Design and Construction of the SB-11

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Over the past ten years several attempts have been started to build a sailplane with a wing chord-extending flap. Such a type of flap 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 during normal flying operations, such as cross-countries or – even better – contests.

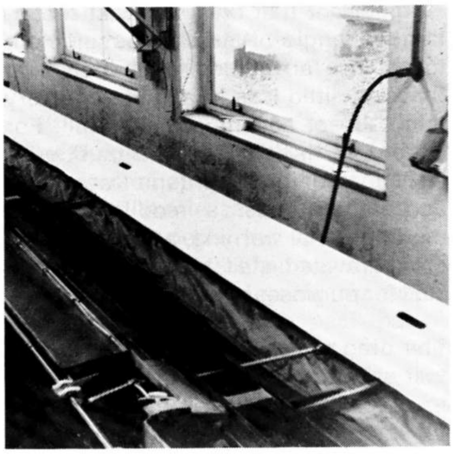
Based on experience with these prototypes some principles can be established, which should be kept in mind when designing a Wortmann flap glider:

- 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 maintain the very effective cross-country techniques that have 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 better, if well-proven techniques are used wherever possible, when designing a Wortmann flap glider, too.
- 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 way to an aerodynamic fiasco.

These three maxims have affected 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 given comparatively big ailerons and camber-changing flaps, which are attached to the Wortmann flaps. They move reerwards when the chord is extended.

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

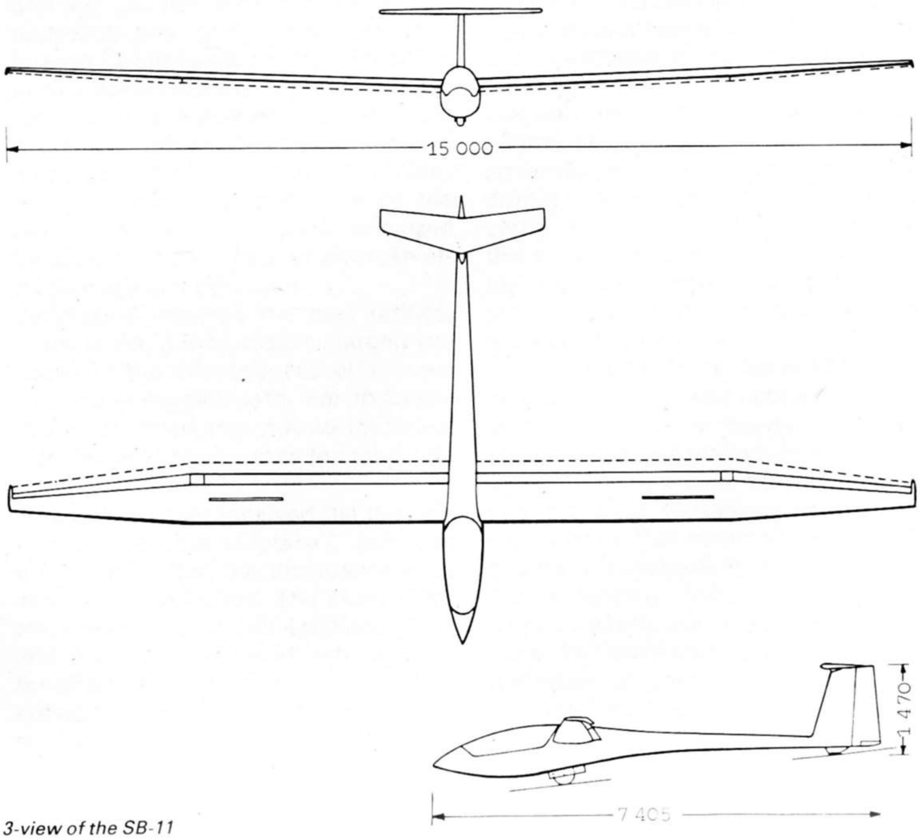
A wing area of 10.56 m² and an empty weight of 270 kg together with big water tanks in the wings make it possible to vary the wing loading from 33 to 44.5 kg/m². The camber of the wing section is comparatively small. From the root to the wing-tip the same profile is used with no special wing section provided for the aileron.



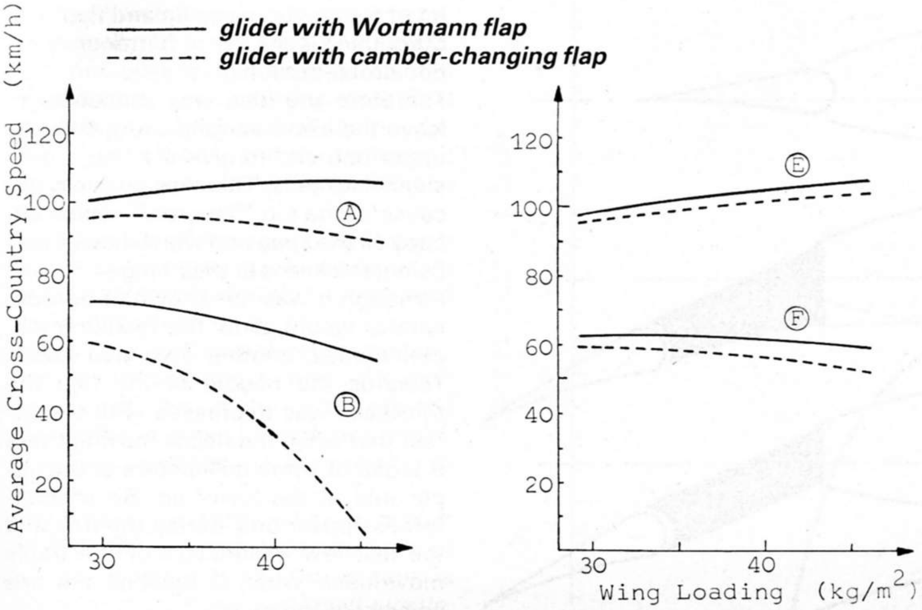
Open wing showing flap extended and all mechanisms

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°-to-45° roll-fine of about 2.8 seconds at 1.4 x stalling speed.

Besides there are no unusual flying-characteristics. The tail-arm is pretty long — fuselage over all 7.4 m –, the control surfaces rather big. The T-tail has an all-moving elevator and was built in the moulds of Schempp-Hirth's two-seater "Janus".



3-view of the SB-11



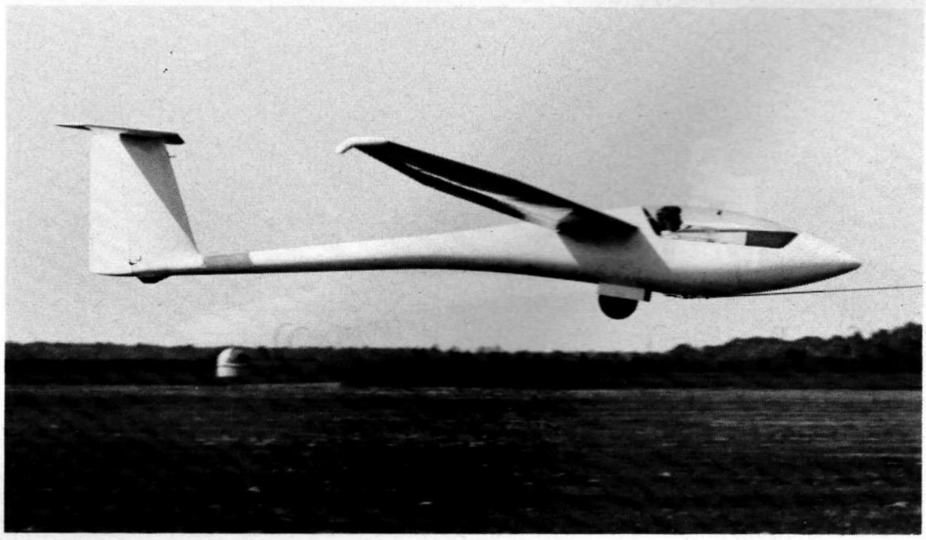
type A: narrow and strong thermals
type B: narrow and weak thermals
type E: wide and strong thermals
type F: wide and weak thermals

Average cross-country speed of 15 m-gliders

For the front fuselage industrial moulds have been used, too: Schleicher allowed us to use those of the ASW-19 when building the fuselage for 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 15 m sailplanes, we can expect it to have much the same performance. This is confirmed, when we look at its glide polar.
For circling-flight the SB-11 has a Wortmann flap, which can be extended during flight. What does this flap bring about?

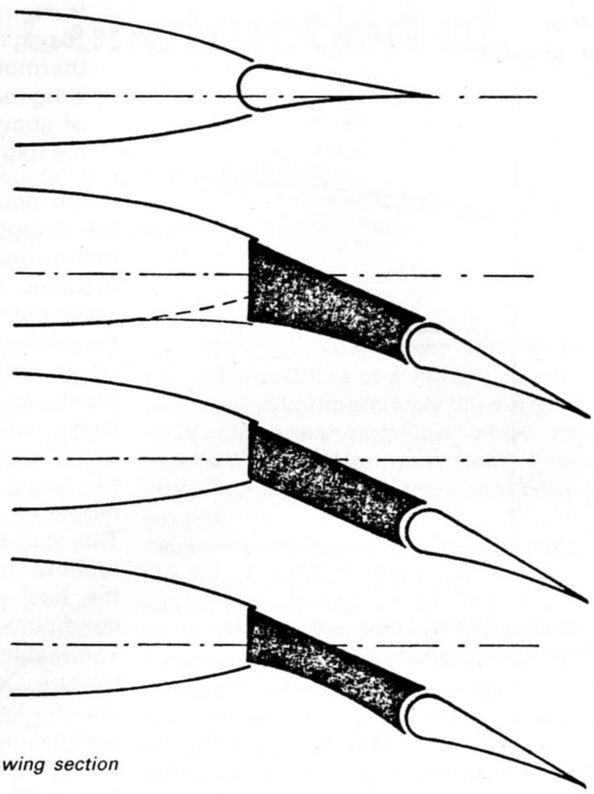
1. The wing area increases from 10.56 to 13.2 m². This makes the wing loading go down from 33 to 26.5 kp/m² or, in case the wing tanks are full of water, from 44.5 to 35.5 kp/m². This improves the climbing performance of the glider, because it is possible to circle with less speed, if the wing-loading is reduced.
2. The reduction in speed results also 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 decreased aspect ratio. At low speeds a big part of the total drag results from the induced drag, and so most of the advantage from the increased wing is wasted. The Wortmann flap would be of no value, if there were not a third effect:
3. 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.

SB-11 on tow



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 it would be on triangles. 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 brings 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 look as follows: Comparing the average cross-country speed to that of a 15 m glider with a camber-changing flap the Wortmann flap brings an improvement between 4% and 15% depending on the shape and on the 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 with difficulty only, the improvements are remarkable.
This fact involves another advantage, which must 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 again, the wing-loading with water gone would be too low, and so would cause a loss in cross-country speed.



Development of a Wortmann flap wing section with rigid lower surface

It was a big problem to design a wing-section which would have the desired characteristics for both the high-speed and the low-speed configuration. It was necessary to take into account aspects of both structural mechanics and kinematics from the outset.
For example: About the first 55% of the 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 SB-11 the decision has been 25% to Wortmann flap and 21% to aileron.
With these proportions you get an aileron of 17% when 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, which bends down when the flap moves out, because there is work necessary to deflect the elastic lip itself and there is a lot of friction between lip and flap. The other thing is the risk of flutter or vibration problems at high speeds.
Therefore the idea was conceived to leave the lower surface as rigid as the upper one and to give the flap a constant thickness. This was possible because of the big "flaperons" which occupy all the span and which have a sufficient thickness at their hinges.
Although it was not known, if aerodynamics would allow the resulting discontinuities, another step was taken. Towards the middle of the flap the thickness was decreased with the effect that while the flap is moving there is a gap of some millimeters at the upper and at the lower lip. So friction-forces appear only during the first and the 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 1.5 m span and 0.75 m chord was built and mounted on a tandem two-seater Kranich III. Testing in free flight brings 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-visualisation 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 registered 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 evident, if you draw its polar into the c_L/c_D-diagram of the basic profile, which means that you base the coefficients on the flap-retracted chord.
When designing the component parts of the SB-11, well-known and approved solutions were chosen as far as possible.

SB-11 in flight

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

To achieve such low operating forces it was necessary to take some more measurements in addition to the rigid lower surface.

The wing is built completely 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.

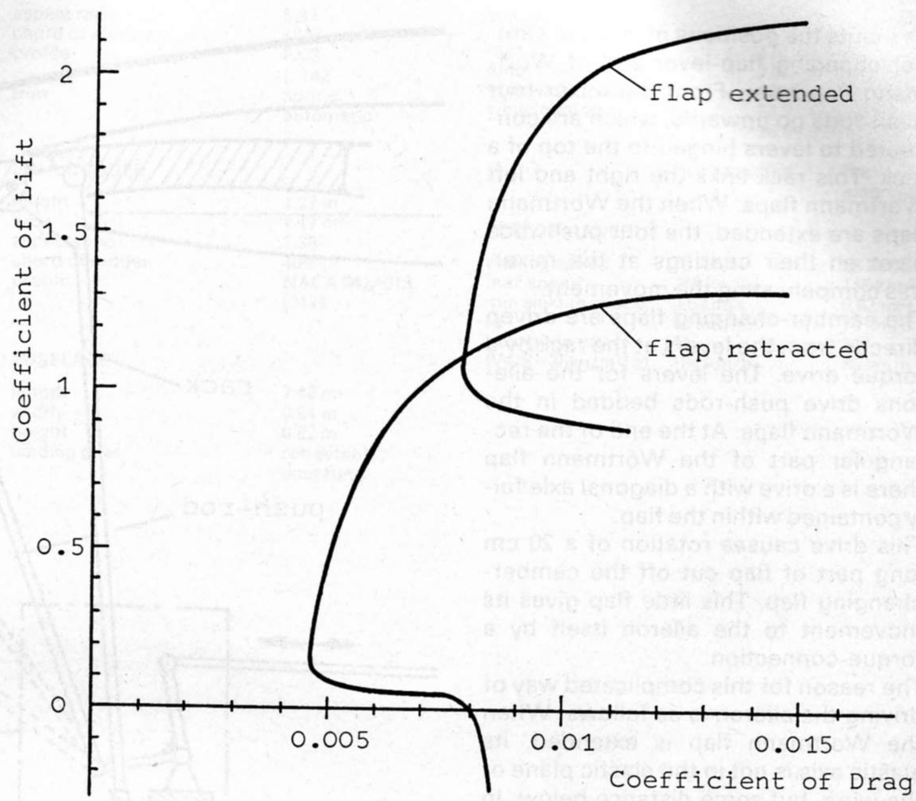
The fuselage and tail-unit are also built of CRP, but in these cases because of weight reasons. Only the rudder is made of glass-fiber reinforced plastic, for there is the VHF-antenna in it, which would be screened by the conductive carbon-fibers.

The Wortmann flap of each wing is devided at the wing joint. 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 fixed to the wing, a pair of rollers fixed to the flap, a pair of tracks fixed to the wing, and a pair of tracks fixed to the flap. This type of support has the advantage that at high speed — with the Wortmann flap retracted — the larger base of the support 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 hingeing would cause jamming, too, if the wing. were deflected.

The chosen type of flap-support and flap-drive resulted in big 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 needed theoretical and experimental studies, because up to now they have not occurred in glider spars of reinforced plastic material.

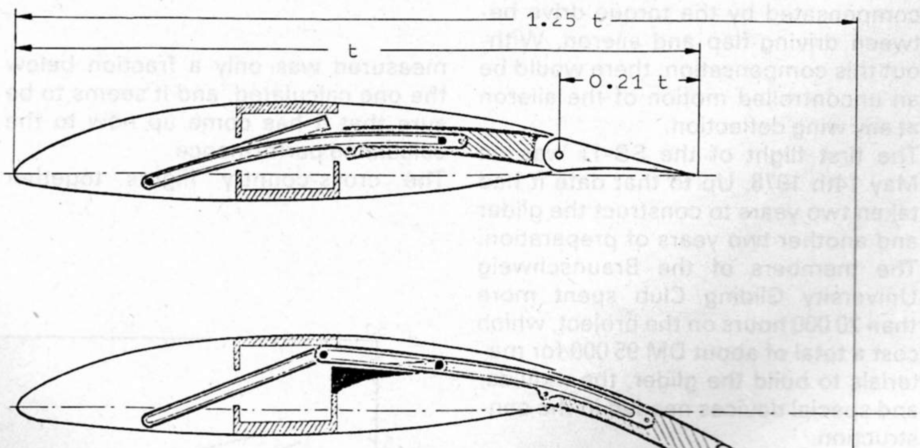
Gliders with Wortmann flaps require special drive-mechanisms for the ailerons and the camber-changing flaps, because they move in a chord wise direction together with the Wortmann flap. With the SB-11 this movement is compensated between Wortmann flap and fuselage.

Below the wing, at the bottom of the fuselage, the "mixer" is situated. This is a kinematic mechanism, which has

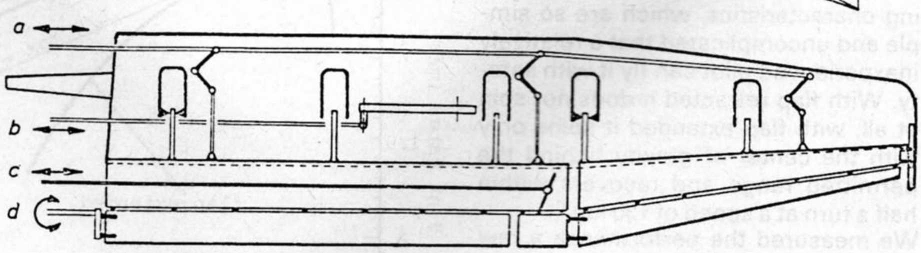


Characteristics of HQ 144-39 W 3 wing section

curves envelope optimum flap positions
curves are corrected for flight RNs at W/S = 35 kg/m² and chord = 0.8 m (Wortmann flap retracted)



The wing profile with track and roller support system



The flap system of the SB-11

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

as inputs the positions of stick, of camber-changing flap-lever and of Wortmann flap-lever. From the mixer four push-rods go upwards, which 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, this compensating the movement.

The camber-changing flaps are driven directly from the levers at the rack by a torque drive. The levers for the ailerons 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 20 cm long part of flap cut off the camber-changing flap. This little flap gives its movement to the aileron itself by a torque-connection.

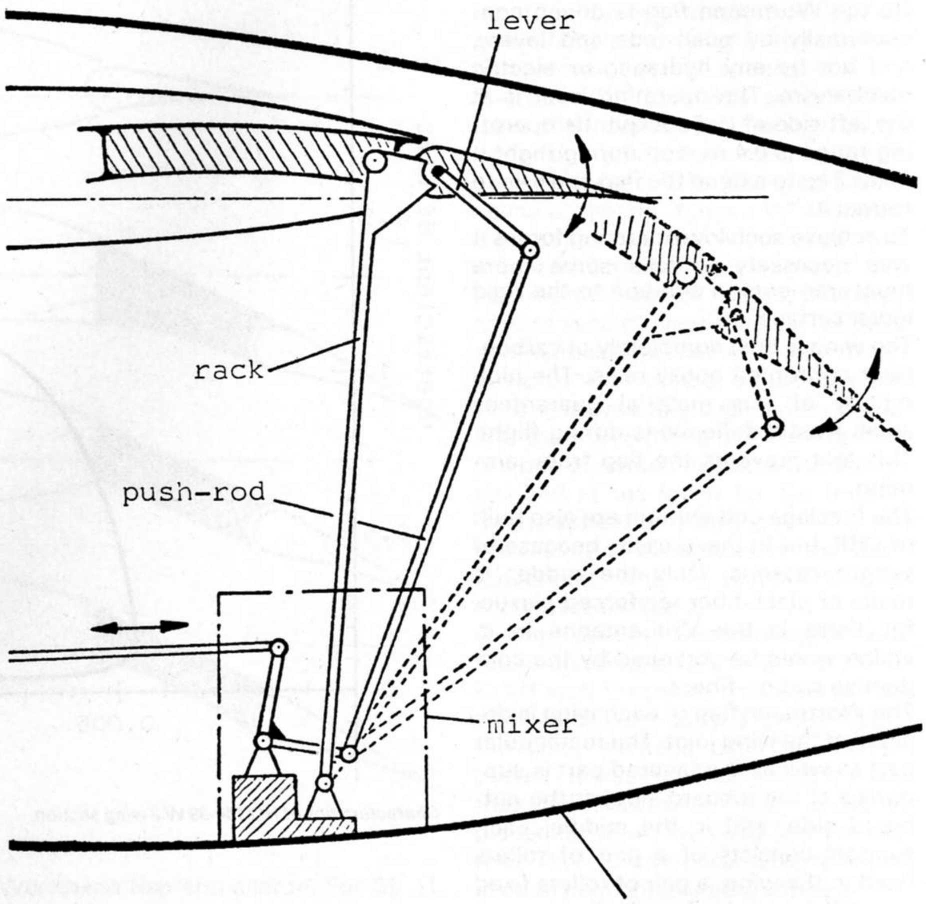
The reason for this complicated way of driving the aileron is as follows: When the Wortmann flap is extended, its elastic axis is not in the elastic plane of the wing, but some distance below. In addition the elastic plane of the flap now leans at an angle of 26° towards the elastic plane of the wing. 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 at any wing deflection.

The first flight of the SB-11 was on May 14th 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 spent more than 20 000 hours on the project, which cost a total of about DM 95 000 for materials to build the glider, the moulds, and special devices needed in the construction.

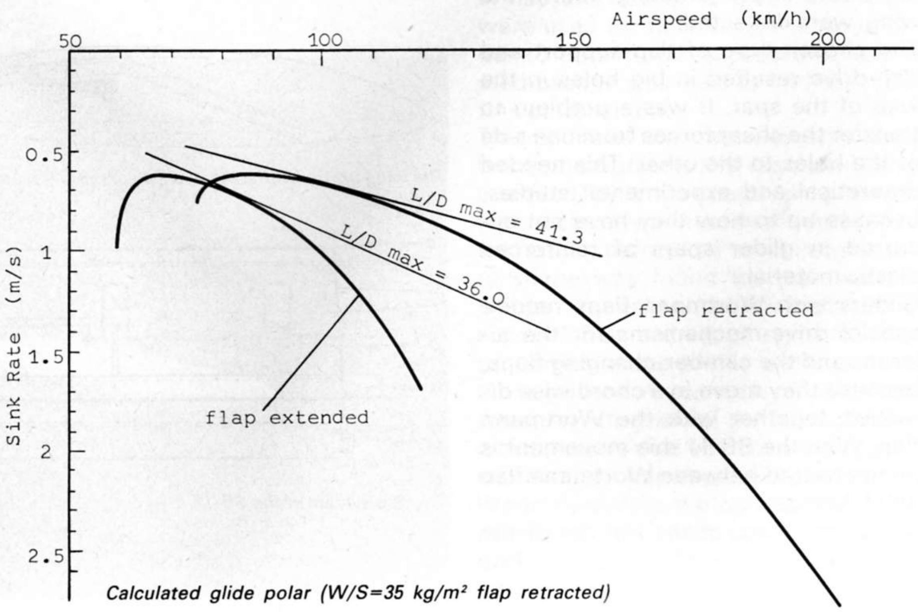
Pilots have been surprised by the flying characteristics, which are so simple and uncomplicated that a relatively inexperienced pilot can fly it with safety. With flap retracted it does not spin at all, with flap extended it spins only with the center of gravity behind the permitted range and recovers within half a turn at a speed of 130 km/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 to be sure that it has come up now 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.



Principle of the mechanism driving the flaperons



Calculated glide polar (W/S=35 kg/m² flap retracted)

SB-11 Data Sheet

	flap retracted	flap extended
WING		
span	15.00 m	
area	10.56 m²	13.20 m²
position of joint	y/s=0.6	
chord at root	0.80 m	1.00 m
chord at tip	0.32 m	0.40 m
aspect ratio	21.3	17.0
dihedral	2.3°	
sweepback	0°	
chord of Wortmann flap	–	25%
chord of flaperons	21%	17%
profile	HQ 144-39 W 3	
airbrakes	Schempp-Hirth, on upper surface	

TAILPLANE	
span	2.70 m
area	1.24 m
aspect ratio	5.87
chord of elevator	100%
profile	FX 3 L-142
trim	spring, automatic
FIN & RUDDER	
height	1.27 m
area	1.17 m²
aspect ratio	1.38
chord of rudder	40%
profile	NACA 64_A-013 (012)
FUSELAGE	
length	7.40 m
width	0.64 m
height	0.82 m
landing gear	retractable, unsprung

WEIGHTS	
max T/O	470 kg
empty, equipped	270 kg
max water ballast	130 kg
wing loading	33.2...44.5 kg/m² 26.5...35.6 kg/m²

	flap retracted	flap extended
PERFORMANCE		
stalling speed	75 km/h	58 km/h
max speed	265 km/h	145 km/h
min sinking speed	0.62 m/s	0.62 m/s
at	80 km/h	70 km/h
best glide ratio	41	36
(W/S=35kg/m²) at	104 km/h	85 km/h