TWO - SEAT SAILPLANES

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1. INTRODUCTION

This article attempts to summarize the technical development of two-seat sailplanes during the past thirty years. There is no attempt to contribute anything new to the art, but only to bring together information from various sources. It is also hoped that the data collected will be found useful to designers.

In the olden days of soaring the two-seater saw little progress, most of the effort being put into the smaller and lighter and cheaper single seater. Hence the useful two-seat sailplane was a late development. In the early days of gliding the rather heavy weight of the two-seater made it unpopular due to its bad ground-handling qualities. Another difficulty was the manpowered shock-cord launch. It was not until aero-towing and winching were developed as normal launching methods that the two-seater became practical and popular.

2. SHORT HISTORY

A rather fantastic biplane glider which Fokker flew at the Wasserkuppe in 1922 was probably the first two-seater. He made a glide of 37 minutes, but there is no record of any soaring. During the following ten years two-seater development was slow. By 1925 the best two-seater performance was a distance of 10 km (6 miles) and an altitude of 336 metres (1100 ft). These earlier two-seaters were not refined sailplanes, but secondary machines of very limited capabilities. Even as late as 1929 when Gunther Groenhoff flew Lippisch's Rhoenadler (not to be confused with the later single-seater Rhoenadler) the two-seater was good only for duration. In 1932 Lippisch designed the Obs with a span of 26 metres (85 feet) and an aspect ratio of 17.8 as a weather research machine. This was technically very interesting, but was not in the line of development.

Also in 1932 Czerwinski designed his 18-metre (59 ft) high wing tandem CW-4 in Poland and Wolf Hirth produced his 14.5-metre (47.6 ft) Grunau 8. These were along useful lines but due to lack of production and the slow development of aero-towing such machines as these were not widely used. The real start was made when Hans Jacobs developed the Kranich from his single-seater Sperber. Not only did he produce an excellent machine, but he had enough foresight to put it into production and it became generally available in Europe in about 1936. Jacobs' commercial instincts, although criticized by purists, made the two-seater widely used and enabled its advantages to be studied. The altitude of 8200 metres (27.000 ft) reached by a Kranich demonstrated its ability.

Shortly before the 1939 war the Hirth-Huetter Goevier (Goeppingen 4) was developed and put into production. War-time design produced a series of American two-seat trainers and some German designs. Apart from some Swiss and French developments, perhaps the most interesting post-war projects were the designs put forward in response to the British Gliding Association design competition for two-seaters in 1947.

Most of the development to date has been because of the demand for two-seat trainers (advanced and ab initio) and it will be of interest to study this line of development and discover where it leads us.

3. GENERAL DESIGN NOTES

The single-seat trainer must be a cheap machine because crashes are all too frequent. Cheapness usually means low performance. Early two-seat trainers such as Falcon were also of fairly low performance for the sake of cheapness. However, it soon became obvious that even trainers could have a fairly high performance if they were two-seaters because the crash rate was low and a more expensive glider could be afforded.

Actually the expense of two-seat training can be lowered if a high performance trainer is used, because for a given initial height, there is more time for instruction and the use of an intermediate type for early solo flying may be avoided. This line of thought leads to the conclusion that the operational need for two-seaters is limited to the high performance type. The only modifying factor is cost. There is however scope for a cheap two-seater of moderate performance such as the T-21B and SG4-2-22. The design of cheap two seaters is not considered in this paper because the problem is very specialized.

Apart from training, the two-seater is favoured by many because two heads are better than one. A pilot and a navigator may well be able to operate more efficiently than a pilot alone, as long as the sailplane performance is good enough.

The high performance aspects of two-seater design have not in the past received much attention, so it is worth while to discuss some of them here. The most difficult problems have been:

1. To give a good view for the second pilot.
2. To achieve a low all-up-weight.

These are now discussed.

1. *VIEW.* The view for the second pilot is important if he is to do any piloting or navigating. Even for a passenger a good view is desirable.

The design aspect is complicated by the virtual necessity for the second pilot to be seated on or close to the centre of gravity of the sailplane. If he does not sit on this spot, the sailplane would have to be ballasted when flying solo, which is undesirable and dangerous if omitted.

The view depends mainly on wing position and seating arrangement. Figure 1 *) has been drawn to show the various layouts which have been used to date.

The side-by-side two-seaters such as Goevier (Fig. 1a) and Falcon II (fig. 1b) have good views. The Goevier is rather cramped in beam, the fuselage width being only 36" (92 cm). With two up it is very comfortable and there is no room for any serious navigation by the second crew member. The other extreme has been achieved by the Pratt Read TG-32 (LNE-1) which has a fuselage beam of 46 inches (117 cm) and as a result is very bulky. There is little doubt that the large cross-sectional area of the side-by-side two-seater does increase the drag and that one can always design a tandem seater with a better performance. To achieve a side-by-side arrangement without using ballast is not easy, since with both crew on the centre of gravity it is rather difficult to get a normal balance with ordinary tail arms and control volumes. A slightly staggered layout improves this aspect and has been used, but Huetter's scheme for adjustable sweep solves the problem completely.

Of the tandems, we may start with the low-wing type exemplified by the Short Nimbus (fig. 1c). Here the view of the second pilot is excellent, except in the downward direction. The difficulty is that the low wing is likely to be damaged in anything other than an airport landing, and the avoidance of buffeting is difficult. The Schweizer TG-3A has a slightly higher wing than the Nimbus, but the designer Ernest Schweizer agrees that such a low position has undesirable features. In the Schweizer TG-2 (fig. 1d) and Kranich (fig. 1e) the wing is sufficiently high to clear obstacles, but the second pilot's view suffers as a result, being good only upwards and forwards. Raising the wing still further brings the second pilot under the wing as in the Briegleb BG-8 (Fig. 1f) and the CW-4 (Fig. 1g). Here the view upwards is negligible. For a dual primary (Fig. 1h) such an arrangement is acceptable and it is also satisfactory for joy-riding. For serious soaring the second man would be of little help and he would probably be extremely frightened most of the time, with his lack of view. The vertical stagger used on the Yamazaki (Fig. 1i) and others is a development of this arrangement to give the second pilot good forward and upward view. This has many merits for training, but the severe blindness downwards limits its usefulness.

To get the view he needs, the second pilot should sit forward of the wing leading edge so that his view is blocked neither up nor down. This can be done, still keeping him on the centre of gravity, by sweeping forward the wing. The Russian solution of marked continuous

*) All the sketches forming Figure 1 were drawn by W. Czerwinski.

CREW ARRANGEMENTS FOR TWO-SEATERS

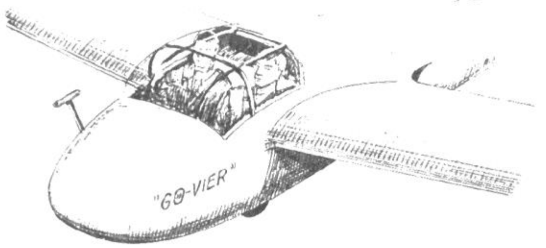


Fig. 1a Goevier

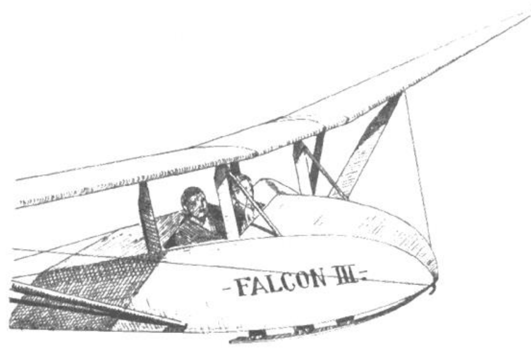


Fig. 1b Falcon III

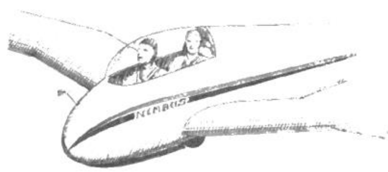


Fig. 1c Nimbus

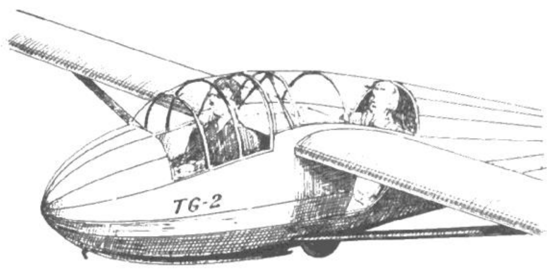


Fig. 1d TG-2

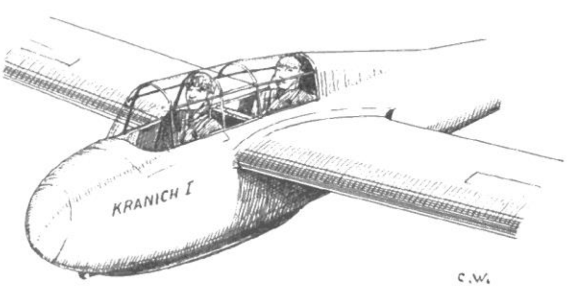


Fig. 1e Kranich

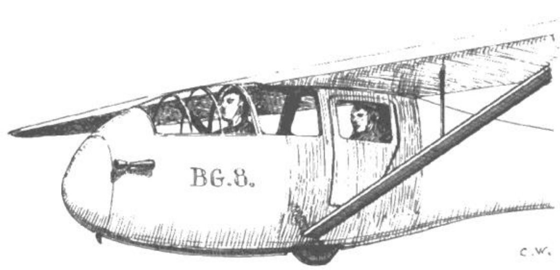


Fig. 1f BG-8

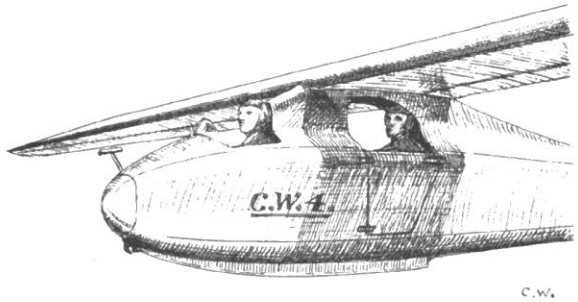


Fig. 1g CW-4

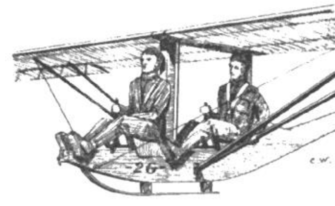


Fig. 1h 2G

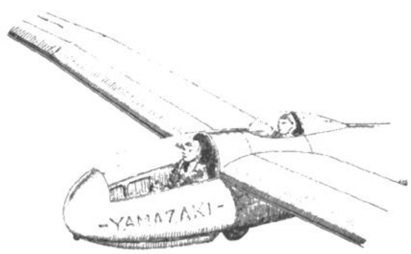


Fig. 1i Yamazaki

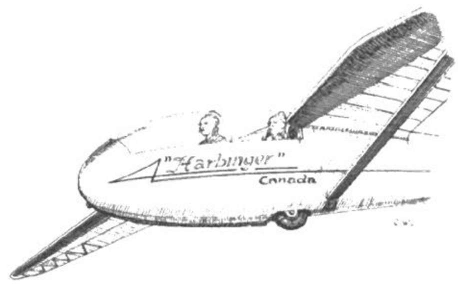


Fig. 1j Harbinger

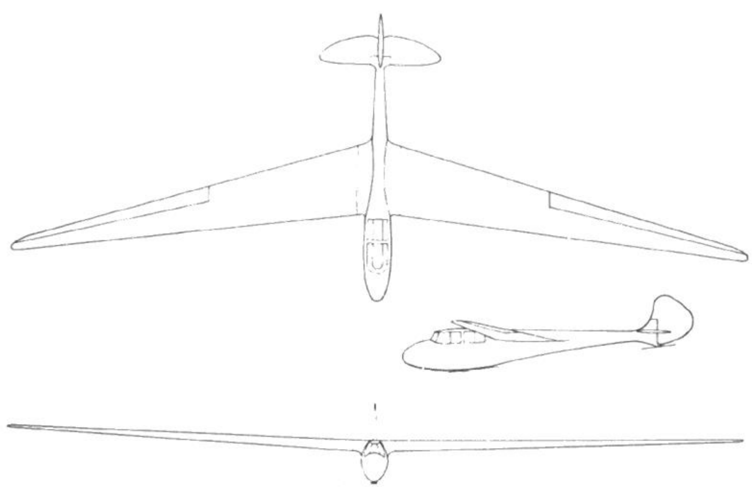


Fig. 2 Stakhanovitch - General Arrangement.

sweep as on the Stakanovitch is perhaps a little extreme. The compromise shown on the Swiss S-25, the French CM-7, and the Harbinger (Fig. 1j) gives the desired result also. In these types the inner portion of the wing is swept forward. the outer wings being without marked sweep. By a little juggling of the wing form, the centre of gravity can lie just ahead of the root leading edge. This wing form may cost some structural complication and this aspect is considered below.

On fig. 2 is shown a general arrangement of the Russian Stakanovitch which shows clearly the forward sweep and the good view. On fig 3 are shown half wings with varying amounts and kinds of sweep forward. Crabpot has an unswept leading edge which results in a small effective sweep forward of the line joining the aerodynamic centres of the wing sections. S-25A and Harbinger show two modes of broken sweep and lastly the simply swept Stakanovitch wing is shown.

2. *WEIGHT*. It is always a problem to keep the weight down without going to extremes of refinement which increase the cost. On the other hand, a heavy sailplane is awkward and expensive to handle. As far as sinking speed and gliding angle are concerned, weight in itself is not a critical factor, for if a heavy sailplane is large enough it can perform as well as a smaller lighter type and of course weight does not affect gliding angle. However, a large glider is not so manoeuverable as a small one. It may therefore be stated that handling both in the air and on the ground is improved by having a light and small two-seater.

It may seem trivial to stress the importance of ground handling, but to anyone who has helped to manhandle 800 lb. (365 kg) of empty glider in and out of hangars it is a real problem. A heavy beast of a sailplane gets a bad name. More important operationally is the effect of weight on launching. On auto-tow take-offs a heavy sailplane can wear out a motor-car transmission in a short time. On aero-tow, which would now be the most normal take-off method, the heavy sailplane requires a heavier and more expensive tug, particularly if any reasonable altitude is to be attained quickly.

Weight has, as stated above, no advantage. But lightness is difficult to achieve. To achieve it we should have:

Small span.
Small wing area.
Inherent light construction.
Carefully designed main fuselage frame and wing junction
Short fuselage.
Small tail, or none at all.
Generally simple structure.

One cannot have all these features for nothing. A very light wing would be very thick or wire braced, resulting in increased drag. Too small a wing area or span results in high minimum sinking speed. The urge toward small span is a good one if tempered by a sense of proportion. How far the designer can go in this direction depends on the performance he needs. A two-seater to operate in tropical or sub-tropical continental conditions (Texas, Central Australia, etc.) will meet strong thermal conditions and good range and altitude could be obtained with a two-seater having a span as low as 15 metres (49.3 ft). For temperate conditions (Central Europe, U.K., Canada, etc.) a normal two-seater needs a span of about 18 metres (say, 60 ft) for reasonably good effectiveness. The problem of span is given further consideration later in this paper.

The above limits are for normally designed sailplanes. It is worth considering what means exist for reducing span without sacrificing performance. Apart from special light structure, the means are:

Aerodynamic refinement.
Low drag flaps.

Aerodynamic refinement would consist of reducing profile drag and could be accomplished by making the wing as thin as possible and as smooth as possible, by reducing the height, width and skin area of the fuselage, improving its shape and by paying unusual attention to sources of possible interference.

For a given span the size and weight may be reduced by increasing the wing aspect ratio (reducing wing area) and although this can result in improved penetration, it suffers at the lower speeds if overdone. The only way to improve the minimum sink is to increase the usable lift coefficient without increasing the drag too much. Leading edge slots do not help. Some form of camber increase is the most fruitful method. The nearest approach to a low drag camber increase is the use of a low-drag high-lift flap. A simple flap has often been used, but to do a proper job something better is required. Experience with the plain flap has been disappointing, the expected gain being hardly ever achieved. A flap which increases wing area as it increases camber is most likely to be effective, but is very difficult to design. Some form of Fowler or Youngman flap is suggested. At least two single-seaters, the Polish B-38 and the German AFH-4 have used such flaps, but they have proved almost impossible in detail design, due to the very small scantlings necessary. So far no flap has been found to be as good as cambering the wing in actuality. Ingenious methods for doing this have been put forward (by Huetter for instance) but no successful schemes have been built and used.

It will now be useful to examine how weight does in fact vary with size. Span may be taken as the basis of weight variation. There are of course many other factors affecting weight such as wing area, load factor, wing thickness, structural material, designer's skill, designer's care, etc. etc. These factors doubtless cause much of the scatter shown in fig. 4 on which the equipped weights of 40 actually built 2-seaters are plotted against span. The general trend is clear, but the scatter is fairly wide. Of particular interest are the five very heavy machines from 54 to 62 ft span. These are TG-32, TG 3A, CM-7, Nimbus and Mihm. The first two were quickly designed and quickly built sturdy trainers for the U.S. Army and Navy. There was no time for detailed refinement and their heavy weights are no surprise. In the case of TG-3A, Schweizer who had always built metal wings had to build a wooden wing because of shortage of light alloy. The CM-7 for reasons unknown to the writer came out 230 lb. overweight, but it has a high ultimate load factor of 12. Nimbus was a first attempt and could no doubt be refined. Background of Mihm is unknown to the writer. In view of the above this heavy group may be ignored in the trends. Striking a line through the rest in a reasonable fashion gives the dotted line, the equation of which is:

$W_e = 13b - 230$ (lb) (ft)

$W_e = 19.4b - 105$ (kg) (m)

Wilkinson (Ref. 1) uses greater refinement and takes into account one further variable, the aspect ratio. Applying this method results in the full diagonal lines on fig. 2 for aspect ratios 10, 15 and 20. The weight equation is:

$W_e = -370 + b(22.6 - 0.44A)$ (lb) (ft)

$W_e = -163.5 + b(31.2 - 0.44A)$ (kg) (m)

The possibly surprising point that the higher the aspect ratio the lighter the weight is dealt with later in this paper. Those who disbelieve this trend may use the formula which omits aspect ratio.

There may be some who object to the assumption of a linear relation between span and weight. It can easily be shown that wing weight varies as b^n where n is greater than unity. However, if all the other weights not varying with span are taken into account, the deviation of the curve from a straight line is not great over the range of span shown. It should also be mentioned that the writer is not concerned here with what <u>ought</u> to be but only with things as they <u>are</u> in practice. The group of points cries out for a straight line. Indeed the scatter is so great that any other shape would be an unnecessary refinement. Again the designer of large-span sailplanes is always very conscious of the danger of overweight and usually makes unusual efforts to achieve a low weight. The very short fuselage of the Obs is a case in point and also the extreme wing taper of the same machine (see fig. 5). On small-span types the designer is aware that weight may not be so critical and tends to design a little more heavily. In any such collection of data it is clear that the mean line indicates something that any designer with reasonable skill could achieve. The most interesting points are those below the line. The little Poppenhausen is not really as good as it looks because it was an old stick-and-wire braced type which paid for its light weight by having no worth-while performance. However, the Darmstadt D-31 is quite another story.

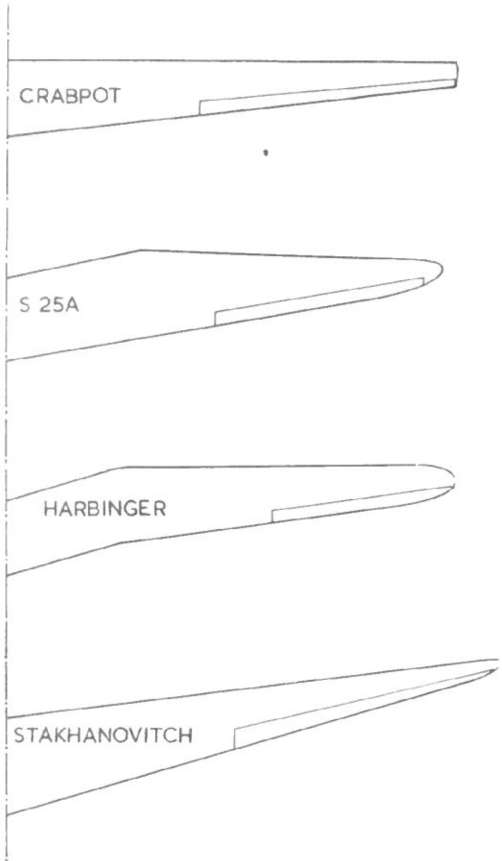


Fig. 3 Examples of Wing Sweepforward.

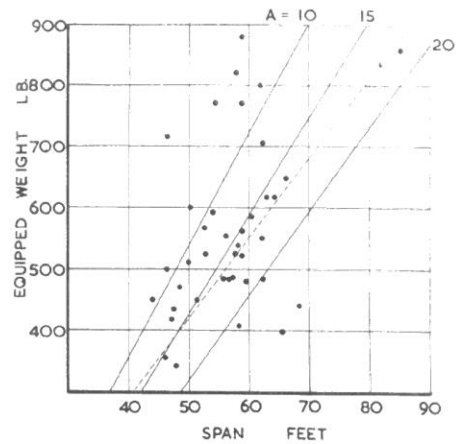


Fig. 4 Variation of Empty Weight with Span.

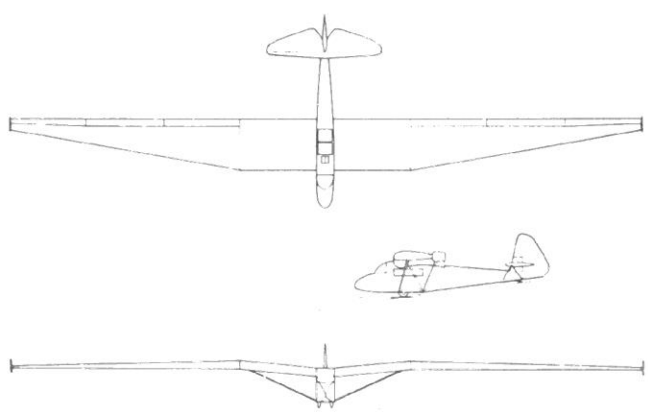


Fig. 5 Obs: General Arrangement.

With a thin cantilever wing (Root section NACA 4415) and an ultimate load factor of 9, it is a first-class achievement. We can say with reasonable confidence that although anyone should be able to build a 2-seater with an empty weight of 600 lb with a 60 ft span, a very brilliant designer could do it for 375 lb.

Fig. 4 probably shows more than anything else the effect of designer's care in detail design. It is there that the weight can easily be won or lost. Carelessness in detail structural design can spoil a design just as much as choosing the wrong aerodynamics.

4. PARTICULAR DESIGNS

Designs chosen for discussion have been picked out either because they have been built in large quantities or because they show interesting features or trends. Those produced in large numbers, even if inferior, are important because their use is widespread and they inevitable become standards of comparison. On the other hand, designs incorporating special features can be of more interest technically even if they have never been built.

Three-view drawings of only a limited number of types are shown, mainly because of the great labour involved in drawing them.

The following types have been manufactured in the greatest numbers as far as the author knows:

Type:	Number manufactured:
Kranich	400
C-800	270
Goevier	125
Laister-Kauffmann TG. 4A	125
Schweizer TG. 3A	110
Slingsby Sedbergh (T-21B)	106
Castel 25S	100
Slingsby Tandem Tutor	77
Pratt-Read TG-32	74
Schweizer TG-2	55

There may be others produced in large numbers, but the author has no information on them.

(a) Kranich and Goevier

Although they are now obsolescent, it is worth studying these types with some care. Kranich (fig. 6) is a shoulder wing sailplane of wooden construction, with tandem seating, the aft seat being practically on the centre of gravity of the machine, enabling it to be flown as a single-seater without ballast. This characteristic is one which is desirable for any two-seater for obvious reasons. The various means for its fulfilment are described above.

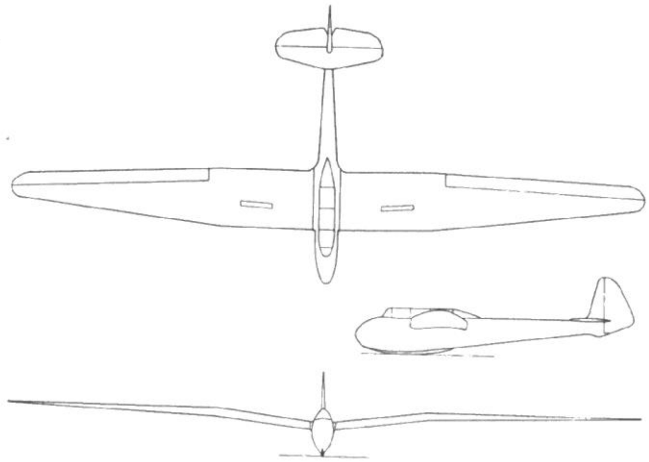
The detail design of the Kranich will not be described, since there are no features which today are of particular interest. General data on the Kranich are reasonably complete. The weight breakdown is given on Table II and the measured performance in fig. 7. It will be seen that its empty weight is below the mean line on fig. 4 which is to be expected of an experienced designer such as Jacobs. The performance would not nowadays be considered particularly good, but did permit good pilots to put up world records. It is of interest to see what are the results of actual tests on handling the Kranich. During the war there took place in Germany a series of comparative handling tests of various sailplanes. Of the Kranich the report says among other things that:

> "Since there is no trimmer, the stick load under tow is high and only just acceptable. It would have been too high if the free flight trim speed had not been as high as it was i.e. 65 kph (40 mph). At this speed at which the Kranich trims with free elevator, the aircraft shows a tendency to go into a spiral drive if the stick is left free. (This characteristic is met with on many types of aircraft and is not surprising.) The stall is first felt at 53 kph (33 mph) and at 50 kph (31 mph) the wing drops, but not fiercely, and normal flying attitude can be quickly regained by pushing the stick for-

TYPE	SPAN		GROSS WT		LOAD WT		Equipped WT		WING AREA		ASP...
	m	ft	kg	lb	kg	lb	kg	lb	m^2	ft^2	RATIO
SGU-2-22	13	43	377	830	173	380	205	450	19·55	210	8·8
Koma	14	46	323	710	161	355	161	355	18·2	195	10·8
Jalon	14·1	46·3	530	1167	205	452	325	715	18·4	198	10·8
TG-1A	14·1	46·3	418	920	191	420	227	500	18·1	194·3	11
Grunau 8	14·5	47·2	360	792	170	374	190	418	22	236	9·57
Göpp 2	14·5	47·6	398	875	200	440	198	435	21·5	231	9·8
Poppenh'n	14·6	47·8	315	692	160	332	155	341	22·9	246	9·3
Göpp 4	14·8	48·5	410	902	196	431	214	471	19	204	11·5
TG-4A	15·2	50	397	911	181	400	232	511	15·4	166	15·05
BG-8	15·3	50·3	465	1020	192	420	273	600	17·7	190	13·3
TG-2	15·7	51·3	390	858	186	410	204	448	20	215	12·65
C-25 S	16	52·5	431	950	174	384	257	566	20	215	12·8
C-800	16	52·5	470	1130	230	506	240	528	22·05	237	11·6
T-21B	16·5	54	450	992	182	400	269	592	24·2	260	11·2
TG-32	16·6	54·5	523	1150	173	380	350	770	21·4	230	13
S-25	17·1	56·2	412	905	160	352	250	552			
Mü-13D	17·1	56·2	400	880	180	395	220	485	18·6	200	15·9
S-21-1	17·3	56·8	380	837	161	355	220	485			
S-21-2	17·5	57·5	382	840	161	355	221	486			
Musger 19	17·6	57·8	438	965	200	440	238	525	20·7	228	14·2
TG-3A	17·7	58	550	1220	182	400	372	820	22·1	237	14·2
MG-9	17·8	58·5	415	913	170	374	245	539	20·9	225	15·1
Mü-10	17·8	58·5	365	803	180	396	185	407	20	215	15·85
Kranich	18	59	435	957	180	396	255	561	22·7	244	14·25
C-242	18	59	415	913	178	392	237	521	21	233	15·5
Mihm	18	59	532	1170	182	400	350	770	20	215	16·2
CM-7	18	59	574	1260	174	383	400	880	22·27	240	14·6
Yamazaki	18·2	59·6	368	810	150	330	218	480	18·7	201	17·7
Spyr V	18·4	60·5	426	938	161	355	266	586			
Nimbus	18·9	62	546	1200	182	400	364	800	22·27	240	16
Mü-15	19	62·3	450	990	200	440	250	550	18·8	202	19·3
B-9	19	62·3	480	1055	160	352	320	705	23·1	248	15·6
EW-1	19	62·3	400	880	180	396	220	484	22·8	245	15·85
CV-V6	19·2	63	460	1010	180	396	280	616	21·6	232	17
Hi-21	19·6	64·3	530	1165	250	550	280	616	24	258	16
D-31	20	65·7	350	770	170	374	180	396	20	215	20
Stak.	20·2	66·2	454	1000	160	352	294	647	23	247	17·75
E-3	21·2	68·5	360	792	160	352	200	440	20	215	22·5
Sturm	25	82	560	1230	180	396	380	835	31	333	20·2
Obs	26	85·3	640	1410	250	550	390	858	38	408	17·8

TABLE I: Two-seater Spans and Weights (Data for Fig. 4).

Fig. 6 Kranich:
General Arrangement.



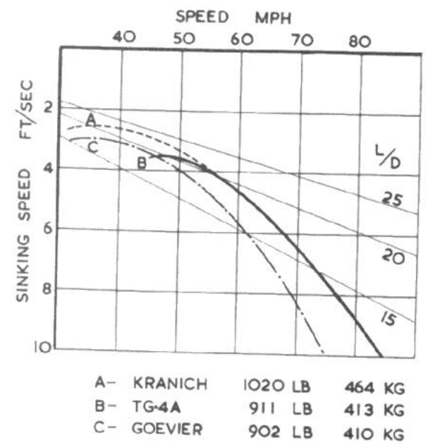


Fig. 7 Performance:
Kranich, TG-4A & Goevier.

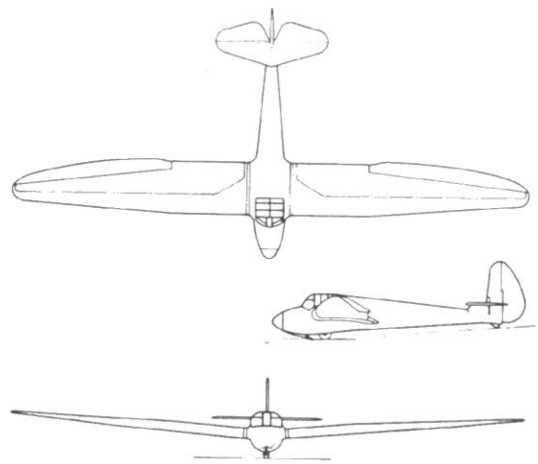


Fig. 8 Goevier:
General Arrangement.

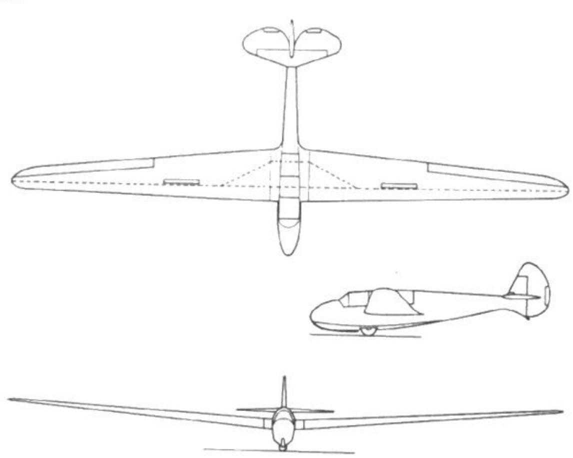


Fig. 9 TG-4A:
General Arrangement.

ward slightly. As for the controls themselves it was found that the aileron stick loads were too large compared to those of the other controls. Controls were not well harmonized. The ailerons had an adverse yawing moment of moderate amount. To make a turn reversal from 45° one way to 45° the other took 5,5 seconds using full aileron and rudder. That compares with 4,2 seconds for the Olympia. The best value measured was 4 seconds for the Berlin B-5 single-seater. The longitudinal stability of the Kranich is very small. Static stability is small and dynamic stability at 70 kph (43 mph) is neutral and presumably there is instability at higher speeds. Many slightly stable aircraft have been very popular. As for directional stability, it is very great with free rudder and, as indicated above, there is a tendency toward a spiral dive."

On a Kranich equipped with an elevator trimmer tab tested by the BGA No. 2 Test Flight Group Cambridge, it was found of course that the elevator stick loads in steady flight were no problem. The control loads on tow were all very small. The stalling speed at 1150 lb (523 kg) was found to be 40 mph (64.5 kph), there being a position error of 5 mph (8 kph) at that speed. This position error was probably ignored in the German tests. No remarks were made about the harmonization of controls. The time for turn reversal at 60 mph (97 kph) was 4.5 seconds from 45° one way to 45° the other way. Although it was found to be statically stable, it was longitudinally dynamically unstable throughout the C.G. range.

In general, Kranich was considered by this group to be suitable for dual training and was considered to be viceless and easy to fly on instruments.

That, briefly described, is probably still the most used two-seater in the world.

In an effort to develop a lighter and more handy two-seater, the Goevier (Gö 4 or Göppingen 4) was designed by Huetter. It was the first production side-by-side two seater with any pretensions toward performance. The crew (see Fig. 1s and Fig. 8) sit closely side by side in a fuselage just over 36 inches (about 92 cm) wide. They are set as far back as possible so that the unbalance with one man crew will not require too much ballast. Such a position allows the wing root to be used locally as increased fuselage width. The relatively small span of 14.8 metres (48.5 ft) means that the Goevier is lighter than the Kranich but the result is also a lower performance. Fig. 7 shows Huetter's calculated performance. There is no measured performance available. The weight breakdown is on Table II.

The German handling study quoted above has also useful remarks about the Goevier. The most interesting are:

"Goevier is very heavy on controls during aero-tow. In fact, at speeds over 80 kph (50 mph) they are most unpleasantly heavy. This refers not only to elevators, but also to the other controls. The machine hunts about all axes, particularly in yaw. The Goevier trims in free gliding flight at 65 to 70 kph (40 to 43 mph). Tests with free elevator were not possible due to the large friction in the system. As for the stall, this starts at 59 kph (37 mph) and is complete at 54 kph (33.5 mph). In calm air there is no wing dropping, lateral control being retained, but in gusty conditions a wing drops slowly and can be recovered quickly by increasing speed a little. In normal flight the controls are well harmonized, although at high speeds the ailerons are rather heavy. The adverse aileron yaw is very small. The 45° turn reversal time is 5 seconds, achieved with full rudder and only about half aileron travel. Possibly the time might have been shorter had it been possible to use full aileron. In other words, the rudder power should have been greater. Longitudinal stability is small and positive, much like that of the Kranich. It was not possible to measure the directional stability with free rudder due to the high friction in the control system."

These, then, are our standards, imperfect to be sure, but nevertheless something to go by. To be acceptable today, handling characteristics would have to be very much better indeed.

(b) American Types

Quite independent of the German developments, two-seater development proceeded slowly in the U.S.A. just before the war. When U.S.A. entered the war in December 1941, it was decided to use two-seat gliders for trainers for troop carrying gliders. Five types were or-

NAME		KRANICH		GOEVIER		TG-4A		Hi-21		C-25·S		MC-JALON		CM-7	
Designer		H. Jacobs		W. Huetter		J. Laister		W. Huetter		Castello – Mauboussin					
Seating		Tandem		SS		Tandem		SS		SS		Tandem		Tandem	
Span	ft. m.	59	18	48·5	14·8	50	15·2	64·3	19·6	52·5	16	46·3	14·1	59	18
Length	ft. m	25·2	7·7	23·6	7·2	21·3	6·5	27	8·25	24	7·3	25·6	7·8	27·8	8·47
Wing Area	ft^2 m^2	243	22·7	203	19	166	15·4	257	24	215	20	198	18·4	240	22·27
Aspect Ratio		14·3		11·53		15		16		12·8		10·8		14·55	
Wing Section Root		G. 535		Modified Jouk.		NACA-4418		–		–		–		–	
Tip		Symm.				NACA-4409		–		–		–		–	
Thickness/Chord Root		16		–		18		–		–		–		–	
Tip		–		–		9		–		–		–		–	
Twist °		–8·8		–5·5		–4		–		–		–		–	
L/D max		22·8		19·25		22		25·1		22		26		27	
at V	mph, kph	43·4	70·5	42·8	69·3	53·5	86	45·8	74·2	42·2	68	59	95	49·7	80
Min Sink	fps, m/s	2·52	0·77	3·02	0·92	3·5	1·07	2·23	0·68	2·62	0·8	2·95	0·9	2·46	0·75
at V	mph, kph	33·4	54	36·2	58·5	48	77	34·6	56	36	58	52·8	85	43·5	70
at Weight	lb. kg.	1050	465	872	396	911	413	1065	484	950	431	1165	529·7	1260	574
Wing Load	lb/ft^2 kg/m^2	4·32	21·1	4·29	20·8	5·48	26·8	4·14	20·2	4·43	21·6	5·9	28·8	5·5	25·8
$Span^2$ Load	"	0·3	1·46	0·37	1·81	0·36	1·76	0·26	1·26	0·345	1·68	0·545	2·66	0·363	1·77
Fus. Beam	in. m	23·6	0·6	36	0·92	24	0·61	45	1·14	–		–		–	
Fus. X sect.	ft^2 m^2	5·6	0·52	10·4	0·97	5·3	0·49	12·5	1·16	–		–		–	
Fus. Skin Area	"	130		137	12·7	110	10·2	214	19·9	–		–		–	
WEIGHTS	lb. kg.														
Wing		352	160	256	116	212·9	96·6	300	136	321·5	146	375	170·4	528	240
Ailerons												19·8	9	35·3	16
Fuselage & Fin		185	84·2	185	84·2	158·4	71·8	238	108	193	87·6	262	118·9	250	113·3
Rudder		27·3	12·4	6·5	3	27·7	12·6	6·5	3	6·8	3·1	8·8	3·95	9·7	4·4
Horiz. Tail Unit				24·2	11			30·5	14	28·2	12·8	33	15	40·4	18·3
Chassis						25·3	11·6	70·5	32	9	4·1	9	4·1	11	5
Skids										7·5	3·4	7·4	3·35	6·6	3
Equipment						86·7	39·4								
Contingency								19·5	9						
EQUIPPED WT.		564·3	256·6	471·7	214	511	232	665	302	566	257	715	324·7	881	400
LOAD		400	182	400	182	400	182	400	182	400	182	400	182	400	182
ALL-UP WT.		964·3	438·6	871·7	396	911	414	1065	484	966	439	1115	506·7	1281	582
Alternate Load		485·7	208·4	440	200			550	250	383	174	452	205	383	174
Alternate All-Up		1050	465	911·7	414			1215	552	949	431	1167	529·7	1264	574

TABLE II: Measured Data on Two-seaters.

dered and a total of 389 built. However, there was a change of policy before much of the training was done and before many of the gliders were crashed. As a matter of fact. as late as 1947 about 300 of the 389 still existed. Although these gliders were not meant for sporting purposes and were not designed for quick dis-assembly, they quickly swamped the U S A glider market after the war when they were sold by the government at mere fractions of the original prices. This series of glider has the designation TG (training glider) and were produced quickly in production without sufficient development time. Some were designed by inexperienced people and some were designed under peculiar difficulties.

A training aircraft has usually a rather short life, but this group has had a long life and as a result many faults appeared which would have been of no importance in their original roles. For instance, the plexiglass canopies have not worn well, nor have the tail skids. Due to the lack of development, the controls tend to lack harmony. There are other aerodynamic and structural faults such as wing-dropping, rough exteriors and secondary structural weaknesses which normal development should have cured. In spite of all this, this group of gliders, and particularly the Laister-Kauffmann TG-4A have done great things for gliding in the U.S.A. as far as the pilot is concerned, although their existence has prevented the development of a modern two-seater.

In Table III the characteristics of the TG series are summarized.

TABLE III

TYPE	TG-1		TG-2		TG-3A		TG-4A		TG-32	
Maker	Frankfort		Schweizer		Schweizer		Laister Kauffmann		Pratt-Read	
Span (ft) (m)	46.3	14.1	51.3	15.65	54.	16.5	50.	15.2	54.5	16.6
Length (ft)(m)	23.2	7.1	25.2	7.7	27.6	8.42	21.25	6.5	26.1	7.97
Wing Area (sq.ft)(sq.m)	194.3	18.1	215	20.	237.	22.1	166.	15.4	230.	21.4
Wt. Empty (lb)(kg)	500.	227.	448.	204.	820.	372.	511.	232.	770.	350.
Gross Wt. (lb)(kg)	920.	418.	858.	390	1220.	555.	911.	413	1150.	523.
Wing Loading (lb/ft^2)(kg/m^2)	4.72	23.1	3.99	19.5	5.15	25.1	5.48	26.8	5.	24.5
Span Loading (lb/ft^2)(kg/m^2)	4.28	2.1	3.26	1.59	4.18	2.04	3.65	1.79	3.87	1.9
Aspect Ratio	11.		12.65		12.3		15.05		12.9	

It can be seen at a glance from the above table that these are in no sense high performance gliders. They are of short span and heavily loaded, having high minimum sinking speeds.

Of the group many consider the TG-2 to be the best, but the only one on which much data are available is the TG-4A. A three-view drawing of the TG-4A is given in Fig 9, its weight breakdown on Table II, and Fig.7 shows its performance at the above weight based on tests by August Raspet at 300 lb (363 kg). It will be seen that the minimum sink is about 3.5 fps (1.07 m/sec) and the best glide is about 1/22. Raspet has made considerable efforts to improve the aerodynamics of the TG-4A. He claims that with the canopy removed, and replaced with a simple bubble canopy for one man, and much detail cleaning-up, the performance is improved to a sink at 602 lb (273 kg) of 2.25 fps (0.7 m/sec) and a gliding angle of 25.6. Since the TG.4A has practically the same wing area and span as the Olympia and the above quoted performance is almost indentical with that quoted for the Olympia at 560 lb (255 kg), this is a reasonable claim. Dr. Raspet's recent work on the successful development of the RJ-5 into a record breaker does show the value of such detailed intelligent studies.

It is hoped that the wide experience obtained by the Americans on these gliders will result in the emergence of a really good two-seater of high performance.

(c) EUROPEAN TWO-SEATERS

Apart from the important Kranich and Goevier described above, there have been other groups of European two-seaters worth some mention here. For instance, there were the Munich two-seaters, the Mü-10 and Mü-15 both of the typical Munich steel tube fuselage construction with normal wooden wings. Both these show up well on the weight graph. Fig. 4, particularly the Mü-10. Other notable German types were the EW-1 and the E-3 of the FAG-Esslingen. All these were light in structure, but relatively lightest of all was the Darmstadt D-31. This was extremely light and had a high performance. It was a high wing type rather on the lines of the single-seater D-30, having a pod fuselage with single tail boom.

The Swiss two-seaters should not be forgotten, but none have been produced in any quantity. Perhaps the most interesting of the group is the S-25 with its swept forward inner wing and the later Spyr.

The two French two-seaters, the Nord Caudron C-800 and the Castel-Mauboussin 25-S, were both built in considerable quantities. The C-800 is a braced high wing type of 16 m (52.5 ft) span with an elliptical plan form. The seating is staggered side by side. The C.25-S is also of 16 m (52.5 ft) span, but has a cantilever wing and the seating is side by side.

The loaded and empty weights for both types are shown on Table I and other interesting data given below:

	C-800				C-25S			
Minimum Sink	0.87	m/s	2.85	fps	0.8	m/s	2.62	fps
at Speed	65.	kph	40.3	mph	58.	kph	36.	pmph
Best L/D	19.7				22.			
at Speed	72.	kph	44.5	mph	68.	kph	42.2	mph
Sink at 100 kph (62 mph)	1.9	m/s			-			
Ultimate Factor	9.				-			
Wing Section Root	Gö 654				-			
Tip	Gö 676				-			

It will be seen that neither type has any pretensions to high performance and may be classed as specialised trainers.

For data on other French two-seaters, see Table II.

(d) Wartime German Designs

During the war a specification was issued for an improved two-seater in Germany and it is of great interest to see that it was apparently built around the Kranich and required improvements on it. The main requirements were:

1. Performance better than Kranich.
2. Faultless flying qualities.
3. Load to be carried to be variable between 60 and 250 kg. (132 lb and 550 lb) without requiring trimming ballast.
4. Retractable sprung single-wheel chassis.

5. Provision for a detachable sprung normal undercarriage for three-point landing practice.
6. Adjustable controls for pilots of various sizes.
7. Perfect view for both pilots.
8. Dive brakes.
9. Interchangeable wings for aerobatics and performance flying.
10. Plenty of room even for fat pilots.
11. Oxygen equipment.
12. If separate seats, pupil's controls to be so arranged that they could be disconnected if required.
13. The cabin to be constructed of steel tubing with fabric covering to avoid injury from splinters in crashes.

These requirements are of considerable interest. They try to combine a trainer and a high performance machine. Is the roomy cockpit to be balanced by the retractable chassis? Is the costly high performance worth while in a machine used for landing practice or designed for crashery?

On this specification three designs were ordered. One by Hans Jacobs was a tandem shoulder wing machine with the second man sitting on the centre of gravity. The pilots were staggered in height like the Yamazaki shown in Fig. 11. This machine was not completed and the designer advised the writer that he had no drawings or sketches available.

Another design was by Kracht who designed a low wing machine with an undercarriage retractable into the wing. The tandem seats were staggered in height. It will be noted that the undercarriage did not fulfil the specification requirement. This machine was never finished.

The only machine which was finished was the Hütter Hi-21 which is shown in Fig. 10. This was a side-by-side shoulder wing machine with a bubble canopy and a retractable tail wheel undercarriage. This was also at variance with the specification. The very difficult problem of trimming without ballast is accentuated in a side-by-side machine with the crew fairly far forward as in the Hi-21. It was solved by making the wing angle of sweep adjustable in flight.

The Hi-21 flew in 1944. After the war it was flown by American soldiers at Nabern Teck. It was last heard of in Erding near Munich and was unserviceable. The calculated performance is shown in Table II. It will be seen to be better than the Kranich throughout. The measured weight breakdown is also given in Table II. The undercarriage geometry is sketched in Fig. 11, and in that figure some indication is given of the fuselage structure. The wooden rear fuselage picks up on three points on the steel tube front portion. The aft part of the front portion carried the wing and chassis, and as far as can be gathered, the nose part containing the cockpit was bolted to this part.

(e) <u>The Britisch Gliding Association Design Competition 1947.</u>

The most important effort made since the war was in 1947 when the BGA offered prizes for the best design for a two-seater. The main points of the specification were:

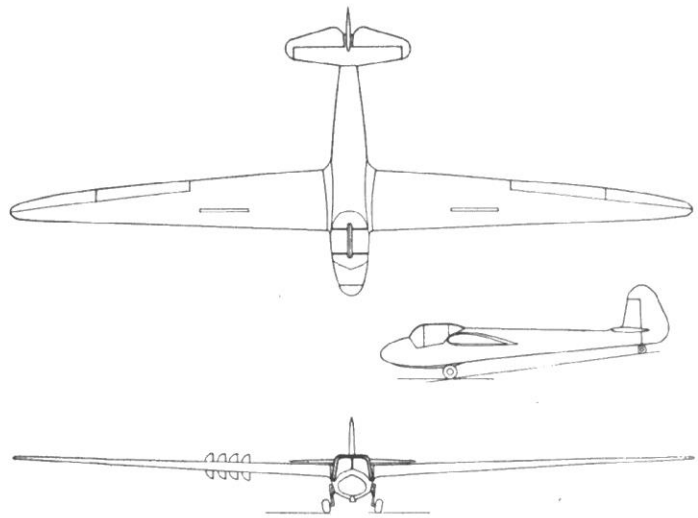
A. <u>General</u>
1. Suitable for cross-country soaring, and club and private owner use.
2. Latest aerodynamic and structural ideas.
3. Small, light and cheap. Not over 60 ft (18.3 m) span.

B. <u>Particular</u>
1. Room for two pilots 6 ft tall (1.83 m).
2. Good view for both pilots.
3. Built-in wheeled undercarriage.
4. Minimum sink not more than 2.4 fps (0.73 m/s) at not over 40 mph (64.5 kph). Sinking speed not to exceed 10 fps (3.05 m/s) at 80 mph (129 kph).
5. Crew weight to be 400 lb (182 kg).

DESIGN		30		39		51		22		50		53		47		11		6	
NAME		Crabpot		—		Nimbus		—		Harbinger		—		Cu-Nim		—		—	
Designer		H. Kendall		D. J. Farrar, L. G. McFarlane		A. O. Mattocks		T. A. Brown, J. C. Reussner		W. Czerwinski, B. Shenstone		C. J. Godwin		C. W. Prower		F. H. Robertson		K. Turner, R. Wijewardene	
Seating		SS		SS		Tandem		SS		Tandem		SS		Staggered		SS		Tandem	
Span	ft. m	60	18·3	60	18·3	62	18·9	60	18·3	60	18·3	60	18·3	60	18·3	60	18·3	59	18
Length	ft. m	27	8·24	25·6	8·1	26·83	8·2	25·67	8·13	25	7·62	25	7·62	26·67	8·15	24	7·31	30·4	9·27
Wing Area	ft^2 m^2	200	18·7	240	22·4	252	23·5	240	22·4	240	22·4	223·4	20·8	234·2	21·9	225	21	239	22·3
Aspect Ratio		18		15		15·3		15		15		16·1		15·35		16		14·6	
Wing Section	Root	43018		64,2-418, a=4		G·535		2 R_1 15		4410		23015		4417		BR-11		65_3-816	
"	Tip	43012·A		"		Clark Y		2 R_1 09		4409		23012		4413		"		2 R_2-12	
Thickness/Chord	Root	18		18		16		15		10 [13 at strut]		15		17		15		16	
	Tip	12		18		10		9		9		12		13		12		12	
Twist °		-3		-5		-6		-2		0		-2·3		-4·81		-5		-3	
Wing $C_{D min}$		0·0084		0·0063		—		0·0082		0·0085		0·007		—		0·007		0·007	
Wing C_D at L/D max		0·021						0·0185		0·022		0·021				0·022		0·021	
L/D max		27		26·8		25·8		26·8		25·9		29·5		23·9		26·2		33·5	
at V	mph, kph	49	77	42	68	45	72·5	50	80·5	46	74	46	74	44	71			50	80·5
Min. Sink	fps, m/s	2·28	0·7	2·3	0·7	2·2	0·67	2·36	0·72	2·32	0·71	2	0·61	2·51	0·765	2·5	0·76	2	0·61
at V	mph, kph	41	66	40	64·5	30	48·3	40	64·5	37·5	60·5	37	59·5	39·5	63·7	42	68	40	64·5
Sink at 80 mph	fps, m/s	7·6	2·32	8·2	2·5	7·75	2·36	7·35	2·24	8·75	2·67	6·6	2·01	9·1	2·77	7·3	2·2	6	1·83
at Wt.	lb. kg	860	391	952	433	1204	546	982	447	840	382	948	431	1030	468	942	428	1008	458
Wing Load.	lb/ft^2 kg/m^2	4·3	21	3·97	19·35	4·8	23·2	4·09	19·9	3·5	17·1	4·25	20·7	4·4	21·4	4·18	20·4	4·2	20·5
$Span^2$ Load	"	0·24	1·12	0·26	1·29	0·31	1·52	0·27	1·33	0·23	1·14	0·26	1·28	0·29	1·40	0·26	1·28	0·29	1·41
Fus. Beam	in, m	42	1·07	45	1·14	29·5	0·75	44	1·12	24	0·61	44	1·12	36	0·92	43·5	1·10	23·8	0·60
Fus. X sect	ft^2, m^2	10·2	0·95	12·3	1·13	8·9	0·83	11	1·02	6·4	0·6	11·5	1·07	9·7	0·9	13	1·21	7·2	0·67
Fus. Skin Area	"	182	16·9	174	16·2	181	16·8	140	13	148	13·9	155	14·4	181	16·8	154	14·3	160	14·9
WEIGHTS	lb. kg																		
Wing		311	141	300	136·5	345	157	341	155·2	222	101	271	123	365	166	271	123	388	176·7
Ailerons						32	14·6					21	9·5	24	10·9	20	9·1		
Fuselage		173	78·8	120	54·5	303	138	204	93	112	51	124	56·4	123	55·8	95	43·2	187	85·2
Coupé		in Fus.		15	6·8	23	10·5	in Fus		18	8·2	20	9·1	22	10	14	6·3	in Fus	
Fin		6·1	2·8	9	4·1	in Fus		"		in Fus		8	3·6	6	2·7	8	3·6	"	
Rudder		6·2	2·9	in Fin		9	4·1	7	3·2	} 30	13·6	6	2·7	5	2·3	6	2·7	"	
Hor. Tail Unit		15·3	7·	20	9·1	41	18·6	22	10	}		25	11·4	24	10·9	24	10·9	23	10·5
Chassis Wheel		in Fus		25	11·4	20	9·1	in Fus		11	5	14	6·4	14	6·4	55	25	in Fus	
Skids		"		15	6·8	in Fus		"		15	6·8	7	3·2	12	5·4			"	
Controls		"		30	13·6					14	6·3	29	13·2	36	16·3	28	12·7		
Instruments		"		8	3·6			8	3·6	8	3·6	8	3·6	10	4·6	9	4·1	8	3·6
Seats		"		10	4·6	31	14·1			8	3·6	2	0·9	16	7·3	12	5·4		
Hooks		"								2	0·9	3	1·4	3	1·4				
Contingency												10	4·6						
EQUIPPED WT.		511·6	232·5	552	251	804	364	582	265	440	200	548	249	660	300	542	246	606	276
LOAD		400	182	400	182	400	182	400	182	400	182	400	182	400	182	400	182	400	182
ALL-UP WT.		911·6	414·5	952	433	1204	546	982	447	840	382	948	431	1060	482	942	428	1006	458
Alternate Load										510	232								
Alternate All-Up										950	432								

TABLE IV: Data on BGA Design Contest Entrants.

Fig. 10 Hi 21: General Arrangement.



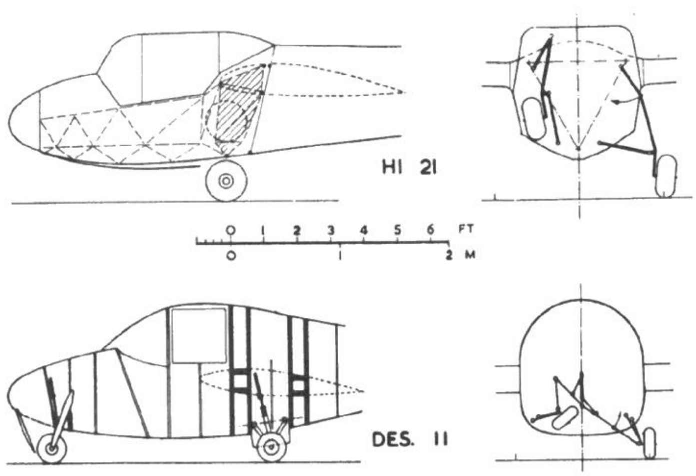


Fig. 11 Retractable Undercarriages.
Hi 21 & Design 11.

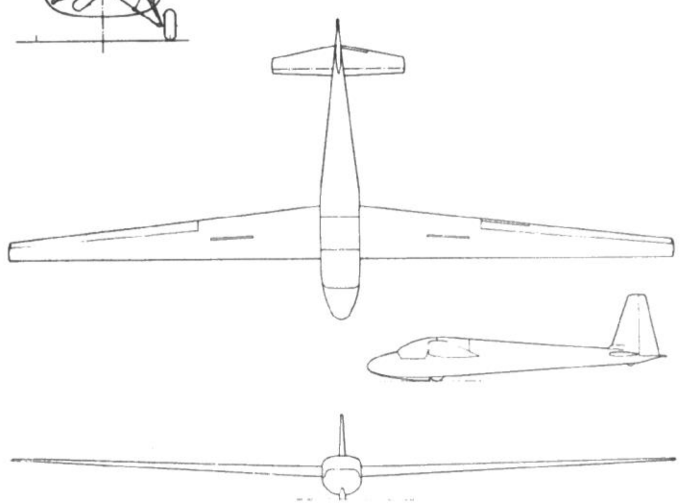


Fig. 12 Crabpot I - Design 30:
General Arrangement.

There was a very good response to this specification, and although many were amateurs who had never made a design before, a number of useful designs were put forward. Altogether over 50 applications were made and 20 designs actually entered. Places were given to the six best. The writer has been able to examine the first six and three others considered to have special merit by the adjudicators. These designs are discussed below because they show interesting lines of thought. In the writer's opinion they also show some indecision due to difficulty in deciding what was really wanted from the specification. They were torn between something advanced which might be too experimental and something straightforward to build and aerodynamically unquestionable. It was probably realised that funds for building would be limited and the result was a rather restrained group of submissions. As a matter of fact, it was not until 1950 that funds became available to build the prizewinner, and even it has not been completed early in 1953.

General arrangements of those given the first six places are shown in Figs. 12 to 17. On Table IV are given the general data for these six machines and for three others in the contest.

The requirements involving a very low sinking speed were clearly pointed toward Western European and Eastern U.S.A. conditions rather than Mid-Continental conditions met in Russia, Texas and in the Argentine. With the limit of 60 ft on the span, the wing loadings all came out quite light, something like 4.5 lb/sq.ft (22 kg/sq.m) on an average, and the aspect ratios varied from 15 to 18. The concentration on low minimum sink at the low forward speed given certainly tended toward rather lower penetration than might have been desired.

In working to the specification it was difficult for the contestant to know what was really wanted. A club machine with the latest aerodynamic and structural ideas might clearly be impossible if the latest ideas involved mechanisms such as Folwer flaps and a retractable wheel and variable sweep. But it was also to be cheap which threw one back into the club and threw out the amusing developments. Many sound structural ideas are only useful for large production, but of course large production was unlikely, so that here was a clear limitation.

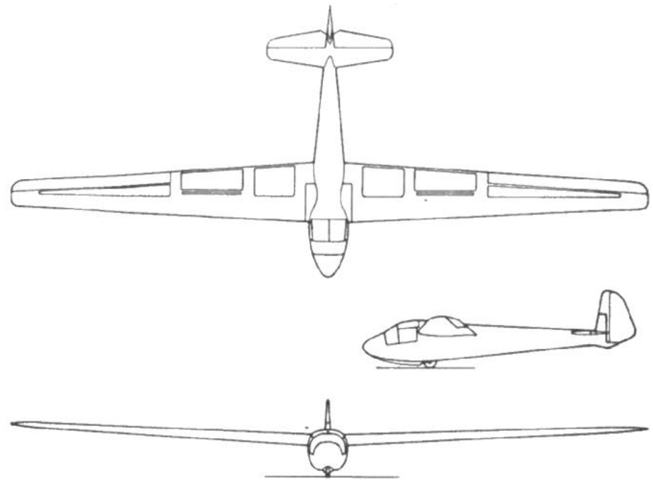
<u>WINNER.</u> The winner was Hugh Kendall's Design 30, called the Crabpot because his mocked-up cockpit looked like one. This is a side-by-side machine rather like a larger and more modern Goevier and has much in common with Hütter's Hi-21. Kendall made the maximum use of simple shapes and straight lines. He follows the modern tendency toward rather square tips on wings and control surfaces, which although not so attractive to many as the rounded tips, has a firm basis of wind tunnel tests to back it up. Kendall uses single-curvature surfaces throughout the Crabpot except forward the wing. Perhaps his most interesting aerodynamic feature is the use of an anti-balance tab on al all-moving tailplane. All earlier sailplanes used all-moving tailplanes which had at times rather difficult characteristics of overbalance and lack of stick-free stability. The use of the anti-balance tab should cure such troubles. This scheme was first used successfully on the PWS-102, as far as the writer knows.

Kendall used a higher aspect ratio than other entrants which was probably the right thing to do and doubtless helped him to win.

Kendall's structure was normal frame and plywood for the fuselage, but his wing was most unusual when you looked inside. There were several spanwise webs and few ribs. The flanges of the spars were wide spruce planks 16 inches wide (41 cm) at the root and tapering in plan toward the tip. The planks were of constant thickness of 0.6 inch. (15 mm) on the top surface and 0.5 inch (13 mm) on the bottom surface. The ribs were from 3 to 4 ft (90 cm to 120 cm) apart. The nose plywood was supported by these ribs and by spanwise stringers so that the unsupported surfaces were about 36 inches by 6 inches (90 cm by 15 cm). The wings were joined together at the centreline by four vertical pins.

It is not worth while to describe or comment on this structure further, as it has been discarded for an asbestos reinforced low pressure thermo sitting plastic structure. Contributions from the Kemsley Trust and the Ministry of Supply have made it possible for work on this plastic prototype to proceed. The type of structure was devised by the R.A.E. Farnbo-

Fig. 13 Design 39:
General Arrangement.



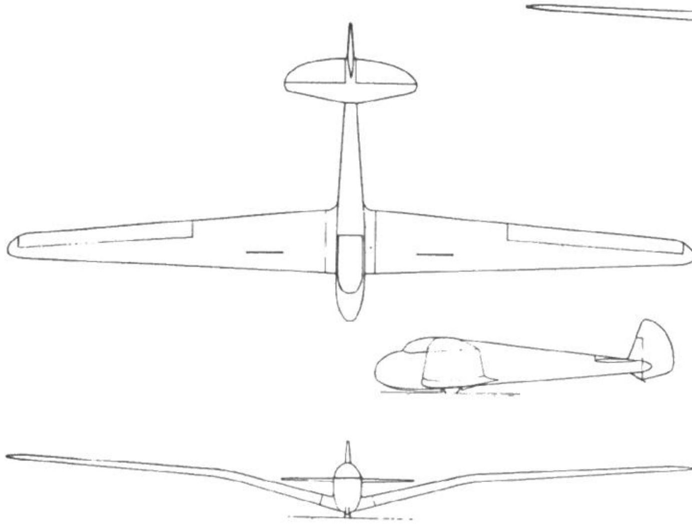


Fig. 14 Nimbus, Design 51:
General Arrangement.

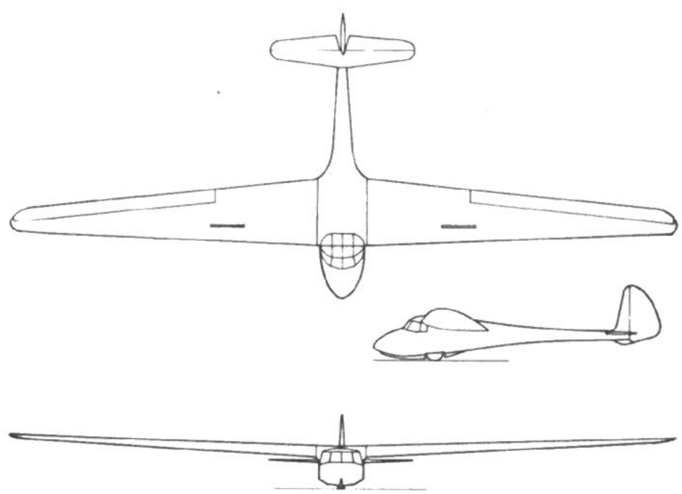


Fig. 15 Design 22:
General Arrangement.

rough and is being applied to the Crabpot by Miles Aircraft. The method which involves heated concrete moulds and tailored felts cannot be described here, but it is hoped that the technique will be published in detail elsewhere.

In the spring of 1953 the prototype Crabpot had not been completed. The machine being built differs aerodynamically from that shown in Fig. 12 by having slightly less span (18 m), a butterfly tail, long narrow full span ailerons, and no wing twist, tip section being 53015A.

SECOND PLACE. Farrar and McFarlane's Design 39 was second in the BGA competition. This is also a 60-footer side-by-side two-seater. The main dimensions are given in Table IV and a general arrangement plan in Fig. 13. This sailplane is characterized by a thick wing, 18% thick from root to tip, but of laminar flow section, 64, 2-418. The wing structure features a double skin with spanwise stringers, the plywood covering being $\frac{3''}{32}$ for the first 20 ft of span and thereafter $\frac{1''}{16}$.

THIRD PLACE. Third in this competition was Mattocks' Design 51 Nimbus shown in Fig. 1 and described in Table IV. The Nimbus had actually been built at Short Brothers before the competition took place and considering the rule of anonymity might well have been scratched. However, the judges decided otherwise. The Nimbus has a wing with a root section of 16% (G. 535), tapering to 10% Clark Y which might be called a good old-fashioned wing. It was of 62 ft span, which was 2 ft more than the maximum allowed. The fact that Nimbus is much heavier than any other design is at least partly due to the fact that it had been built whereas the others had only paper weights. However, a low wing on a glider like this may well be heavy. Its lower surface near the fuselage must be unusually robust to avoid damage from rough grond. The kink in the wing must also cost weight. In addition, the high fuselage necessitated by seating the crew on top of the wing must also be heavy. Perhaps the greatest latent disadvantage is the sensitivity of the low wing type near the stall. The fuselage-wing juncture would have to be kept very smooth to avoid early stall and a drastic increase of minimum sinking speed.

The Nimbus construction is largely normal, the wings have a D-nose and single spar with diagonal drag spar. The wing roots are built into the fuselage, projecting 28" each side. The centre section spar booms are laminated and bent to form the dihedral. The outer wing spar booms are of spruce, but not laminated, the spar being of I form.

The main wing fittings are drawn out as for steel in three laminations and bolted to the spar. The female fittings on the centresection are in two separate pieces, clasping the spar. Most of the fitting design for the Nimbus is very good although complicated in the best aircraft style. As was to be excepted, the Nimbus drawings are more detailed and complete than any of the other competitors'. In fact, they were far more elaborate than necessary for the building of a prototype.

FOURTH PLACE. Brown's and Reussner's Design 22 won fourth place. This is also a side-by-side job, but with a higher wing than Kendall's, the top surface being coincident with the top of the fuselage. See Fig. 15 and Table IV.

Design 22 is characterized by a fabric-covered rear fuselage and a welded steel centre section. Aft of the rear main fuselage frame, the fuselage is octagonal in section, the frames (average spacing 15") being crossbraced to one another in the vertical and horizontal planes which are also the planes of the four main longerons. The four secondary longerons are secondary structure. In the writer's opinion, such a structure would be far more difficult to build than the more normal curved laminated frame structure covered with plywood. The fuselage is considerably tadpoled. Whether the reduction in wetted surface can compensate for increase in form drag cannot be known. Extreme tadpoling has certainly no advantages, because of the difficulty of distributing loads into the boom and the problem of boom flexibility, and in such cases the form drag increase can easily be very serious.

The metal wing centresection, which is a built-in jig, has certain attractions. The use of such a scheme enables the wing pick-up points to be easily and accurately positioned.

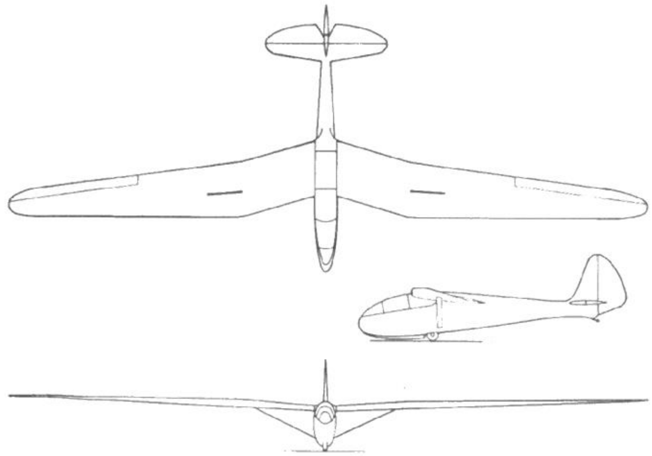


Fig. 16 Harbinger, Design 50:
General Arrangement.

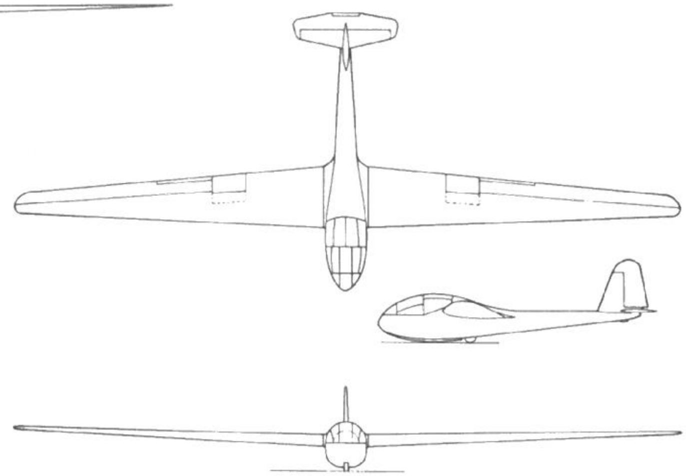


Fig. 17 Design 53:
General Arrangement.

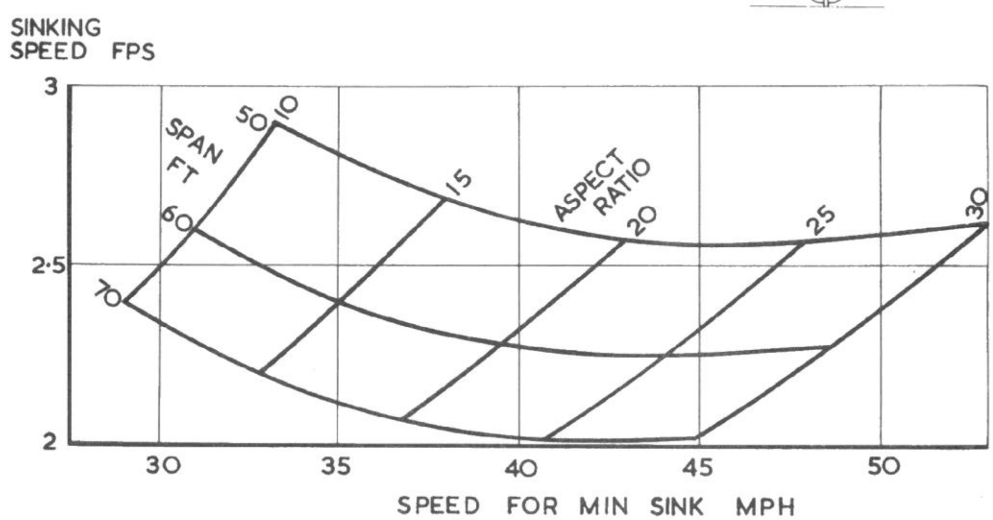


Fig. 18 Influence of Span & Aspect Ratio on Minimum Sinking Speeds - Two-Seaters.

FIFTH PLACE. Czerwinski's and Shenstone's Design 50 is shown in Fig. 16 and Table IV. It should be noted that since the writer of this article had a share in the design, he is doubtless unduly influenced in its favour. Design 50 or Harbinger is a tandem seated high wing type with the rear seat at the centre of gravity so that it can be flown single-seated unballasted. The sweepforward of the inner part of the wing enables the man in the rear seat to have a good view, his eye being ahead of the root wing leading edge. This kink in plan means either a kinked spar or a straight spar and a bracing strut. The designers chose the latter and made the wing as thin as they dared (10% at root, 13% at strut, 9% at tip).

As in Design 22, the Harbinger has a metal main frame, but in this case it is vertical, picking up the main spar and the struts. The rear spar fitting is not attached to this frame. One other feature worth mention is that instead of using a wooden diagonal spar, a metal tripod is used which has advantages if a welder is easily available.

Apart from many interesting details which the writer has no space to expand upon, perhaps the most interesting point about the fuselage is its shape. It is not of an arbitrary shape. It is elliptical in section throughout and the longitudinal shape was worked out carefully to follow the pattern of airflow in the neighbourhood of the wing root at a speed near that for L/D max. It is a cambered shape so formed that it meets the upwash at the right incidence and conforms with the downwash.

The competition judges did not like the use of a bracing strut and were somewhat doubtful about the sweep. The judges also did not like the initial weight estimate which was, in the opinion of many, low. Prototypes of this design are being built in England and in Canada.

SIXTH PLACE. Godwin's Design 53 was the last to be placed. This design has perhaps more style to it than any of the others (Fig. 17). Again a side-by-side seater, it has a wide area of transparency and an excellent view. Wing and fuselage are of normal plywood construction, the wing being entirely ply covered except for the trailing edge portion inboard of the ailerons. There is a rear spar which is pin jointed at the root and no diagonal spar. The airbrakes are of an unusual semi-split construction. Part of the wing trailing edge hinges upwards and a paddle-like balance moves down under the wing. This scheme has its attractions, but the effect of brake operation on trim would need checking.

UNPLACED ENTRANTS. Mention is made of a few unplaced entrants which have some specially interesting aspects. It is not meant to imply that other unmentioned designs did not also have much of interest.

(a) PROWER's Design 47 (Cu-Nim).

The particular interest of this design is the staggered seating, the feet of the man seated aft being beside the front seat, thus achieving a fuselage beam of 36" and improving the balance with one crew.

(b) ROBERTSON's Design 11.

This design features a retractable tricycle undercarriage of considerable ingenuity which is shown diagramatically in Fig. 11 on the same scale as Huetter's Hi-21. He claims a weight of 55 lb (25 kg) for this which is probably optimistic considering that Huetter's cost him 70.5 lb (32 kg). Such an undercarriage would have many attractions for quick ground handling, although its weight, maintenance and vulnerability disadvantages are obvious. An excellent set of small scale detailed drawings accompanied this entrant. They were a model of good pencil tracing work.

(c) TURNER's & WIJEWARDENE's Design G.

This design shares the thinking behind Design 50 in that the seats are in tandem with the wing swept forward to improve the view from the rear seat. The wing is cantilever and the spar centreline sweep is 4^o.

The above inadequate sketch of the designs is all that space allows. Interesting comparisons on wing sections, plan forms, fuselage shapes, fitting design, materials, controls, view and many other aspects should be made and would be instructive. A few data on some of these points are given in Table IV.

V. SOME ANALYSIS OF TWO-SEATER PERFORMANCE.

The weights and performances of a number of two-seaters have been collected by K G Wilkinson in Ref. 1 Fig. 18 and Fig. 19 are reproduced from his article.

The main thing we learn from these curves is that most two-seaters to date have been too conservative. They have carried too much wing for a given span or been too heavy These curves show, for instance, that a 60-footer with $A = 15$ would give a minimum sinking speed of 2.4 fps at 35 mph, fulfilling the BGA specification. Most of the entrants had these dimensions. However, Fig. 18 shows that had the aspect ratio been increased to 21 at the same span, the sinking speed would be 2.25 fps at 40 mph, which also fulfils the specification. Referring to Fig. 19, the same tendencies are shown with regard to best L/D conditions and sink at 80 mph (130 kph).

Since Wilkinson's study did not assume optimum figures, but only averages he cannot be considered to reflect anything more than what has often in fact been achieved. Why, then, are the BGA Design Competition entrants so conservative? The reasons may have been:

(a) Lack of statistical data.
(b) Lack of realisation of actual performance trends depending on sailplane geometry.
(c) Lack of knowledge of the features likely to be attractive to the judges of the competition.

The first and third reasons are clear enough, but the second may need some explanation. Reference is made to Wilkinson's conclusion that for a given span the high aspect ratio sailplane is:

Lighter and
Has a better performance

within reason, compared to one with a lower aspect ratio. It has been argued for years that a high aspect ratio wing is heavy and so it is if the span is increased. However, for a given span the wing, regardless of aspect ratio, has the same load to carry and if it is possible to keep the same spar depth, the spar cannot change in weight. To do this, the root thickness/chord ratio must be changed, but not so much as one might think For instance, for a wing of 60 ft span and 3 : 1 taper and a root spar depth of 9", the root section would vary as follows with aspect ratio:

A	12	15	18	21
Root Thickness/Chord %	10	12.5	15	17.5

The higher aspect ratio wing has less area, shorter ribs, etc., and therefore should be lighter. The rear fuselage and tail unit will also be shorter and lighter so that one comes out with a smaller and lighter sailplane. Whether this is sufficiently light to counteract or neutralize the greater rate of sink one would calculate for the smaller wing is the doubtful point Lack of dependable weight data would make one cautious and one needs an analysis such as Wilkinson has made to clarify the shape of the variables.

It may be instructive to apply Fig. 18 and Fig. 19 to the types detailed in Table IV and Table II. The results are shown on Table V. Assuming that Wilkinson is right, the worst showings on weight are for the Nimbus (Design 51) which is actually 31% high and Harbinger (Design 50) which is 25% low on calculation. Revised calculation is shown in brackets. It is notable that the winner is right on the mark and that all the others are within 6% of the calculated weights. The bracketed figures for TG-4A allow for a reduction of 50 lb in the large allowance of 87 lb for fixed equipment.

As for performance, the given gliding angles are all better than given by Fig 19 except for Kranich, TG-4A and Goevier for which the real performance is pretty well known, and which show up rather worse than Fig. 19 says they should. Here we see the usual designer's optimism, particularly in Design 53. The sinking speeds agree much better with Fig. 18, except that TG-4A shows up badly. However, as mentioned above, cleaning up this type has made remarkable improvement, even improving on Figs. 18 & 19. It is also to be noted that Goevier appears to have a worse high speed performance than Fig 19 would allow.

Special reference should be made to Table II. This contains all the actual detail weights and performances available to the author. It is not a great deal; there is no consistency in it. One should be grateful to Jacobs, Laister, Huetter, Castello and Mauboussin for making weight data available in spite of the fact that some of the weights are very high. As for performance measurements, all that are available were published before the war on Kranich and after the war on TG-4A. All other performances given are calcualted or based on evidence or comparison but not on precise measurements. If more actual data could be made available, development could be much more rapid, and the author appeals to designers to weigh detail parts and publish the weights and make efforts to measure performance under precise and technically acceptable conditions. The greater the volume of precise data, the less would be the necessity for inexact discussions and descriptions and guesses of which this present paper consists.

VI. FUTURE TRENDS IN TWO-SEATERS.

In the above discussion and descriptions, there is no obvious design trend to be observed. The state of development is still too tentative for the essentials to be generally obvious. What the author believes these essentials to be (as he writes in 1952) are described below.

Design effort must be directed toward obviating the basic disadvantages of the two-seater. These are:

Too great a size.

Too much weight.

Bad view for second pilot.

We should like to have two-seaters which are, <u>for a given performance</u>, no larger and no heavier than the single seater. The second pilot should have as good a view as the first pilot, if he is to enjoy the flight and make his contribution towards its success.

To cut down size certainly means reducing span below the optimum. The problem is then by other means to bring the chosen restricted span as close as possible to the optimum. This means that the profile and friction drags must be made as low as possible, and the aspect ratio as high as practicable. Following this idea gives us the conclusion that it will be more important to make the two-seater aerodynamically clean than the single seater which is in any event of manageable size. It should be more worth while in a two-seater to give careful attention to the cabin enclosure regarding shape, flush fitting of panels and to air leaks. It might be worth while retracting the chassis and suppressing all small external details, such as openings through which air might leak, knobs such as control horns and control surface gaps. If it is possible to attain a greater measure of laminar flow over sailplane wings by suitable section shapes, it would be well worth while. The value of extremely thin wings must be considered but this conflicts with the second requirement of low weight.

Low weight must be attempted. The crew of two should be able to manhandle their two-seater on the ground and remove the wings. Weights of present-day 60 ft wings are about 150 lb (68 kg) each. As shown above, it is essential, quite apart from this, for the weight to be kept low for the sake of performance. The combination of high aspect ratio and low drag camber flaps is likely to be essential. The design complication is increased thereby but will have to be accepted.

View and comfort are of great importance and are not indivisible. A good view in itself is comforting if not comfortable. In a single-seater a considerable degree of comfort is necessary if a long flight is to be bearable. The pilot cannot rest because the flight depends on his constant watchfulness. In a two-seater, comfort is not quite as essential, because the pilots can fly in turn and rest when off duty. This argument gives the designer some leeway. He can make quite a constricted accommodation for each pilot as long as the pilots are able to change the position of their limbs when not piloting. This means that the fuselage crosssection for a high performance two-seater need be no greater than for a single-seater and possibly even slightly less although, considering the cramped seating of some sailplanes, let us hope not.

Reference 1: K.G. Wilkinson: "The Design of Sailplanes for High Performance" Aircraft Engineering Vol XXIII Sept. 1951 PP 263-271

Fig. 19 Influence of Span & Aspect Ratio on L/D & High Speed Performance - Two-Seaters.

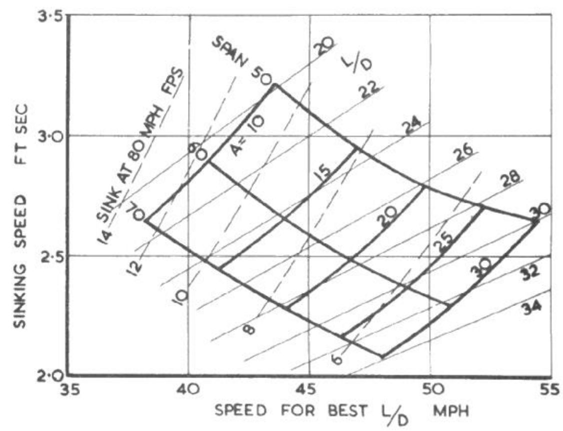


TABLE V:
Comparison of Actual and Claimed. Performance with Wilkinson's Estimates.

TYPE	Equipped Wt.		Ratio	L/D max		Min. Sink		Sink at 80mph	
	Given or Actual	From Equation	Actual / Equation	Given or Actual	Figure 19	Given or Actual	Figure 18	Given or Actual	Figure 19
30	512	510	1·0	27	26·3	2·28	2·3	7·6	7·5
39	552	590	0·94	26·8	24·2	2·3	2·4	8·2	8·4
51	804	612	1·31	25·8	24·5	2·2	2·35	7·75	8·3
22	582	590	0·99	26·8	24·2	2·4	2·4	7·4	8·4
50	440 (550)	590	0·75 (0·93)	25·9	24·2	2·3	2·4	8·8	8·4
53	548	560	0·98	29·5	25	2·	2·35	6·6	8·2
Kranich	564	590	0·96	22·8	23·6	2·52	2·45	8·95	9·
TG-4A	511 (461)	430	1·19 (1·07)	22	23·6	3·5	2·7	8·7	8'
Goevier	472	480	0·99	19·3	20·8	3·02	2·9	13	10
Hi-21	665	630	1·06	25·1	24·8	2·23	2·3	7·65	8·8.
Units	lb.					ft/sec.		ft/sec	