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Flight Tests of a Youngman Flap on Fairey P.4/34. K.7555

By

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COMMUNICATED BY THE PRINCIPAL DIRECTOR OF SCIENTIFIC RESEARCH (AIR), MINISTRY OF SUPPLY

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Summary.—Reasons for Enquiry.—Full-scale tests were required of the lift and drag characteristics of the Youngman flaps fitted to Fairey P.4/34 K.7555. These flaps are of the external aerofoil type, and can be lowered to two positions, one giving medium lift and low drag for take-off, the other (similar to a Fowler flap) giving high lift and drag for landing.

Range of Investigation.—$C_{L\,max.}$ was determined when gliding and at full throttle. Glides and partial climbs were made in order to establish lift and drag curves. From the experimental results, the effect of flap setting on the minimum radius of horizontal turn was estimated.

Further tests were made to determine the effect of adding an extra 12·1 sq. ft. to the flap area at the centre-section.

Conclusions.—(i) Values of $C_{L\,max.}$ are given below.

Flap setting	$C_{L\,max.}$ Glide	$C_{L\,max.}$ Full throttle
Up	1·35	1·91
Take-off	1·67	2·41
Landing	2·03	—

(ii) When set for take-off the flap drag is small.

(iii) When fully down the flaps give adequate drag for landing.

(iv) The estimated minimum radius of turn without height loss at 5,000 ft at full throttle is 520 ft with flaps up, 430 ft with flaps set for take-off, and 360 ft with flaps set for landing.

(v) Reducing the central cutaway from 5·5 ft to 1·0 ft by adding 26 per cent. to the flap area at the centre-section, increases gliding $C_{L\,max.}$, flaps fully down, from 2·03 to 2·30, and slightly *reduces* the overall drag at any given C_L.

1. *Introduction.*—A Fairey P.4/34 was fitted with Youngman flaps by Messrs. Fairey Aviation Ltd. These flaps are of the external aerofoil type, and by an ingenious link system can be used in two positions, one giving medium lift and low drag for take-off, the other higher lift and high drag for landing. When not in use the flaps are housed in the wing.

Full-scale measurements of the lift and drag characteristics of the flap installation were required, and a request was also received that the effect of this type of flap on turning performance should be examined, with a view to its use for improving the turning circles of fighter aircraft. The aircraft was sent to the Royal Aircraft Establishment for the tests, which were made during August, 1940.

The aircraft was later returned to the Royal Aircraft Establishment for further tests with larger flaps, the central cutaway having been reduced by extending the flaps under the body. The results of these additional tests are given in an Addendum at the end of the report.

* R.A.E. Report B.A.1687—received 27th August, 1941.

2. *Description of the Flaps*.—A plan of the aircraft, showing the position of the flaps, is given in Fig. 1, which also includes a list of aerodynamic data for the aircraft and flaps. Detailed drawings of the flap and its linkage system are given in Fig. 2. Photographs of the flaps in various positions are reproduced in Figs. 3 and 4.

The flap is attached to the wing at each end by two arms of unequal length. The hinge positions are so chosen that during the first part of the opening motion the flap moves downward and backward, rotating meanwhile through only a small angle (Fig. 2); this gives the medium lift, low drag position used for take-off. During the latter part of the motion the flap moves further back and also rotates through a fairly large angle, finishing up behind the trailing edge of the wing in a similar way to a Fowler flap; this is the landing position. A modification to the link system allows the flap to be set at a negative angle behind the trailing edge of the wing, for use as an air brake when diving. This modification was not incorporated in the Fairey P.4/34 sent to the R.A.E., but has been flown by the firm on a similar type of aircraft, the Fulmar.

With the present linkage system the rather large housings shown in Figs. 2 and 4 are necessary to fair in those portions of the linkage which protrude above the wing. The firm now have a design in hand whereby these fairings are considerably reduced in size, with a consequent saving in drag.

3. *Programme of Tests*.—The aircraft was fitted with a swivelling pitot head and a trailing static head (60 ft cable). Glides and climbs were made, with the flaps up and in their two extended positions, in order to establish lift and drag curves. Stalling speeds were measured both when climbing and at full throttle, and the effect of flap setting and slipstream on $C_{L\ \mathrm{max.}}$ thereby determined. Finally, from a knowledge of the rates of climb and stalling speeds at full throttle, turning performance diagrams were constructed, by the method of R. & M. 2381[1], for the three cases, flaps up, flaps set for take-off, and flaps set for landing.

4. *Results*.—4.1. *Lift and Drag*.—Curves of C_L plotted against α (wing incidence at root) for the three flap positions when gliding are given in Fig. 6A. Corresponding curves of C_L at full throttle, obtained from the partial climbs, are plotted in Fig. 6B; the C_L values represent overall lift, including any upward component of the airscrew thrust.

The drag of the aircraft was deduced from the glides, and in Fig. 7A overall C_D is plotted against α for the three flap settings, while in Fig. 7B the induced drag* has been subtracted, giving curves of C_{D0} against α.

Gliding attitude $(\alpha - \gamma)$ and gliding angle γ are plotted against C_L in Figs. 8A and 8B.

4.2. $C_{L\ \mathrm{max.}}$—Straight stalls were done when gliding and at full throttle (8·5 lb/sq in boost pressure, 2,900 r.p.m.), the air speed V_i at the stall being obtained from the trailing static and swivelling pitot heads. The results obtained are set out below.

TABLE 1

Stalling Speeds and $C_{L\ \max}$ — W = 8,660 lb

Condition	Flap setting	Pilot's A.S.I. at stall, m.p.h.	V_i at stall (trailing static), m.p.h.	C_L max.
Glide	Up	70	81·5	1·35
	Take-off	62	72·2	1·67
	Landing	54	65·7	2·03
Full throttle	Up	60	68	1·91
	Take-off	54	60·5	2·41
	Landing	—	—	—

* This has been taken as $C_L^2/\pi A$, in the absence of reliable data on the induced drag of flaps extending behind the trailing edge; the C_{D0} values, flaps down, may thus be slightly pessimistic.

The stall could not be reached at full throttle with flaps fully down. At low speeds a large amount of rudder was required to hold the aircraft straight, engine on, and when the flaps were fully lowered to their landing position the rudder force required on approaching the stall was so excessive that the pilot was unable to prevent the aircraft turning quite rapidly to the right.

4.3. *Trim.*—Detailed measurements of the change of longitudinal trim due to the flaps were not made. Pilot's impressions were that the aircraft became very slightly nose-heavy when the flaps were lowered to the take-off position during the glide, lowering the flaps fully caused pronounced nose-heaviness, but this could be readily corrected. There was no difficulty in getting the tail down on landing.

It may be noted here that, during the firm's initial flight tests with this flap, difficulty was experienced in getting the tail down on landing. This was overcome by changing from a set-back hinge to a horn-balanced elevator; the hinge was moved to the leading edge, and the effectiveness of the elevator thereby increased.

4.4. *Turning Circles.*—In a recent paper[1] Gates gives an analysis whereby the full throttle turning performance of an aircraft can be calculated from a knowledge of its performance in straight flight (partial climbs). He points out that the minimum radius of turn without loss of height is achieved by flying at full throttle as near the stall as possible, at a comparatively low normal g. Before the optimum turning performance of the Fairey P.4/34 with various flap settings can be estimated, it is therefore necessary to consider briefly what values of $C_{L\,\text{max.}}$ are to be expected during banked turns at full throttle.

4.41. $C_{L\,\text{max.}}$ *in the Turn.*—If an aircraft is brought to the stall during a banked full-throttle turn, the stalling speed will be higher than that in straight flight because of the higher normal acceleration, or g, on the aircraft. The slipstream will therefore be less intense at the stall, and consequently $C_{L\,\text{max.}}$ in the turn will be smaller than the $C_{L\,\text{max.}}$ achieved during a straight stall at full throttle. In very tight turns the stalling speed will be so high that the slipstream effect will practically vanish, and $C_{L\,\text{max.}}$ will approximate closely to that obtained during a straight stall with the engines throttled back (assuming no marked scale effect on $C_{L\,\text{max.}}$ for fairly small changes in Reynolds number).

On the Fairey P.4/34 we thus know $C_{L\,\text{max.}}$ at full throttle when $g = 1 \cdot 0$ (straight stall at full throttle) and when g is very large (equivalent to straight stall when gliding). Intermediate values were obtained by measuring the stalling speeds in $1 \cdot 5g$ turns; satisfactory results could not be obtained in tighter turns, as the piloting difficulty involved in stalling slowly and steadily when the angle of bank is over 60 deg. is very great. The results are given in the middle column of the following table.

TABLE 2

Variation of Full Throttle $C_{L\,\text{max.}}$ with "g" at which Aircraft Stalls (8·5 *lb./sq. in. boost pressure,* 2,900 *r.p.m.,* 6,000 *ft.*)

Flap setting	$C_{L\,\text{max.}}$ 1·0 g (straight stall at full throttle)	$C_{L\,\text{max.}}$ 1·5g	$C_{L\,\text{max.}}$ Large g (equivalent to straight stall, throttled back)
Up	1·9	1·59	1·35
Take-off	2·41	2·0	1·67
Landing	(3·0)*	(2·48)*	2·03

* Not measured, owing to high rudder forces. Estimated from results at the other flap settings.

The results are plotted in Fig. 9. The form of the curves beyond $1 \cdot 5g$ (for which experimental evidence was not available) was estimated by assuming that

$$\frac{(\triangle C_L)_S}{C_L} = 0 \cdot 65 \times \frac{S_s}{S} \left\{ \sqrt{\left(1 + \frac{8}{\pi} T_c\right)} - 1 \right\},$$

$S_{s/S}$ being the fraction of the gross wing area in the slipstream; $0 \cdot 65$ is a constant based on wind-tunnel data.

4.43. *Turning performance with various flap settings.*—Using the analysis of R. & M. 2381, the turning performance of the Fairey P.4/34 with various flap settings may now be calculated. The basic 'performance curve' of Gates' turning performance diagram is known for each flap setting from the partial climbs which were made when establishing the C_L curves of Fig. 6B; while the 'stall boundaries' are determined from the curves of Fig. 9.

The main results of the calculations are given in Fig. 10, and are summarised below.

TABLE 3

Effect of Flap Setting on Full Throttle Turning Performance at 6,000 *ft.*

Flap setting	Minimum radius of turn without height loss, ft.	Corresponding time to turn through 360 deg. secs.	V_i m.p.h.	Normal acceleration	Angle of bank, deg.
Up	520	19	110	$2 \cdot 2g$	63
Take-off	430	19	89	$1 \cdot 8g$	56
Landing	360	20	$71 \cdot 5$	$1 \cdot 5g$	48

It will be seen that the best turning circle is obtained by lowering the flaps fully. This is an important conclusion, as it was previously believed that the optimum turning performance would be achieved with the flaps in their take-off position, when the added profile drag due to the flaps is small. More detailed calculations on the effect of flaps on optimum turning performance[2] indicated that at moderate altitudes the added drag due to a flap is comparatively unimportant provided that it is accompanied by a substantial increase in lift.

4.43. *Flight tests.*—An attempt was made to obtain an experimental check on the calculated turning performance diagrams by measuring the change in height during a 360 deg. steeply banked turn at full throttle. It was found impracticable to do this, as even a highly skilled pilot was unable to turn steadily at a constant speed, g and bank when the angle of bank was large. If, for example, the speed began to wander, the corrections necessary to check it altered the g and the bank, and such wide variations occurred in all these quantities during the turn that the experiment was abandoned after a considerable number of trials.

A rough, though quite interesting, test was next tried. A dog fight was staged between a Spitfire ($\varpi = 24 \cdot 8$ lb./sq. ft.) and the P.4/34 ($\varpi = 22 \cdot 8$ lb./sq. ft.). The calculated minimum radius of turn without height loss is about 580 ft. for the Spitfire, compared with 520 ft. for the P.4/34 with flaps up and 430 ft. with flaps in the take-off position. It was found that, with the Spitfire leading during tight turns near the stall, the P.4/34 could follow it without difficulty when the flaps were up, and could turn inside the Spitfire with ease when the flaps were set for take-off. Tests could not be made with the flaps fully down, because of the directional trim difficulties mentioned in section 4.2.

5. *Discussion.*—The increase in $C_{L\ \max.}$ on lowering the flaps to their landing position is $0 \cdot 68$. This is roughly the increment to be expected, from wind-tunnel data[3], for an efficiently designed partial-span flap of the Fowler type.

Fig. 7B shows that the increase in drag on lowering the flaps to their intermediate position is very small, a desirable feature in a flap designed to assist take-off.

When fully down the Youngman flaps provide adequate drag for landing, while the large nose-down change of gliding attitude on lowering the flaps (Fig. 8A) ensures a good view of the aerodrome during the approach glide.

More elevator power than usual is necessary when using a high-lift flap of the Fowler type. This is emphasised by the experience of the firm during the preliminary flight tests of Youngman flaps on the P.4/34. The effectiveness of the elevator had to be increased in order to get the tail down on landing. No difficulty of this sort was experienced on the standard P.4/34 with split flaps.

The turning performance of the aircraft has been shown to be appreciably improved by lowering the flaps to their intermediate position, and to be still further improved on lowering the flaps fully. Advantage cannot, however, be taken of this further improvement unless means are provided of trimming the aircraft directionally when flying at low airspeeds with flaps right down and the engine at full throttle.

If flaps are to be used in aerial combat it is essential that they should be quickly operable. It is understood that the hinge moment characteristics of the Youngman flaps are such that no difficulty would be experienced in designing for quick operation.

The main advantage of the Youngman scheme is that it combines in one flap installation means of providing

(i) medium lift and low drag for take-off, and for circling flight,

(ii) higher lift and high drag for landing, and

(iii) high drag for diving.

The third arrangement, in which the flaps are set at a negative angle and used as dive brakes, has not been tested at the R.A.E., but it is understood that flight tests by the firm on a Fulmar revealed signs of tail buffeting trouble unless the negative flap angle was restricted. In their take-off and landing positions the flaps have been shown to be efficient.

ADDENDUM

Further Tests with Increased Flap Area at the Centre Section

1. *Modification to the Flaps.*—On completion of the tests described in the main part of the report, Messrs. Fairey Aviation Ltd. decided to reduce the rather large central cutaway of the flap, with a view to still further improving $C_{L\ max.}$. This was done, and the aircraft then returned to the R.A.E. for further tests.

The modification can be seen in Fig. 5 (which should be compared with Fig. 3), and is also indicated in Fig. 1. Two additional pieces of flap were added under the centre section, thereby reducing the central cutaway from 5·5 ft. to 1·0 ft., and adding 12·1 sq. ft. (26 per cent.) to the total flap area.

The additional flaps were permanently fixed in the landing position. They formed a continuation of the original flaps, and prevented these from being raised. Thus all the flying had to be done with flaps fully down.

2. *Tests.*—Glides were done to establish the lift and drag curves, and $C_{L\ max.}$ was determined, using swivelling pitot and suspended static heads. Rough measurements were also made of rates and angles of descent during a rumble approach, as when deck landing, at the request of the firm.

3. *Results*.—3.1. $C_{L\,\max.}$—$C_{L\,\max.}$ when gliding was $2\cdot30$, compared with $2\cdot03$ before the modification. Since $C_{L\,\max.}$, flaps up, was $1\cdot35$, the increment in $C_{L\,\max.}$ on lowering the flaps has been raised from $0\cdot68$ to $0\cdot95$ by adding flap area at the centre section.

Stalls could not be done at full throttle, because the aircraft could not be held straight at very low speeds, engine on. This tendency to yaw to the right appeared to be more marked with the larger flaps.

3.2. *Lift and Drag*.—C_L is plotted against α (wing incidence at root) in Fig. 11A, while C_D and C_{D0} are given in Fig. 11B. Gliding attitude $(\alpha - \gamma)$ and gliding angle (γ) are plotted against C_L in Figs. 12A and 12B. Finally, in Fig. 13, curves of C_D plotted against C_L are given for the unmodified flaps and the larger flaps; this diagram gives the best picture of the change produced by adding flap area at the centre section.

3.3. *Rumble Approach*.—The firm required information on this in connection with deck landings. Rates and angles of descent are given in Fig. 14 for a rumble approach at about $\frac{1}{5}$ throttle. It is unsafe to open up the engine to much more than $\frac{1}{4}$ throttle during an approach with flaps fully down, as at larger throttle openings it is difficult to hold the aircraft straight when the airspeed is low.

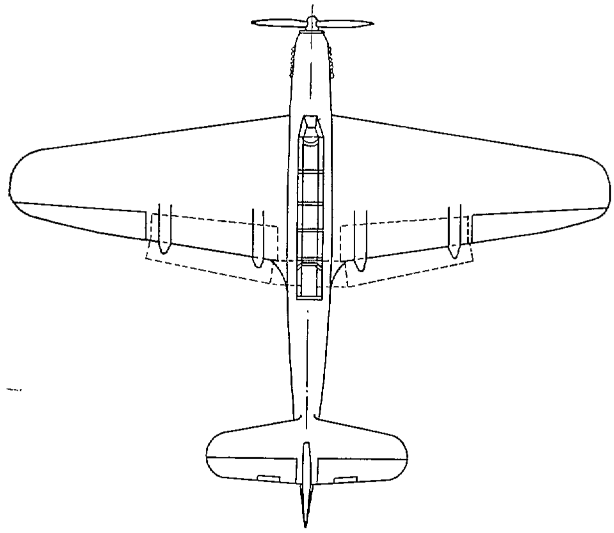
3.4. *General Flying*.—No great difficulty was experienced in taking off or landing with the flaps fixed fully down. The main complaint was that care had to be exercised in using the engine during the approach, as mentioned above.

4. *Discussion*.—The general effect of adding flap area at the centre section can be clearly seen from the C_D against C_L curves of Fig. 13. Reducing the central cutaway appears to have much more influence on lift than on drag, and at constant C_L the drag is in fact slightly reduced by this modification; this probably comes about, in spite of the added flap area, because the decreased central cutaway gives less induced drag losses, and lessens the breakaway under the body between the flaps.

Although the drag is less, the higher $C_{L\,\max.}$ enables the aircraft to be flown at lower speeds, so that it is possible to attain larger gliding angles than with the original flaps.

REFERENCES

Author	*Title, etc.*
Gates	Notes on the Dog Fight. R. & M. 2381 (June, 1940).
Morgan and Morris	Note on the Turning Performance of the Spitfire as Affected by Altitude and Flaps. R. & M. 2349 (April, 1941).
Platt	Aerodynamic Characteristics of a Wing with Fowler Flaps including Flap Loads, Downwash and Calculated Effect on Take-off. N.A.C.A. Technical Report No. 534 (1935).



AIRCRAFT		FLAPS	
WEIGHT LB	8660	TOTAL FLAP AREA/WING AREA	0·122
GROSS WING AREA S SQ.FT	380	FLAP CHORD/ LOCAL CHORD	0·25
WING SPAN 2S FT.	46	FLAP SPAN/ WING SPAN	0·427
ENGINE	MERLIN	FLAP ANGLES TAKE OFF	7°
HORSE POWER	1100	FLAP ANGLES LANDING	37°
WING LOADING LB/SQ FT	22·8	FLAPS EXTENDED UNDER BODY	(SEE ADDENDUM TO REPORT)
POWER LOADING LB/BHP	7·88	TOTAL FLAP AREA/ WING AREA	0·154
		FLAP SPAN/ WING SPAN	0·525

FIG. 1. Fairey P4/34 (Youngman flaps) Aerodynamic Data.

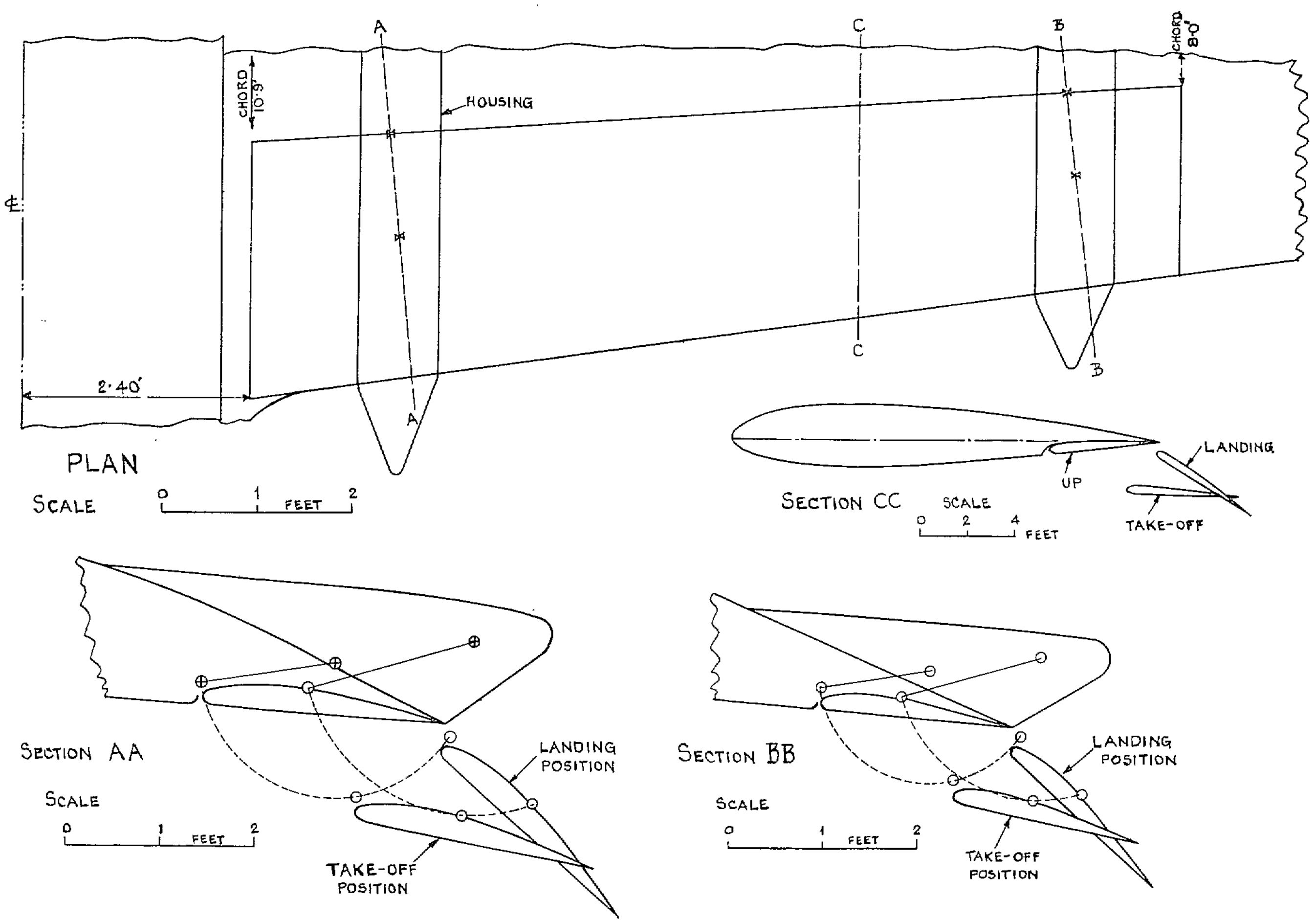


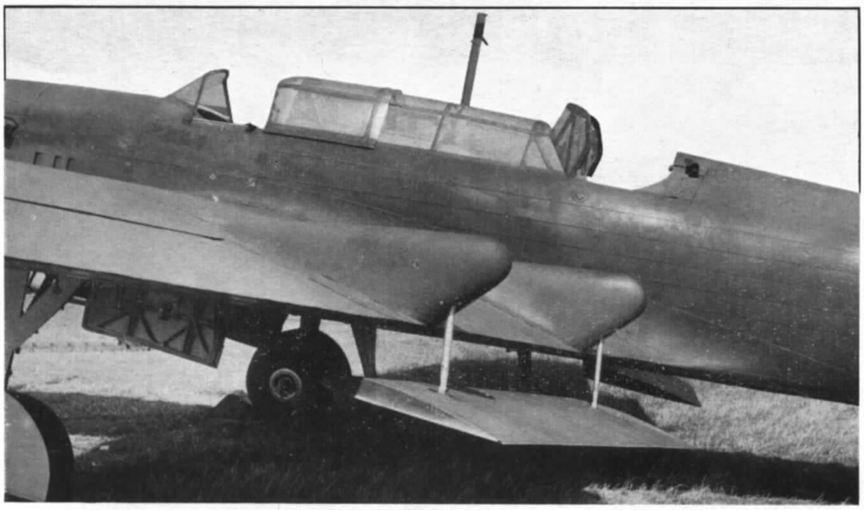
FIG. 2. Youngman Flaps on Fairey P4/34.

Flaps Set for Take-off.

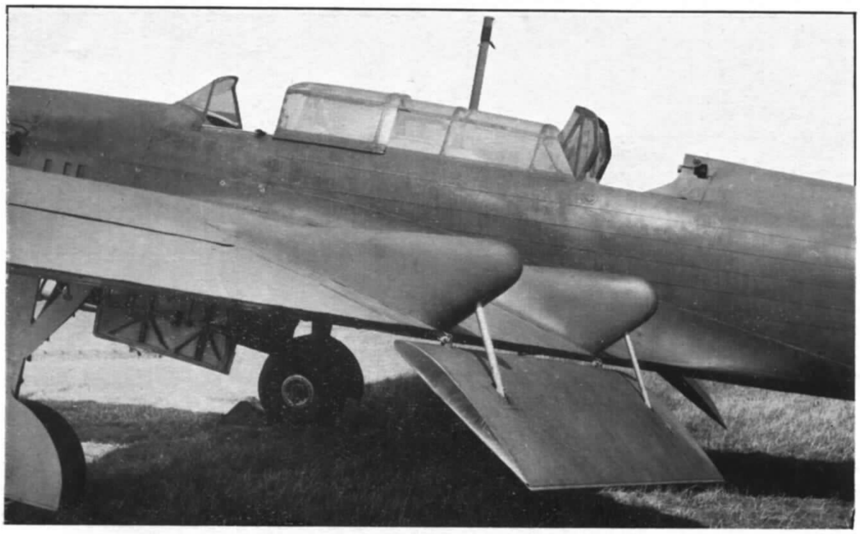
Flaps Set for Landing.

FIG. 3.

FLAPS UP



FLAPS SET FOR TAKE-OFF



FLAPS SET FOR LANDING

FIG. 4.

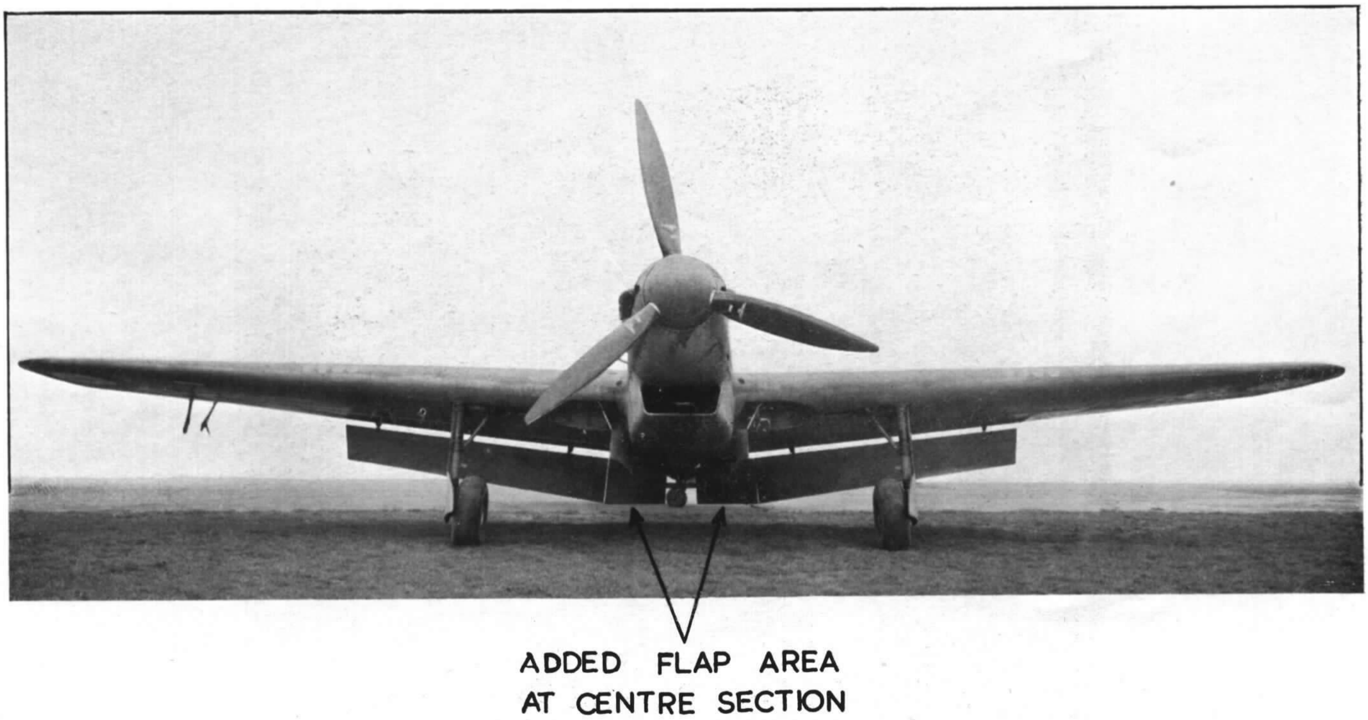


FIG. 5. Flaps Set for Landing—Increased Flap Area.

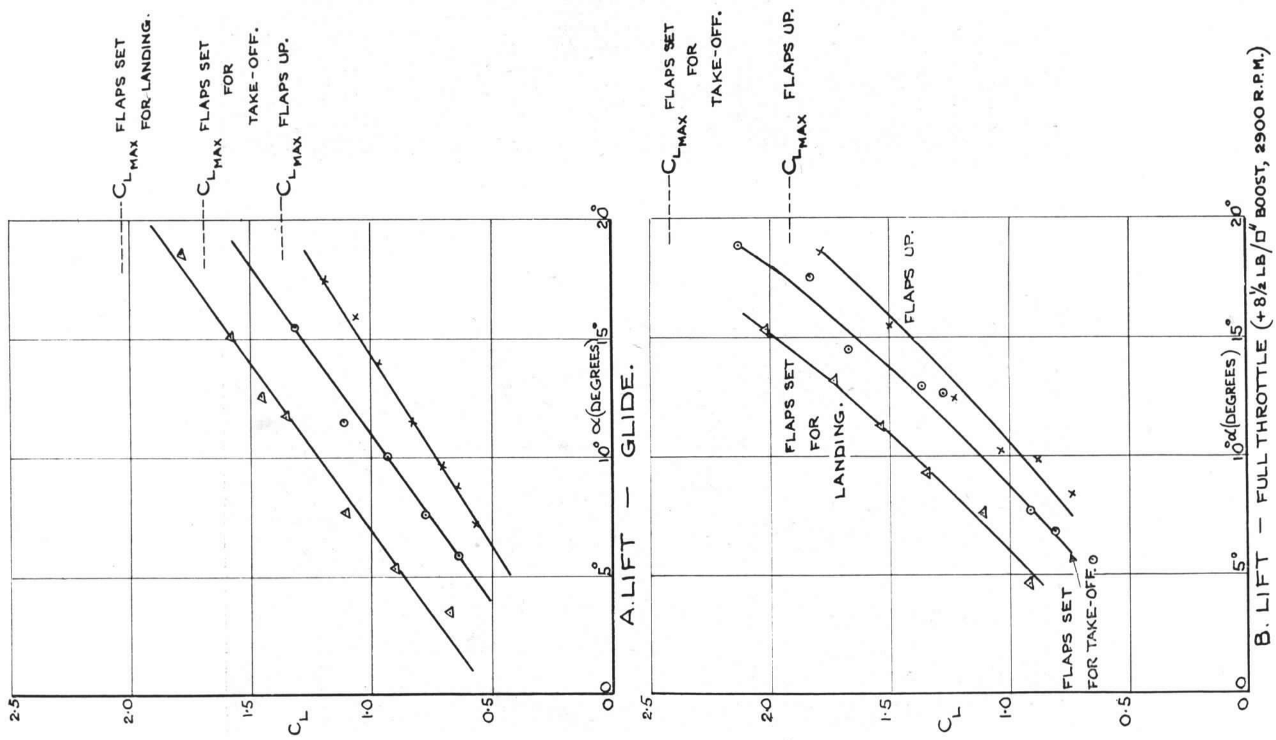
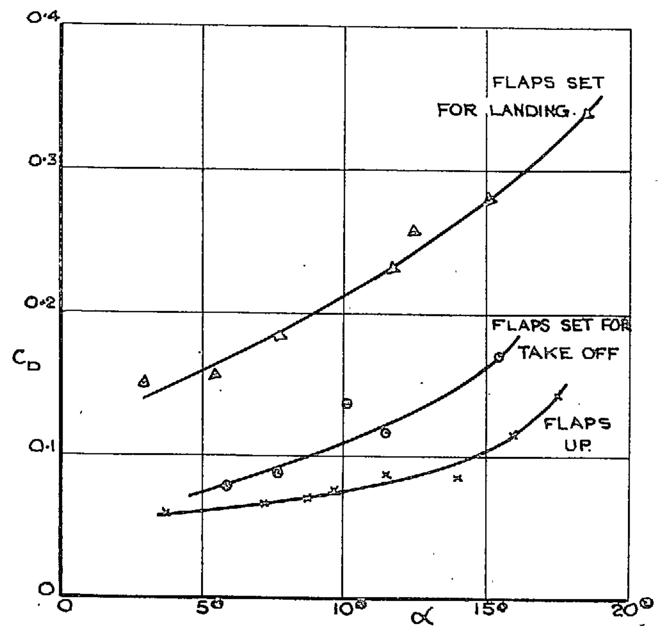
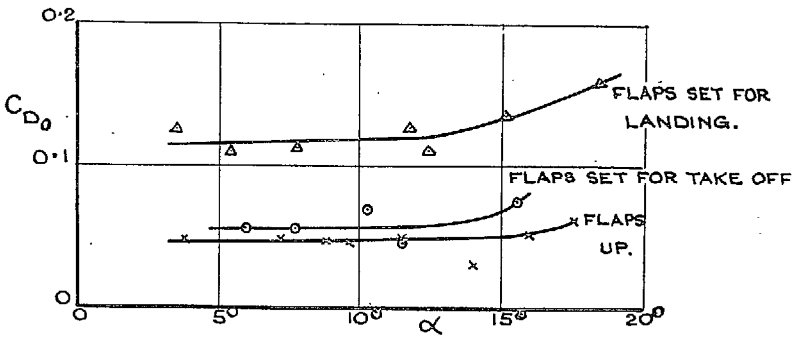


FIG. 6.

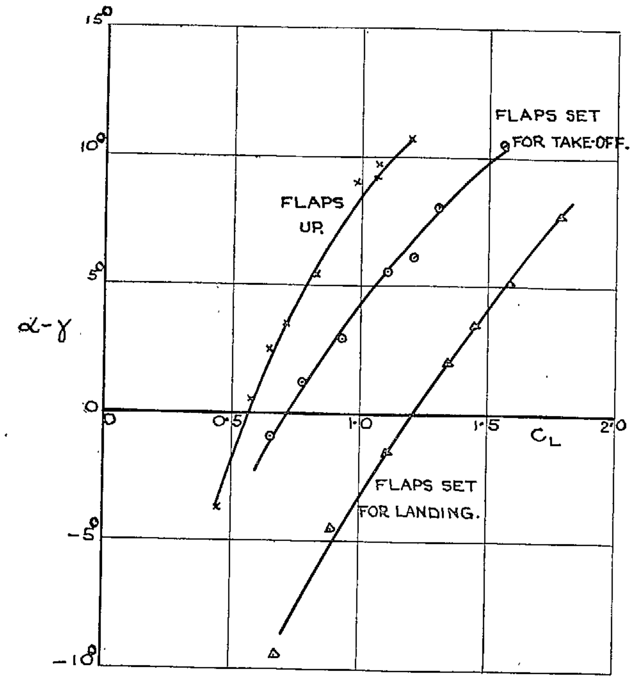


A. C_D — GLIDE.

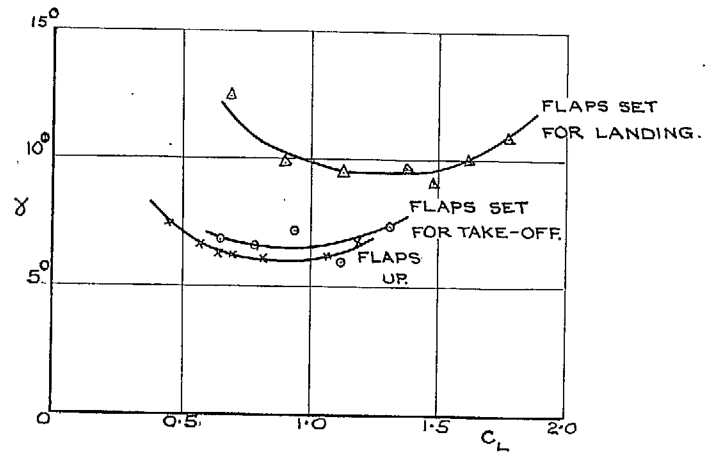


B. C_{D_0} — GLIDE.

FIG. 7.



A. GLIDING ATTITUDE.



B. GLIDING ANGLE.

FIG. 8

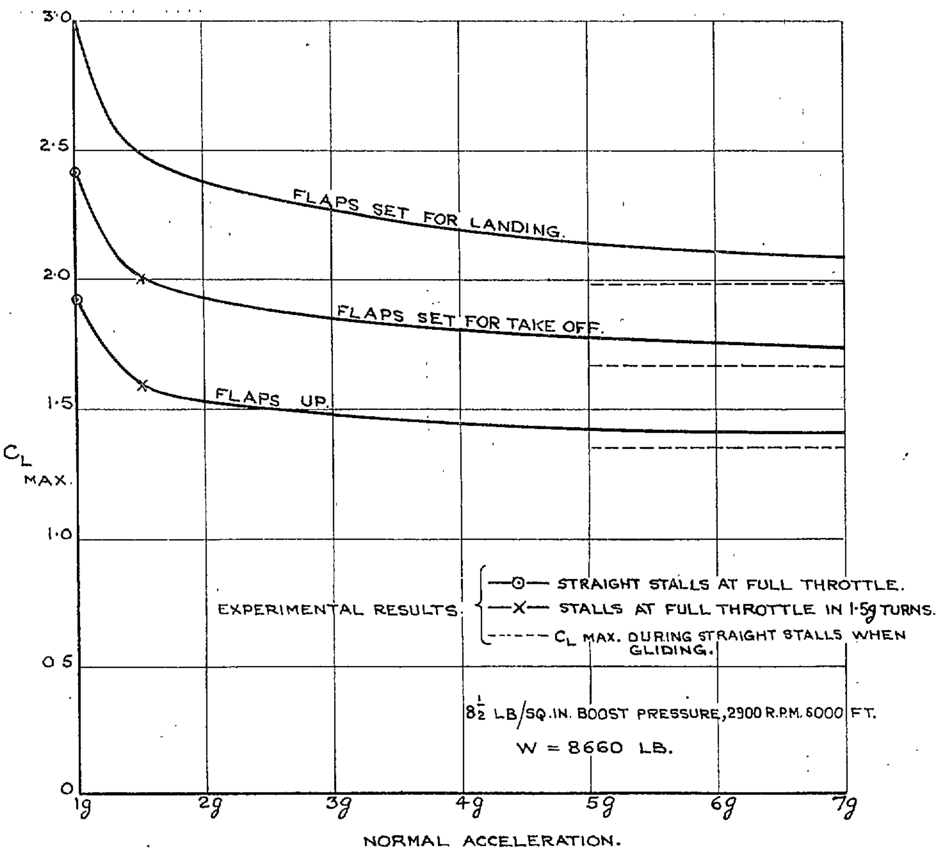


FIG. 9. Variation of Full Throttle $C_{L\ max.}$ with g at which the Aircraft Stalls.

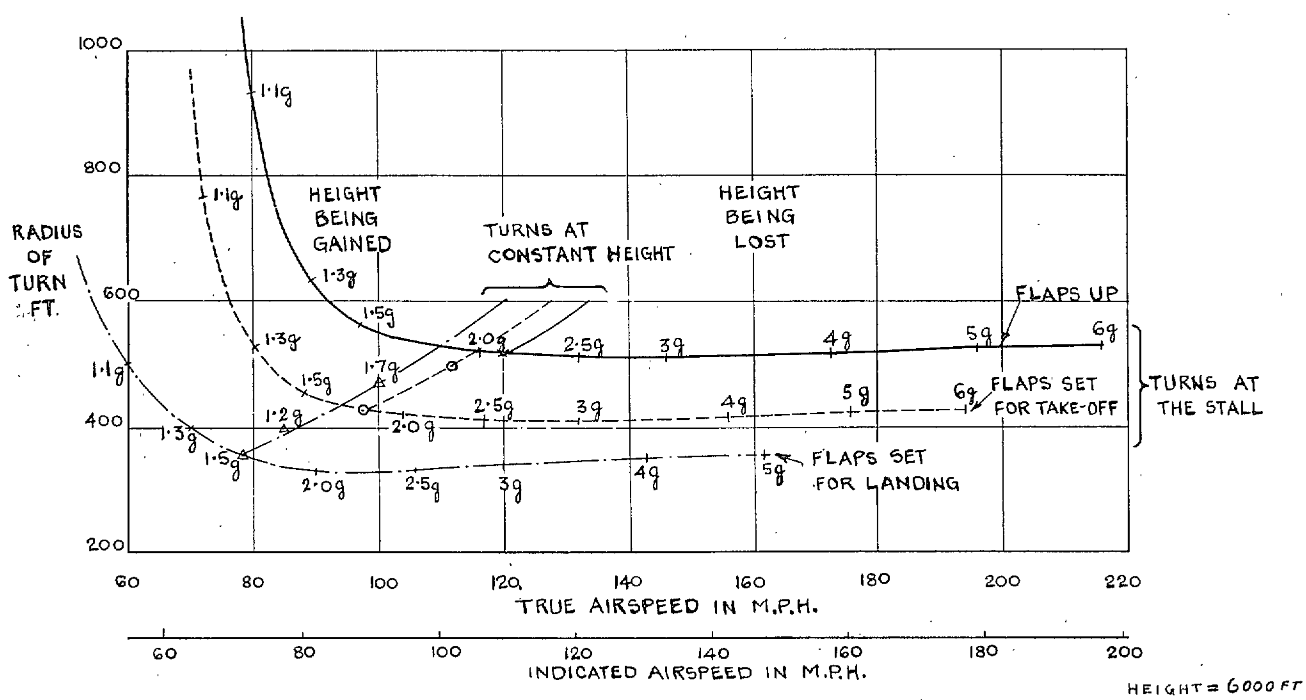


FIG. 10. Effect of Flap Setting on Turning Performance at Full Throttle.

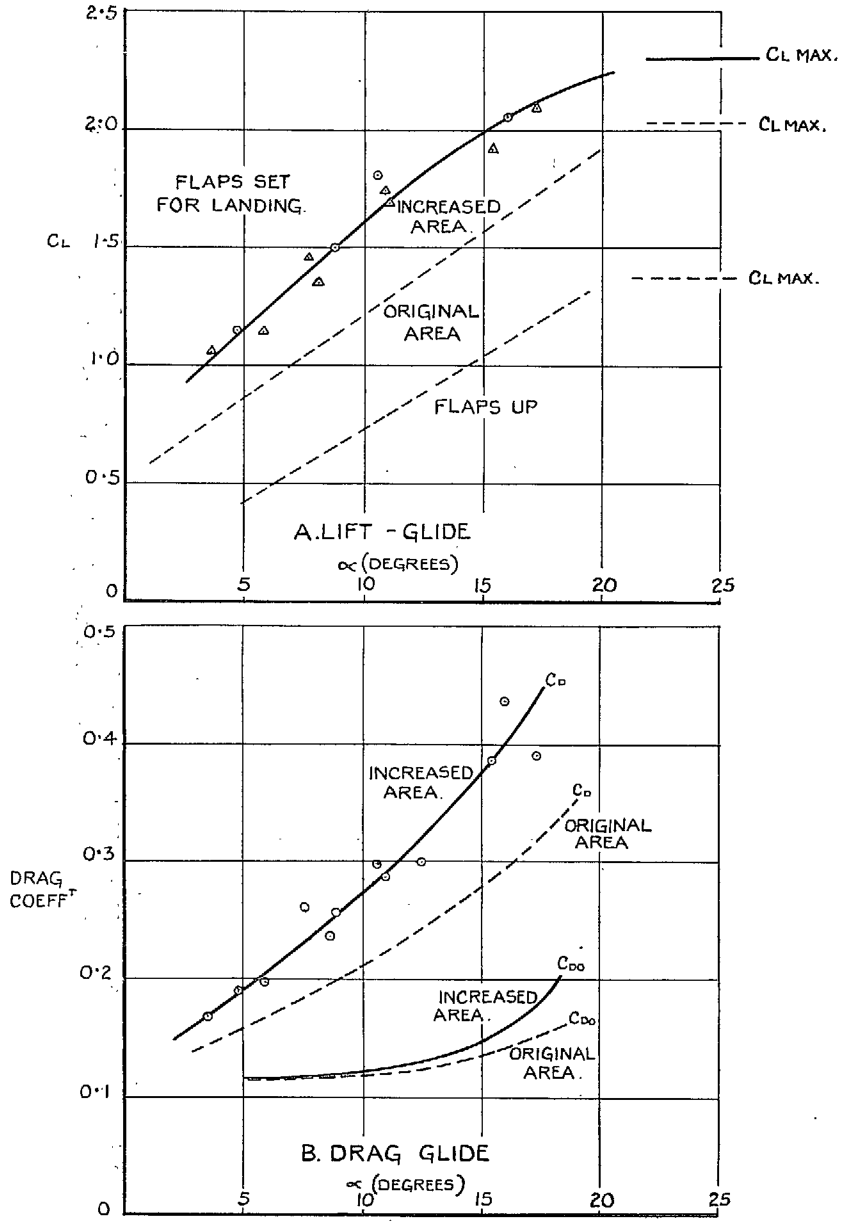


FIG. 11. Youngman Flaps Extended under Body—Set for Landing.

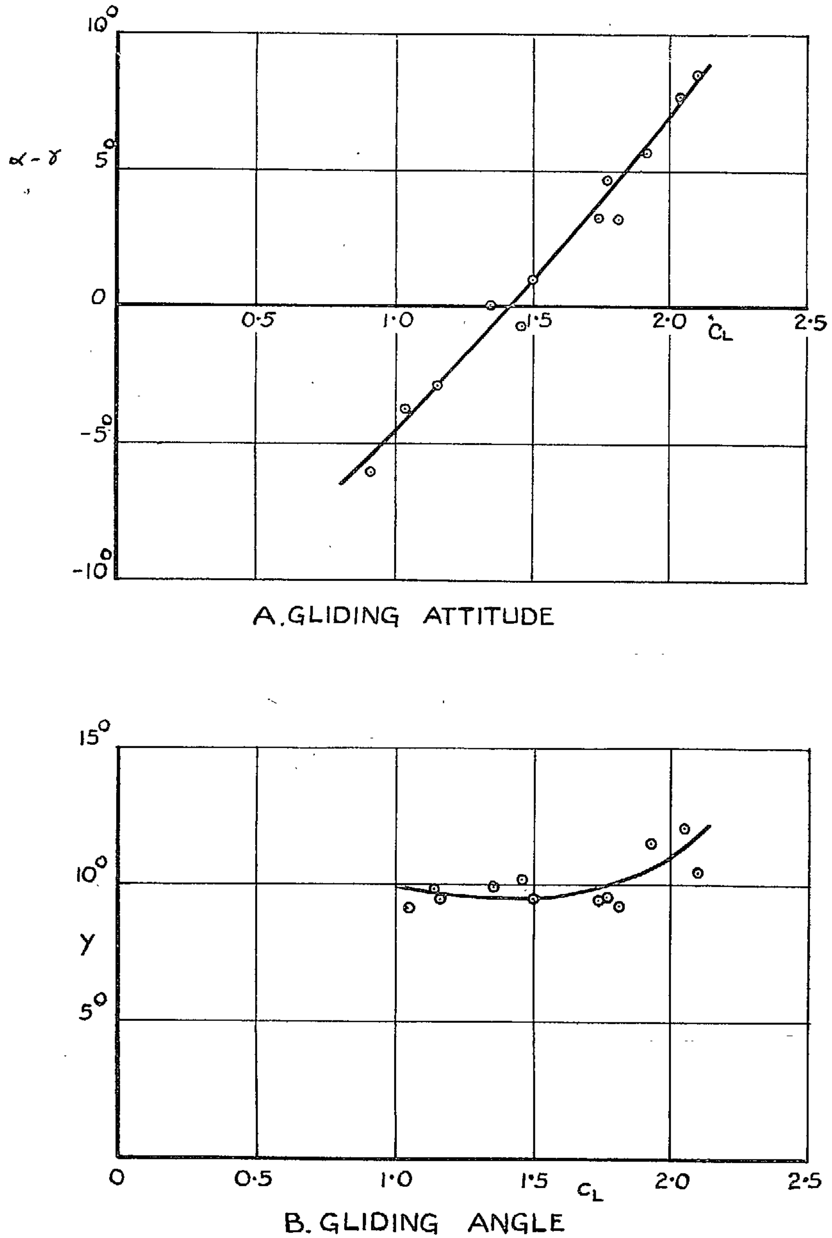


FIG. 12. Youngman Flaps Extended under Body—Set for Landing.

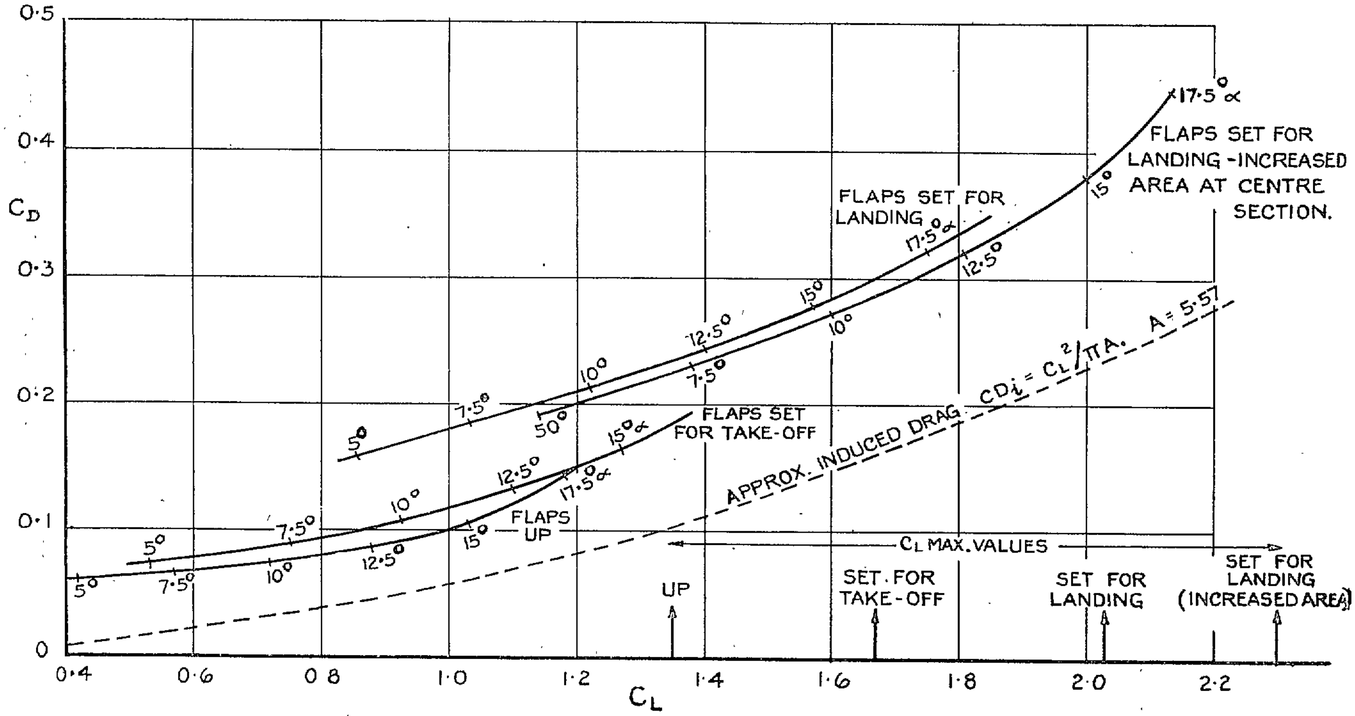


FIG. 13.

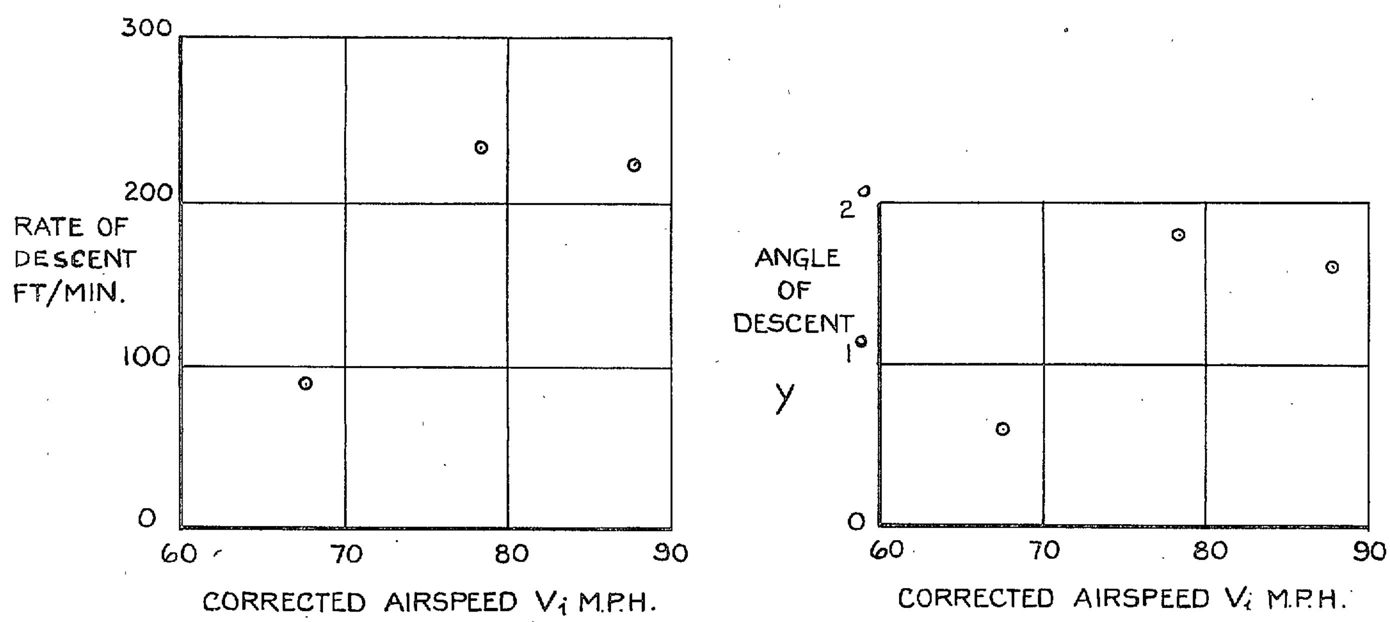


FIG. 14. Youngman Flaps Extended under Body—Set for Landing.—Rumble Approach at about $\frac{1}{5}$ Throttle (2,300 r.p.m.—$2\frac{1}{4}$ lb/sq in boost pressure).

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