Progress in Sailplane Design

by

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Introduction

Compared with the general advance of aeronautics in the past decade, or indeed with sailplane development in the 20's and 30's, progress in sailplane design has recently been very leisurely. This is due in part to the fact that there is less scope and partly because little effort has been expended. The most important advances in the art have been in the understanding and use of meteorological conditions which make soaring flight possible; sailplanes good enough for the purpose have existed.

Before the Second World War the main design impetus came from Germany and Poland and in most current designs the German influence is still strongly evident. Since the war there have been outbreaks of activity in Switzerland (W.L.M.I., Moswey), Canada (where Shenstone and Czerwinski have inspired designs at Toronto) and in the United States. The total effort has not added up to that in pre-war Germany.

This paper first summarises briefly the characteristics and performance of two pre-war and two post-war designs. The pre-war examples are outstanding German designs which illustrate the extent to which special developments were pursued in that country. They are not representative of the main stream of development, which is probably epitomised by the work of Hans Jacobs and the D.F.S.; this design school has been admirably illustrated by B. S. Shenstone's definitive study of the Reiher development(1). The examples considered here indicate the talent which was devoted to sailplane design at that time; the first (D.30) was designed and built by the students of a Technical Institute; the second (Horten IV) was the penultimate in a line of development followed by an individualistic pair of brothers with original ideas who devoted (and are still devoting) themselves to sailplane design. Plenty of other examples could have been quoted from the products of Technical Institutes and Universities throughout Germany, reflecting the opportunity and encouragement given to the youth of the country to learn flying and the principles of design through the gliding movement. Of the two post-war examples considered, the first is an outstanding American design notable for its aerodynamic refinement, and the second the British Gliding Association prize-winning two-seater which incorporates some radical departures from conventional design practice.

Comparison of the pre- and post-war designs shows an important improvement in potential performance through attention to basic design and detail finish and a new, but as yet unproved, approach to the constructional problem. Insufficient has been published on the American design to enable a detailed comparison of stability and control features, but certain important changes have been made in wing and lateral control design. The B.G.A. two-seater shows some parallel trends in design for performance and stall behaviour and in addition a new approach to tail unit layout.

The second part of the paper discusses aerodynamic design features which, in the author's opinion, demand fresh appraisal in the light of knowledge gained since the best pre-war designs were conceived. In some instances improvements to be gained from a change in practice have already been indicated by research having a bearing on sailplane problems; an example of this is the application of the low-drag aerofoil. In other cases, such as the evaluation of stability and control characteristics, the use of proved theoretical methods enables the pre-war design practice to be reviewed critically.

It is concluded that a number of traditional features can be altered with advantage, including the basic aerodynamic design of the wing, the lateral controls and the tail unit.

PART I—FOUR EXAMPLES OF PRE- AND POST-WAR DESIGN

1. Darmstadt D.30(2)

History: This sailplane was designed in 1933 and built during the period 1936-38 by members of the students flying club at the Darmstadt Institute of Technology. The work was carried out under the direction of Bernhard Flinsch who, a few weeks after its first flight set a goal and return record of 190 miles by flying from Bremen to Lübeck and back. The same aircraft and pilot later won an international students soaring contest at Vienna.

Description: Figure 1 shows the general arrangement. The wing structure comprised a dural box spar with ply nose and trailing edge. The whole trailing edge was plain flapped; the outer section worked as aileron and also drooped $+34°$ as a flap; the inner section could be moved over a range $-40°$ to $+34°$ as a lift flap. Spoiler type airbrakes were fitted to the upper surface of the wing.

The outer half of the wing had dihedral variable between $+8{\cdot}5°$ and $-4{\cdot}4°$ in flight. Altogether this represents one of the most ambitious sailplane wing structures ever attempted.

The fuselage comprised a ply nacelle with a slender Electron beam carrying the tail surfaces. The canopy was jettisonable.

The tail surfaces were of conventional ply and fabric construction. Although an elevator was fitted, the

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tailplane incidence also changed when the stick was moved back and forth, being geared to move at half the rate of the elevator.

Flight handling and performance: Sixteen pilots flew this sailplane in a flight test programme designed by the D.V.L. The consensus of opinion was that it was a simple and pleasant aircraft to fly and safe in all flight conditions. Performance tests were made with automatically recording instruments.

Of particular interest are the results obtained in handling tests with various dihedral angles. Two of the standard tests (the second made at a range of flight speeds) were:—

(*a*) Reversal of 45° banked turn using co-ordinated rudder and aileron, time taken to complete the manoeuvre being observed.

(*b*) Application of full rudder for one second from initial straight flight conditions, controls then being held fixed. A record of bank angle against time was then made.

The result of test (*a*) at 56 m.p.h. showed times ranging from 6·2 seconds at −4·4° dihedral to 4·9 seconds at +8·5° dihedral.

Test (*b*) at max. L/D speed with 0 to −4·4° dihedral gave a steepening spiral, after initial roll in the opposite direction in the latter case. At +8·5° dihedral a steady banked turn (20° bank, 7 m.p.h. increase of speed) resulted. Flap or spoiler deflection and increase of initial speed gave improved spiral stability.

Control forces were all light; this is commonly the case for rudder and elevator but not for aileron. Aileron effectiveness was good in spite of the large span, as demonstrated by the results noted.

Stalling and spinning characteristics were satisfactory.

Some special wind tunnel tests were made at Braunschweig to compare the drag of the "pod and boom" type fuselage with that of the conventional (*e.g.* Weihe, D.28) type. The conclusion reached was that no drag saving resulted from the unconventional arrangement. Drag per unit frontal area was the same in both

TABLE 1

DATA FOR THE FOUR SAILPLANES DISCUSSED

Type	D.30	H.IV	R.J.5	B.G.A.
Span ft.	66	65·6	55	60
Aspect ratio	33·6	21·3	24·5	18
Taper ratio	3·9 : 1	5·5 : 1	3·5 : 1	3 : 1
Dihedral	+8·5° to −4·4°	+5°	2°	3°
Wing section Tip	N.A.C.A. 44 series Camber, 12% t/c, Gö 600 fairing	Symm. 8% t/c	63_2-615	64_1-612
Root	N.A.C.A. 24 series Camber, 14% t/c, Gö 600 fairing	Reflex 16% t/c		64_3-618
Flap	Plain flap on inner wing, also drooping ailerons	Nil	Nil	Whole T.E. deflects up or down to vary camber
Performance L/D max.	37·6	32	40·5	31·5
Speed for L/D max. (m.p.h.)	48	47	50	50
Weights Empty lb.	448	530	492	
Load lb.	227	190	178	
Gross lb.	675	720	670	1,000 approx.

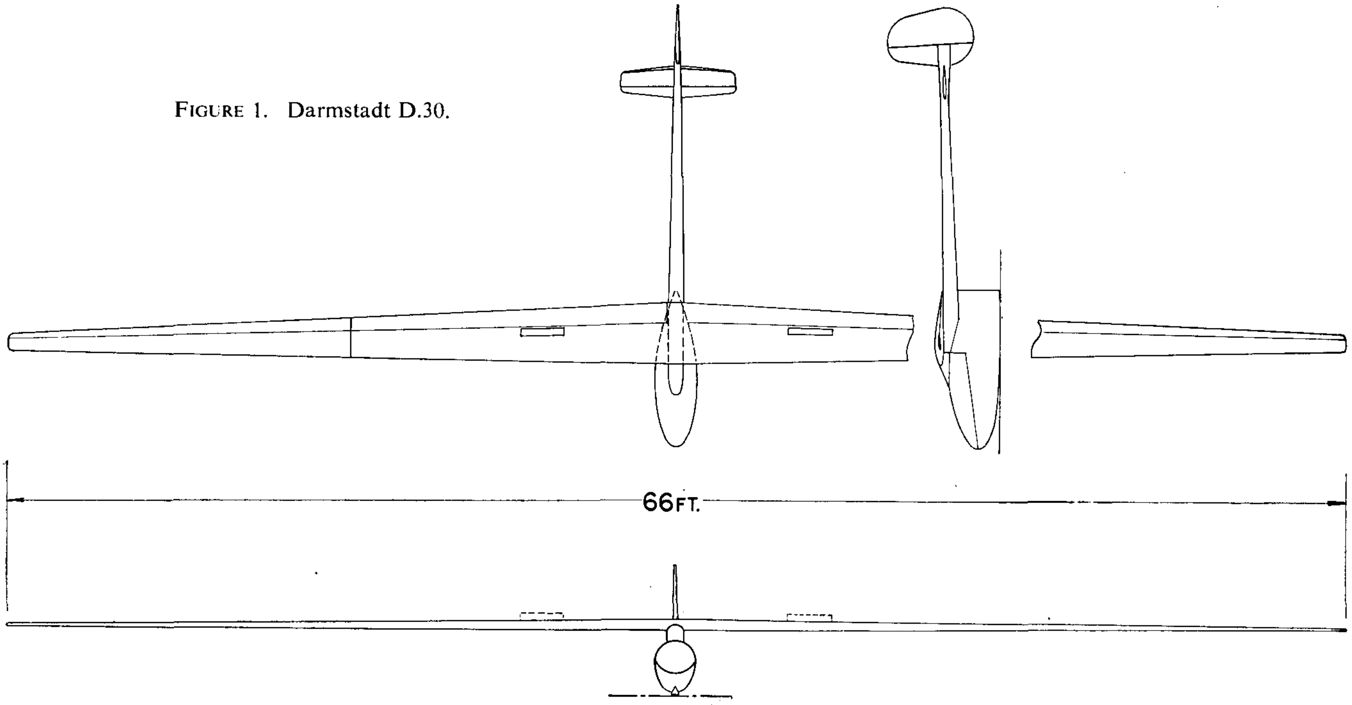


FIGURE 1. Darmstadt D.30.

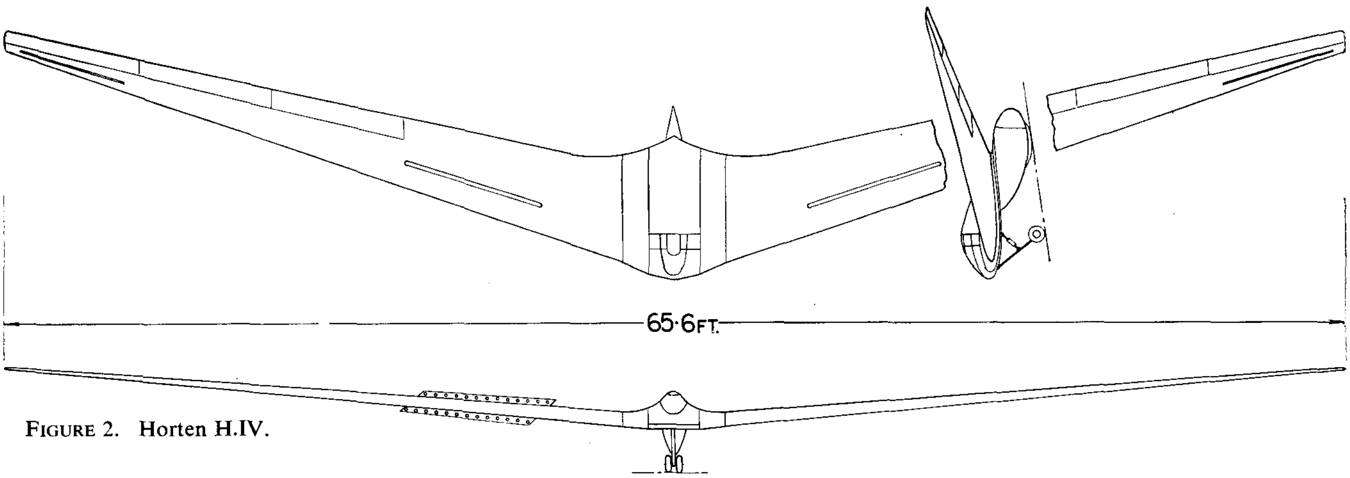


FIGURE 2. Horten H.IV.

cases, although the surface area of the D.30 fuselage was nearly 40 per cent. less.

2. Horten IV[3]

History: The design was planned during 1936 and the prototype built during late 1938 and 39. Several more were built subsequently; at the end of the war one originally built in 1942 was brought to Farnborough, repaired and flown there. Later it was acquired by the late Robert Kronfield and reconditioned. It was flown by several B.G.A. pilots before being sold to the U.S.A.

Description: Figure 2 shows the general arrangement. The centre-section (Fig. 3) with its prone position bed was built around a welded steel tube primary structure with Elektron sheet leg well and rear canopy (Fig. 4). The whole of the leading edge was covered with moulded Plexiglass. The wings were each in two sections, the main root section of conventional construction having a sheet Elektron tip. The nose wheel jettisoned automatically when the skid was retracted.

Elevator and aileron control was by three part elevons. Maximum deflections for the two functions of these control surfaces were:—

	Inner Flap	*Middle Flap*	*Outer Flap*
Aileron down	+13°	+ 9°	+16°
up	− 2°	− 7°	−28°
Elevator down	+16°	+14°	+ 2°
up	− 3°	−14°	−14°

The outer flap had a Frise nose; the inner flaps were plain.

FIGURE 4. Retractable nose skid, jettisoning nose wheel and pilot's leg well on H.IV.

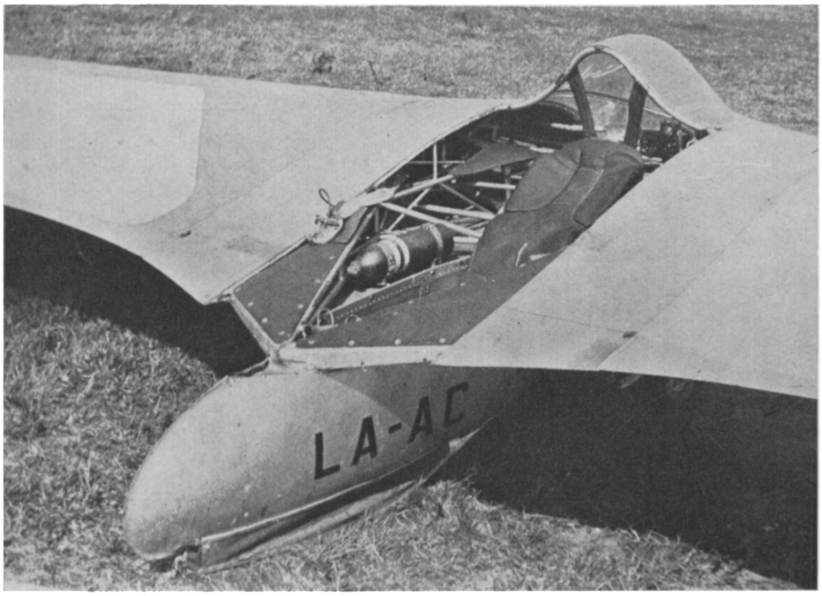


FIGURE 3. Pilot's bed on the H.IV.

Rudder control was by drag rudders (DFS dive brake type) on the upper and lower surface of the wing tips, just behind the main spar. Large dive brakes, also of DFS type, were fitted to the main wing.

Flight Handling and Performance: Flying characteristics were somewhat unconventional and it took some time for a pilot to become thoroughly accustomed to them. Low speed flight characteristics were docile and enabled the normal sailplane manoeuvre of slow speed circling to be made without trouble. At high speed in bumpy conditions, wing flexure produced a rapid pitching motion which could make conditions extremely uncomfortable, particularly on aero-tow. Directional stability was poor and the lateral oscillation poorly damped; this, combined with a rather rough rudder control proved disconcerting at first. Directional control during the rather prolonged ground run of an aero-tow was also more difficult than for conventional sailplanes.

Aileron control was good; the reversal of 45° banked turn at max. L/D speed took 5 seconds which compares well with conventional designs.

A great deal of flying was done in Germany on this type, including high altitude wave flights and thermal distance flights. The Hortens' own view was that 50 hours' experience was necessary to become used to the unconventional characteristics and be able to make the most of the potential performance.

Performance tests[2] were made to determine the sinking speeds relative to the D.30, which had previously been carefully calibrated. The results are shown in Fig. 8. In these tests the two aircraft were flown side by side at the same forward speed, and the change in relative vertical position observed after 3 minutes. These two aircraft were considered to have the best performance of any produced in Germany before the war, the Horten IV having previously proved better than the Reiher in comparative flight tests. The D.30 is clearly superior at high speeds but the Horten IV can outclimb it in slow speed circling flight in thermals, because, although its minimum sinking speed is practically the same, it occurs at 34 m.p.h. compared with the 45 m.p.h. of the D.30.

3. R.J.5

History: In 1947 Harland-Ross (a well known American sailplane designer) was commissioned by R. H. Johnson to build him an "ultimate performance sailplane." At the end of 1949 Johnson took the partly completed sailplane to the Mississipi State College to finish it. The Engineering and Industrial Research Station there realised the potential value of the aircraft for aerodynamic research and helped Johnson by providing space and technical help. Dr. August Raspet, of the Engineering and Industrial Research Section, worked with Johnson during 1950 and 1951 on a notable series of test and research flights to study and improve the performance of the aircraft. This work has been reported by Raspet[5]; to whom the present author is indebted for permission to reproduce the illustrations of aircraft and test results.

In addition to research flying, Johnson has made some fine distance and speed flights, including a record distance flight of 575 miles in August 1951[4].

Description: The feature of main interest is undoubtedly the aerodynamic form of the wing. This has 63_2-615 section throughout; the structure comprises an aluminium box spar with flush riveted sheet aluminium skin ahead of the spar, forming a D-nose torsion box. The after portion of the wing is built up from aluminium ribs with fabric covering. During the "cleaning up" process the front part of the wing was filled with pyroxilin putty and smoothed to give a waviness of less than $\pm 0{\cdot}004$ in. on a 2 in. base. Fuselage and tail surfaces are of conventional construction.

Lateral control during the early flights was by small ailerons (Fig. 5) assisted by spoilers. It was later found that the spoilers did not contribute much to control but appreciably to drag, so they were sealed up and not used. Split flaps (acting as dive and landing flap) were fitted to the bottom of the wing. These also caused a good deal of drag in the retracted position and were felt by Johnson to be of little value, so they too were fixed shut and sealed up.

Performance and Handling: The performance testing on this aircraft has been extensive and has included both wing profile drag determination by wake traverse and overall performance measurement by the rate of descent method. The overall effect of the "cleaning up" treatment, which both sealed all the leaks and produced an aerodynamically smooth surface, was to increase the maximum glide ratio from 30·3 to 40·5 (Fig. 8) and to reduce the profile drag of the clean (*i.e.* not behind the aileron) wing to a value very close to the low turbulence tunnel value for the section concerned (Fig. 9).

Stability and control and general handling have not been reported on. It would be useful to have results from a standard set of handling tests such as established by the D.V.L.[7] or contained in the British Airworthiness Requirements, Section E.

Comparative performance curves in Fig. 8 show that the R.J.5 in its final condition probably exceeds the performance of the D.30 over the whole speed range. It must be remarked, however, that the final curve for the R.J.5 was calculated by Raspet from glide tests in a less clean condition corrected to the final state using results from wake traverse tests after further smoothing. The results are therefore probably less reliable than those for the D.30.

4. B.G.A. Two-seater

History: In 1946-7 the British Gliding Association organised a design competition for a high performance two-seater. There were thirty entrants and the winner was selected by a judging committee appointed by the Association. First prize was awarded to Hugh Kendal. Shenstone has described the six "placed" designs and several others having features of interest[8].

Financial backing was obtained in 1950 by the B.G.A. from the Treasury and the Kemsley Flying Trust which enabled plans to be made for building two prototypes. By this time, Kendal had put in further work on his design and tried out some ideas on the Wanderlust

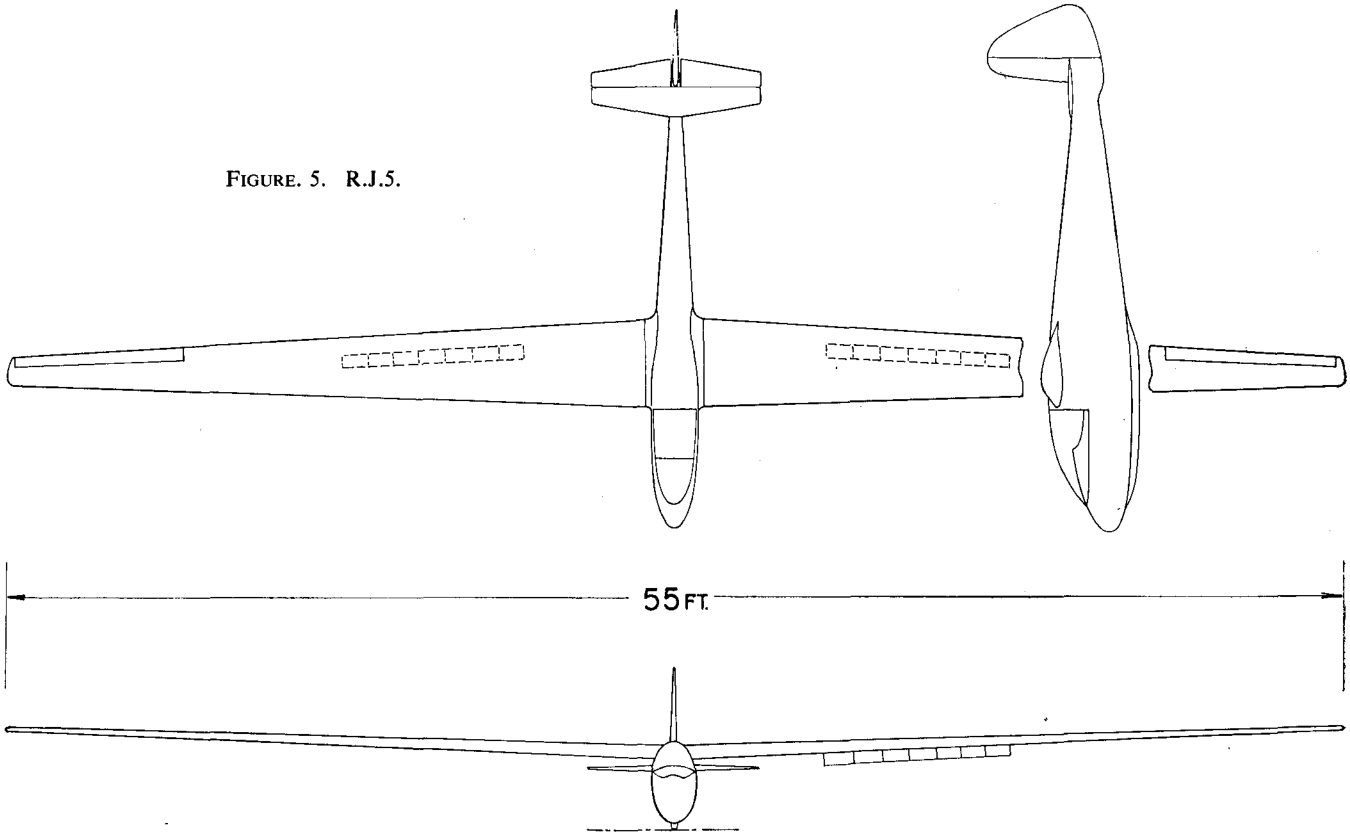


FIGURE. 5. R.J.5.

(a small single-seat sailplane which he used for experimental work). This led to a Mk. II design (Mk. I was described by Shenstone) which became the basis for the final design work. Certain aerodynamic and structural changes were made to take advantage of recently available knowledge on N.A.C.A. 6 series aerofoils and developments at R.A.E. in structural plastics. The Miles Company at Redhill were given a contract to build the prototypes with design supervision by Kendal.

Description: It was decided to build the wing structure from "Durestos," an asbestos-thermosetting plastic material. J. E. Gordon[9] has described the fabrication of structures from Durestos, using a vacuum moulding technique developed at R.A.E.; the product has the advantage of providing an aerodynamically smooth and accurate surface with relatively small labour, once the master mould has been made. Although the R.A.E. had done a great deal of pioneer work on this type of construction, the application to a sailplane presented many new problems and the decision to try the method was a bold one. At the time of writing, a complete wing has not yet been produced and a wooden wing is being built for the prototype to get it flying. Four test wings are meanwhile being built in plastic for structural tests. It was hoped that plastic construction would, when developed, lend itself to a cheap production run.

The wing is a lobster shell construction of double Durestos skins interleaved with "Dufalite" honeycomb to give stability. A few widely spaced ribs to preserve the section under load and a trailing edge closing member complete the structure. Wing root fittings are made by inserting high tensile steel "spades" between the Durestos felts before curing. The curing process bonds the fittings to the shell and appropriate local building-up of the felt thickness disperses the concentrated loads at the pick-up points into the shell. Ailerons are made from resinated fibre glass with a foamed filling.

Aerodynamic features: As in the R.J.5, N.A.C.A. 6

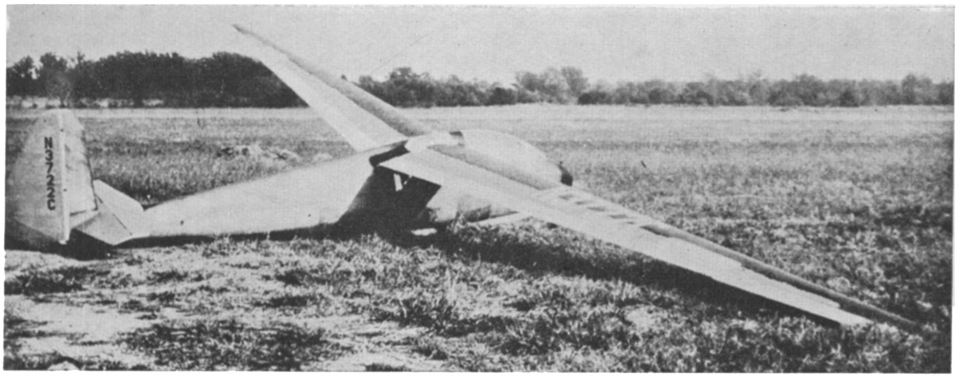
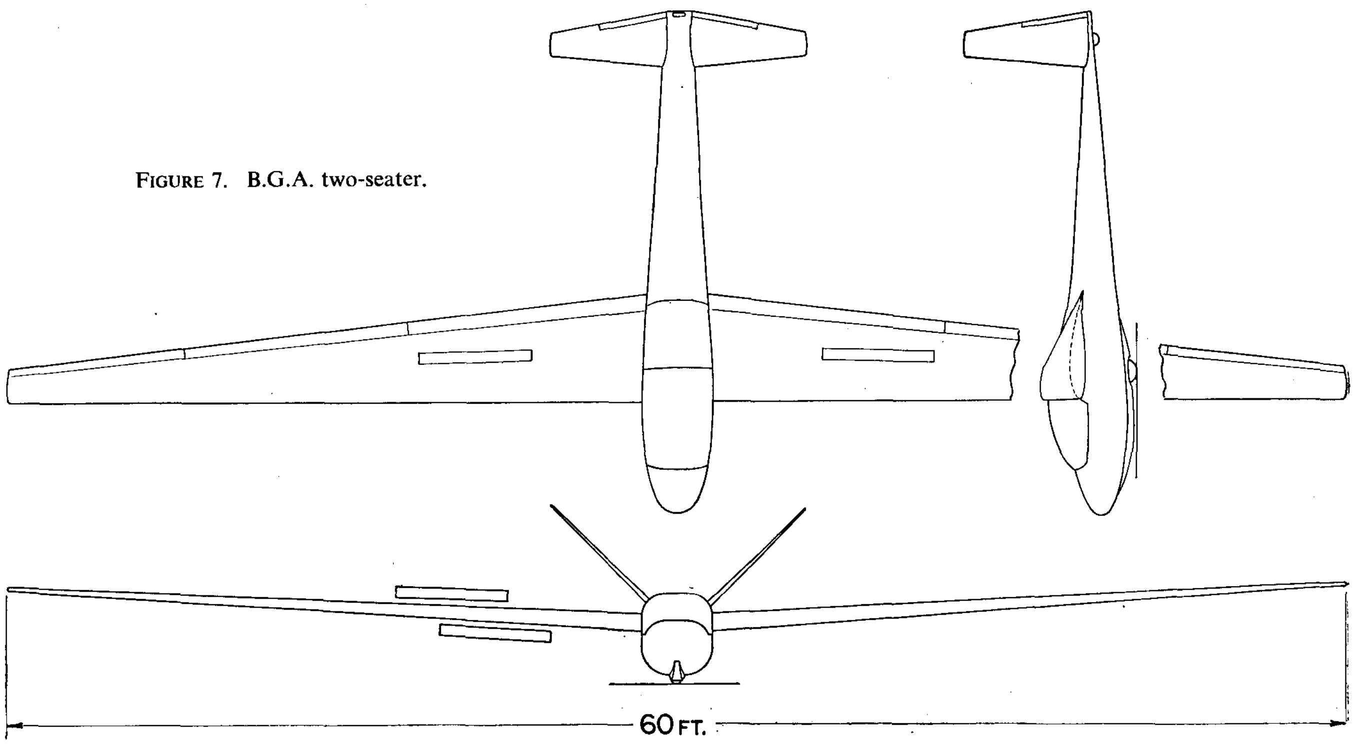


FIGURE 6. R.J.5 Sailplane.

FIGURE 7. B.G.A. two-seater.



series aerofoils have been used. The reasons for this choice are discussed in the second part of the paper; briefly, the combination of smooth surface finish and type of section is thought to give the highest attainable performance.

Ailerons are of narrow chord and extend over the full span.

The tail surfaces are all moving, with anti-balance tabs to give stick-free stability and satisfactory "feel" to the controls at the low air speeds involved. This arrangement is convenient operationally because it simplifies packing and transport and because good tail clearance is provided for operation into rough fields. It also simplifies construction and provides a low drag tail unit with good control power. Estimated performance, assuming that the laminar flow sections perform as well as they do on the R.J.5, is shown in Fig. 8.

Comments on Design Progress

In terms of proved progress, the important advance which can be demonstrated in the designs compared is the superior aerodynamic form of the R.J.5 wing, leading to a higher proportion of laminar flow and better performance for given dimensions. The same basic design trend is apparent in the B.G.A. 2-seater, although the results have not yet been proved in flight. It appears that this advance has more important results than the adoption of a tailless layout, which can only be justified if much improved performance is achieved.

Lateral control design shows evidence of new thinking along two different lines. The H.IV, for all its unconventional layout, shows proportioning of lateral controls—the high tip chord ratio and high span ratio—which is typical of pre-war designs: the D.30 shows ailerons of smaller chord ratio but still covering half the span. In both cases aileron area is nearly 10 per cent. of the wing area. The R.J.5 has half this area ratio but approximately the same mean chord ratio as the D.30: the B.G.A. 2-seater, on the other hand, has nearly double the area ratio but a smaller chord ratio of mean value 19 per cent. Mean chord ratio is an important parameter and the trend to smaller values,

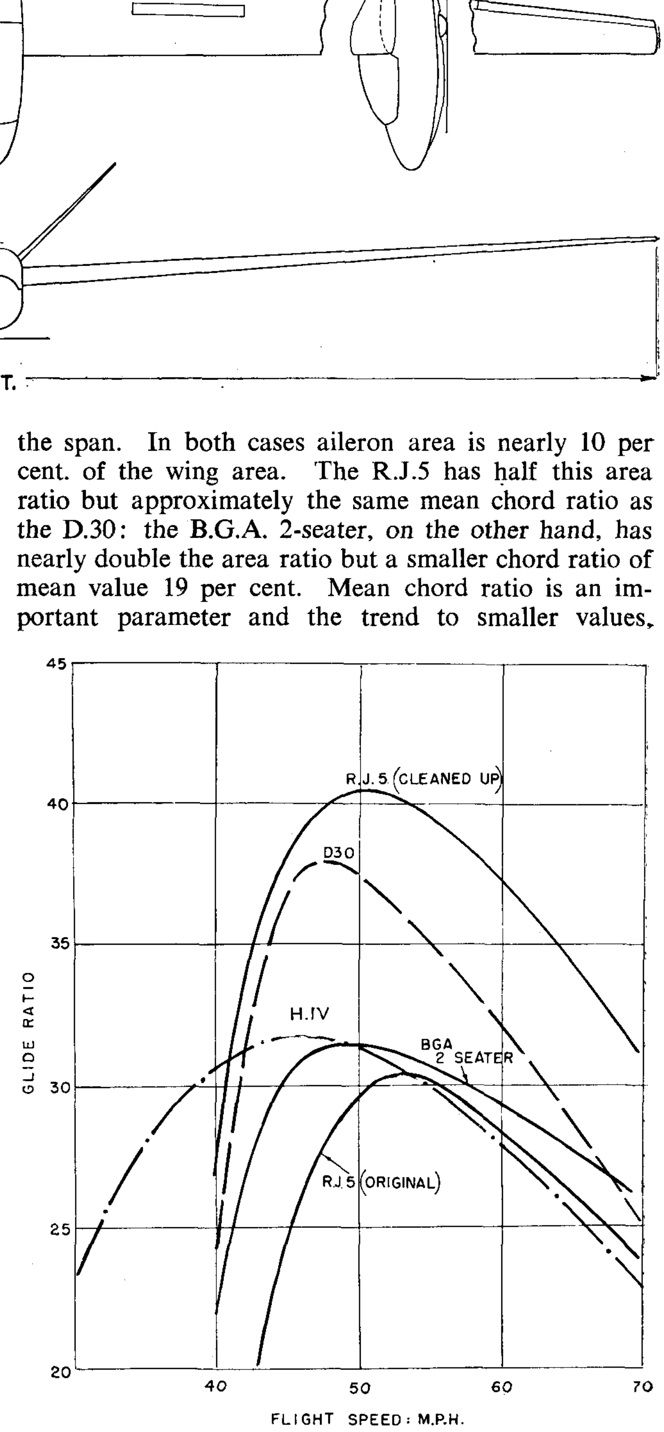


FIGURE 8. Glide ratio comparison.

particularly noticeable on the B.G.A. design, is good if coupled with sufficient torsional stiffness of the wing; the D.30 was already anticipating this trend in 1936. A full evaluation of design merit calls for a more detailed analysis, which is made in Part Two of the paper.

The aerodynamic design of the wings shows an interesting variety. The Horten wing has a special longitudinal trim function which has led to employment of high twist: the D.30 has no aerodynamic washout but an increase in incidence at mid semi-span to give elliptic load distribution, and more highly cambered sections at the tip than the root to prevent early tip stalling. These features on the D.30 were radical departures from traditional pre-war design which tended to have symmetrical tip sections with a high degree of wash-out (of the order of 10° of aerodynamic twist in many cases) to avoid early tip stalling. Both the R.J.5 and B.G.A. 2-seater follow the more rational design methods of the D.30 which was an advanced design in this respect also.

The tail surface design proposed for the B.G.A. two-seater represents a useful development giving good control power, stick free stability and a number of useful practical advantages. No change from pre-war conventional design has occurred in the R.J.5, nor indeed in other post-war sailplanes of which the author is aware.

Adequate dive brakes are a vital feature for high performance sailplanes but there has not been any design development since the merits of the D.F.S. type were established: this type seems to meet all requirements and now appears on most sailplanes. Oddly enough the D.30 has an apparently inferior upper surface spoiler, while the R.J.5 has no brakes at all.

In comparing the four structural designs, it appears that the D.30 presented the most difficult structural problem because of the high aspect ratio, thin wing and variable dihedral. The resulting design not only solved these problems but gave a very low structure weight (30 per cent. lower than average design[10]); the H.IV and R.J.5 are both near to mean design in structure weight while the unconventional B.G.A. design has not yet a sufficiently firmly established weight on which to comment. The new problem for the structural designer since the war has been the provision of a sufficiently accurate and smooth surface to support laminar flow over the wings. The R.J.5's metal wing gave the required firm surface far enough back from the leading edge, but needed a great deal of filling and smoothing; the more radical solution attempted in the B.G.A. design should avoid this difficulty but even when the technical difficulties of manufacture are overcome, may prove expensive for small production runs. It is quite possible that the best solution has yet to be found and may prove to be a wooden structure designed to meet the new requirement for surface finish, in addition to the older strength and stiffness requirements which it has met successfully in the past.

PART II—DISCUSSION OF AERODYNAMIC DESIGN

The four designs just considered have exhibited a variety of approaches to basic aerodynamic design. It is natural, having seen such variety, to enquire whether any objective assessment of merit can be made, and how important is the influence on the overall effectiveness of the machine. In the following discussion some important aspects of design for performance, stability and control are considered: traditional design and some of the new trends apparent in the R.J.5 and B.G.A. 2-seater are compared and an evaluation attempted.

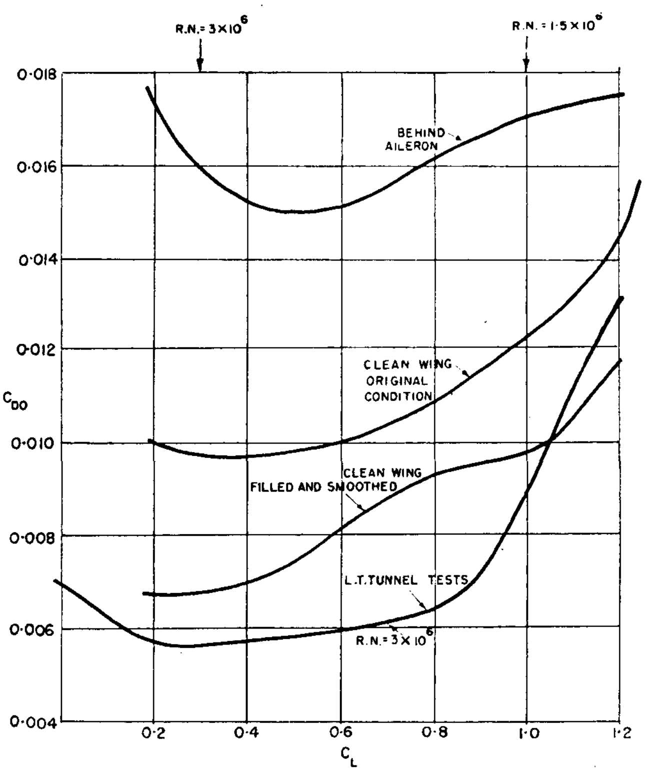


FIGURE 9. Flight measurements of section drag N.A.C.A. 63_2-615 on the R.J.5. sailplane.

Overall Performance

Since the raison d'etre of the sailplane is to perform well as a soaring machine it is appropriate to study firstly the flight performance in terms of glide ratio and its relationship to results obtained in soaring conditions. The basic gliding performance of the four designs discussed has been referred to: of these sailplanes the D.30, Horten IV and R.J.5 may be compared directly because they were intended to do the same job. It seems that the R.J.5 has slightly bettered the D.30 performance and has achieved this result with a more compact shape (11 ft. less span). The importance of attention to detail finishing of the wing is obvious, for, before this attention was given the R.J.5's performance (Fig. 8) was slightly below average for a sailplane of its dimensions.

The tailless H.IV does not compare very well with the D.30 or R.J.5 at high speed but it has, as previously remarked, good characteristics at low speed. Reference 10 discusses relative performance analytically and concludes that the tailless configuration sacrifices rather more in wing efficiency, through compromises resulting from control function, than it gains from suppression of fuselage and tail unit drag.

The B.G.A. two-seater performance curve is not of great interest as it has yet to be flight proved and, being a two-seater, it is being considered out of its class. If expectations are realised, it will be an outstanding design.

The value of good performance in terms of glide ratio lies in the ability it gives to cover distance across country after gaining height by the use of thermal up-currents. Reference 10 suggested a criterion of average cruising speed for a range of thermal strengths to give a compact statement of performance merit. It is assumed in working out this criterion that the climbing manoeuvre is performed with a standard radius of turn (200 ft.) which ensures the sailplane keeping within the limits of the average diameter thermal, and that the cruising speed between thermals is controlled at an optimum speed determined by the strength of the up-currents being encountered.

Johnson's record distance flight[4] in the "cleaned up" R.J.5 has been analysed in Ref. 6, where the thermal strengths encountered throughout the flight, inter-thermal speeds and wind strengths are set out. This information enables the achieved performance to be compared with the criterion (representing ideal operation) and the value of flying technique, thermal strength and aerodynamic cleanness to be estimated. From the description of the flight Johnson was able to stay up for 8·83 hours with a mean tailwind component of 25 m.p.h. and a pattern of thermal strengths represented by the cumulative frequency diagram of Fig. 10 (the strengths plotted were calculated from rates of climb recorded on the barograph, corrected for the sinking speed of the sailplane in circling flight).

To illustrate the importance of a few of the fundamental factors in a high performance flight, Johnson's actual performance has been compared with the "ideal" and an efficiency factor determined; assuming the same efficiency the following variation in conditions has been supposed: —

(*a*) Cruise control employed by Johnson
(*b*) Flight between thermals at max. L/D ratio
(*c*) Weaker thermal conditions.

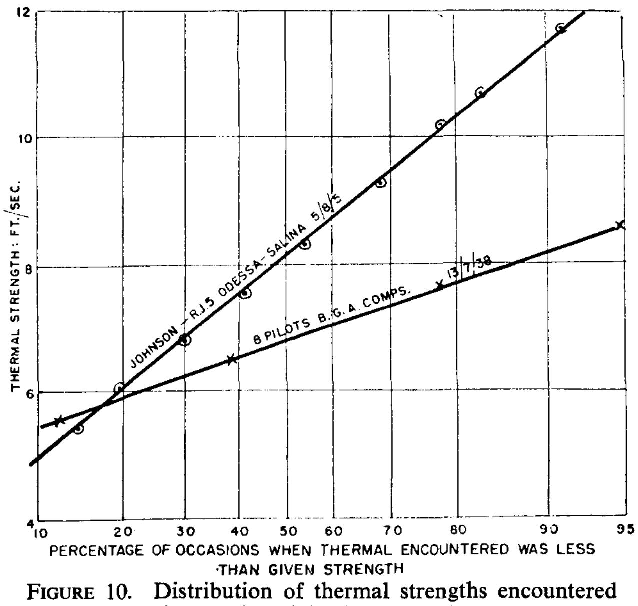


FIGURE 10. Distribution of thermal strengths encountered during soaring flights in U.S. and U.K.

For each of these conditions the performance has been considered with: —

(1) R.J.5 in the "cleaned up" condition
(2) R.J.5 in original condition

as shown in Fig. 8.

Johnson's description of his flight shows that he controlled his inter-thermal speed very closely to the theoretical ideal and his achieved performance amounts to 92 per cent. of the ideal. Since the theoretical average speeds make no allowance for down currents at any time during the flight it is to be expected that some shortfall would occur. Condition (*c*) has been taken from barograph records returned by 8 pilots during the British Gliding Association Competitions in 1938, similarly corrected for sailplane sinking speed; the cumulative frequency curve for these data is given in Fig. 10 and probably represents typical English conditions. The R.J.5 in condition (2) had a rather poorer performance than the average sailplane of its size and shape[10] but in condition (1) was appreciably better.

Table II sets out the performance, in terms of distance covered over the ground, for the six cases.

Thus

(*i*) If his sailplane had only average performance, he would have covered 11 per cent. less distance (18 per cent. less in still air).
(*ii*) Had his cruise control been "max. L/D" instead of optimum, he would have covered 16 per cent. less distance.
(*iii*) In the assumed weaker thermal conditions he would have covered 6 per cent. less distance.

The effect of the sailplane's performance on distance covered is therefore very appreciable and, as a percentage, amounts to about two-thirds of the percentage improvement in glide ratio. It is even more important to achieve optimum operational technique.

The value of aerodynamic shape and glide ratio performance can clearly have a decisive effect in competition flying, other things being equal, and the importance of the R.J.5 development lies in the appreciable advance in design for performance which it has made while keeping to convenient dimensions. For record breaking purposes a design of the dimensions of the D.30 could obviously be built with further performance improvement, but at considerable cost. Experience gained with the R.J.5 has focused attention on the value of good wing and surface finish and good choice of section, for it is to these features that the high performance of this sailplane is due.

Choice of Wing Section

When care of the kind taken with the R.J.5 is expended, it seems possible to equal the results obtained in a low turbulence wind tunnel and an examination of these results therefore becomes of value in determining the basic limitations of various types of wing section. The problem is less simple than for large fast aircraft because sailplane wings operate at Reynolds number and lift coefficients (C_L) which make the phenomenon of laminar separation of primary importance in determining suitability. Although theoretical studies have given insight into boundary layer behaviour in these conditions, they are not powerful enough to enable a determination of the right shape and selection has to be made primarily on the basis of test results. There have been relatively little data until recently on which to base a selection[11].

Briefly, the problem is to get low drag over the required working range of lift coefficient, which with high aspect ratio extends to high values (if flow breakdown could be prevented a lift coefficient of around 2 would be useful). Without boundary layer suction, however, it is difficult to retain the desired characteristics much above a lift coefficient of one.

In the absence of a boundary layer separation problem, the optimum aerofoil would incorporate variable camber (by flap or otherwise) and a section with far back location of designed minimum pressure point. Satisfactory performance has been demonstrated in a wind tunnel at large Reynolds number with such a section designed to give a "roof top" pressure distribution at high lift coefficient and fitted with a flap which, by negative deflection, could extend the low drag range to zero lift coefficient. At sailplane Reynolds numbers there is a limit to which high camber (high design lift coefficient) and far back design minimum pressure point (determining the potential laminar flow region) can be pursued.

The farther back the minimum pressure point on the aerofoil moves, the more severe the pressure recovery has to be towards the trailing edge. It has been found that the laminar boundary layer separates (leaving approximately tangentially to surface) after a small pressure recovery, becomes unstable, suffers transition to turbulence and reattaches after a separation "bubble" if the local curvature and the size of the bubble are not too large. There is evidence that the R.N. of the "bubble" formed near leading edges is always about 50,000 (Doenhoff's hypothesis) so that for decreasing aerofoil R.N. the bubble gets relatively larger and predisposes to laminar separation, or, even if laminar separation does not occur, the thickness of the turbulent layer formed after reattachment becomes thicker and the drag becomes larger. As the design minimum pressure point moves aft, there is, therefore, a contest between the drag saving due to increased areas of laminar flow and the drag increase due to increasing thickness of turbulent layer, or the complete separation of the laminar layer.

Figure 11 shows low turbulence wind tunnel (L.T.T.) test data for 15 per cent. thick 6 series aerofoils of design lift coefficient 0·4. This illustrates the effect of progressive rearward movement of the design minimum pressure point at a Reynolds number appropriate to wing root conditions on the B.G.A. 2-seater at a given C_L. Note that since climbing and gliding times are of the same order in thermal flying, drag increments at high lift coefficients (on climb) have a significant effect on overall performance, the more so since once the low drag is lost, the drag increase is rapid.

The behaviour of 15 to 18 per cent. sections at design lift coefficient 0·6 are not available for the same range of minimum pressure points and Reynolds number, but extrapolation of test points suggests that the curves are of the same shape, but with the drag rise occurring as a lift coefficient about 0·2 higher.

TABLE II

Condition	Distance covered in 8·83 hr. flight with 25 m.p.h. tail wind (statute miles)		
	Optimum cruise control Strong thermal	*Max. L/D cruise control Strong thermal*	*Optimum cruise control Weak thermal*
Original R.J.5	510	420	480
"Cleaned up" R.J.5	575	480	540

Taken by and large, a design minimum pressure location at 40 per cent. chord seems a good compromise —it loses at low lift coefficient compared with farther aft locations but retains its performance at high lift coefficient (best glide ratio and minimum sinking speed condition) in a markedly better fashion.

Figure 12 compares the performance (on the basis of Low Turbulence Tunnel tests) of three types of section which have been, or will be, flown on sailplanes. Six series sections show better results than the older N.A.C.A. types over practically the whole range of lift coefficients—particularly in the case of 18 per cent. thick sections. Indeed the older type sections are unattractive at that thickness, whereas the new ones offer almost no disadvantage at 18 per cent. compared with, say, 15 per cent. thickness. Note that a 60 per cent. minimum pressure aerofoil will have suffered a catastrophic drag rise at a lift coefficient of 0·8 and give substantially worse results; the 6 series sections shown represent near optimum design lift coefficient and minimum pressure locations. The difficulty of getting tip sections to operate efficiently is illustrated by the upward slope of the profile drag curve with decreasing Reynolds number.

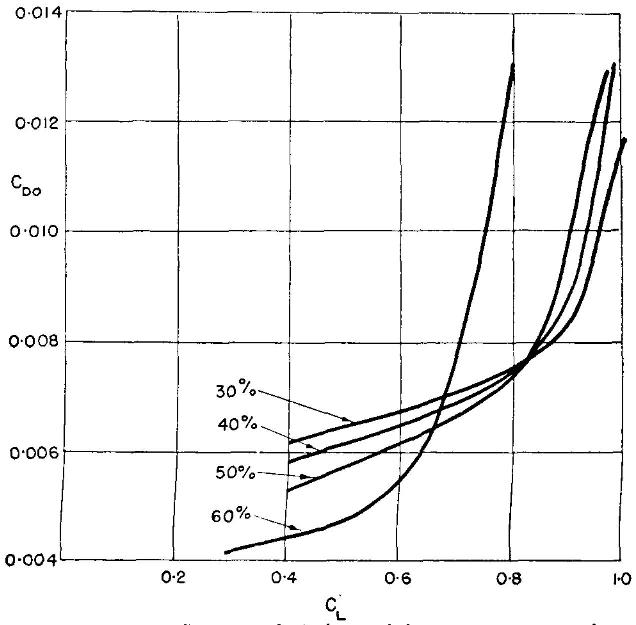


FIGURE 11. Influence of design minimum pressure point location on profile drag at sailplane flight Reynolds numbers (15 per cent. t/c design C_L 0·4).

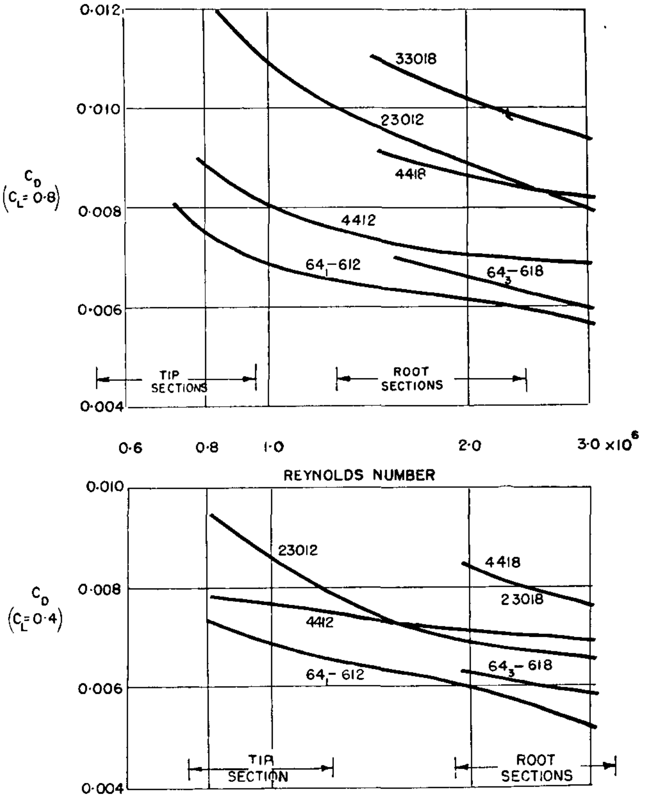


FIGURE 12. Effect of Reynolds number on the profile drag of several sections.

Low or zero cambered tips are unable to approach even the performance shown for the 23012 sections and if used have to be combined with high aerodynamic twist to prevent tip stalling. This has a bad effect on high speed performance and introduces awkward stressing cases at high speed and at the negative points of the flight envelope. The sailplane designers' habit of using symmetrical sections is inherited from the pre-war German school where the combination of symmetrical tip, high washout and high percentage chord aileron was found empirically to give satisfactory lateral control. This problem will be discussed later; it may be remarked here that the 64_1-612 section has a much better performance at low Reynolds number and high lift coefficient than either 23012 or symmetrical sections.

The wind tunnel evidence, therefore, gives some lead to the problem of section selection, but can this performance be reproduced in flight? Raspet has gone some way towards answering this question by wake traverses on the R.J.5 (Fig. 9). It seems that with rather more attention to profile accuracy and finish than is usual on a sailplane wing, the low turbulence tunnel results can be approached closely. Had tunnel test data been available for Reynolds number of $1\frac{1}{2}$ million, the agreement between flight and tunnel at high lift coefficient would probably have been even better.

Behaviour at the Stall

It is important for a sailplane wing to be designed to give good control at the stall and freedom from vicious wing dropping. Good damping in roll has, therefore, to be retained up to the commencement of the stall. Pre-war sailplane tradition was to use symmetrical tip sections with sufficient aerodynamic washout to avoid early tip stalling. Research programmes at R.A.E. and N.A.C.A. have, however, shown that, by choosing a section with flat topped lift coefficient—incidence characteristics and designing for the stalling incidence to be reached first locally in the inner third of the span, the desired characteristic can be ensured, provided the wing is not swept back. Fig. 13 gives data on a wing designed for the B.G.A. two-seater and shows the calculated lift distribution at the stall and also at lift coefficient for best glide ratio. Fig. 14 shows the corresponding section lift-incidence data taken from low turbulence tunnel tests at the appropriate Reynolds number. Two wings with similar plan form and twist have been investigated, using the same tip section (64_1-612) but different root sections (64_3-618 and 66_3-618). The section with the 60 per cent. design minimum pressure point gives better performance at high speed, but suffers from an early drag rise which is accompanied by a decrease in slope of the lift coefficient-incidence curve (Fig. 14). The effect of this on span loading at the stall is marked and it will be seen that whereas the 64_3-618 root section gives an ideal load distributed with 3° twist, the 66_3-618 section results in a high local lift coefficient towards the tip, which is undesirable, and an increase in twist, probably to 6° would be required to give equally good results. This amount of twist is bad at high speed.

The shape of the lift coefficient-incidence curves is

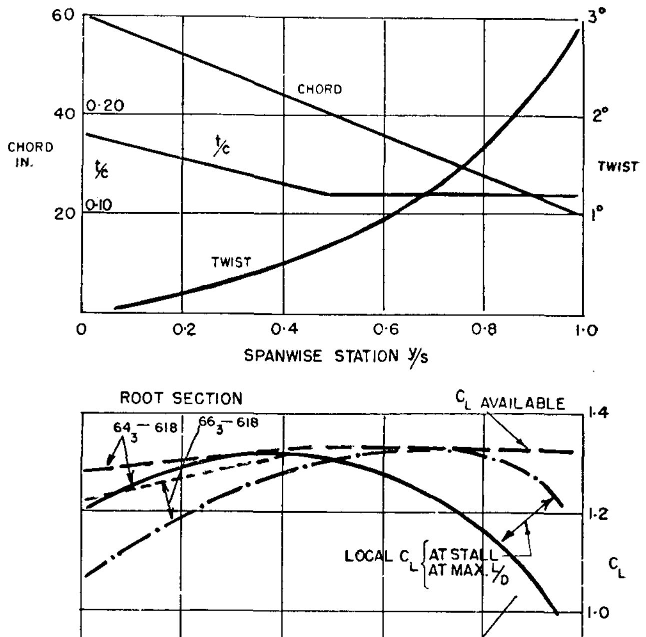


FIGURE 13. Load grading at the stall for two wings for B.G.A. two-seater.

very satisfactory and indicates a gentle stall without sudden loss of lift. This type of stall is usually associated with flow separation spreading gradually forward from the trailing edge. In the load grading curves it will be seen that the margin between local lift coefficient and lift coefficient available towards the tip (64_3-618 root section) is sufficient to give reasonable lateral control and freedom from wing dropping at the stall. It is also desirable to avoid (as in this case) reaching local stall incidence at the wing root itself, as this might make the flow at the intersection with the fuselage unduly sensitive.

The difference between the load grading for L/D_{max} and the stall shows how important the effect of non-linear incidence curves can be in determining stall characteristics.

The importance of a high value for available lift coefficient at the wing tip is obvious in designing for good stalling characteristics. It is also important in enabling an aerodynamically efficient wing to be built for max. L/D or minimum sinking speed conditions. A symmetrical tip with high twist is bad from this point of view as it gives low tip loading and high effective aerodynamic taper and induced drag.

It appears that modern methods of load grading analysis and tip section selection can lead both to improved performance and behaviour at the stall, at the same time avoiding some of the structural problems associated with more traditional forms. The more highly cambered tips lead to greater upfloating tendency of the ailerons and wing torsional stiffness problems; the former will not be serious with small chord ratio ailerons and the latter can be designed for.

Design for Lateral Control

To be considered good, ailerons should be able to reverse a 45° banked turn at the flying speed for minimum rate of sink in about 5 seconds, using rudder to co-ordinate the turn. It is, therefore, advisable to design for this and to ensure that rudder power is ample to deal with the initial adverse yaw. Sudden aileron rolls should also produce response in roll without unpleasantly large directional disturbance; this calls for adequate fin area and ailerons giving low adverse yawing moments.

Ailerons can be given a variety of yawing moment characteristics by the provision of Frise nose, geared spoilers or differential; wing twist also has a powerful effect. Since the bulk of the adverse yawing moment with well designed ailerons originates from the distribution of induced drag during rolling acceleration, there is merit in avoiding drag devices which not only provide yaw during acceleration, but throughout the roll.

Approximate response calculations on the B.G.A. two-seater (Fig. 7) give the values shown in Table III for initial yaw following abruptly applied full aileron at minimum sinking speed; taking two values for tail volume and the derivative n_v.

At high speed, the yaw is much less and does not have to be considered as a handling criterion.

Systematic D.V.L. tests on a large number of sailplanes by a large number of pilots have led to the conclusion that a value of 10° for initial yaw is acceptable and 5° good, on general handling evaluation; test conditions were as for the calculated results on the B.G.A. two-seater. It may be concluded, therefore, that the higher value of n_v combined with differential ailerons and the 3° washout proposed for other reasons, could be expected to give very satisfactory handling characteristics.

So far as control performance is concerned, ailerons have commonly been the most unsatisfactory control on sailplanes, because they have given inadequate rate of roll and have tended to be disproportionately heavy. Wing twist and control circuit stretch have had a lot to do with this and have produced some queer anomalies; it is likely that this explains the cases reported by Raspet, where better roll performance was obtained on a Pratt-Read and a T.G.3A glider by locking the

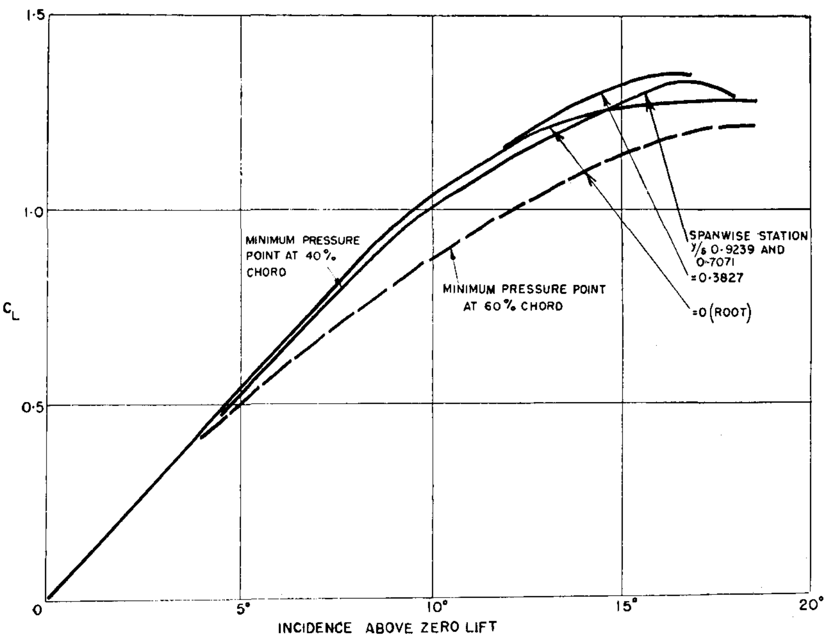


FIGURE 14. C_L *versus* incidence data for four points on B.G.A. two-seater wing at stall Reynolds number showing effect of root section change.

TABLE III

EFFECT OF AILERON AND n_v ON YAW DUE TO AILERON APPLICATION

*Aileron**	$n_v = 0{\cdot}0175$	$n_v = 0{\cdot}040$
Equal deflection	28°	12°
2:1 Differential	23°	10°
Differential and 3° Wing Twist	16°	7°

* 40° total deflection and plain sealed aileron in all cases

inboard half of the aileron in the neutral position and using only the outer half of the original area for control.

A general investigation by N.A.C.A. has shown that the maximum rolling power for a given stick force with plain ailerons is obtained by using a large span ratio and narrow chord. A comparison has therefore been made for the B.G.A. two-seater between conventional sailplane ailerons (50 per cent. span ratio, 50 per cent. chord ratio at the wing tip, constant chord) and narrow chord ailerons (full span, 25 per cent. chord ratio at the wing tip, constant chord). A typically low value for aileron circuit stiffness has been assumed, the stick deflection per pound of force at the top of the stick, with aileron locked at the wing, being taken at 10 lb./inch in both cases; aileron reversal has been assumed at 140 m.p.h. in both cases. Fig. 15 shows the roll performance with these two ailerons in terms of time to roll +45° to −45°, with co-ordinated rudder, at various flight speeds. Curves are given for the cases of full stick deflection and a maximum of 10 lb. stick force. The superiority of the longer narrow aileron over conventional design is evident; further, their calculated performance comes well inside the criterion value of 5 seconds for reversal of a 45° bank, indicating very satisfactory lateral manoeuvrability.

In assessing sailplane ailerons in this manner there is an element of uncertainty due to the unknown effect of the low Reynolds number on flap hinge moments and lift increments. This is minimised if the margin previously discussed is left between available and required lift coefficient at the wing tip.

The results so far discussed have been with non-differential ailerons. Differential can be used as a device for giving a measure of aileron balance. Fig. 16 (which will be discussed more fully later) shows the effect of two possible differential systems on stick forces at minimum sinking speed conditions. With this degree of differential (which is desirable to reduce aileron yaw) stick forces are quite light enough and it is unnecessary to employ set back hinges or Frise nose ailerons to get any higher degree of balance; these types of balance are undesirable on a sailplane because they prevent satisfactory sealing and give an unacceptable drag increment.

It may be concluded that the aerodynamic design of ailerons does not present a serious problem with the recommended types of wing section (which give small trailing edge angles) if low chord ratios and differential gearing are used. Steps have still to be taken to ensure adequate circuit stiffness and freedom from friction. Again, a significant departure from conventional design is suggested by analysis in the light of more recent knowledge.

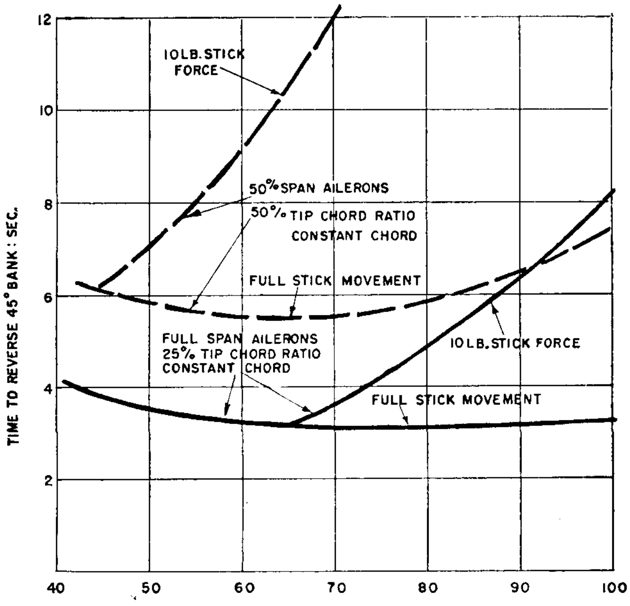


FIGURE 15. Effect of aileron plan form on rolling performance (equal aileron area, ±20° deflection range in both cases).

Lateral Stability

It is desirable to have good damping of the lateral oscillatory mode. This is fairly easy to ensure by providing sufficient fin area in relation to dihedral but Table IV shows that it has not always been done.

German development has been in the direction of providing increased n_v, leading to sailplanes with such excellent characteristics as the Olympia. Since negligible performance sacrifice is involved it appears sound design practice and n_v numerically at least half l_v seems advisable.

On tailless aircraft, design for oscillatory damping may be a problem. On the H.IV the lateral oscillation is virtually undamped at high forward speed (57 sec. to half amplitude at $C_L = 0{\cdot}2$) but due to a 20-fold increase in n_v at $C_L = 1{\cdot}0$ the damping is good in this condition.

On conventional layouts, the use of high chord ratio rudder, with large negative values of b_1 can produce a strong tendency for the rudder to trail in a sideslip. The movement allowed by stretch and slack in the control circuit can then appreciably reduce the effective value of n_v and hence the effectiveness of an apparently adequate tail area. This in turn may lead to inadequate oscillatory damping. On the B.G.A. 2-seater, the dual purpose tail surfaces have been designed with virtually zero b_2 but fairly large (and adjustable) b_1, which should eliminate this trouble without spoiling the feel of the control.

Spiral stability in a conventional sailplane depends virtually on keeping $l_v > l_r$, since n_r tends to be slightly larger than n_v. With fixed controls it is almost impossible to provide spiral stability because of the large size of l_r ($\simeq C_L/4$ for elliptical load distribution). The helpful effect due to incidence distribution over the span in a descending spiral is too small to assist appreciably. In fact, ailerons are not fixed and this can modify results profoundly. Consider again the B.G.A. 2-seater

TABLE IV

EFFECT OF n_v AND l_v ON LATERAL STABILITY AND HANDLING, FROM FLIGHT EVALUATIONS

Type		*B.G.A 2-str.*	*Olympia*	*Weihe*	*Bussard*	*Kranich*	*Mü* 13
$-l_v$	$C_L=0$	0·088	0·087	0·079	0·048	0·067	0·082
	$C_L=1$	0·078	0·078	0·069	0·038	0·083	0·074
n_v	$C_L=0$	0·040	0·052	0·033	0·022	0·028	0·021
	$C_L=1$					0·033	
Lateral stability and handling		—	Good	Good	Poor oscillatory damping	Good	Marked adverse yaw in aileron rolls

ailerons, assuming them for the moment to be frictionless. The trailing angle they will take up if the stick is free will be influenced by the change of speed from tip to tip in a turn, on the value of b_0 (upfloat tendency) for the ailerons and on the exact nature of the differential gearing. The trailing angle, if not neutral, will produce an apparent change in l_r, due to freeing the stick; indeed, as Table V shows, a very small change in angle will alter l_r considerably.

For the pilots' point of view a more apparent index of satisfactory spiral behaviour is the stick force in a steady 30° banked turn. This manoeuvre should be performed, ideally, with zero aileron force and rudder to hold the turn or with rudder and aileron both in a sense to hold the turn.

Calculation for the B.G.A. 2-seater is shown in Table VI.

For all practical purposes the differential gearing gives the desired result. Control friction would mask the residual force of 0·1 lb., whereas the force of 0·7 lb. associated with symmetrical gearing, would undoubtedly be noticed and be rather irritating. Although detail design for spiral stability has not been usual in the past, the desired results have on occasions been achieved by accident. It seems worth while to pay some attention to this aspect of design, since the circling manoeuvre figures so largely in the function of a sailplane. Oscillatory stability is easy to obtain and there is no excuse nowadays for any deficiency in this respect.

Longitudinal Control and Stability

This aspect of the aerodynamic design of a sailplane is straightforward and should present no problems, since there is no slipstream to complicate matters and very little change in configuration throughout the flight. The most common fault has probably been the absence of stick free stability—which is not serious but unnecessary

TABLE V

INFLUENCE OF STICK FREE AILERON CHARACTERISTICS ON SPIRAL STABILITY

Condition	l_r	*Spiral Stability*
Stick fixed	0·20	Unstable
Symmetrical gearing—stick free	0·12	Neutral
Differential gearing No. 2 (Fig. 16)—stick free	0·09	Stable

TABLE VI

AILERON STICK FORCES IN A 30° CORRECTLY BANKED TURN

Ailerons	*Stick force*
Symmetrical gearing	0·7 lb. holding off bank
Differential gearing No. 2	0·1 lb.

and irritating. The fondness for high chord ratio controls previously noted is responsible for accentuating this tendency, already present in plain unbalanced elevators.

A number of conventional solutions to this problem are available. An original method proposed for the B.G.A. two-seater is worth mentioning, however, because this offers a number of other advantages when used on a sailplane. The proposal is an all-moving V-tail performing rudder and elevator function. This has the advantages of simplicity, low drag and high control power, but in the past examples of all-moving tails have failed to give adequate stick free stability or manoeuvring stick loads. To overcome this, an unbalancing tab is used, producing a large (but adjustable) negative b_2, the control surface being pivoted near to its aerodynamic centre to give zero (or slightly positive) b_1 and thus no change (or slight stabilisation) on freeing the stick.

There are certain practical operating advantages with a V-tail. The dismantled sailplane is very compact and the tail clearance is good for landing in long grass and bushes.

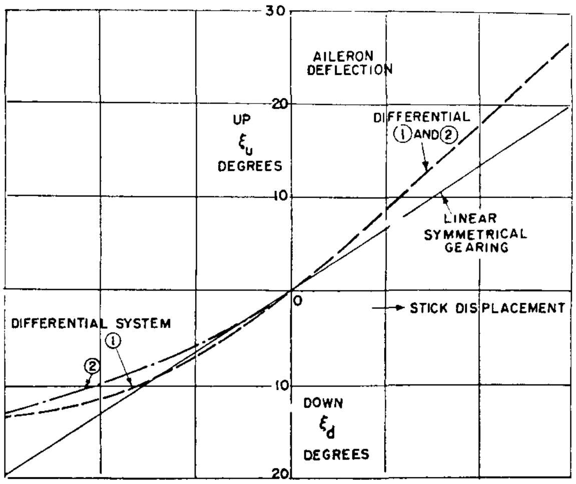


FIGURE 16(*a*). Three aileron gearing systems for B.G.A. two-seater.

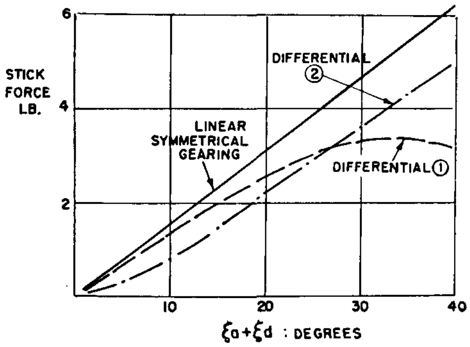


FIGURE 16(*b*). Stick force-displacement curves for the three systems.

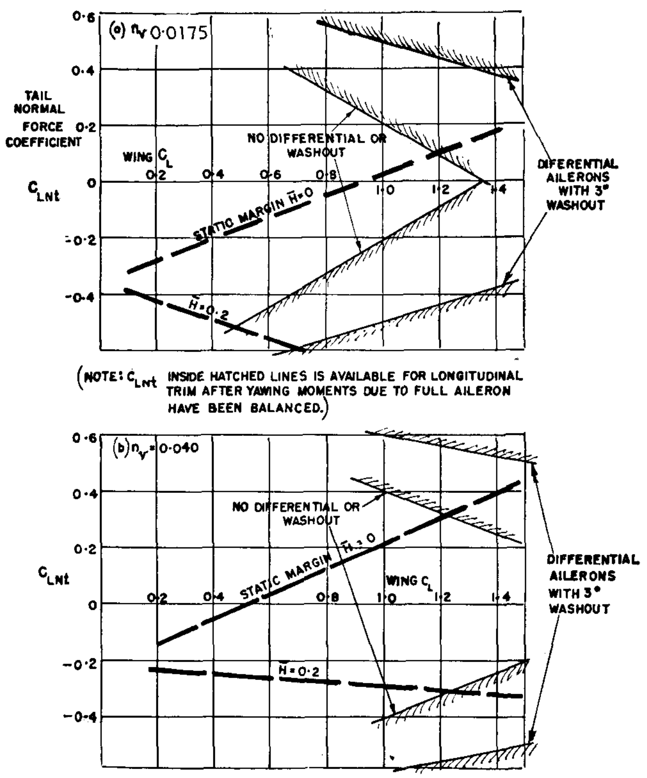


FIGURE 17. V-tail loading on B.G.A. two-seater during rolling manœuvres at extreme C.G. positions, showing effect of tail volume.

When designing dual purpose tail surfaces for a sailplane it is necessary to ensure that they are adequate for the dual task. Lateral manoeuvres, particularly aileron application at high lift coefficient, can produce high side loads on the tail and the combination of this and vertical balancing load on the tail over the design c.g. range can design the tail volume. This problem is particularly significant for a sailplane where the span/tail arm ratio is usually large. Fig. 17 illustrates this point and suggests that for the B.G.A. two-seater the larger tail volume (giving $n_v = 0{\cdot}040$) and differential ailerons with 3° washout are necessary to provide the desired c.g. travel (determined by a requirement to fly with either one or two crew without ballast) and at the same time to keep within the loading limits of the tail surfaces.

Thus, for longitudinal stability and control, as for directional control, the need for attention to the stick free case seems to be suggested by a study of past designs. The B.G.A. two-seater offers an interesting development which promises to take care of this point and to offer other practical advantages.

Conclusions

The discussion of aerodynamic design has shown a number of ways in which modern designs could excel the best pre-war types in comparable classes.

Performance is of great importance in competitive flying and can be improved only by aerodynamic refinement. Recent developments in wing section design and experience in flight have shown that we can appreciably improve on conventional design by choosing the right section and paying attention to wing surface finish.

Choice of wing section and attention to load grading at the stall, taking account of non-linearity of lift-incidence curves near the stall, can lead to improved stalling characteristics and lateral control near the stall. The traditional extreme washout in a sailplane wing can also be avoided by proper design on this basis.

The development of ailerons giving improved rolling performance, with lighter stick forces and lower adverse yaw, seems possible. Together with attention to fin areas, this should ensure satisfactory handling in rolling manoeuvres, which was often not present in pre-war designs.

Handling qualities in circling manoeuvres, which have frequently been poor in the past, seem susceptible to estimation in the design stage. A suitable choice of dihedral and design of aileron should lead to better control of characteristics.

Traditional tail surface design can be improved to avoid loss of stability in yaw and pitch on freeing the controls. This would improve the pleasantness of handling and the comfort of the pilot.

The total effect of these changes would be to produce an aircraft of appreciably higher performance, which would be easier and more pleasant to fly and more highly manoeuvrable in the critical slow speed flight condition, compared with the average pre-war sailplane.

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