DESIGN AND CONSTRUCTION OF THE SB-11

by

M. Hansen
Akademische Fliegergruppe Braunschweig

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Over the past ten years, several attempts have been made to build a sailplane with a wing fitted with a chord-extending flap. Such a device is known as a Wortmann flap and it can be described as a non-slotted Fowler flap. Nearly all the sailplanes that resulted from those attempts show a high standard of technology.

In spite of this fact, and in spite of their theoretically outstanding performance in comparison with conventional flapped gliders, it has not been possible to demonstrate the anticipated performance gains during normal flying operations such as cross-countries or - even better - contests.

Based on experience with these prototypes, some principles can be established which should be kept in mind when designing a Wortmann flap glider:

- Operation during flight must be easy. If operation of the flap system is complicated, or if operating forces are too high, the pilot will be distracted from his other tasks to such a degree that the aerodynamic advantage will be lost due to operational mistakes and tactical misjudgements. Beyond this its flying qualities must not differ too much from those of conventional gliders so that pilots can continue to use the very effective cross-country techniques that have already been developed.
- Modern sailplanes are of very high standard as regards both the aerodynamic qualities and the mechanical systems used. Therefore, the chances of success will be increased if well proven techniques are used wherever possible when designing a Wortmann flap glider.
- Compromises with regard to aerodynamics cannot be tolerated. Whoever thinks 'This little defect does not matter because I have my flap' is on the best route to an aerodynamic fiasco.

These three maxims have influenced the 11th sailplane design of Akaflieg Braunschweig.

The SB-11 makes use of a Wortmann flap in addition to all the good qualities of a modern glider. It was fitted with comparatively large ailerons and camber-changing flaps which are attached to the Wortmann flaps. They move rearward when the chord is extended.

When the Wortmann flap is retracted, the SB-11 hardly differs from a conventional flapped glider of the Unlimited 15m Class. The data sheet (Table 1) shows a complete conformity concerning dimensions, weights, and loadings.

A wing area of $10.56m^2$ and an empty weight of 270kg, together with large water ballast tanks in the wings, make it possible to vary the wing loading from 33 to $44.5kg/m^2$. The camber of the wing section is comparatively small. From the root to the wing tip, the same profile is used with no special wing section provided for the aileron.

Aileron and camber changing flaps are of 21% chord. This fact, together with the camber changing flaps also working as ailerons, provides an outstanding 45^0 to 45^0 roll rate of about 2.8 seconds at 1.4 x stalling speed.

In addition, there are no unusual flying characteristics. The tail arm is long, the fuselage overall is 7.4m, and the control surfaces are rather large. The T-tail has an all-moving elevator and was built in the molds of Schempp-Hirth's two-seater 'Janus'.

For the front fuselage, industrial molds have also been used: Schleicher allowed us to use those of the ASW-19 when building the fuselage of the SB-11.

The approach is controlled by Schempp-Hirth airbrakes on the upper surface of the wings only. However, they are twice as high as normal in order to give steep approaches.

Since the SB-11 with its flaps retracted is very similar to the modern 15m sailplanes, we can expect it to have much the same performance. This is confirmed when we look to its glide polar.

For circling, the SB-11 has a Wortmann flap which can be extended during flight.

What does this flap accomplish?

1. The wing area increases from 10.56 to $13.2m^2$. This allows the wing loading to change from 33 to $26.5kp/m^2$ or, in case the wing is full of water, from 44.5 to $35.5kp/m^2$. This improves the climbing performance of the glider, making it possible to circle with less speed as the wing loading is reduced.
2. The reduction in speed also results in another effect which is disadvantageous, namely an increase in the induced drag. It should be noted that the increase results only from the lower speed and not from the decreased aspect ratio. At low speeds, a large part of the total drag results from the induced drag. Consequently, most of the advantage from the increased wing area is wasted.
3. The Wortmann flap would be of no value if there were not a third effect: by extending the Wortmann flap, the camber of the wing section increases while the relative thickness goes down from 14.4 to 11.5%. But now a well-cambered, thin wing section is able to produce high lift coefficients at a very low profile drag. This fact gives the SB-11 an outstanding climbing ability.
   In comparison: if a conventional 15-m glider wants to climb in narrow thermals as well as the SB-11, its wing must produce a lift coefficient of about 2.1. Usual camber-changing flap profiles reach 1.4 or 1.5.

When deciding whether to build the SB-11 or not, most concern was given to the question: How fast would it be over a triangular course? That is because the average cross-country speed is the criterion for the performance of a modern glider.

Of course, the cross-country speed depends on the thermal strength and shape, and this presents many difficulties. When calculating the cross-country speed of the SB-11, the thermal model of K. H. Horstmann was used. This model distinguishes four different types of thermals and we think that it is the best one for the meteorological conditions in Central Europe.

The results of the calculations appear as follows: Comparing the average cross-country speed to that of a 15-m glider with a conventional camber-changing flap, the Wortmann flap results in an improvement of between 4 to 15% depending on the shape and strength of the thermal. If the thermals are very wide, the SB-11 has only a small advantage. But with narrow thermals which can be centered only with difficulty, the improvements are remarkable.

This fact provides another advantage which should not be undervalued: It makes it possible to keep the water ballast in the wings during a weak period, while the conventional glider has to drop its water. If the thermal conditions improve, the wing-loading, with water gone, would be too low, thus causing a decrease in cross-country speed.

It was a major problem to design a wing section which would have the desired characteristics for both the high speed and low speed configuration. In this case, it was necessary to take into account aspects of both structural mechanics and kinematics from the outset.

For example: About the first 55% of chord has to be reserved for structure, in order to provide adequate strength and stiffness without too much weight penalty. So, the question is how to distribute the remaining 45% to Wortmann flap and aileron. For the SB-11, the decision has been to allocate 25% to Wortmann flap and 21% to aileron.

With these proportions, you get an aileron of 17% when the Wortmann flap is extended. This seems to be an aileron of sufficient size to guarantee a satisfactory roll-rate.

Another problem was the elastic part of the wing's lower surface. It bends down when the flap moves out because work is required to deflect the elastic lip itself and there is a lot of friction between lip and flap. In addition, there is the risk of flutter or vibration problems at high speeds.

Therefore, the idea was conceived of leaving the lower surface as rigid as the upper one and giving the flap a constant thickness. This was possible because of the big flaperons which occupy the full span and have a sufficient thickness at their hinges.

Although it was not known whether aerodynamics would allow the resulting discontinuities, another step was taken. Towards the middle of the flap the thickness decreases, with the result that while the flap is moving there is a gap of some millimeters at the upper and lower lip. Thus, friction forces appear only during the first and last few millimeters of the flap's movement when it touches the lips and closes the gaps.

A wing section was developed with those conditions in mind. The FX-62-K-131 was chosen as the basis for this work because it has the lowest drag of the wing sections used on modern gliders. It was modified in such a way that the Wortmann flap could be placed between the wing and the aileron. Then a computer program was used to help optimize the shape.

With this first design, a wing model of 1.5m span and 0.75m chord was built and mounted on a tandem two-seater Kranich III. Testing in free flight has the advantage that the results are not falsified by wind tunnel turbulence.

Surface static pressure measurements were made in order to measure lift coefficient. The drag coefficients were measured by means of a Pitot-rake. Measurements were taken for a range of Reynolds numbers and several flap and aileron angles. Wool tufts were used for flow visualization in order to detect flow separations, and a stethoscope was used to find the position of transition.

The results of the measurements have been photographically recorded and analysed by a computer program. It was necessary to modify the wing section twice before the most satisfactory shape was found for the requirements: It achieves lift coefficients above 1.7 at a drag of $c_D<0.01$. The properties of the profile become even more obvious if you draw its polar on the c_L/c_D diagram of the basic profile, which means that you base the coefficients on the flap retracted chord.

In designing the component parts of the SB-11, well-known and approved solutions were chosen as far as possible.

The Wortmann flap is conventionally driven by push rods and levers, and not by any hydraulic or electric mechanism. The operating lever is on the left side of the cockpit. Its operating range is 0.4m; during flight it takes 2kp to extend the flap and 6kp to retract it.

The wing is completely built of carbon fiber reinforced epoxy resin. The high rigidity of this material guarantees small elastic deflections during flight. This fact prevents the flap from jamming.

In addition, the fuselage and tail unit are also built of CRP, but in these cases for weight saving reasons. Only the rudder is made of glass fiber reinforced plastic because the VHF antenna is mounted in it and would be screened by the conductive carbon fibers.

The Wortmann flap of each wing is separated at the wing break. The rectangular part, as well as the tapered part, is supported at the inboard side, at the outboard side, and in the middle. Each support consists of a pair of rollers and tracks fixed to the wing and to the flap. This type of support has the advantage that, at high speed - with the Wortmann flap retracted - the larger support base causes a decrease of forces at the rollers and a reduction of the free motion of the Wortmann flap. The fastening of the curved tracks to the flap is carried out in such a way that the different parts of the flap are simply supported. A redundant hinging would induce jamming if the wing were deflected in bending.

The chosen type of flap support and drive resulted in large holes in the web of the spar. It was a problem to transfer the shear forces from one side of the holes to the other. This required theoretical and experimental studies because, up to now, they have not occurred in glider spars of reinforced plastic material.

Gliders with Wortmann flaps require special drive mechanisms for the ailerons and the camber-changing flaps because they move in a chordwise direction together with the Wortmann flap. With the SB-11, this movement is compensated between Wortmann flap and fuselage.

Below the wing, at the bottom of the fuselage, the 'mixer' is situated. This is a kinematic mechanism which has as inputs the positions of the stick, camber-changing flap lever, and Wortmann flap lever. From the mixer, four push rods go upwards. These are connected to levers hinged to the top of a rack. This rack links the right and left Wortmann flaps. When the Wortmann flaps are extended, the four push rods pivot on their bearings at the mixer, thus compensating the movement.

The camber-changing flaps are driven directly from the levers at the rack by a torque drive. The aileron levers drive push rods bedded in the Wortmann flaps. At the end of the rectangular part of the Wortmann flap, there is a drive with a diagonal axle fully contained within the flap.

This drive causes rotation of a 20cm long section of flap cut off the camber-changing flap. This little flap gives its movement to the aileron itself by a torque connection.

The reason for this complicated way of driving the aileron is as follows: When the Wortmann flap is extended, its elastic axis is not in the elastic plane of the wing, but some distance below. In addition, the elastic plane of the flap now inclines at an angle of 26^{o} towards the elastic plane of the wing. So, when the wing bends, there is a spanwise and chordwise displacement between the wing and flap. This displacement is compensated by the torque drive between driving flap and aileron. Without this compensation, there would be an uncontrolled motion of the aileron with any wing deflection.

The first flight of the SB-11 was on May 14, 1978. Up to that date, it had taken two years to construct the glider and another two years of preparation. The members of the Braunschweig University Gliding Club have spent more than 20,000 hours on the project, which cost a total of about DM 95000 for materials to build the glider, the molds, and special devices needed in the construction.

Pilots have been surprised by the flying characteristics, which are so simple and uncomplicated that a relatively unexperienced pilot can fly it with safety. With flap retracted, it doesn't spin at all; with flap extended, it spins only with the center of gravity behind the permitted range, and recovers within half a turn at a speed of 130km/h.

We measured the performance a few days after the maiden flight. At that time, the wings had not yet been finished, there were still holes between flaps and fuselage, and the CG was too far forward. Nevertheless, the polar measured was only a fraction below the one calculated, and it seems certain that it has now come up to the calculated performance.

The cross-country flights together with other gliders during the training for the XVIth World Championships, have shown that the concept of the SB-11 promises to take glider design a step further.

Table 1. SB-11 Data

WING	Flap Retracted		Flap Extended
span		15.00m	
area	10.56m^2		13.20m^2
position of break		y/s=0.6	
chord at root	0.80m		1.00m
chord at tip	0.32m		0.40m
aspect ratio	21.3		17.0
dihedral		2.3^o	
sweepback		0^o	
chord of Wortmann flap	-		25%
chord of flaperons	21%		17%
profile		HQ 144.39 W 3	
airbrakes		Schempp-Hirth, on upper surface	
TAILPLANE			
span		2.70m	
area		1.24m	
aspect ratio		5.87	
chord of elevator		100%	
profile		FX 3 L-142	
trim		spring, automatic	
FIN & RUDDER			
height		1.27m	
area		1.17m^2	
aspect ratio		1.38	
chord of rudder		40%	
profile		NACA 64_A-013(012)	
FUSELAGE			
length		7.40m	
width		0.64m	
height		0.82m	
landing gear		retractable, unsprung	
WEIGHTS			
max T/O		470kg	
empty, equipped		270kg	
max water ballast		130kg	
wing loading	33.2...44.5kg/m^2		26.5...35.6kg/m^2
PERFORMANCE			
stalling speed	75km/h		58km/h
max speed	265km/h		145km/h
min sinking speed	0.62m/s		0.62m/s
at	80km/h		70km/h
best glide ratio	41		36
(W/S=35kg/m^2) at	104km/h		85km/h

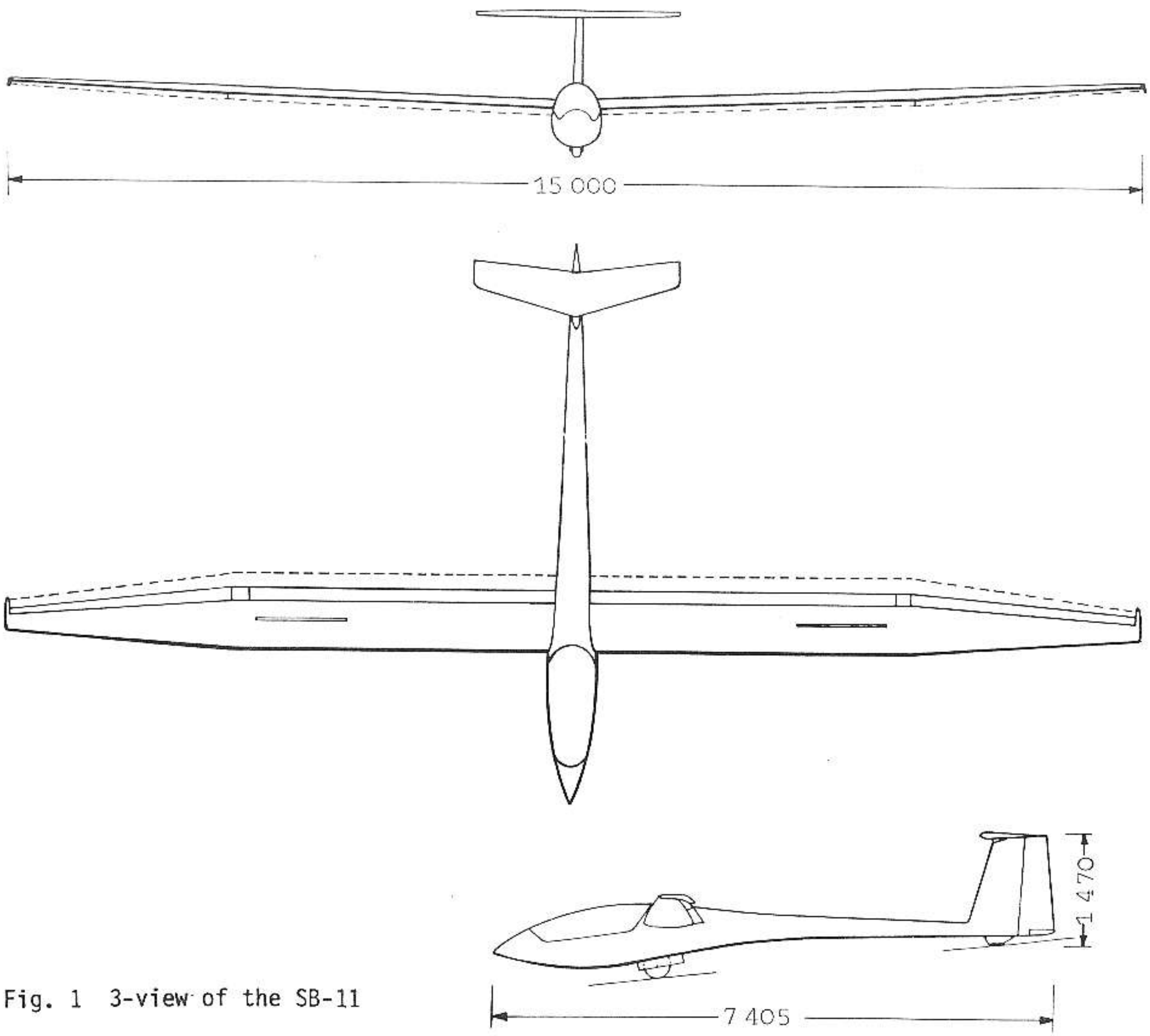


Fig. 1 3-view of the SB-11

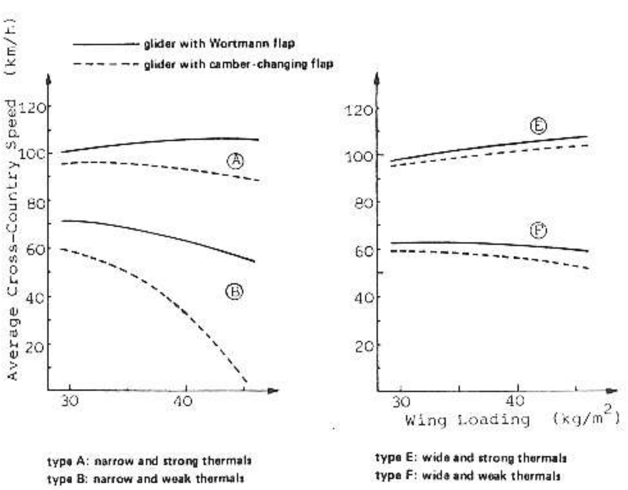


Fig. 2 Average cross-country speed of 15-m gliders.

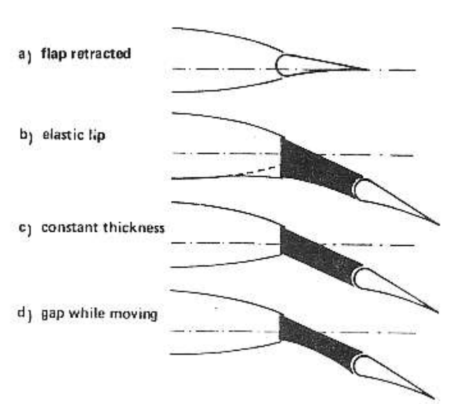
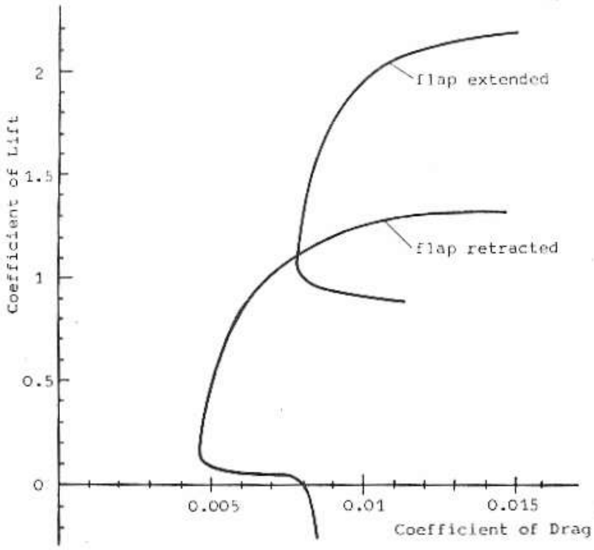


Fig. 3 Development of a Wortmann flap wing section with rigid lower surface.



curves envelope optimum flap positions
curves are corrected for flight RNs at W/S=35 kg/m^2 and chord=0.8 m (Wortmann flap retracted)

Fig. 4 Characteristics of HQ 144.39 W 3 wing section.

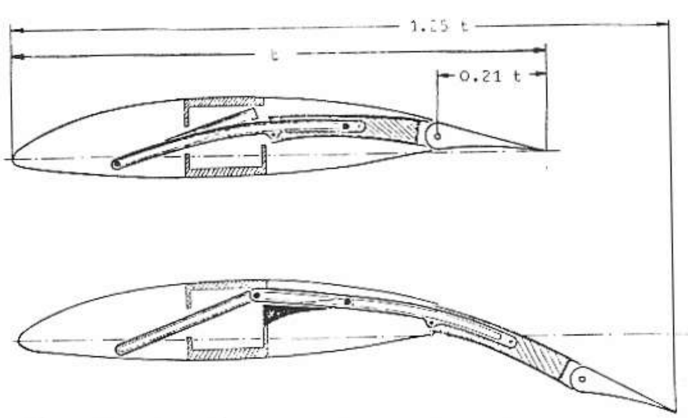
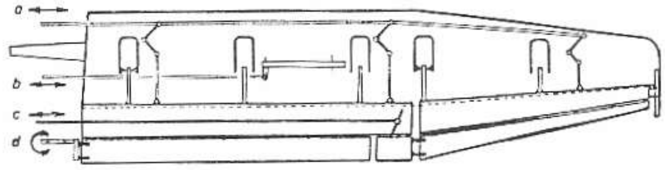


Fig. 5 The wing profile with track and roller support system.



drive of Wortmann flap: *a*
airbrakes: *b*
ailerons: *c*
camber-changing flaps: *d*

Fig. 6 The flap system of the SB-11.

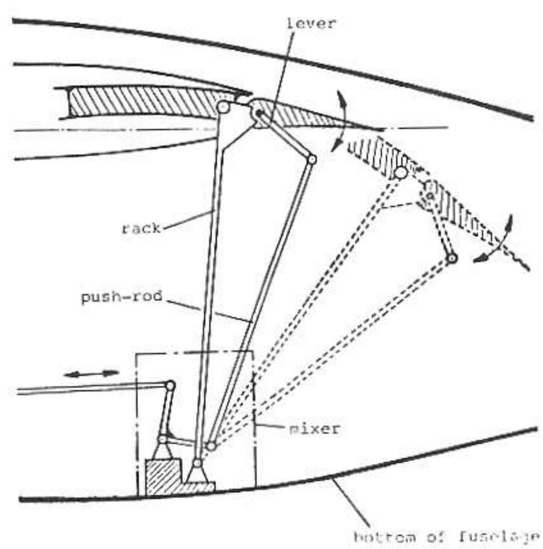


Fig. 7 Principle of the mechanism driving the flaperons.

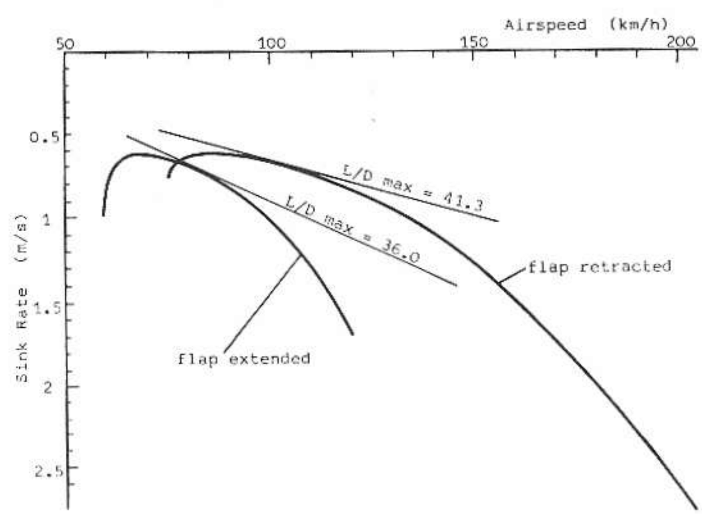


Fig. 9 Calculated glide polar
(W/S = 35 kg/m^2 flap retracted).

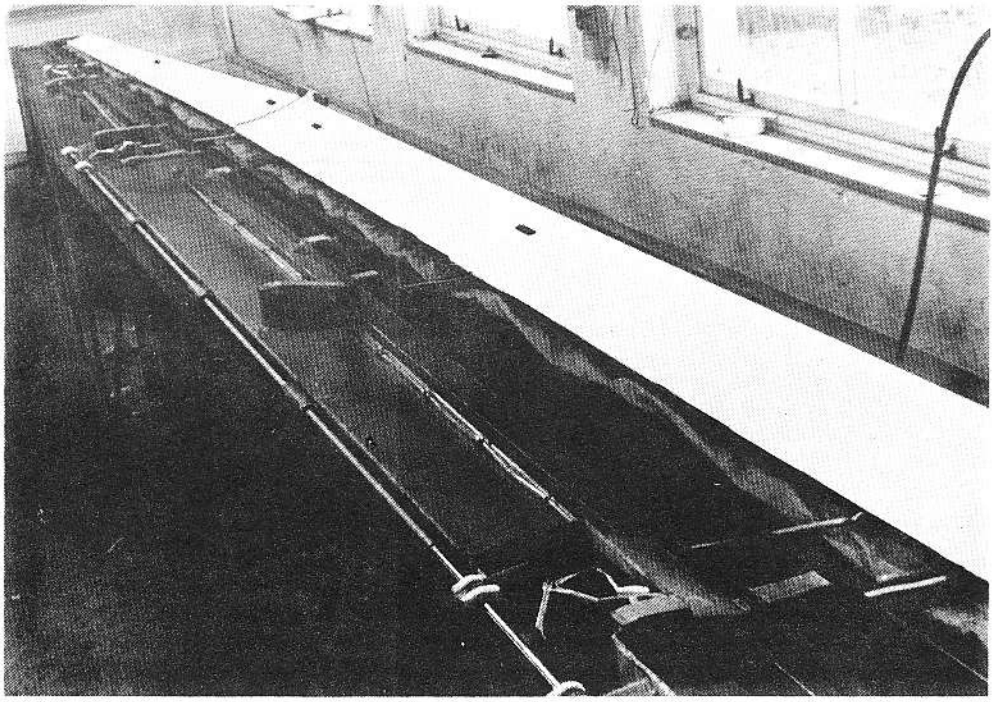


Fig. 8 The SB-11 wing

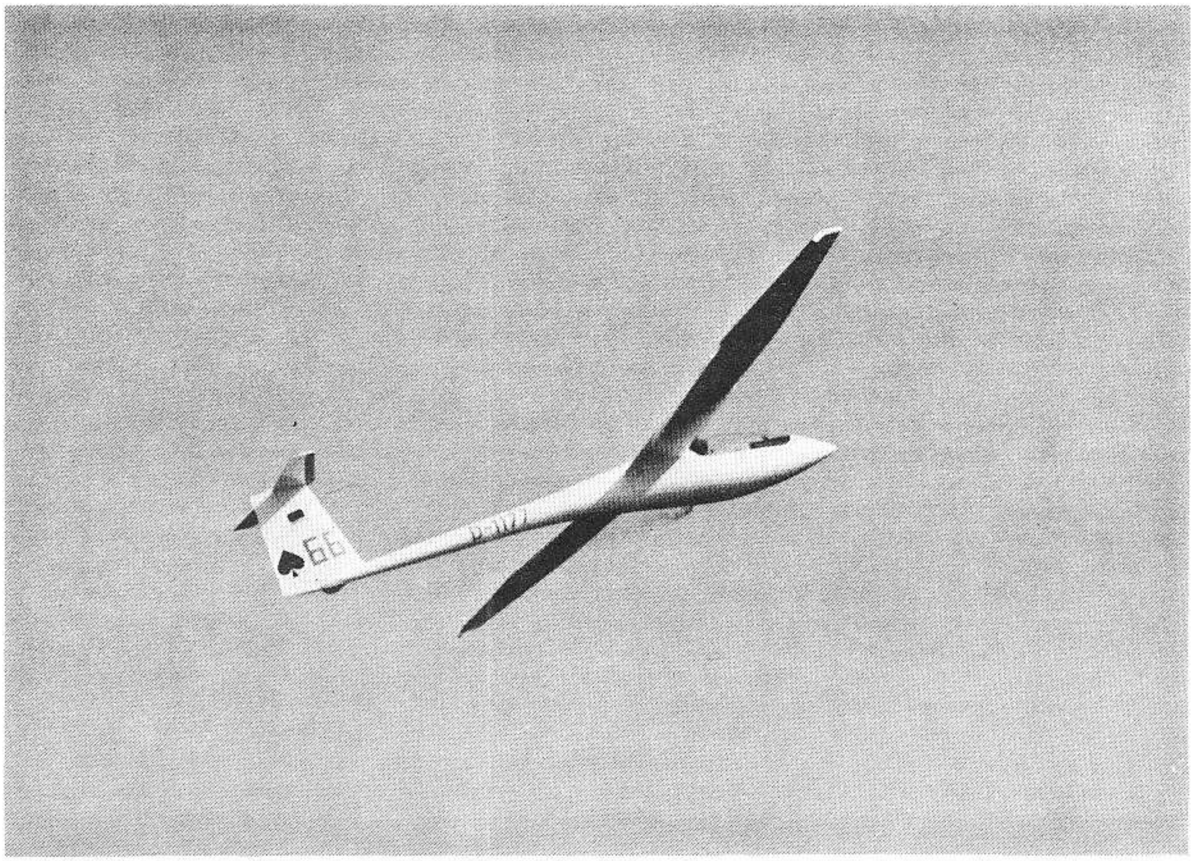


Fig. 10 The SB-11