The contribution of aerodynamics to the development of recent sailplanes in Czechoslovakia

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Introduction

A great effort is at present directed towards analytic development of new laminar airfoil sections, structural development and testing of laminar wings suitable for sailplanes. Several sailplanes, recently designed employ airfoil sections of the NACA 6 family. Low drag of these sections in the laminar flow range enables a considerable increase of performance of the sailplanes. Unfortunately sailplane designers stress the need for good circling flight performance and in this aspect, wings, designed on the basis of NACA 6 family of sections tend to be too fast. One possible solution to this problem is to use high lift devices in conjunction with the basic section.

When developing in Czechoslovakia a new training sailplane, the L 13, considerable work was done on the design and testing of a suitable slotted flap. The requirement was a substantial increase in maximum lift with a minimum drag penalty.

The flap developed during this work gave good results and it was possible to use it also on other types.

I shall give here a short summary of the results achieved.

Increasing the maximum lift of a laminar wing

The sailplane performance is bettered by aerodynamic refinements. Therefore when designing the training sailplane L 13 we decided to use for the wing laminar sections of the 63 6xx family. It was clear from the beginning that since this was to be a training sailplane, the minimum speed would have to be kept very low indeed. This requirement could not

Fig. 1a *Sketch of slotted flap configuration.*

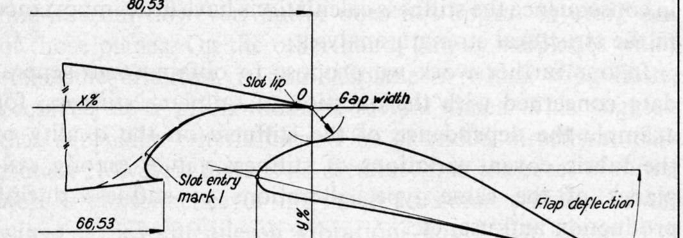
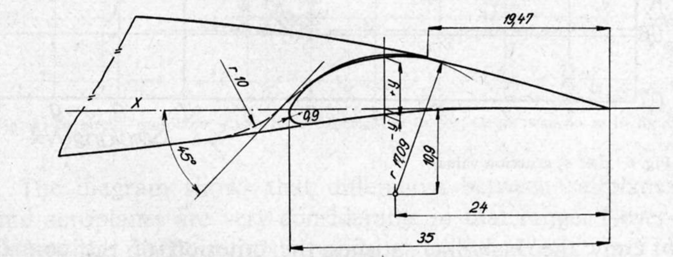


Fig. 1b *Geometric characteristics of flap.*



Ordinates of flap shape

X	65,3	65,6	66	67	68,5	70	71,5	73,1	74,5	76	77,5	79	89,5	80,0
+y	1,1	1,57	2,185	3,15	4,15	4,85	5,35	5,69	5,90	6,0	5,95	5,82	5,60	
−y			1,0	1,10										

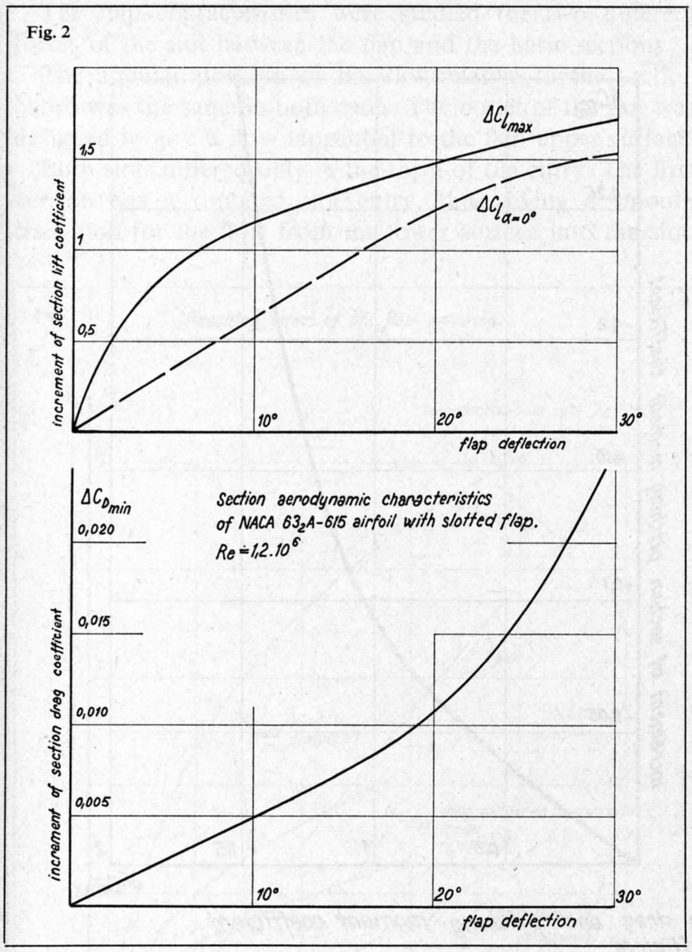


Fig. 2

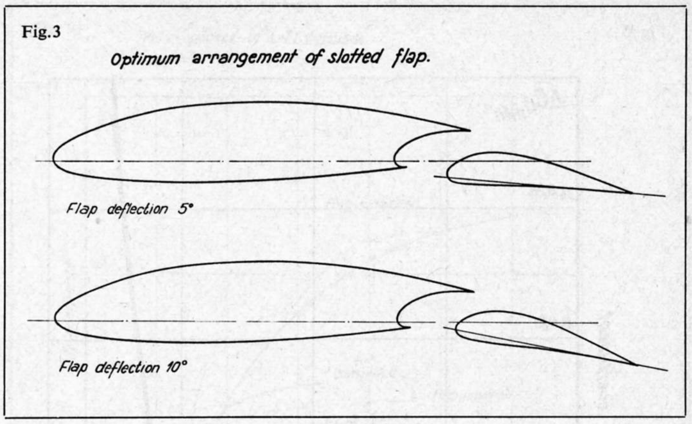


Fig. 3

This can be demonstrated in the following analysis

$$V_s = \frac{C_d}{C_L{}^{3/2}} \cdot \sqrt{\frac{2}{\varrho} \cdot \frac{W}{S}} = \varepsilon \cdot V$$

$$x = \frac{C_d}{C_L{}^{3/2}} = \varepsilon \cdot \sqrt{\frac{1}{C_L}}$$

$x =$ is a nondimensional number defining the influence of lift and total drag on the sailplane rate of sink.

When the value of x is minimum, the rate of sink shall be minimum. Relative increase of the x value due to small change in drag and lift is obtained by differentiating the equation.

$$\frac{dx}{x} = \frac{dC_D}{C_D} - \frac{3}{2} \cdot \frac{dC_L}{C_L}$$

From this equation it is clear that the rate of sink can be better decreased by increasing the lift with a minimum drag penalty than by only decreasing the drag.

A properly designed lift flap can therefore substantially increase the basic section lift at the cost of minimum or even zero increase in the rate of sink.

The right solution of this problem has a decisive influence on the sailplanes performance in circling.

possibly be fulfilled with the chosen wing section. On the other side it was not possible to increase the wing area or to decrease the weight of the sailplane sufficiently to obtain the required low speed by decreasing the wing loading.

Some work was therefore directed towards the exploration of possibilities offered by the use of high lift devices. We were sure that a laminar wing with airfoils properly applied would give the sailplane minimum rate of sink. For this purpose only devices which increase drag of the basic section as little as possible can be considered. The rate of sink increases proportionately to the increase of drag due to the use of the flap.

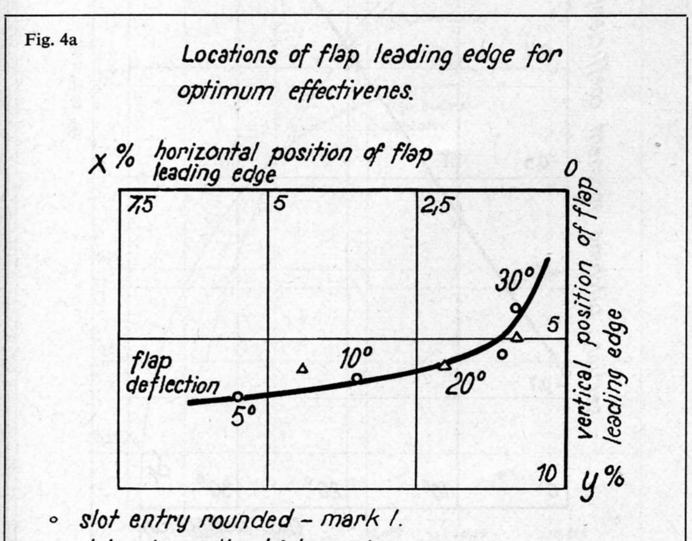


Fig. 4a

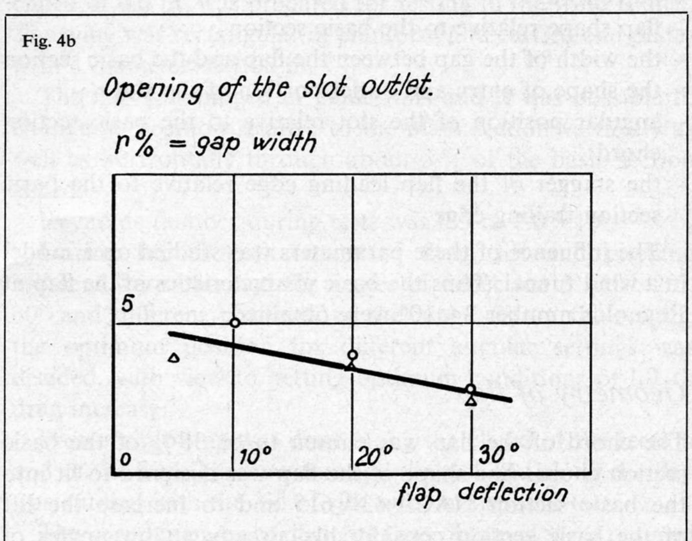
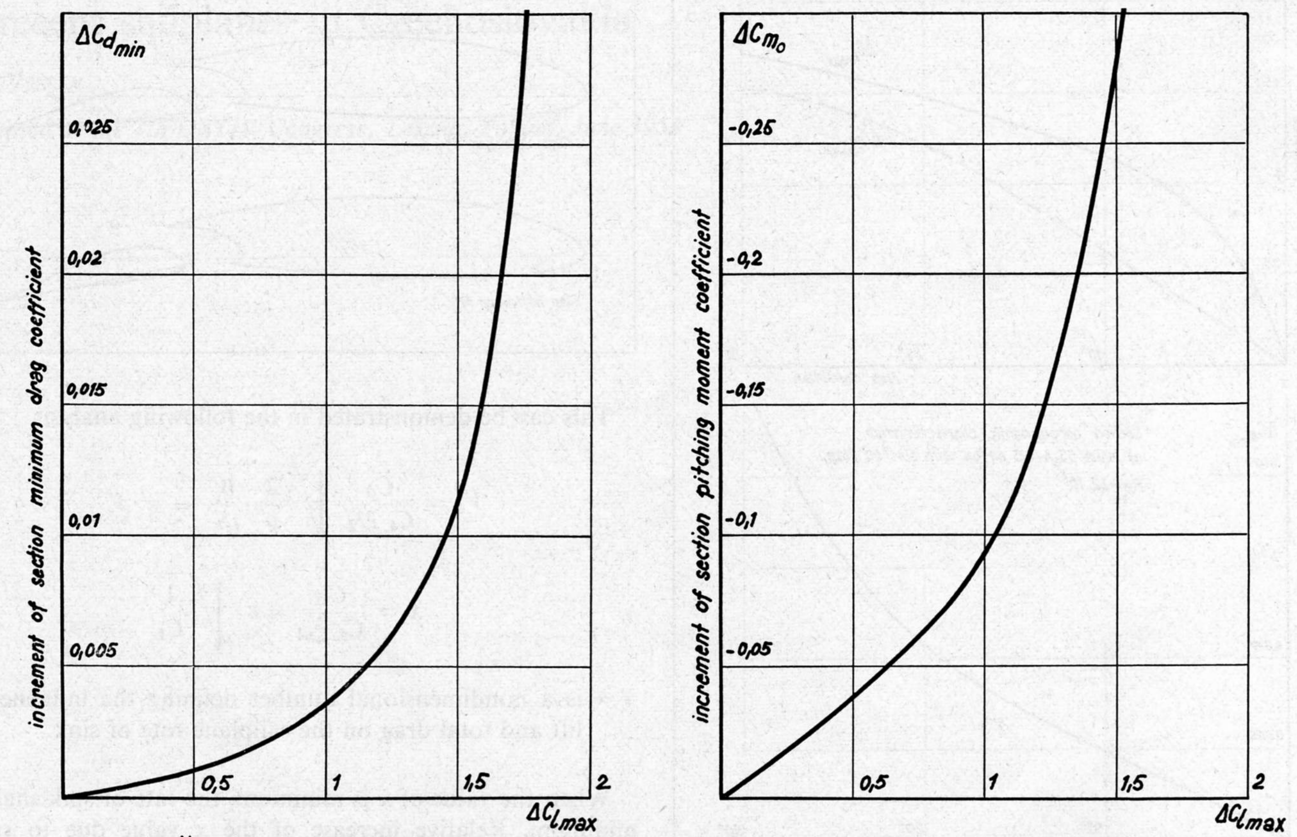


Fig. 4b

Fig. 5



Variation of increment of section minimum drag and pitching moment coefficient to increment of section maximum lift coefficient.

Wing area increasing slotted lift flap

The characteristics of this slotted flap were studied especially in the range of small deflections. The drag increase is very small as long as there is no flow breakaway in the gap or in the accelerated flow around the suction side of the flap. The flow must be directed by the slot in such a way, as to insure minimum changes in the flow velocity and thus also prevent unwanted pressure changes.

We list here main parameters influencing the characteristics of area increasing slotted flap.

- flap chord
- flap shape relative to the basic section
- the width of the gap between the flap and the basic section
- the shape of entry and outlet portion of the slot
- angular position of the slot relative to the basic section chord
- the stagger of the flap leading edge relative to the basic section trailing edge

The influence of these parameters was studied on a model in a wind tunnel. Thus the basic characteristics of the flap at Reynolds number 2×10^6 were obtained.

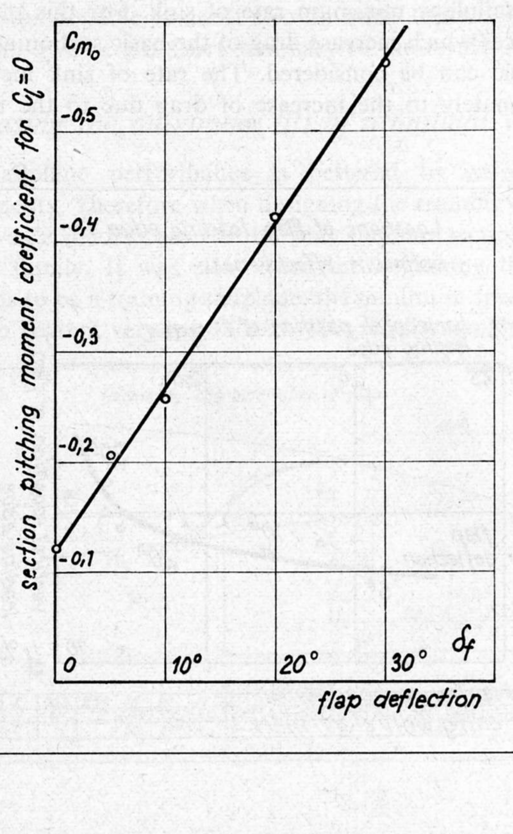
Geometry of flap

The chord of the flap was chosen to be 35 % of the basic section chord. The shape of the flap was designed to fit into the basic section NACA 63A 615 and to increase the lift of the basic section considerably already at low angles of flap deflection.

Fig. 6

Variation of section pitching moment coefficient to flap deflection.

$C_{m_0} = -0{,}117 - 0{,}0148 \cdot \delta_f$



The flap characteristics were studied for two different forms of the slot between the flap and the basic sections.

The angular position of the slot relative to the section chord was the same in both cases. The outlet of the slot was designed to give a flow tangential to the flap upper surface.

Both slots differed only in the form of the entry. The first version has a rounded slot entry, thus giving a smooth transition for the flow from the lower surface into the slot.

Fig. 7 Resulting effect of lift flap on wing.

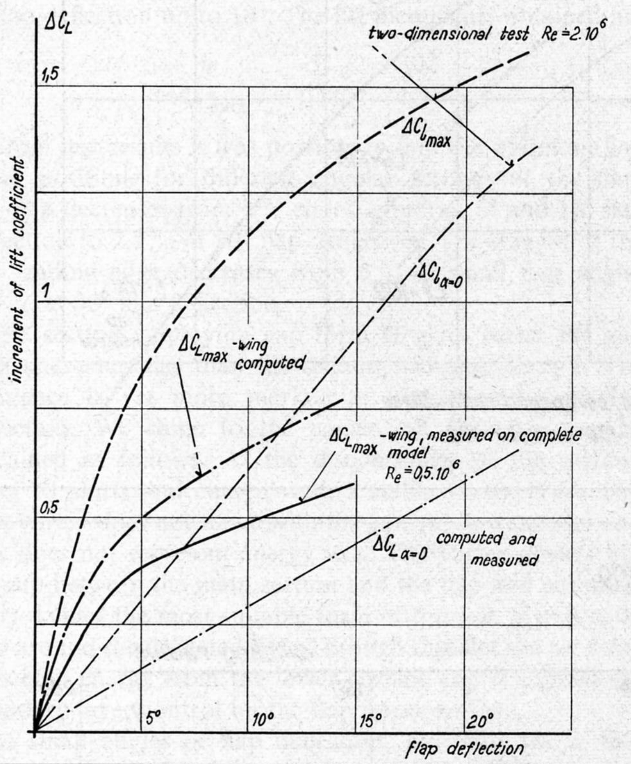


Fig. 8 Polar curves of L-13 sailplane.

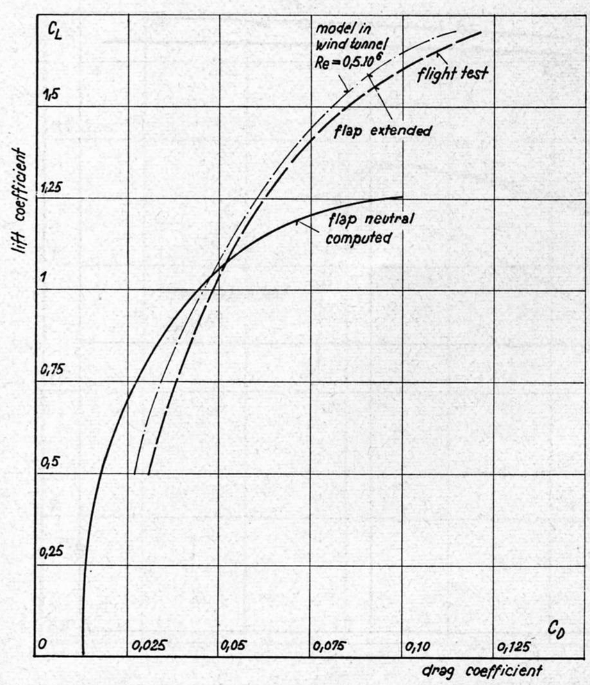
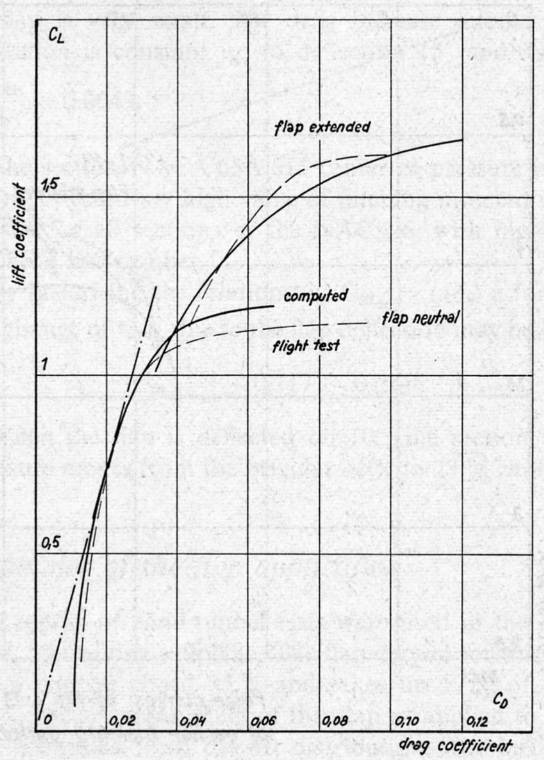


Fig. 9 Polar curves of L-21 sailplane.



The fairing radius is 0.1 c. When the flap is set to zero deflection, there is of course a sharp discontinuity in the lower surface between the main section and the flap. This version is marked I.

The other version is so designed that there is no marked discontinuity between the basic section and the flap. The flap, when retracted, does not in any way disturb the flow along the lower surface. When the flap is extended, there is sharp discontinuity in the shape of the lower surface between the main section and the flap. This version is marked as slot II.

Description of the model and tests

A wing model with a flap having a span of 1.2 m. and a chord of 0.6 m. was prepared for testing in the wind tunnel. The wing was rectangular in planform and carried end plates with a diameter of 1.08 m.

The flap was hinged in guide rails and it was possible to change its position relative to the main section vertically as well as horizontally through about 5 % of the basic section chord.

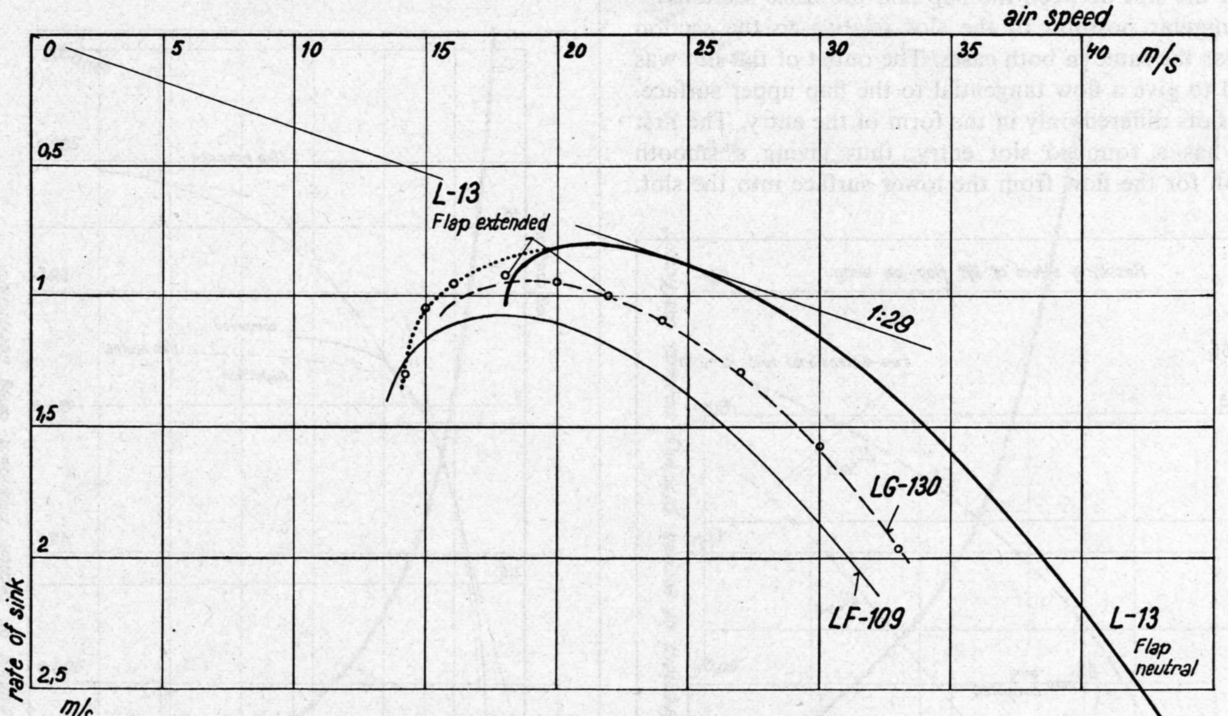
Reynolds number during tests was 0.5 to 2.0×10^6.

During tunnel tests curves of drag, lift and pitching moment were obtained for angles of deflection 5°, 10°, 20°, 30° and different positions of the hinge. From the results, the optimum position for different angular settings was decided, with view to getting optimum conditions of lift to drag increase.

Pressure plotting was done along the chord of the section and of the flap. The flow through the slot and along the flap was studied with the aid of silk tufts in a special test.

The aerodynamics coefficients thus obtained were reduced analytically for a infinite span.

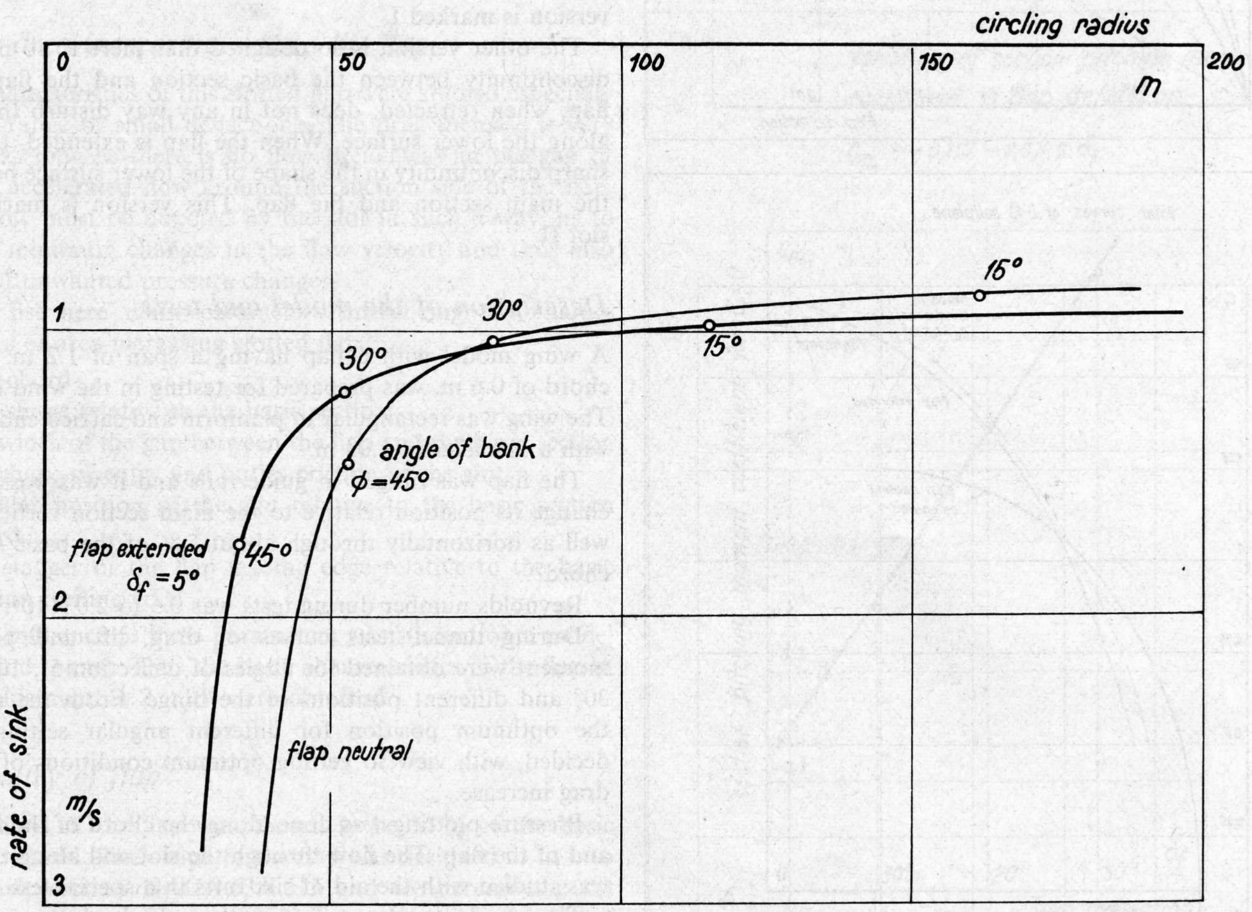
Fig. 10



Polar curves of the L-13 sailplane, compared with these of earlier training sailplanes LG-130 and LF-109.

Fig. 11

Rate of sink of L-13 sailplane in circling.



Conclusions drawn from tests

Tests in the wind tunnel produced characteristics of the flapped airfoil in the range of Reynolds numbers 0.5 to 2.0×10^6.

The section 63A 615 employing flap with slot form II has shown values of minimum drag by about 10 % lower than section with slot form I, when flap was set to zero deflection angle.

The above mentioned flap is aerodynamically very effective. From the relationship $\Delta C_{L\max} = f(\delta_f)$ can be seen that highest derivative of lift increment is obtained at low angles of flap deflection up to 10°. The lift increments obtained are

δ_f	5°	10°
$\Delta C_{L\max}$	0.86	1.15

From test results it was possible to find the optimum flap hinge positions for different angular settings of the flap. The gap decreases from 4 % chord length at 5° and 10° flap deflection to 2.5 % at 30° flap deflection. The stagger of the flap leading edge decreases from 5 % at small flap angles to 1 % at 30° flap deflection.

The section employing gap form II gives better lift and drag characteristics than the section with gap form I. The difference is yet more marked at higher angles of flap deflection. We came to the conclusion that this can be explained as follows. At the discontinuity of the section, given by skirts and curved wall, a stable vortex is formed. This vortex does not move with the general flow pattern and thus does not represent energy loss. The vortex always fills the gap between the main section and the flap and automatically defines the most suitable form of the slot, giving good flow around the deflected flap. Through this slot the air flows with high energy from the lower surface and is utilised for boundary layer control on the flap upper surface.

At small angles of flap deflection, the influence of flap hinge position on maximum lift increment is relatively small.

From relationship $\Delta C_{D\min}$ on $\Delta C_{L\max}$ can be seen that up to lift increment $\Delta C_{L\max} = /\cdot 3$ the drag increase due to flap is very small. The drag increase due to unit flap deflection is constant up to deflection 15° and its value is

$$\frac{\Delta C_D}{\Delta \delta_f} = 0.0048.$$

The section NACA 63A 615 center of pressure is at 24 % chord. A relatively high value of pitching moment is characteristic for all sections of the NACA 6, with higher values of chord line camber.

By linearising the relationship $C_{m_0} = f(\delta_f)$ a formula for the change of C_{m_0} due to the flap deflection may be obtained.

$$C_{m_0} = -0.117 - 0.0148 \cdot \delta_f$$

When the flap is deflected on 10°, the section center of pressure moves from the original 24 % to 27 % chord length.

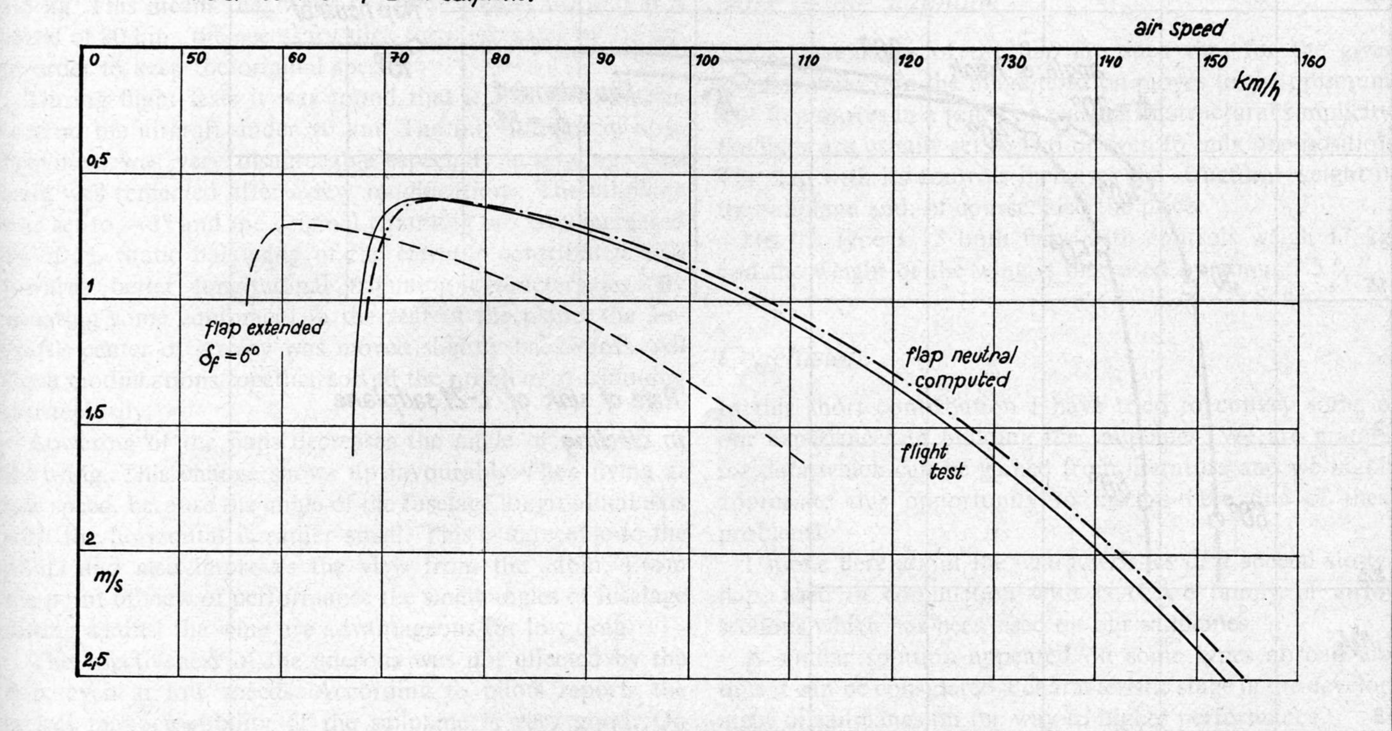
Examples of the flap application

The results of wind-tunnel tests were used in the design of the L 13 training sailplane. The flap chosen for this machine has a relative chord 35 % and takes up 57 % of the wing span. The resultant effect of this flap as applied to the wing was computed from the lift distribution. The increment of maximum wing lift due to flap deflection is shown in diagram 7 and for the most used angles of deflection is

δ_f	5°	10°
$\Delta C_{L\max}$	0.5	0.66

Due to the necessary increment of the balancing force acting on the horizontal tail surfaces when the flap is deflected the resultant increments of lift decrease by about 10 %.

Fig. 12 *Polar curves of L-21 sailplane.*



Polar curves of the sailplane obtained in flight, calculated and obtained in the wind tunnel on a model (scale 1 : 7,5), were compared. Reynolds number obtained in the tunnel with the above mentioned model was 0.5×10^6. The resultant increments of lift obtained on the model were smaller (about 20 %), probably due to the low Reynolds number.

The drag as obtained by calculations from flight-test results is higher than the drag indicated by calculations.

According to flight-test results the best glide ratio 1 : 28, obtained with flaps retracted, drops to 1 : 23 when flaps are set to 10°. The minimum rate of sink increased by about 10 cm/sec. and is obtained at a speed lower by about 15 km/h. than with flaps retracted. The flap area is 20 % of the total wing area.

The L 13 sailplane is designed for elementary training as well as for high performance.

From the speed polar curves (relationship between sinking speed and airspeed) for the aircraft it can be seen that the L 13 sailplane is better in straight flight, as well as in circling, than both training types used at present, which will be replaced in future by this new aircraft.

The laminar wing of the L 13 with its very effective lift flap enables flying at low speeds comparable with the type LF 109 but with a much lower rate of sink.

For comparison, geometric characteristics of sailplanes used earlier for elementary training are given in the accompanying figures.

Sailplane LG 130 is a two-seater with seats side by side.

Sailplane LF 109 is a two-seater training plane with seats in tandem. This aircraft is designed for elementary training.

In the following table are compared the dimensions, weights and performances of these types.

The effect of the lift flap is especially marked in circling. By setting the flaps to 5° when circling with a radius of turn 50 m., the angle of bank may be decreased by 15° and the rate of sink is 20 % lower. When circling with a radius of 40 m., the application of the flap lowers the rate of sink by 50 % against the value when flying with flaps retracted. A similar flap was used on sailplanes VSM 40 (manufactured 1956) and L 21 (manufactured 1957), which whilst having a wing loading 24 kg./m.² are able to circle in thermals on a radius of 45 m. with a rate of sink of approximately 1 m./sec.

The effect of the lift flap used on high-performance sailplanes is shown in the following table.

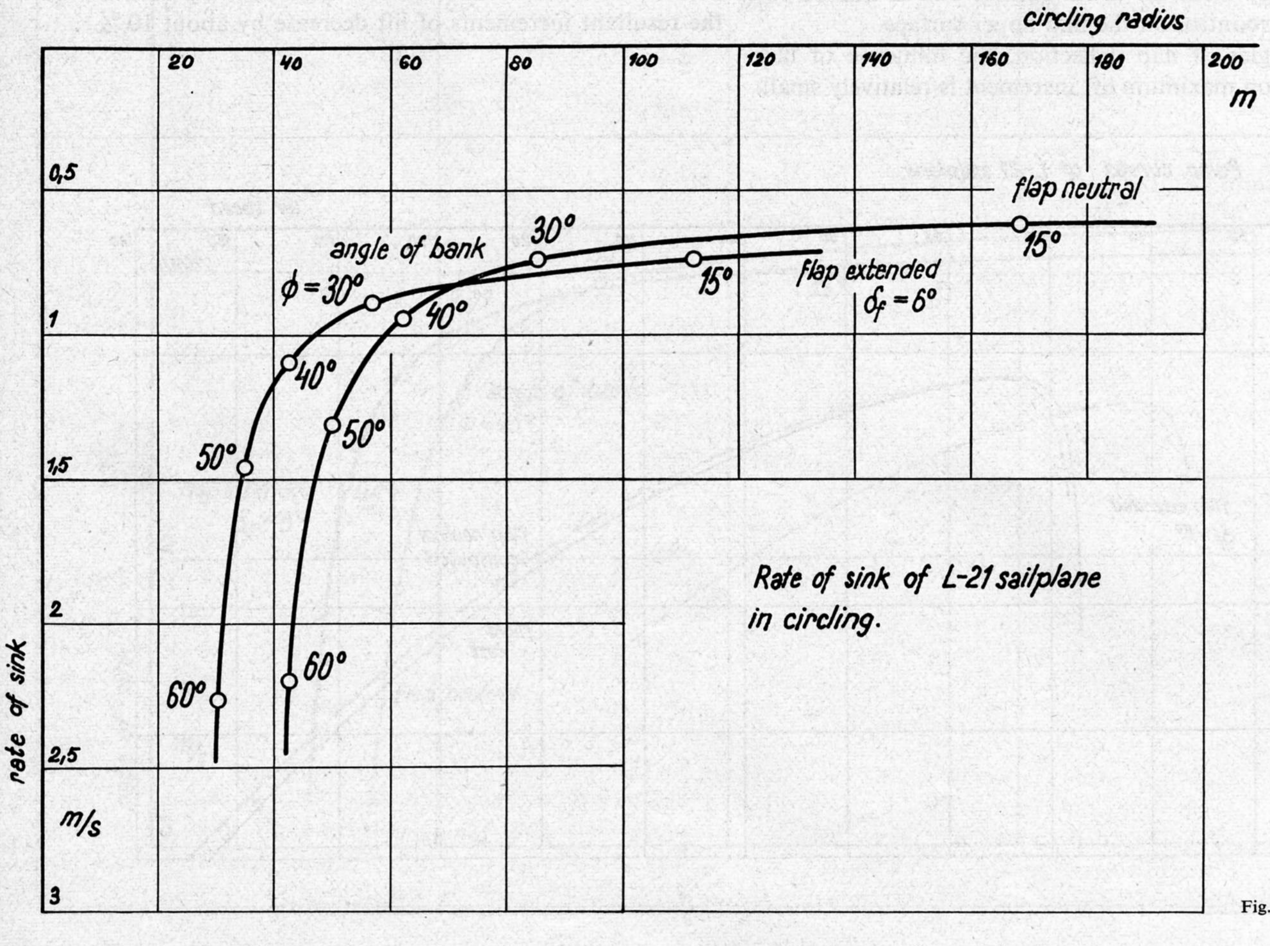


Fig. 13

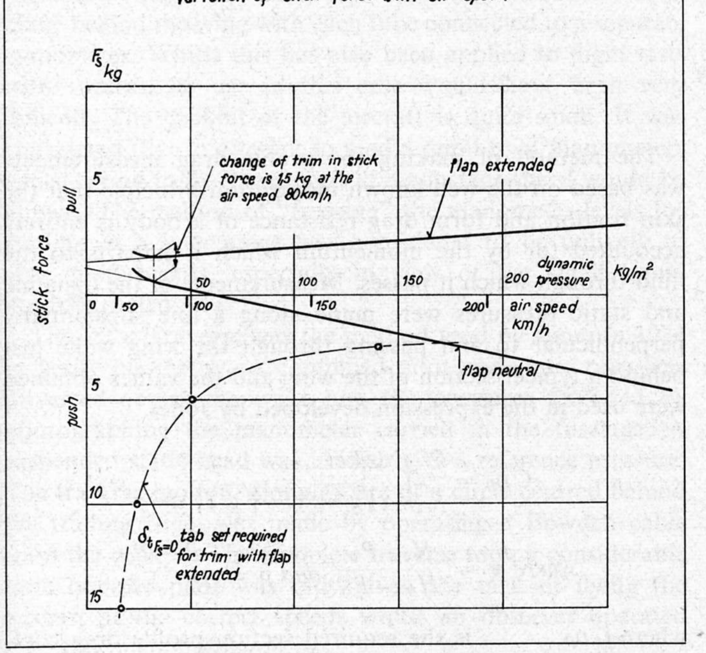


Fig. 14 *Variation of stick force with air speed.*

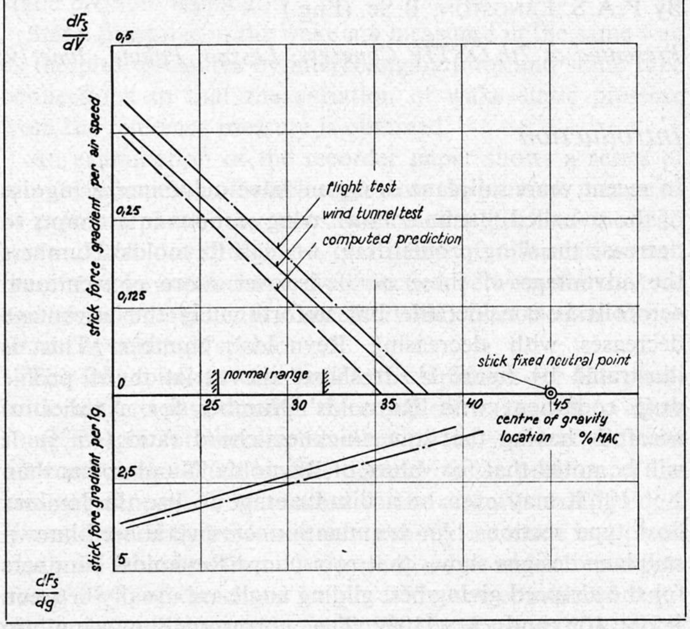


Fig. 15 *Determination of longitudinal stability neutral point of L-13 sailplane.*

Sailplane VSM 40, lowering the flap by 10°, minimum best glide ratio drops from 1 : 33 to 1 : 28. Minimum rate of sink increases by 7 cm./sec. and is obtained at a speed 12 km. lower.

Sailplane L 21, lowering the flap, the best glide ratio 1 : 35 drops to 1 : 25. The minimum rate of sink increases by 10 cm./sec. and is obtained at a speed by 12 km./h. lower.

Both types with the lift flap are characterised by a wider range of flying speeds and thus have increased possibilities for high performances.

The effect of lift flaps on flying characteristics

The high lift of the flap is accompanied by high pitching moments which have to be balanced. On the L 13 sailplane the change of trim when the flaps are set at 80 km. is about 1.5 kg. This means that when the pilot applies the flap at a speed of 80 km., the necessary stick force increases by 1.5 kg. in order to keep the original speed.

During flight tests it was found that it was not possible to trim the aircraft under 90 km. The fair amount of nose heaviness was very disagreeable especially in circling. This snag was remedied after a few modifications. The tailplane was set to —3° and the original trimming tab area increased by 20 %. Static balancing of the elevator contributed also towards better longitudinal trimming characteristics. By situating some equipment in the rear of the plane, the aircraft's center of gravity was moved slightly backwards. All these modifications together solved the problem of trimming satisfactorily.

Lowering of the flaps decreases the angle of zero lift of the wing. This change shows up favourably when flying at low speed, because the angle of the fuselage longitudinal axis with the horizontal is rather small. This is agreeable to the pilots and also improves the view from the cabin. From the point of view of performance the small angles of fuselage setting against the wing are advantageous for low drag.

The effectiveness of the ailerons was not affected by the flap, even at low speeds. According to pilots reports the lateral manoeuvrability of the sailplane is very good. On the L 13 sailplane the average time necessary to change the angle of bank of 45° from one side to opposite side at a speed 1.4 V min. is 3.5 seconds with flaps lowered against 3.2 seconds with flaps retracted.

The gradient of the stick-force curve as a function of the dynamic pressure increases slighty when the flaps are lowered. Wind-tunnel tests indicate that with the NACA 63A 615 section employed, the neutral point moves back by about 3 % when the flaps are lowered.

When considering unfavourable aspects of the flap, the high pitching moments should be considered first. This aspect must be kept in mind when designing the horizontal tail surfaces.

The effect of the flap on the weight and price of the sailplane

The kinematics of the flap are such that for the given angular deflection the hinge position moves to the optimum. The flap moves in a rail. For reasons of structural simplicity, the flaps are usually set to two or even to only one position. The flap with its controls increases the structural weight of the sailplane and, of course, also the price.

On the type L 13 both flaps with controls weigh 17 kg. and the weight of the wing is increased by about 7.5 %.

Conclusion

In this short contribution I have tried to convey some of our experiences in building the sailplanes. We are grateful for data which can be gained from literature and we highly appreciate this opportunity to discuss here one of these problems.

I spoke here about the characteristics of a special slotted flap, used in conjunction with NACA 6 family of airfoil sections which has been used on our sailplanes.

A similar solution appeared on some types abroad and thus it can be considered a characteristic stage in the development of sailplanes on the way to higher performance.

(Swiss Aero Review 1959/2 and 3)