
10	500	71.0	114	6.56	46	47.3
10	400	67.7	110	5.77	49	48.9
10	300	60.0	103	4.26	54	51.4
8	1000	68.7	110	5.99	34	43.5
8	700	66.7	110	5.55	39	44.8
8	500	63.3	103	4.87	44	46.4
8	400	59.7	103	4.20	47	47.8
8	300	50.9	97	2.93	52	50.1
6	1000	59.2	103	4.12	32	42.9
6	700	56.9	100	3.75	37	44.1
6	500	53.0	97	3.20	41	45.5
6	400	48.6	90	2.66	45	46.8
6	300	38.4	80	1.64	49	48.9
4	1000	45.1	87	2.27	29	42.2
4	700	42.3	84	1.98	34	43.5
4	500	37.4	80	1.56	39	44.8
4	400	31.5	78	1.16	42	46.0
4	300	15.1	67	0.40	47	47.8

original chord. It makes no difference whether the original section is converted to the new one by slats, slits, slots, flaps out or down or extended, provided only that the true original section is not degraded by the mechanisms involved in converting it to the climb section.

Isoclimbs

If we assume a glider of fixed cruising configuration which however has a wing capable of a wide variation of C_L/C_D relationships when in the climb configuration, it can have widely differing achieved rates of climb when flown in the standard thermal. The rate of climb achieved is a direct measure of the value of the particular C_L/C_D relationship which produces it.

Figure 1 shows a C_L–C_D plot on which have been drawn a series of isoclimbs. These relate to a basic glider which has the following characteristics:

wing span	19.5 m
wing area	149 sq ft
aspect ratio	25.8
weight	980 lb
C_D extra-to-wing	0.0044.

This gives a rather high wing loading of 6.6 lb/sq ft but was chosen intentionally since the object is to compare the merits of using higher C_Ls in the climb which in practice will allow higher wing loadings in the cruise.

The isoclimbs enable the standard glider's achieved rate of climb in the standard thermal to be read off given only the C_L–C_D relationship of its wing (related to cruise chord) in the climb configuration. For example if the wing can produce a C_L of 2.0 at a C_D of 0.025 the glider will have a climb of 2.6 knots in the standard thermal.

Specific high lift devices

The C_L–C_D relationships of various high lift devices have been plotted on figure 1. It is assumed that the cruise configuration of all of them is substantially as shown by curve A. (This curve makes allowance for the likely variation of Reynolds Number with C_L.)

Curve B represents the high lift performance of FX-61-163 i.e. one of the best available plain wing sections with no high lift devices. As far as possible this and all the other curves for high lift devices refer to a Reynolds Number of 1.0×10^6.

Curve C is for FX-67-K-150 which is probably about the best section depending solely on a trailing edge flap for high lift. It would appear to offer a climb increment of about 0.2 over curve B provided it is feasible to fly at maximum lift. This point is discussed later.

Curve D is for a 0.30c Fowler flap at 20° deflection (this appears to be about optimum). Despite the high maximum lift coefficient of better than 2.3 the net effect due to the high C_D is to give no advantage over the plain FX-61-163 section. As already pointed out a different result will be obtained if a narrower or stronger thermal is assumed.

Curve E represents the wind tunnel test results on the Sigma wing section as developed by Dr. F. X. Wortmann. The cruise wing section conforms to the normal FX series cruise performance (curve A). The extending flap serves two purposes: first it increases the chord by 35% and second it adds a great deal of camber to the basic wing section thus effectively moving the drag bucket up to very high C_Ls. The result is a C_L max of 2.7 at a C_D of about 0.021. If the performance indicated in curve E is obtainable in practice it will clearly lead to a glider of outstanding performance.

Usable C_L

In comparing the relative merits of various high lift devices it is necessary to consider the value of C_L which will normally be used in circling flight.

In order to get the best climb performance it is necessary to fly as near C_L max as possible. Obviously there will be some margin in order to avoid frequent stalling and consequent loss of climb, but the size of this margin is not known and in any case it probably varies appreciably from pilot to pilot and with such other variables as stall characteristics and shape of C_L–C_D curve.

In curves B and C, for instance, it could easily be that circling is actually done at say $C_L = 1.1$ in both cases, thus eliminating the theoretical benefit of C over B.

Sigma

On the strength of the above assessment there appeared to be a strong justification for building a glider based on the capability of the pair of wing sections which had evolved from discussions between the Sigma group and Dr. F. X. Wortmann.

Wind tunnel test data had been produced for both sections and it was now possible to do performance calculations for a range of possible Sigma designs. For this purpose a computer program was written enabling complete performance calculations to be done on any glider design given the following inputs:

(a) Wind tunnel drag information for the wing sections in the cruise and climb configurations. The tests results must cover the range of Reynolds Numbers at which the glider will actually operate as well as the full C_L range.

(b) Values for the following parameters of the subject glider: span, aspect ratio, total weight, horizontal tail area, vertical tail area, C_{DO} for horizontal and vertical tails, induced drag factor in cruise and climb configuration, miscellaneous drag figure. This last item (which is given as drag in lb at 100 ft/sec) covers the drag of the fuselage, any leaks, protuberances, gaps, interference, etc. It can only be an estimate, however reasonable assumed values are found to give very realistic performance results when the program is run using the parameters of gliders of known performance.

The print out from the computer program consists of four tables as follows:

(a) Table of parameters in imperial and metric units.

(b) Straight flight performance including a breakdown of drag into four constituents.

(c) Turning flight performance in climb configuration.

(d) An analysis of performance in a matrix of thermals over a wide range of U and R values.

The print out for the version of Sigma now being built is given in tables I to IV. For space reasons tables II and III have been somewhat condensed. It should be noted that the climbing C_L in table I is based on the flap-out chord; it must be multiplied by the flap extension factor to get a value relevant to figure 1.

Sigma parametric studies

The version of Sigma chosen for construction resulted from a number of parametric studies made in 1967 at a time when the computer program was in a fairly rudimentary stage and no complete analysis is now available to indicate why the particular values of 21 metres span and 36.2 aspect ratio were chosen.

With regard to span, studies showed a performance improvement of the order of 2% per metre. The decision to go no higher than 21 metres was an arbitrary one based purely on the particular difficulties of achieving adequate roll control in the Sigma configuration.

On aspect ratio, the studies showed increasing performance with very high aspect ratios up to as high as 40. Optimum weight came down rapidly with increasing aspect ratio and the problem was to select the highest ratio which could be built without exceeding the optimum weight.

The choice of an aspect ratio of 36 for Sigma was simply an early estimate of the highest aspect ratio which could be built within the all up weight (1500 lb) required at that aspect ratio.