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EXPERIENCES AND MEASUREMENTS GAINED ON THE LOW-SPEED-AIRCRAFT Fi 156 "Storch"

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Translated Under

Contract Nonr 978(01)

Reported to the

Lilienthal-Gesellschaft fuer Luftfahrtforschung

on

June 14 at Goettingen

Translated By

Georg K. Timm

November 24, 1956

for

The Aerophysics Department

of

Mississippi State College

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Means to increase the lift (high-lift devices) are mostly used to decrease the landing speed of aircrafts with a high wing loading. With the Fieseler "Storch" the goal was different: low-speed flight.

The experiences concerning the flight characteristics of this model will be discussed in this paper. These flight tests and flight measurements have been obtained for this particular airplane at extremely low flight velocities.

Considering the flight performance which led to the design of the "Storch", we had to be able to fly at low speeds, to take-off short, and to land short. These requirements can be obtained by means of high lift coefficients, low construction weight and low wing loading. The wing area (Fig. 1) could be increased only moderately in regard to activity and space required; a wing loading of a little less than 50 kg/m^2 seemed to be the best compromise. The power weight ratio is 5.2 kg/PS.

The construction weight could be held down by relinquishing fairings with low drag, e.g. on the fuselage. Therefore the slat has been fixed in a position favorable for the $C_{L\ max}$ (Fig. 2). Besides that, we were able to hold the construction weight down particularly by improving the structure. The weight of the wing was as low as 6.8 kg/m^2

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(including the fabric covering; without the controls and tanks, but including ailerons, landing flaps and slats together with their struts); a value which is near the lower limit of weight for wings of the same wooden construction and the same aspect ratio of 7.8 for this current strength requirement, P3, which was used here. Slats, together with their fittings, make only 7% of the total weight of the wings, fabric covering 6%, struts 15%, ailerons 7% and landing flaps 4%. Even the paint and finish have been investigated in respect to their weight and a total weight of 300 g/m^2 was obtained for a sufficient protection (6 layers).

The gross weight of 1320 kg consists of:

empty weight including permanent equipment	860 kg
additional (military) equipment	100 kg
structural weight	960 kg
fuel and lubricants	120 kg
3 man crew, 80 kg each	240 kg
full gross weight	1320 kg
normal gross weight (2 place + 20 kg)	1260 kg
total load is 54% of empty weight	

Dimensions:

span	14.3 m
width, wings folded down	4.7 m
total height	3.1 m
total length	9.9 m
wing area	26.0 m^2

engine: Argus As 10 C	2000 RPM
maximum horsepower (5 min.)	240 PS
wing loading (1260 kg)	48.5 kg/m^2
power loading (240 PS)	5.3 kg/PS

Flight performances valid near the ground and for normal gross weight (obtained by flight tests):

maximum speed	180 km/h
guaranteed minimum speed for stationary horizontal flight	48 km/h
maximum lift coefficient (at minimum speed) $C_L = \frac{G}{qF}$	4.0
minimum speed near ground with 3 m/s headwind	37 km/h
maximum climbing speed	4.8 m/s
time to climb from 0 to 1 km altitude	3.9 min.
service ceiling	5.2 km
maximum ceiling	5.9 km
take-off distance, calm	65 m
take-off distance, 3 m/s headwind	50 m
take-off distance from 0 to 15 m altitude, 3 m/s headwind	130 m
length of landing run, applying the brake	20 m
length of landing run, 3 m/s headwind	15 m

Take-off and Landing

The take-off distance is mathematically proportional to the 2.6th power of the gross weight. In order to obtain a short take-off, low gross weight is important. The correctness of the decisions made concerning the structure, which helped to hold the gross weight of the "Storch" down, was also proved in this case. The take-off distance might be decreased by a high take-off-C_L. This is possible by obtaining a sufficient ground-angle of attack $\alpha_{fuselage} = 14^\circ$, $\alpha_{wing} = 16^\circ$. With the assistance of slotted landing flaps we get a $C_L = 2.7$ (production model), Fig. 12. The take-off distance decreases a good bit with deflected flaps (Fig. 6) from nearly 100 m to 65 m. These values are valid with normal gross weight (1260 kg), calm, and a normal and dry grass strip. With wind (Fig. 3) we obtain very short distances, as low wind velocities have a great influence on the comparatively low take-off speed (61 km/h). With 6 m/s wind the fully loaded aircraft will take-off after 40 m at most.

Special attention was paid to the selection of the propeller. The wooden propeller has a diameter of 2.6 m and a pitch h/d 0.56. It was designed as a compromise and climb propeller. It gives, with a figure of merit of 0.65, a net thrust of 400 kg measured at the tail wheel. The landing distance is very short (Fig. 3), 20 m when calm, and only a little more than the over-all-length (with 6 m/s wind). Fig. 3 shows landings with power off; when touching the ground in power landing with approximately half-open throttle, we obtain an even shorter landing distance: about 15 m when calm.

Rate of Climb

The rate of climb corresponds to the wing loading of 48 kg/m^2 and the power loading of approximately 5 kg/PS. The flight path speed of fastest climb and moreover the flight path speed of steepest climb are very low: 85 and 72 km/h respectively. This is due to the lift increasing devices. The polar for climb performance at high lift coefficients improves favorably by using the leading edge slat and moderate deflection of the flaps, $\frac{C_L^3}{C_D^2}$. It climbs at $C_L = 1.4$ and 1.9 respectively.

The rate of climb (Figs. 4 and 5) was obtained by saw-tooth-climb with a difference in altitude of 200 m. This procedure of saw-tooth-climb is more authentic and more informal than the normal way of using a barograph to determine the rate of climb. By using this method it was also possible to obtain the influence of the landing flaps on the rate of climb (Fig. 6). Fastest climb was found at 10° deflection of the flaps, steepest climb at 15°. The steepest angle of climb $\gamma = 13°$ and the ratio of climb $w/v = \tan \gamma = 0.23$ are extremely good values. The aircraft climbs 23 m over a 100 m distance (calm and full normal gross weight). Another remarkable rate of climb is found at v_{min}. It is possible to climb with a speed of 2 m/s in the flight condition of $C_{L\ max}$.

The cruising speed demanded for the "Storch" was 150 km/h. The obtained maximum velocity of 180 km/h without extraordinary improvements, and without adding weight, corresponds to the technical demands for this design. An $\eta / C_d = 11.4$ corresponds to this velocity and at an $\eta = 0.75$; a $C_d \cong 0.066$. This value is rather high; it consists of 7% c_{di} ($C_L = 0.3$; $\mathcal{R} = 7.8$), 48% c_{df} and 45% c_{do}. The latter wing value is high due to the fixed leading edge slat only. An increase of maximum speed of about 20 km/h would be possible by making the leading edge slat retractable. This increase has been neglected so far, as mentioned before, because there was no necessity for it and as the stress was put upon extreme simplicity and lightness. At first the fairings for the landing gear and the wing struts had been omitted for the prototype. The loss in speed compared to an aircraft of the recent series was 20 km/h which corresponded to drag of the struts calculated; therefore the fairings were not relinquished for these parts.

Lateral Control

A difficulty which must not be underestimated for a slow speed aircraft is to obtain sufficient effectiveness of the controls about all three axis. Aerodynamically there is a certain moment coefficient $c_m = \frac{M}{qFt}$ independent of the flight speed, but determined by a given vertical stabilizer and ailerons - based on the wing area. This moment, moving the mass of the aircraft, decreases together with the aerodynamic pressure. Therefore it is essential to design bigger and more effective controls for low speed aircrafts.

The effectiveness of the ailerons can be partly increased by means of the rolling and yawing moment. With the aid of the vertical stabilizer a moderate angle of sideslip is given to the airplane whereby with a sufficient dihedral of the wing, a strong positive rolling moment in the intended direction of the turn is obtained. Therefore it is obvious that the vertical stabilizer can assist the ailerons. Fig. 8 shows an experimental model of the "Storch". Slanted wing tips have an effect similar to a dihedral. By attaching these wing tips, a strong enough rolling moment was obtained to take-off, cruise, and land this airplane even with blocked lateral controls. The measured rolling time, from -45° to +45° lateral bank, was about three seconds, approximately the same for aileron and for rolling and yawing control. Combined it was about two seconds. We are forced to warn one not to use the described method as the only lateral control. The experiments of the American, Weick, proved it. For a lateral control by means of rolling and yawing moment, a slip angle is necessary, which during the landing process might be somewhat dangerous at the touch-down point. The above described way was very satisfying for low speed flights in the air.

The Elevator

There were no difficulties due to longitudinal stability. Due to the leading edge slat we were always able to get a positive stability with elevator free and with the throttle wide open or power off, even for the extraordinarily large angles of attack up to 30°. The influence of the vertical position of the center of gravity on the stability often has not been considered. This high wing aircraft is sufficiently stable with the lower position of the center of gravity at h/t = 36% and the rearward center of gravity position at more than 40%. There is no leading edge slat in the center of the wing over the canopy. Therefore less lift is generated here which correspondingly causes less down wash in spite of the direction of the propeller wash, which is favorable for the stability.

The "Storch" is able, according to its purpose, to land on short unprepared fields and to perform stalling flights. It is possible to fly it beyond $C_{L\ max}$ and be fully under control. Without regard to the necessary stalling safety, it is necessary to have sufficient elevator effectiveness especially for stalling flights.

A normal horizontal tail surface consisting of a fixed stabilizer and an adjoining elevator reaches the limit of its effectiveness in the landing condition, i.e., a local angle of attack of 15^o to 20^o and full elevator deflection (30^o to 35^o). The downward force which is necessary for performing stalling flights with a high wing aircraft, is not obtained. In order to find methods for improvement, investigations were made in a wind tunnel. A slot arranged between the horizontal stabilizer and the elevator in order to achieve a larger angle of deflection was unsuccessful, as shown in Figure 10. A slot arranged above the horizontal stabilizer (like the Junkers Elevator) or below it was also unsuccessful. The flow separated early on the bottom side of the elevator and was not improved but, as a matter of fact, was made worse.

The goal was reached by arranging an auxiliary wing below the leading edge of the elevator, condition C in Figure 10. By using this auxiliary wing the effectiveness of the rudder is obtained for the landing condition ($a_h \approx 20^o$) up to an angle of deflection of about $\beta = 45^o$.

Flight measurements on the same subject are shown in Figure 11. The pitch angle of the aircraft performing a stalling flight with power off depends on the effectiveness of the elevator. This angle is plotted against the angle of deflection of the elevator β. Without the auxiliary wing, the limit of effectiveness is reached at $\beta = 35^\circ$; with the auxiliary wing in a favorable position the limit is reached at $\beta \approx 50^\circ$. To execute a 3-point landing from stalling flight glide with power off, a pitch angle of 14° is necessary for the Fi 156. The additional pitch angle which was required to reach 14° was obtained by extending the elevator beyond the horizontal stabilizer. Here it acts as a pendulum elevator undisturbed by the horizontal stabilizer and at the same time furnishes the balance of control.

$C_{L\,max}$ and v_{min}

Obtaining a maximum lift coefficient deserves the greatest interest in regard to a flight-mechanical consideration. The flight measurements were performed using exclusively a DVL static pressure bomb. The total pressure was measured with a Kiel tube on the airplane. The dynamic pressure was measured with an Askania bellows type meter. These instruments give in comparison with liquid-filled instruments, a much higher grade of accuracy and give faster readings. For the production type "Storch" the following $C_{L\,max}$ values were obtained repeatedly and stationary over any time:

	A	B	C
40° deflection of landing flaps	?	(2.2)	3.1
Leading edge slat (without landing flaps)	1.6	2.2	2.7
Leading edge slat + landing flaps	2.0	2.9	4.0

Column A contains values for power-off flights; B, values recalculated for the wing in free flight without fuselage and propeller wash; C, values valid for horizontal power flight.

The good $C_{L\,max}$ values obtained in the wind tunnel have been verified at the outboard wings, which are undisturbed by fuselage and propeller wash. One must take into consideration that the flaps on the Fi 156 extend only a little more than half the wing span. The ailerons are deflected together with the landing flaps to 15°. By comparison of columns A and B, we see that about 25% of the wing area is so badly disturbed by the fuselage and the idling propeller, that there is practically no lift produced in this area.

The comparison of columns B and C shows the overwhelming influence of the propeller wash on maximum lift generation. The lack of lift described above has not only been improved and filled by the propeller wash, but more than that a further increase in lift has been obtained. The latter value may be calculated from the vertical component of the propeller thrust. For the condition landing flaps and leading edge slats, it results, e.g. at 30° angle of attack in a vertical thrust component (at about 400 kg thrust) of 200 kg. At $v_{min} = 48$ km/h, $q_{min} = 10$ kg/m^2 respectively, it results in a $C_L = \frac{200}{(10)(26)} = 0.76$. The value measured was even larger, probably because the propeller wash was deflected more downward by the landing flap. The great increase of the lift coefficient caused by propeller thrust is possible on a low speed aircraft only as the coefficient is related to the dynamic pressure.

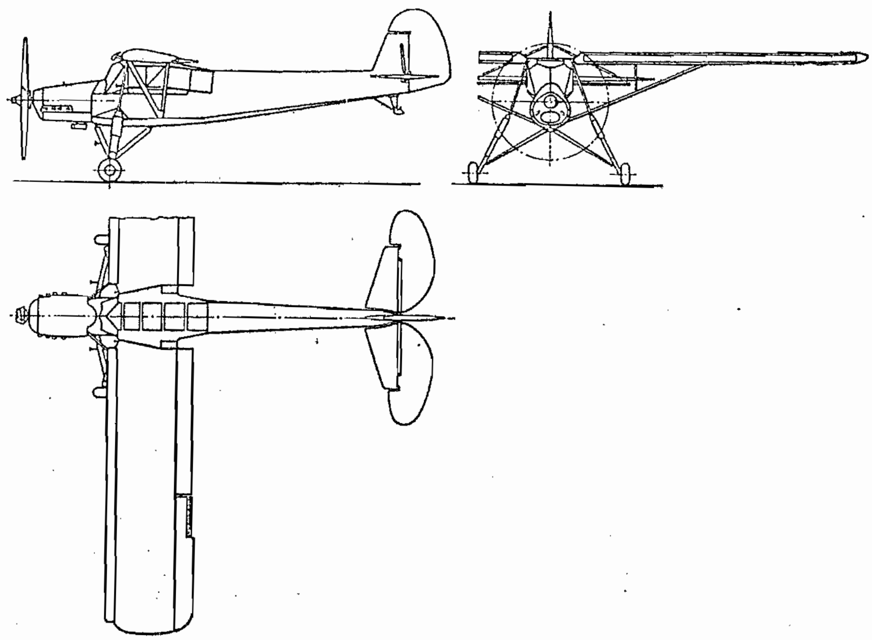
Figure 12 shows lift measurements obtained by use of a DVL-static-bomb during power off flight and horizontal power flight. It is a well known fact that there is a higher lift increase during power flight than during gliding. The concavity of the curve is also correct. The characteristic of the aircraft in the region of $C_{L\ max}$ is excellent. It can be stalled beyond the angle corresponding to $C_{L\ max}$ and nevertheless, be controlled sufficiently. The fact that the aircraft does not stall at $C_{L\ max}$ and beyond, is very important for the practical exploration of such high lift coefficients. The attainable $C_{L\ max}$ peak values have not been obtained on the present production Fi 156 by means of these wings and devices:

A) production aircraft (leading edge slat over the entire wing 40° landing flap deflection over half wing span, ailerons deflected to -15°), $C_{L\ max} = 4.0$, $v_{min} = 48$ km/h

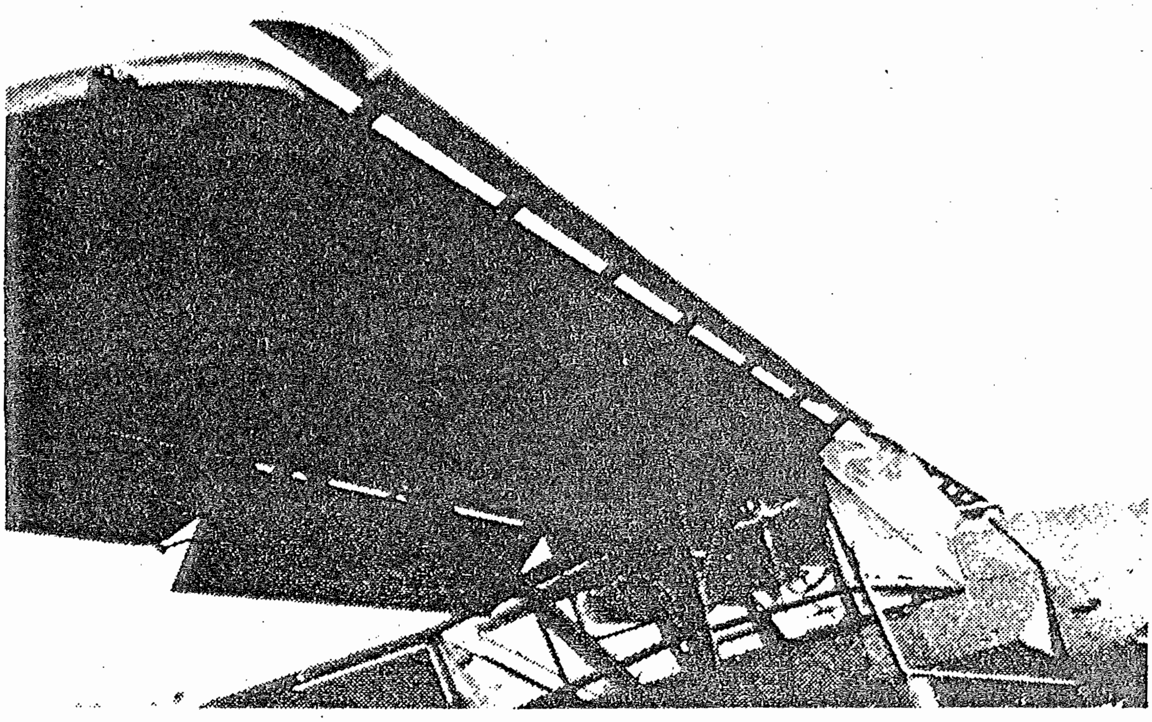
B) 53° landing flap and 38° aileron deflection obtained in flight, $C_{L\ max} = 4.6$; $v_{min} = 46$ km/h

C) 55° landing flap and ailerons deflection, landing flaps extended to the fuselage (at the present time there is a slot of 30 cm), $C_{L\ max} = 4.9$; $v_{min} = 45$ km/h

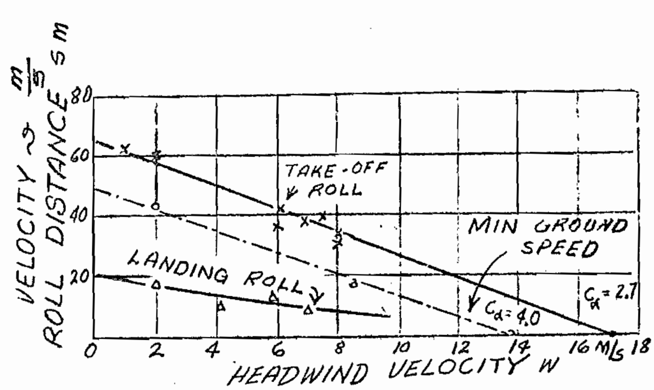
The speed values are valid for normal gross weight of 1260 kg measured in horizontal power flight. The values shown here are with wide open throttle, about $C_L = 0.2$ larger (wide open throttle climbing speed of $C_{L\ max}$ is 2 m/s). $C_{L\ max} = 5$ is then exceeded. It is necessary to say that the measurements published herein have been performed without troublesome, expensive and complicated devices which would be detrimental to flight characteristics.



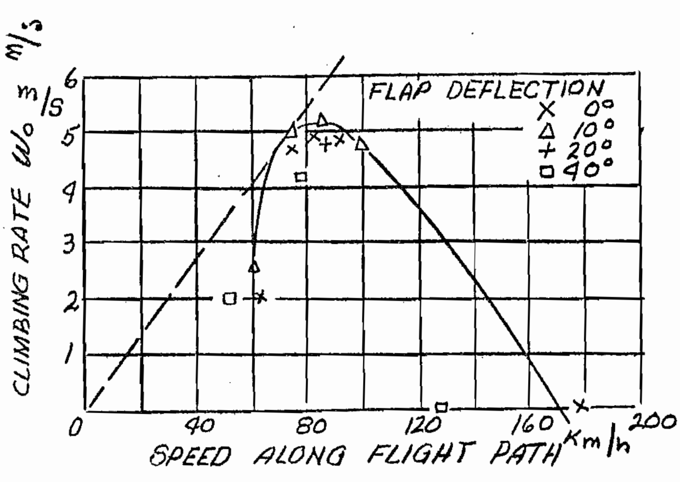
PICTURE 1. LOW-SPEED-AIRCRAFT "STORCH" TYPE "FIESELER" FI 156"



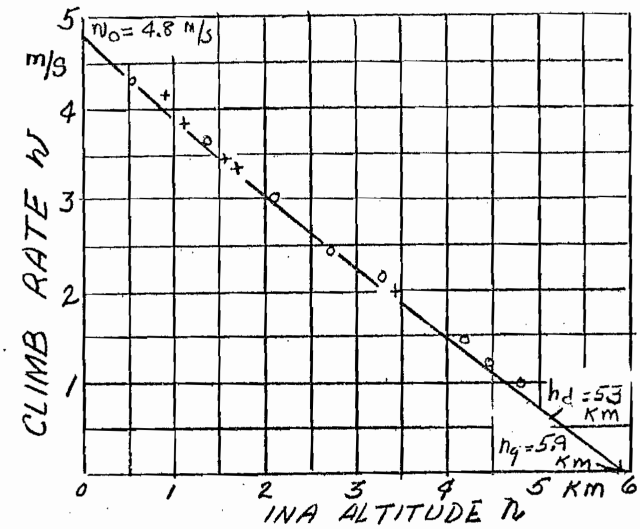
PICTURE 2. CONTINUOUS AND FIXED (NOT RETRACTABLE) SLAT OF THE FI 156



PICTURE 3: GROUND ROLL FOR TAKE-OFF AND LANDING AS A FUNCTION OF WIND VELOCITY. GROUND SPEED IN LEVEL FLIGHT AS A FUNCTION OF WIND VELOCITY WEIGHT 1260 kg 40° LANDING FLAPS.

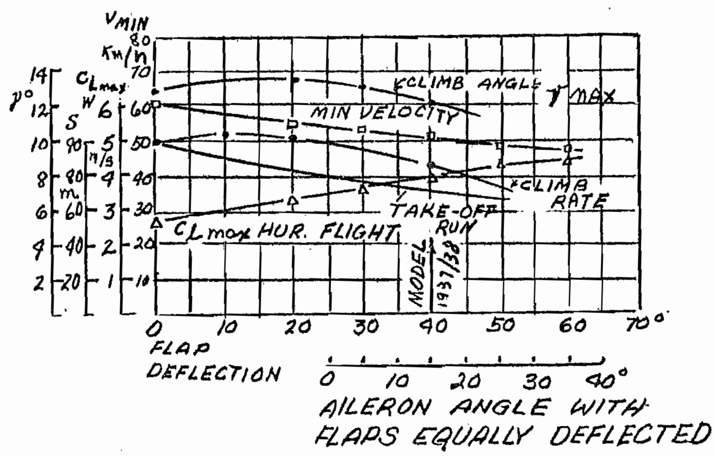


PICTURE 4: RATE OF CLIMB NEAR THE GROUND. WEIGHT 1200 Kg. DATA TAKEN ON 11-11-1937 $\rho = 0.124$.

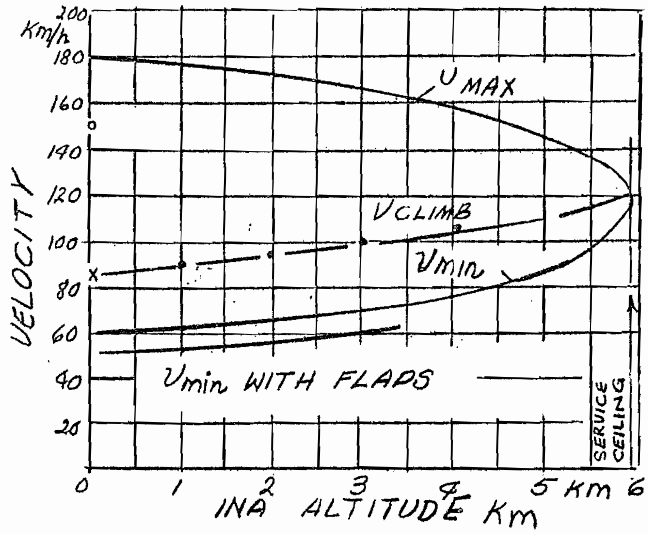


PICTURE 5: RATE OF CLIMB WITH FIXED BLADE, FOR A WEIGHT OF 1260 Kg. (FLAP DEFLECTION $\beta = 10°$

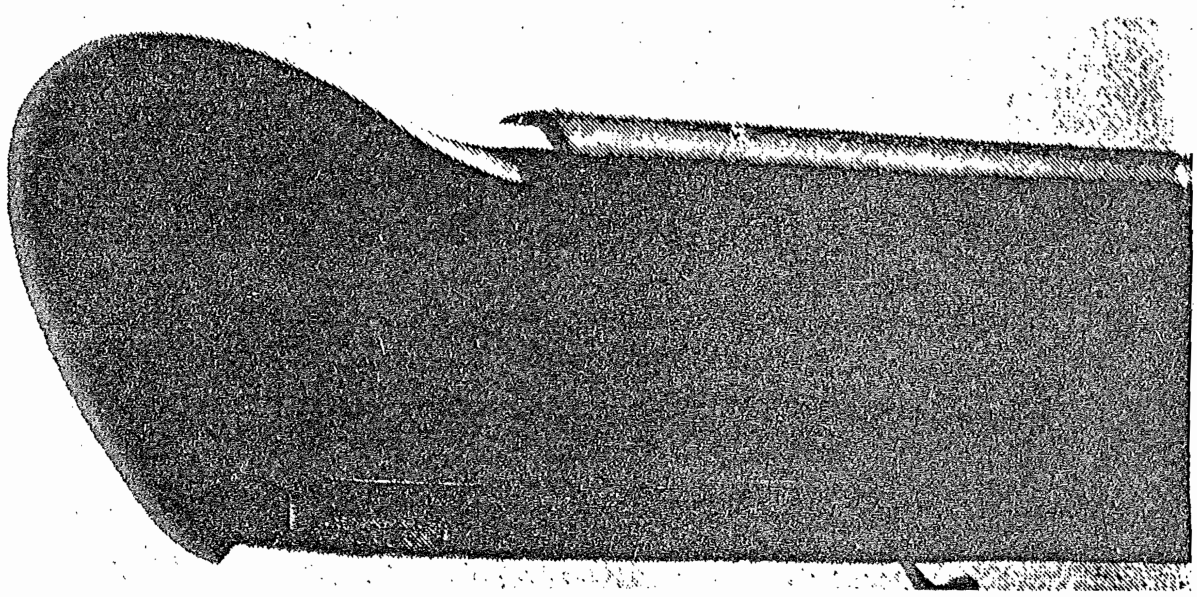
\+ WEIGHT = 1160 Kg. DATA TAKEN ON 14-9-1936.
o WEIGHT = 1080 Kg. DATA TAKEN ON 30-7-1936.
$\} \beta_K = 0°$



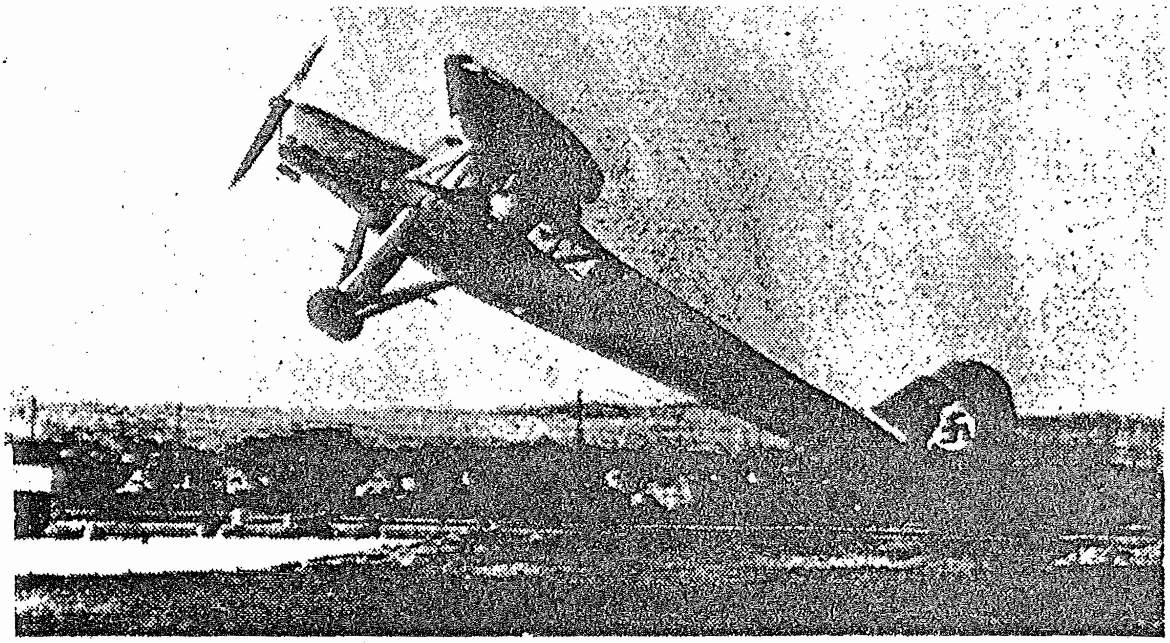
PICTURE 6: FLIGHT PERFORMANCE AS A FUNCTION OF LANDING FLAPS DEFLECTION.



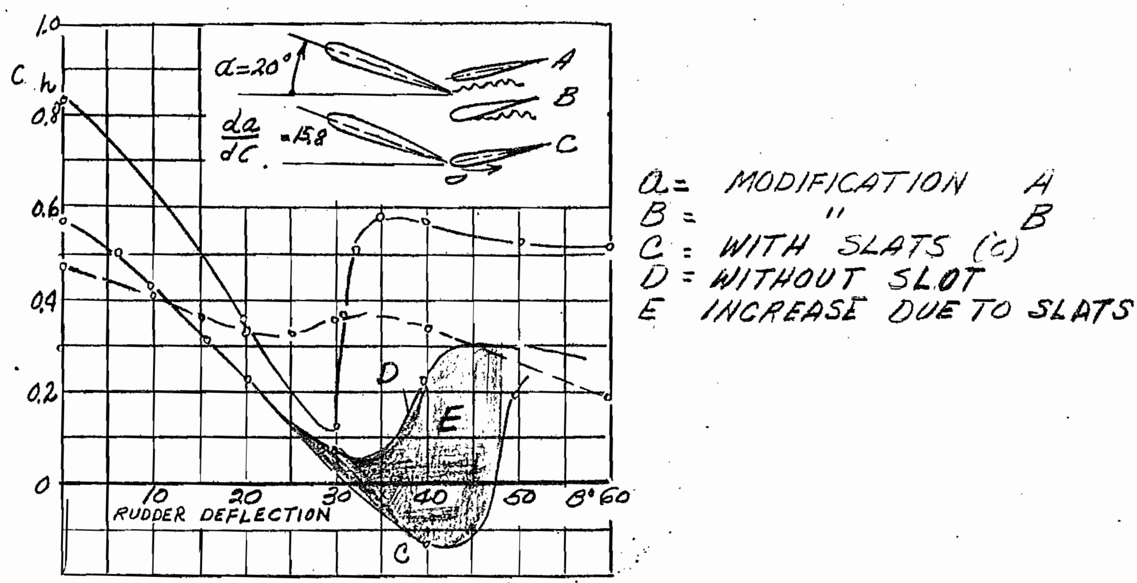
PICTURE 7: FLIGHT SPEEDS AT DIFFERENT ATTITUDES; LANDING FLAP DEFLECTION = 0°.



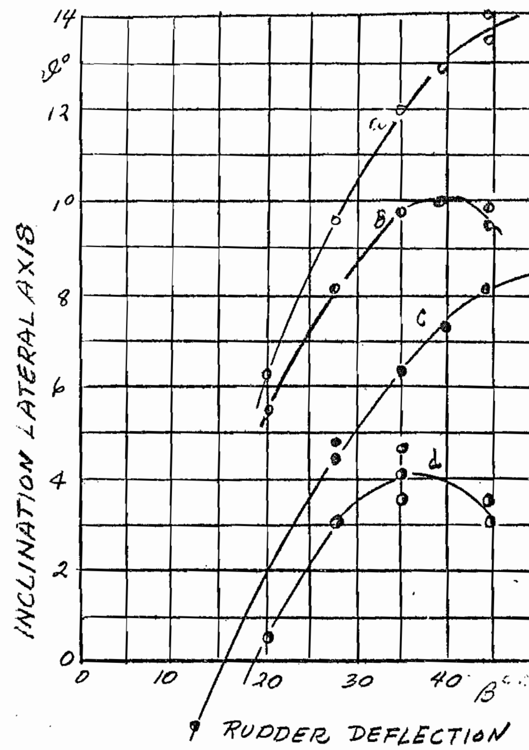
PICTURE 8: FI 156 "STORCH" EXPERIMENTAL MODEL WITH SLANTED WING TIPS



PICTURE 9. FI 156 "STORCH" DURING TAKE-OFF

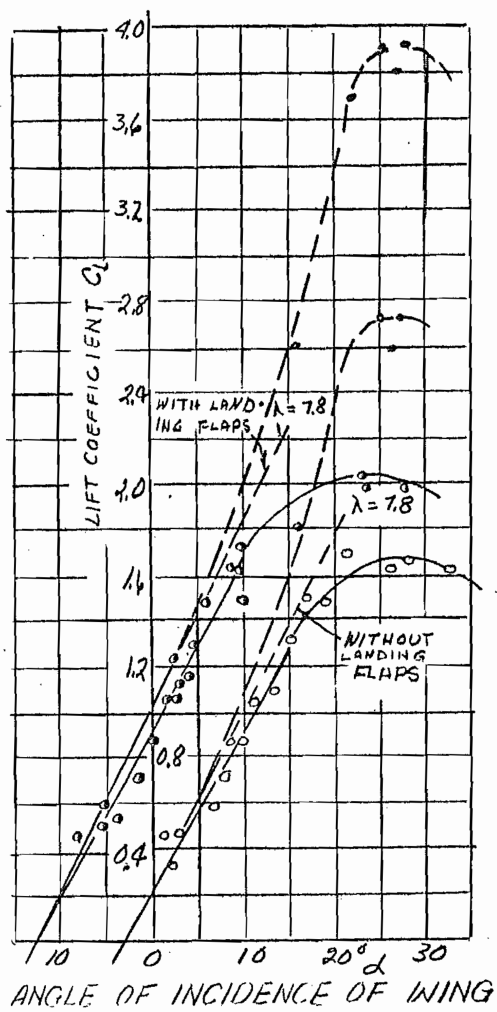


PICTURE 10: EFFICIENCY OF ELEVATOR DURING LANDING $\alpha = 20°$; POSITIVE DEFLECTION ACCORDING TO DATA TAKEN IN THE WINDTUNNEL OF THE FIESELER-FLUGZEUGBAU G.m.b.h.



PICTURE 11: ELEVATOR EFFICIENCY AS A FUNCTION OF STALLING SPEED. FLIGHT MEASUREMENTS MADE DURING POWER-OFF GLIDE

A = ZERO DEFLECTION OF LANDING FLAPS WITH SLATS
B = ZERO DEFLECTION OF LANDING FLAPS WITHOUT SLATS
C = DEFLECTED LANDING FLAPS WITH SLATS
D = DEFLECTED LANDING FLAPS WITHOUT SLATS



PICTURE 12: COEFFICIENT OF LIFT MEASURED DURING POWER-OFF GLIDE AND DURING LEVEL FLIGHT

• WITHOUT LANDING FLAP } POWER-OFF GLIDE
o WITH LANDING FLAP } POWER-OFF GLIDE
-- LEVEL FLIGHT