TECHNICAL MEMORANDUMS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 686

FURTHER FLIGHT TESTS ON THE EFFECTIVENESS OF HANDLEY PAGE AUTOMATIC CONTROL SLOTS

By Wilhelm Pleines

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I. MOTIVE AND PURPOSE OF STUDY

A previous article (reference 1) contained the results of investigations about the efficacy of the Handley Page automatic control slots incorporated in an Albatros type L 75 Ass airplane. Closure of the slots prior to reaching the maximum lift was accompanied by loss of damping in roll; the airplane suddenly sideslipped. When the slots were open, positive damping in roll prevailed at the highest angles of attack attainable. However, the elevator effect within this particular range was so small as to permit exceeding the maximum lift only in exceptional cases with elevator hard-pulled over. It was therefore impossible to attain to a sweeping exploration of the full effectiveness of these types of control slots, especially in the stalling range, for lack of longitudinal controllability. The possibility of improved elevator action made continuation of the first experiments appear fitting and proper.

Besides, in the meantime the Handley Page company, Cricklewood, had developed a new type of automatic control slot and proposed its installation in the Albatros. Accurate information on the aerodynamic qualities of the wing used originally in the L 75 (a modified M 12 airfoil) was lacking at the beginning, with the result that the first slot arrangement conformed probably more to the customary thin sections (R.A.F. 15, 28, 31) habitual in Great Britain. Being apprised of the first flight results, Handley Page, Ltd., immediately proceeded to develop a new control-slot arrangement, which in size, contour, and profile shape was more in keeping with the particular characteristics of the Albatros wing.

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*"Weitere Flugmessungen über die Wirksamkeit von automatischen Handley-Page-Schlitzquerrudern." Z.F.M., May 28, 1932, pp. 287-294.

The installation of the new control-slot arrangement was accompanied at the same time by certain structural changes intended to improve longitudinal controllability. The elevator was considerably enlarged. (Fig. 1.) The new control slot, the location of the auxiliary airfoil with respect to the main wing (upper wing), as well as the extent of the slot across the wing, can be seen in Figure 2, along with the original type. It has a deeper chord (254 mm instead of 188 mm), the span of the auxiliary wing was raised from 2084 to 2500 mm, and the modified cross-section form altered the shape of the leading edge of the main wing. (See also fig. 3.)

II. METHOD, SET-UP, AND PROCEDURE OF TEST

Comparative investigations on the airplane with locked and open control slots were to yield:

1. The maximum angles of attack and lift coefficients;

2. The behavior of damping in roll by interferences in equilibrium position about the longitudinal axis in maximum angle-of-attack range.

The gliding flight polars of the airplane in steady gliding flight with engine throttled to idling were measured first, and the lift coefficients at high angles of attack defined for flight with definite equal throttle setting (slightly less than full throttle). The measurements were continued to beyond the usual range with different c.g. positions* in order to adjudge whether or not an improved longitudinal controllability achieved by backward displacement of the c.g. and less static longitudinal stability would attain to higher angles of attack. Magnitude and time rate of roll at incipient rolling were defined in the further course of the test. This roll was initiated by outside disturbances without application or change in control movement from the original equilibrium position in throttled flight, and specifically in the range of angles of attack for maximum lift.

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*c.g. S I lies at 22.3 of the mean wing chord t_m, c.g. S II at 32.7 of t_m, computed from leading edge of t_m. Figured from leading edge of lower wing at root, S I is 900 mm rearward and 715 mm vertically above, S II is 245 mm to the rear and 720 mm vertically above the chord of the lower wing.

Method, test apparatus and procedure have already been described in the 1931 D.V.L. Yearbook, page 691, Report 221.

The method for setting up moments to disturb the equilibrium position (application of a continuously acting weight moment about the longitudinal axis by dropping a balance weight suspended from the tips of the lower wing) and for determining the rate of roll are likewise explained in that particular report. One very simplifying feature was the arrangement of the additional weights on the wing tips. The method of freely suspended ballast bags, resorted to heretofore, made numerous individual flights necessary. This objectionable feature was removed by the use of cowled-in tanks at each wing tip. (Fig. 4a.) One tank served to receive the water pumped by hand from the main tank in the fuselage through the pipes laid over the wing. The capacity of the main tank is enough for from 8 to 10 wing tank refills (28.5 liters). The wing tank can be shut off from the observer's seat. (Fig. 4b.) A practical proof of the sufficiently rapid emptying of the tank - necessary to initiate a very sudden motion in roll - was afforded by opening the water tank in a test flight and at the same instant releasing a ballast bag serving as balance weight on the other wing tip. It was devoid of any disturbance in initial position of equilibrium. It was also proved by comparative flights that the change in drag set up by opening the water tank, has no influence on the initial position of equilibrium (additive yaw).

The tank on the other wing tip which served as balance weight always contained a fixed weight, corresponding to the amount of water in the other tank (magnitude of consistently equal rolling moment: $M_B = 5.72 \times 28.5 = 163.0$ mkg).

For observance of the flow process and of the release upon reaching maximum lift, two rows of woolen threads were fastened across the top span of the left lower wing. Their actions were to be observed at the various flight attitudes. The lower wing was not slotted. All the same it was essential to ascertain whether, at the attained maximum angles of lift, the separation had equally spread to the wing tip that supplied the greatest quota of damping in roll, and to what extent the "stalled" attitude is at all reached. The woolen threads were cinematographically recorded on various wing sections from tip to root.

III. TEST DATA

1. Polar Curves

Figure 5 depicts the gliding-flight polars* of the airplane, Figure 6, the c_a values versus angle of attack α for throttled engine as well as for flight with certain throttle setting. The reference angle α' denotes the angle formed by the flow direction on a certain point (influenced by the airplane) above the upper wing (about 1.80 m) and the longitudinal axis of the airplane. The angle constitutes in these experiments a comparative measure for the real angle of attack α, defined from pitch angle ϑ, slope of path φ and angle of setting κ. Figures 7a and 7b show α and α' plotted against the actual dynamic pressure q_w.

a) Throttled flight

Locked control slots in range of maximum lift ($1.20 < c_a < 1.25$, $22^\circ < \alpha' < 23^\circ$) are abruptly followed by sideslipping, a sign of sudden loss of damping in roll. A 10° gliding angle corresponds to the angle of maximum lift. Every attempt to exceed this gliding angle for the purpose of shortening the planing distance, means endangering the safety.

With control slots open, the angle of maximum lift ($c_{a\,max} \sim 1.38$) and even up to $\alpha' = 28^\circ$ can always be reached with ample damping in roll. Gliding angles up to 15° and 16° correspond to the highest angles of attack in stalled glide, which means considerably shorter flattening out by ample safety in flight.

Longitudinal controllability is sufficing in every case, although controllability about the normal axis within range of large α is materially lower because of the blanketing of the lateral controls by the fuselage.

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*These polars are not summarily comparable with those given in the 1931 D.V.L. Yearbook. The same type of airplane has been fitted with a new engine of the same type and vibration dampers. The idling r.p.m. of the two engines on the torque stand is materially different. In addition, the new larger control slots together with the increased elevator area, modify the aerodynamic quality of the airplane type.

The opening process of the slots is stable throughout (beginning in throttle flight at $c_a \approx 0.9$, completely open at $c_a \approx 1.20$). There was no sign of vibration.

b) Flight with certain throttle setting

After reaching $c_a \approx 1.45$, with slots closed, a strikingly sudden loss of damping in roll occurred, whereas, with slots open, there was sufficient damping in roll in the maximum lift range ($c_a \approx 1.65$ to 1.70) and even in stalled flight.

As to the evaluation of the order of magnitude the maximum lift coefficients recorded in flight with definite throttle setting, it is to be noted that the real c_a are probably 5 to 10 per cent lower.

The not inconsiderable influence at large pitch variations of the propeller thrust perpendicular to the direction of flight was not taken into account, thus effecting a simplification, which still is permissible for the present comparative measurements. Figure 6 includes the engine r.p.m. (BMW Va engine) plotted against angle α for this throttle setting.

The photographs in Figure 8 show the woolen threads on the top side of the lower wing as abundantly supporting the facts surmised from the polar curve flights. In throttle flight, and more particularly, in flight with constant throttle setting (corresponding to figs. 8A-D), spreading of the separation zone of the flow, when approaching maximum lift, begins at the wing root and advances to the strut fitting and beyond to almost the wing tip.

As the separation spreads the threads become more and more disturbed, flutter stronger and faster, and finally orient forward in flight direction. At first the threads of the rear row, then those of the front row show this behavior.

Contemporary with the start of separation at the wing tip, that is, on the strut fitting, the closed control slots are already accompanied by sudden sideslipping as indication for abrupt loss of damping in roll. But with slots open the initial equilibrium is consistently maintained. There is ample damping in roll even if the separation extends across the entire span to the wing tip. (See fig. 8D.) Neither is there any tendency to sudden sideslip in stalled flight, a proof of the efficacious range of the control slots.

The fact that in flight with certain throttle setting all signs of sudden loss of damping in roll are considerably stronger and more definitely expressed than in throttled gliding flight, must indubitably be ascribed to slipstream effect. It effects, for illustration, such a change in lift distribution across the span that $dc_a/d\alpha$ is greater than on the outside part of the wing with greater support quota, as a result of the increased circulation on the inside part of the wing.

However, there must still be some other influences of the slipstream involved not explainable here, as, for instance, change of effective angle of attack across the span, which also contribute to the strikingly varied behavior of the airplane in a stall.

2. Measurements of Motion in Roll

The proximate results of these measurements, the course of angle of roll μ with respect to time t by initiation of rotations about the longitudinal axis within maximum angle of attack range, are shown in Figure 9 for the airplane, slots open, and in Figure 10, for slots locked.

On the basis of the theoretical assumptions treated in reference 2, for the equilibrium conditions in rolling, it was attempted to define the character of the motion in roll from the time rate of the angle of roll. It is presumed that the rotation is originally a pure motion in roll. Within range of the no longer linear, but approximately strongly parabolic aspect of the lift coefficient above the angle of attack in range of maximum lift this side and beyond $c_{a\ max}$, damping in roll, which decides the behavior of the airplane, is solely dependent upon the angle of attack of the initial equilibrium position. Since upon these premises the lift rise drops linearly with the angle of attack, the loss of damping in roll in the wing half, downward in the sense of the motion in roll, is always balanced by the growth of damping in roll of the up-going wing-half. Hereby it is altogether immaterial whether the angle of attack for maximum lift has already been exceeded by one wing tip, provided the law of the parabolic relationship is still adhered to even above the angle of maximum lift. For $c_{a\ max}$, for instance, the damping in roll, then, is zero.

Table of the Three Principal Cases of

Simplified Motion in Roll

	Lift range of initial equilibrium position	Damping in roll	Time rate of: Angle of roll μ	Time rate of: roll $\dot{\mu}$	Time rate of: Accelerated roll $\ddot{\mu}$	Attitude of rotation about the longitudinal axis
Case I	below $c_{a\ max}$	positive	linear	constant	zero	steady
Case II	$c_{a\ max}$	zero	parabolic	linear	constant	steady acceleration
Case III	above $c_{a\ max}$	negative forced	exponential	exponential	exponential	irregular acceleration

So the character of these simplified rolls and the sign of damping in roll (wing tips are decisive) at start of motion in roll, is theoretically defined in three main categories, which have been compiled in above table.

The next logical step is to ascertain whether evident discrepancies in the degree of uniformity of the motion attitude at the inception of roll obtain to typical discrepancies in damping in roll behavior.

From the available records on the time rate of angle of roll μ it can be proved that, with control slots open, there is a linear rise of μ with the time at the beginning of roll in the entire angle of attack range of stalled flight. It bespeaks the continued presence of damping in roll. Its retention even in stalled flight must without a doubt be due to the effect of the control slots. There is no tendency to sideslip.

Linear relationship of μ, with slots closed, is likewise maintained over t up to $\alpha' = \sim 21°$ (or to c_a = 1.20 to 1.23). Up to this angle of attack damping in roll is positive. (Case I.) A minute digression of this limit results in accelerated roll. The time rate of μ, instead of being linear, is already rather approximately parabolic. Undoubtedly the angle of attack for maximum lift is precisely attained in the initial equilibrium position, although it is difficult to maintain this attitude for any length of time. (Case II - zero damping in roll.)

It had already been attempted to set up a law as to magnitude and aspect of rate of roll $\dot{\mu}$ and accelerated roll $\ddot{\mu}$ from the time rate of angle of roll μ in range of the no longer linear relationship. But it was found that the method of graphic differentiation of μ curves applied at that time was afflicted with many sources of error; a mathematical interpretation of the test data obtained in this flight attitude affords scarcely more than a clue as to the order of magnitude of $\dot{\mu}$ and $\ddot{\mu}$.

Admittedly, graphical differentiation revealed in isolated cases an approximately linear rise of rate of roll $\dot{\mu}$ within the interval of one second. Then $\ddot{\mu}$ is constant, and damping in roll precisely zero. (Case II.) The figures for $\ddot{\mu}$ accordingly, range between 0.150 and 0.205 s^{-2}. The weight moment (M_B) was the same in these cases. For evanescent damping in roll the roll acceleration $\ddot{\mu}$ follows: $\ddot{\mu} = M_B/J_X$, where J_X = moment of inertia of airplane about the longitudinal axis after dropping a balance weight. More recent pendulum tests yield J_X = 725 m kg s^2, $\ddot{\mu} = \frac{165}{725} = 0.225\ s^{-2}$. At any rate, the agreement of the order of magnitude for the experimentally and the mathematically defined $\ddot{\mu}$ values is acceptable and much better, for instance, than with the earlier results. All the same, the limitations indicated previously, must be kept in mind. Any decision as to whether damping in roll is zero or negative, i.e., a forced motion, must be made with greatest reservation.

Sufficiently accurate test methods do permit to attain to the magnitude and time rate of change in a pure rolling moment after a roll has been applied by a known moment, as proved by English calculations and flight tests. (Reference 3.) But to assure that, it is necessary by means of suitable test equipment, that a sufficiently exact record of the typical quantities affecting the motion in roll, such as rate of roll and roll acceleration, be obtained in the very first time interval (about one second) after the rotation has been initiated. Another fact to be kept in mind is the change in moment of inertia about the longitudinal axis and the altered initial equilibrium position following the sudden dropping of the balance weight. According to the English experiments, assuming an instantaneous initiation of weight moment about the longitudinal axis, together with a very exact record of $\dot{\mu}$ within the first second of motion in roll, the determination of the rolling moment is subject to an error of about 15 per cent by neglecting the additive rolling moments due to yaw and sideslip. However, a sufficiently exact definition of μ and $\dot{\mu}$ during a greater time interval of motion (say, 5 seconds) is possible only when at the same time the determination of the amounts of the additive rolling moments is given by exact record of the motion quantities decisive hereto.

However, the purpose of the present comparative study was to decide whether fundamental differences in the behavior of the airplane with open and closed control slots during the consistently identically applied motion in roll, permit inferences of the existence or loss of damping in roll. This purpose has been obviously achieved on the face of the results. Even so, it should be emphasized over and over that measurements within maximum-lift range necessarily require materially different test methods with much more precise equipment than customary heretofore, aside from the fact that manipulation in flight is rendered very difficult.

In conjunction herewith we analyzed certain motion phenomena observed several times, which occurred in connection with motion in roll measurements near maximum lift and which are typical for the airplane with closed control slots, e.g., the sudden sideslip occurred altogether unexpectedly from a different attitude of the yawing motion. After initiating the motion in roll (left wing down), a gradual, incipient slip to the left followed after a comparatively small roll ($\mu \sim 8^\circ$ to 10°) had been reached. In the first experiments the behavior of the airplane during the ensuing sideslip was not followed up any further. The measurements were interrupted and the sideslip ended by appropriate control movements.

Since ordinarily no premature sideslip had been felt until much greater roll had been reached and even then, occurred in these special cases only when the angle of attack of the initial equilibrium position had become greater than $\alpha' = 20^\circ$, it was decided to examine this additive motion more closely. It was found that, in conjunction with the sideslip even after a relatively short-time interval, suddenly a motion in roll with high angular velocity contrary to the original rotation, occurred. The airplane suddenly slipped over the right wing and went into a right-hand spiral. This conduct was subsequently observed at numerous times; the elevator deflections conjugated to the initial equilibrium position were not changed. The time rate of roll μ during the duration of the motion is shown in Figure 11. As soon as the airplane, by definite roll, goes in a sideslip (here, to the left), the ensuing air loads set up a rolling moment which strives to raise the inside wing (left) in spite of the continuously acting weight moment about the longitudinal axis. The result of the sudden and rapid rotation about the longitudinal axis is a very abrupt rise in angle of attack of the right wing (down). This rise of the right wing is at least so great (estimated, $\Delta\alpha = \text{arc tan } \frac{b}{2}\frac{\mu}{v} = \text{arc tan } (0.1 \text{ to } 0.15) = 5^\circ \text{ to } 10^\circ$) that the angle for maximum lift on the outer wing part which supplies the greater quota of damping in roll, is suddenly exceeded.

The sideslip due to rolling moment within range of high α, may become very large. (Reference 4.) On the other hand, it has heretofore never been possible to give a satisfactory explanation of what the contributory causes are that abet the entry of such large rolling moments, apart from the effects due to the specially designed wing shape. In any case, the fact that sudden sideslip can occur in flight near maximum lift, as, for instance, in curve flight, as result of "slipping over the inside wing," deserves specific mentioning as a dangerous moment.

In this connection, one important study would be to determine whether other airplane types also evince a similar conduct. It is not at all unreasonable to assume that in a left curve near maximum lift a slip over the inside wing leads to a sudden right sideslip and inadvertently into a right-hand spin. In early spinning accidents, various statements of eye witnesses to that effect were looked upon as very improbable.

It again speaks for the effectiveness of the control slots that when open, no such motions in roll come into being. To be sure, a closer investigation of the ensuing motion process revealed in isolated cases a reversal of the original motion in roll also as a result of the succeeding sideslip, once the rotation had been initiated. Despite the steady weight moment only a slightly damped aperiodic roll with almost constant amplitude occurred - without changing the initial elevator deflections - superposed by a growing rise in roll and coupled with more or less severe vibrations about the lateral and normal axes. (The latter defined by feel.) The time rate of roll μ during this "wabbling" motion is portrayed in Figure 12 for various flights.

Apparently the reversal of the motion in roll occurs without more pronounced tendency to die out, in contrast to the conduct of the airplane with control slots locked, so that, following the always existing damping in roll, the efficacy of the control slots becomes for once a contributory influence on the damping of the motion in roll. The entry of restoring moments about the longitudinal axis, striving to reestablish the initial equilibrium position, is indicative of the presence of lateral stability even in range of maximum lift. The magnitude of the moments appears quite high. Hence it may be conjectured that the influence of the control slots (change in α and lift distribution across the span) during sideslip at the same time supplies an active quota to these stabilizing moments about the longitudinal axis, in similar fashion, as lateral stability can be achieved by special wing design (such as dihedral, etc.). But whether to ascribe such stabilizing effect to the control slot or whether the motion is due to coupling of pure motions in roll with rotations about the other two axes, awaits further elucidation. In no case is there any tendency to sideslipping, with these motions.

SUMMARY

Investigation of damping in roll within range of maximum lift with the Albatros L 75, with and without Handley Page automatic control slots, revealed the following:

Without control slots, any attempt to go beyond a certain angle of attack near $c_{a\ max}$ in glide and climb, is followed by sudden sideslip. The conduct of the airplane throughout the motions in roll, moreover, confirmed that all attempts to higher angles of attack are accompanied by

sudden loss of damping in roll. So in this range near $c_{a\,max}$, safety in flight is certainly endangered.

The behavior of the airplane was peculiar in all cases in which the gradual slipping following the initial motion in roll was examined. It was not originally intended to follow this part of the motion process. Numerous cases confirmed the fact that, with motions in roll from the original equilibrium positions of the highest attainable angles of attack, the slipping motion sets up, unexpectedly, a slip over the outside wing. All characteristics of sudden loss of damping in roll occurred markedly violent as result of the large rise in angle of attack. Of itself the airplane has excellent flying qualities in the service range of flight. Spinning accidents may find in this fact a further explanation. Cause and effect, to set up such flight motion, for instance, in curve flight at α nearing $c_{a\,max}$, must be cleared up by further extensive investigations.

With control slots, ample damping in roll prevails throughout the entire (about 8° enlarged) angle-of-attack range of maximum lift and of stalled flight. No signs of sudden sideslip were observed. The records of the behavior with motions in roll, moreover, confirm that maintenance of damping in roll in the whole range of large α is exclusively due to the efficacy of the control slot.

The appearance of steady vibrations in roll observed in isolated cases after motion in roll had been initiated, leads one to surmise a stabilizing effect about the longitudinal axis of the control slot even above that.

Translation by J. Vanier,
National Advisory Committee
for Aeronautics.

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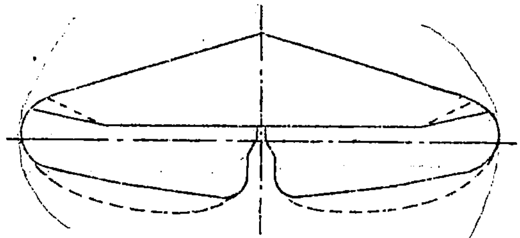


Fig. 1 Outline of lateral controls of Albatros L 75 before and after modification.

The actual enlargement was:

Name	L 75 E	L75 E (U11)	%
Fin	1.854 m^2	1.774 m^2	- 4.3
Effective elevator	1.384 "	1.884 "	+ 36.1
Auxiliary balance	0.280 "	0.360 "	+ 28.5
Inner balance	0.332 "	0.332 "	----
Total area	3.850 "	4.350 "	+ 13.0

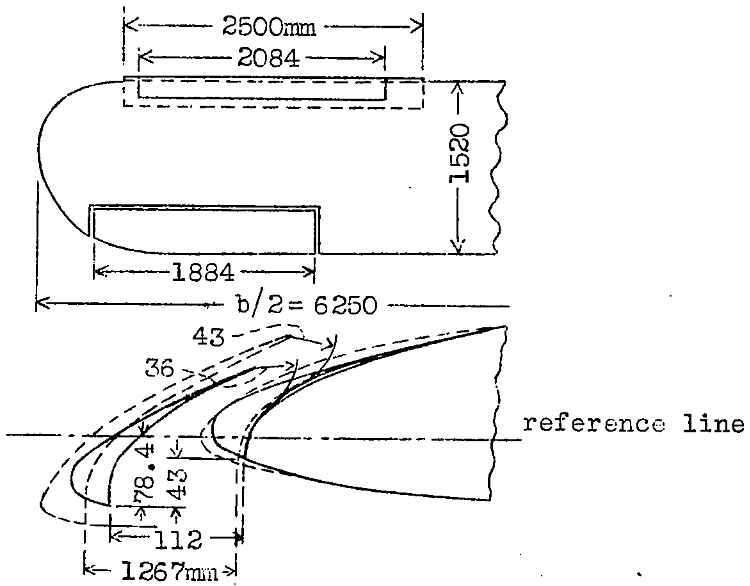


Fig. 2 Position and mounting of Handley-Page automatic control-slot at upper wing. The dotted lines denote the examined new type of slot.

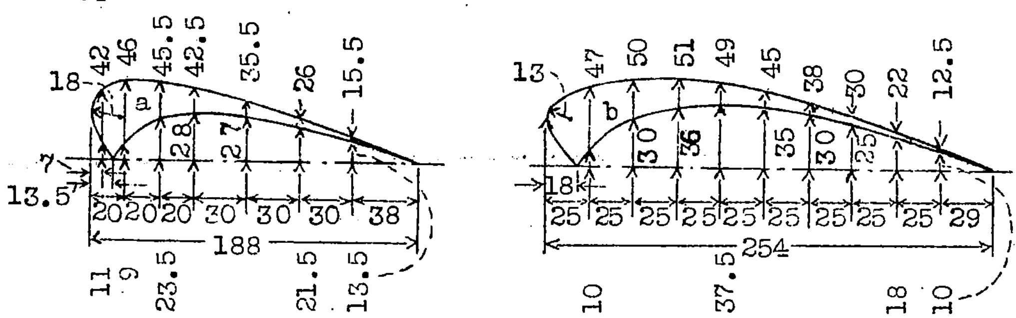


Fig. 3 Dimensions of old (a) and new (b) type of slot.

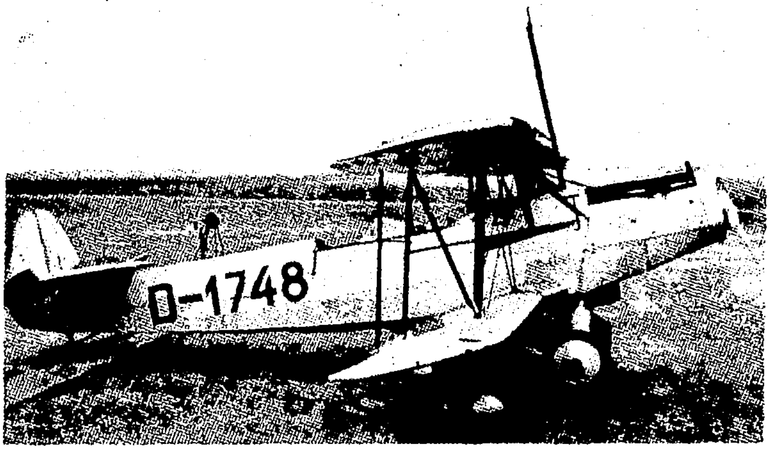
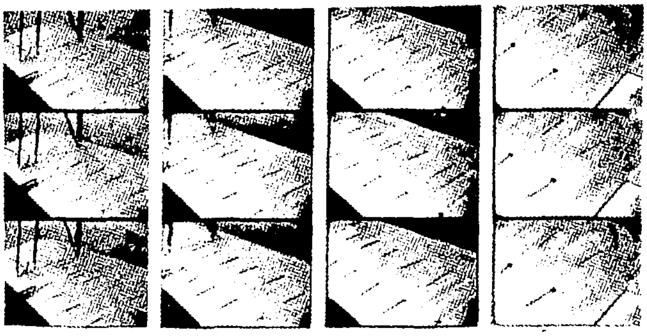


Fig. 4a Albatros L 75 with slots. Note the streamline tanks (Fig.4b) suspended from the lower wing. One tank serves for dropping ballast weight [28.5 liters(7.53 gal.) of water].

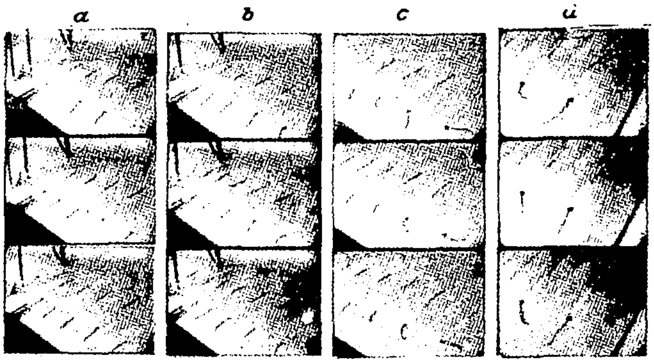
B



a b c d

Fig. 8B Behavior of threads in normal flight. The equilibrium position corresponds to $c_a \sim 0.65$ ($\alpha' \sim 5^0$). Insignificant separation at wing root (film series d).

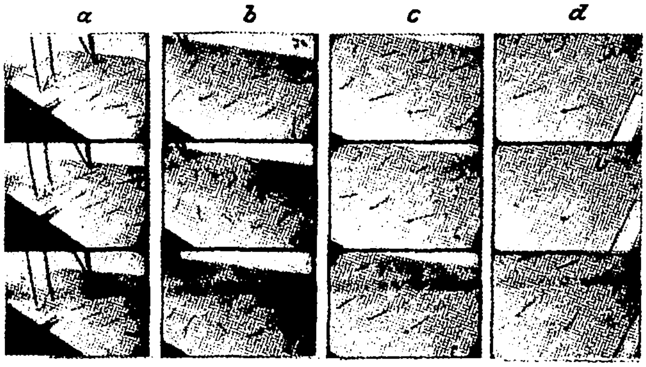
C



a b c d

Fig. 8C Behavior of threads shortly before reaching maximum lift. The equilibrium position corresponds to $c_a \sim 1.15$($\alpha' \sim 12^o$). The separation is more pronounced, starting at the wing root and advancing to the plane of strut (film series b,c and d).

D



a b c d

Fig. 8D Wool threads in stalled flight. The equilibrium position corresponds to $c_a \sim 1.70$ ($\alpha' \sim 22^o$). The entire flow on the topside, wing tips included, is in the throws of separation (film series a,b,c and d). This flight position is maintained only with open control-slots.

Fig. 8 Cinematograph pictures (speed 12- 14 m/sec.) of the action of the woolen threads at different flight attitudes with certain throttle setting.

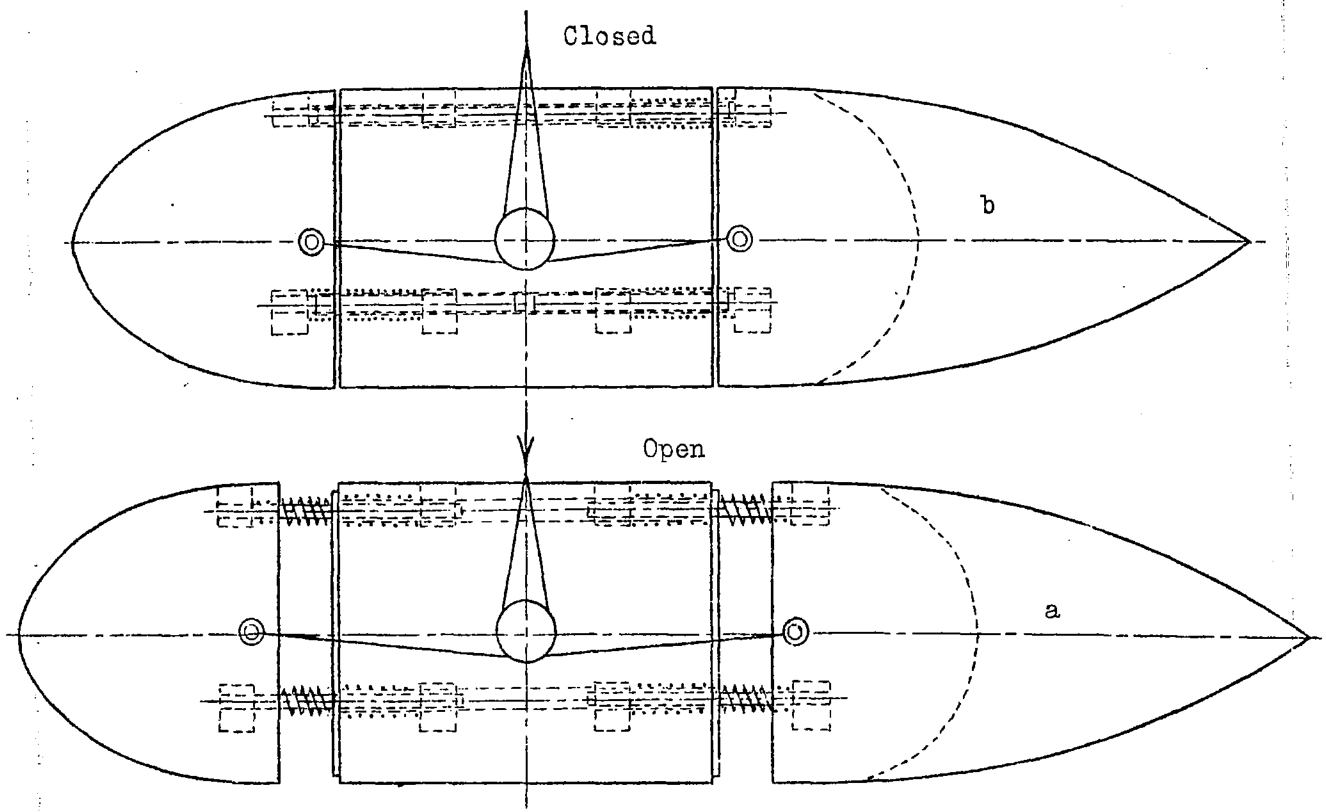


Fig. 4b Sketch of wing tanks, (a) open and (b) closed. The tank is closed from the observers seat by mechanical-cable device and ratchet. Upon release of ratchet, pressure springs tensed on the inside, effect sudden opening of tank. The openings are large enough to assure quick emptying of water.

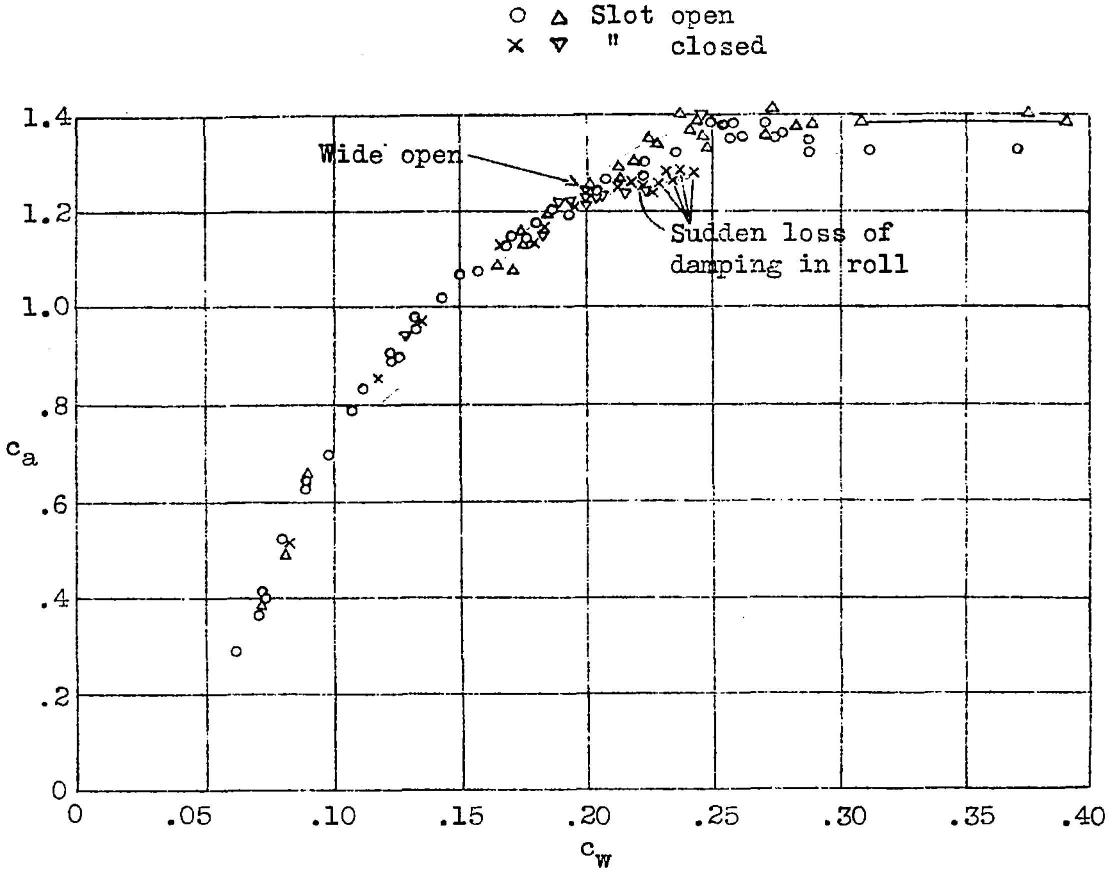


Fig.5 Gliding polar curves (throttle flight) with open and locked slots. The test point of those polars, denoted by △ and ▽ correspond to the different initial equilibrium positions immediately preceding the applied motion in roll.

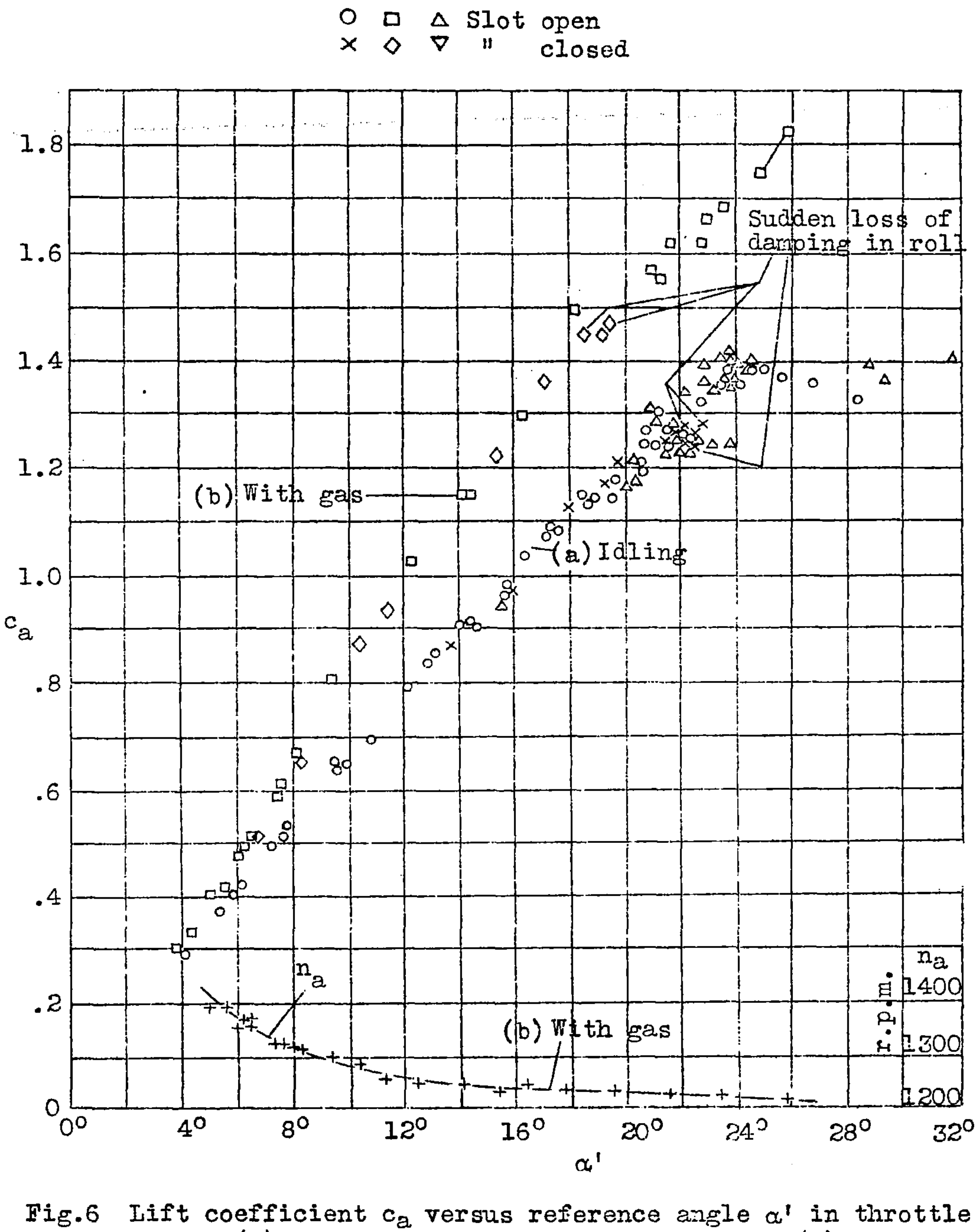


Fig.6 Lift coefficient c_a versus reference angle α' in throttle flight (a) and with certain throttle setting (b).
(The c_a values, shown with △ and ▽ correspond to the different initial equilibrium positions in throttled flight immediately preceding the application of a motion in roll.) It also includes the indicated r.p.m. n_a plotted against α' in power flight.

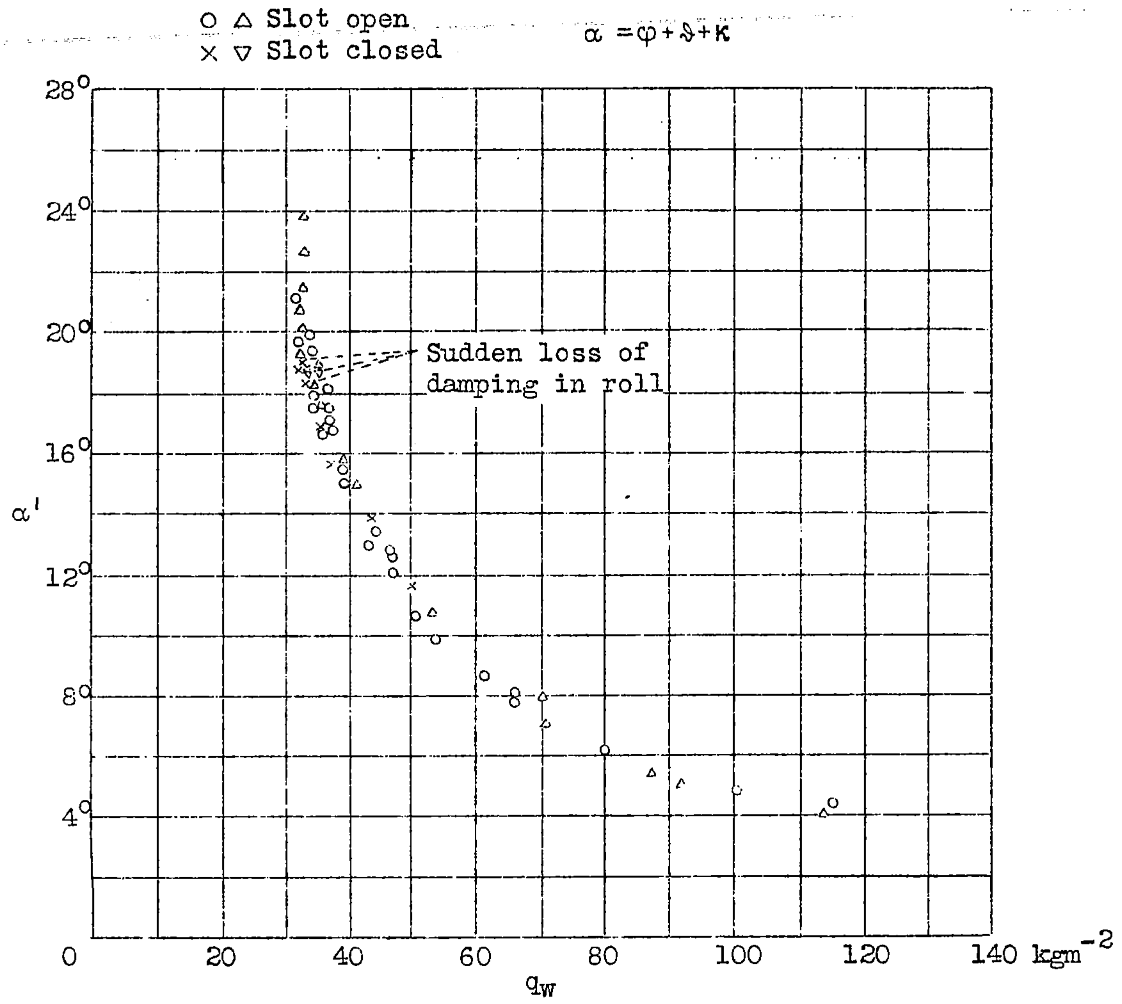


Fig.7a α' against actual dynamic pressure q_W in throttle flight.

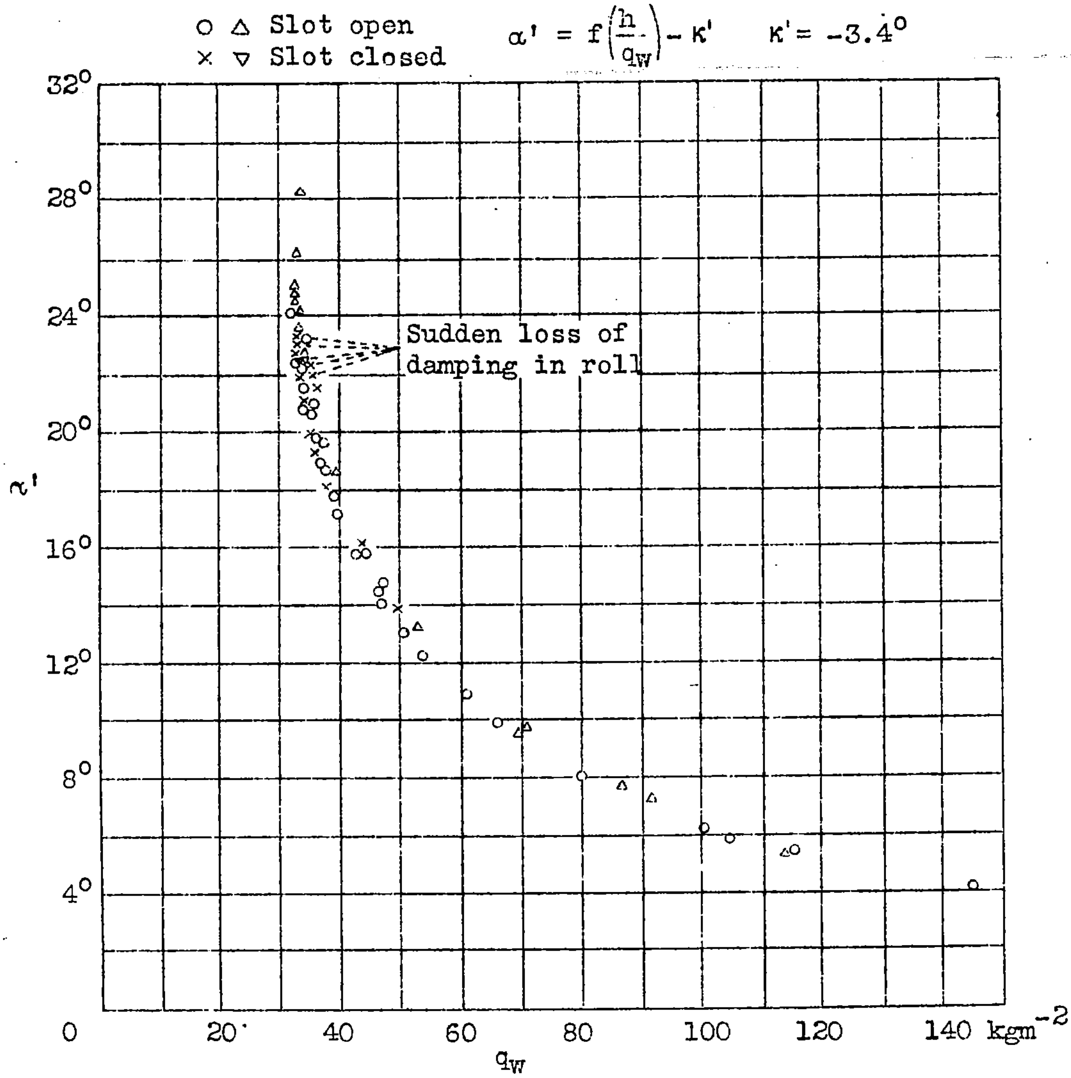


Fig.7b α' against actual dynamic pressure q_W in throttle flight.

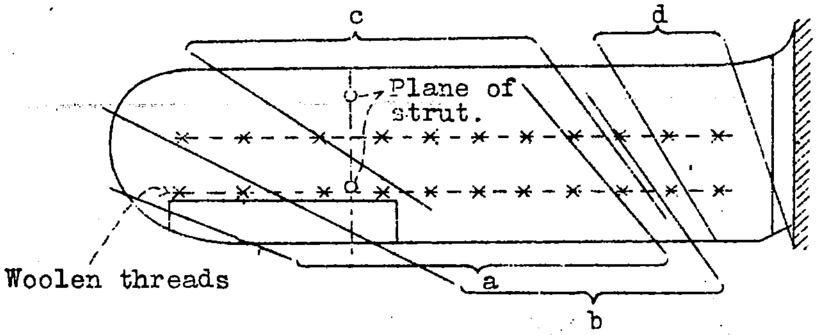
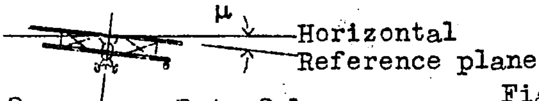


Fig. 8A Threads rigged up on top side of lower wing, and section of picture of series a to d.



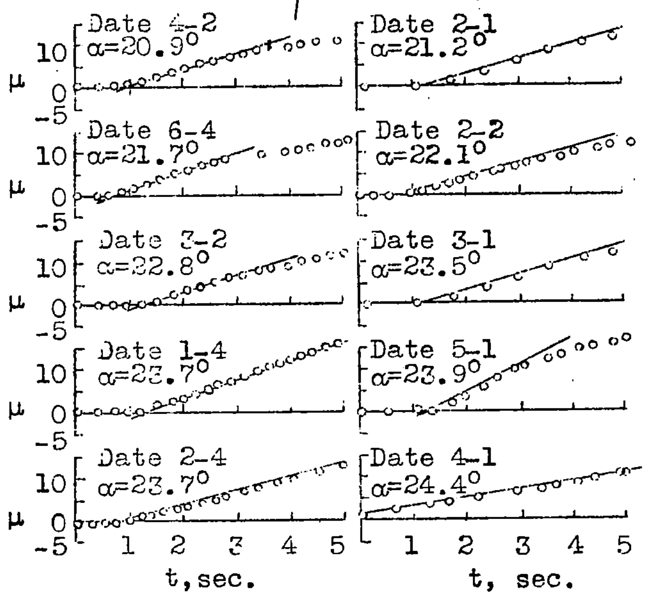
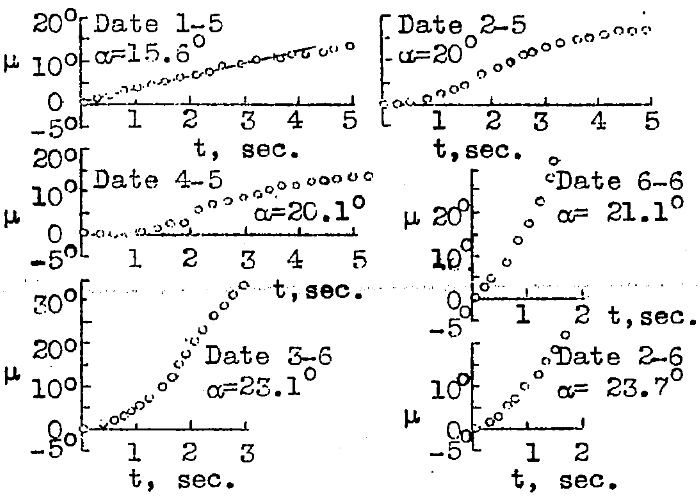
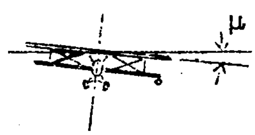


Fig. 9



Fig, 10

Figs. 9 and 10 Angle of roll μ against time t for airplane with slot open (Fig. 9) and locked (Fig. 10) at the beginning of a rotation above the longitudinal axis, always initiated by identical weight moment (163 m kg). The particular initial equilibrium position is shown by α' (reference angle of attack). The time rate of μ is typical for magnitude and sign for damping in roll. With slots open, μ increases linearly, in the entire angle of attack range (α' up to 28°), even in range of stall, hence damping in roll is always positive. With slots locked, μ increases linearly for α' below 21°, parabolic for only a few larger angles (21° > α' < 23°) and exponentially respectively. The varied μ aspect indicates positive damping in roll for α' < 21°, zero or negative for beyond.



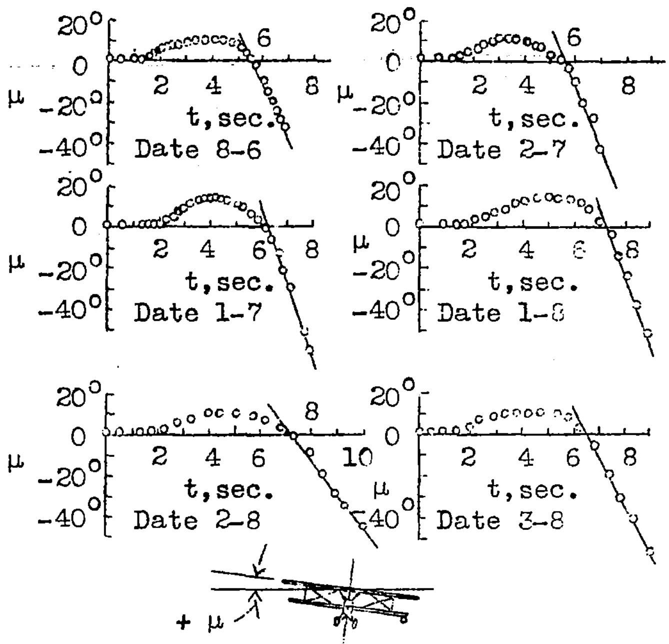


Fig. 11 Time rate of μ for airplane,control slots locked, after initiation of motion in roll and subsequent sideslip.

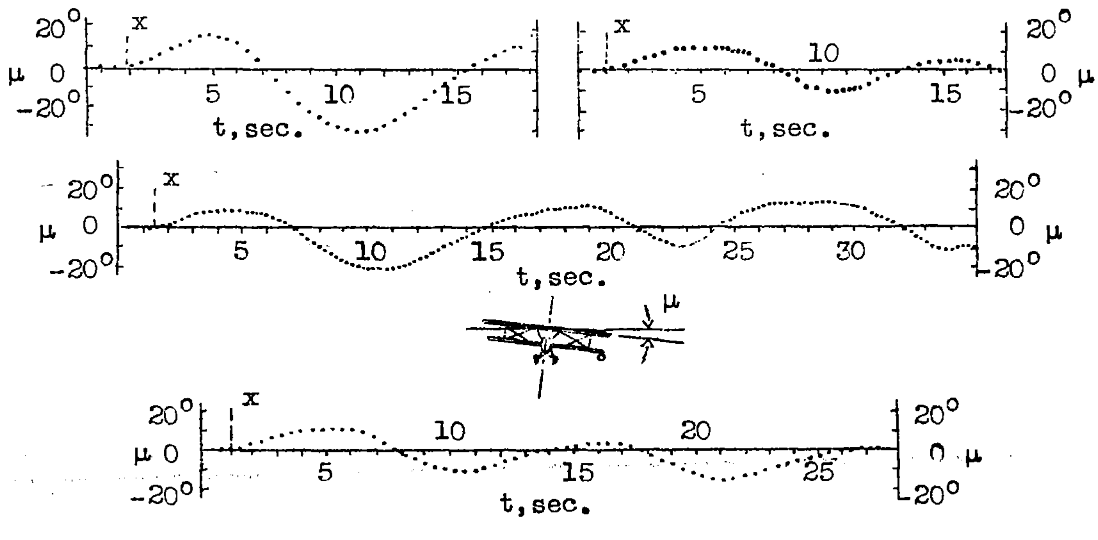


Fig. 12 Time rate of μ for airplane,slots open, after initiation of motion in roll and subsequent sideslip.
x denotes the start of water release.