Notes on the Dog Fight

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Summary.—Two aspects of the dog-fight are analysed :—

(1) The breakaway from line combat at high speed, success in which depends on a high rate of roll and a high blackout figure.

(2) The concentric attack, with the object of turning inside the enemy without losing relative height. This is a slow speed manœuvre, flown as close to the stall as possible, the acceleration being comparatively low. Favourable factors are low wing and power loading, high $C_{L\,max}$ and aspect ratio, and good control near the stall.

The analysis of concentric attack has led to a compact diagram for making a rough estimate of the turning performance when the straight flight performance is known.

1. *Introduction.*—During 1940, discussions on the features of fighter design which produce high manœuvrability were apt to be vitiated by neglect of certain essential factors in the problems, and in particular the vertical motion. The following notes were prepared, in relation to the tactics and performance current at the time, to show more clearly the relation between turning and straight performance and to suggest a compact diagrammatic summary of the subject.

2. *Tactical Aspects of the Problem.*—The dog-fight is well named. It is as unwise to dogmatise about its tactical principles as it is impossible to make a general statement on the dynamics of the complex of motions which it involves. In spite of this there are two manœuvres of the dog-fight which can usefully be abstracted and to some extent analysed. These will be called the breakaway and the concentric attack.

3. *Breakaway.*—If pilot A is being chased by pilot B in line combat, he may either escape or manœuvre for a new attacking position in B's rear by banking vertically and starting a turn horizontally. His success will depend on superiority in (*a*) rate of roll and (*b*) initial radius of curvature.

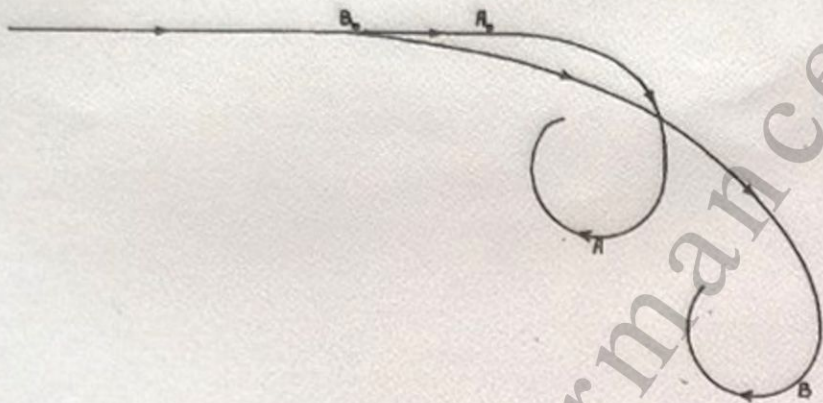
(*a*) *Response to ailerons.*—The important question of designing ailerons so that the response-to-force factor is as high as possible at high speed is fully discussed in Ref. 1 where it is shown that for similar ailerons this factor varies inversely as the fourth power of the span. Aircraft size is therefore a vital factor. If a pilot can make a 40-ft. span aircraft bank vertically in 4 seconds, he will take 10 seconds on a similar aeroplane of 50-ft. span. Alternatively, the ailerons of the 50-ft. fighter must be $2\frac{1}{2}$ times as light to restore parity. Five seconds lost in starting the breakaway may prove a crippling disability.

(*b*) *Initial radius of curvature.*—This is inversely proportional to n, where ng is the normal acceleration. The aerodynamic limit to n is $(V_{max}/V_s)^2$ where V_{max} is the speed and V_s stalling speed. This is of the order of 15–20. The structural limit is not greater than 10. The blackout limit is about 6. Thus the breakaway occurs at a radius much greater than the minimum, and is, in fact, determined by the blackout value, wing loading being unimportant.

* R.A.E. Report No. B.A. 1613 received 31st August, 1940.

It therefore seems highly probable that success in any breakaway manœuvre depends primarily on light ailerons, and that other things being equal the smaller fighter is likely to win. It would clearly be an advantage to increase the blackout limit towards the structure limit if this can be done without sacrificing the efficiency of crew or aeroplane.

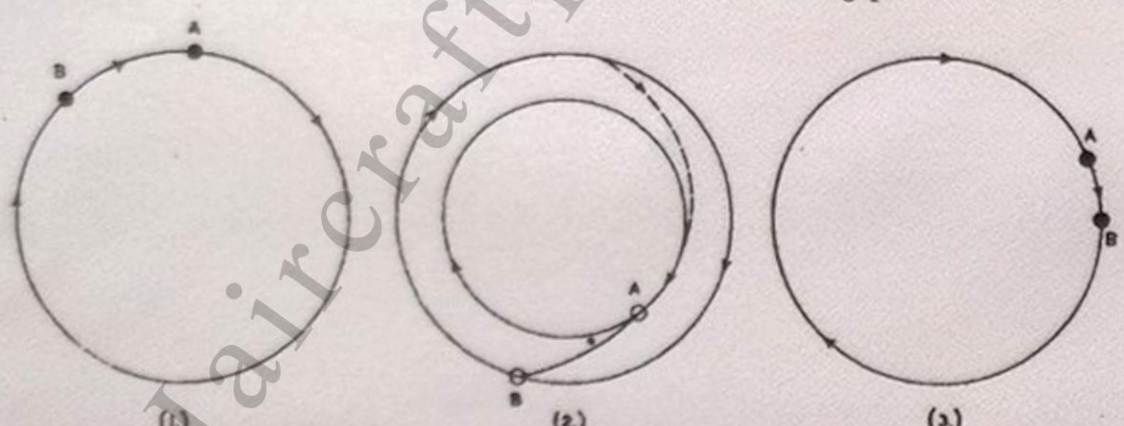
The course of the breakaway when A has superiority over B in roll and equality in radius is shown in the sketch:



A starts the breakaway at A_0.
B attempts to follow him, starting from B_0.

4. *Concentric Attack.*—The concentric attack as developed with fixed-gun fighters may be shortly described as a fight for the minimum steady turning circle *at a given rate of descent.* It is important to be clear at the outset that a discussion based on minimum radius without reference to the height factor is incomplete, for it is obviously of no advantage to pilot A to turn inside pilot B if in doing so he loses relative height, for he can never get his guns on B and will ultimately leave himself open to diving attack.

Without loss of generality we can consider the manœuvre as taking place at constant height.



Suppose that it starts [*see* (1)] with A leading B on the same circle, which is B's minimum but not A's. A can then reduce his circle without losing height. He is now immune from B's fire and has only to continue in his smaller circle until B becomes tangential to it, when he shoots B down [*see* (2)]. But if A can describe a smaller circle than B, he can also describe the same circle at a greater speed.* In this alternative mode of attack he catches up B and shoots him down from the rear (*see* (3)).

* This is true in any practical case (*see* Figs. 3, 6), but ceases to hold if A's wing loading is very low and his power loading very high compared with B.

An analysis is given below of the characteristics of this manœuvre and its dependence on wing loading and power loading, but something can be said at once about its general features. The pilot's object is to fly as near the stall as possible and as fast as possible while maintaining height. The speed is generally low; the acceleration is well below blackout and the bank is well below 90 deg.; and the radius is considerably greater than the aerodynamic minimum V_s^2/g. The factors making for superiority are a low stalling speed, high power and good control at the stall.

5. *Analysis of Turning Performance.*—A framework for the analysis of turning performance has been given in R. & M. 1502[2] and will be used here for the special case of no sideslip.

When the straight flight performance is known, the turning performance can be stated in terms of the four parameters :—

$$V_s,\ C_{L\,max},\ n \text{ and } N\ ,$$

where ng is the normal acceleration, and $N = (V/V_s)^2$.

If R is the radius, T the time of revolution and ϕ the angle of bank, we have :—

$$\left.\begin{aligned} R_{min} &= \frac{V_s^2}{g} \\ \frac{R}{R_{min}} &= \frac{N}{\sqrt{(n^2-1)}} \\ T &= \frac{2\pi V_s}{g}\sqrt{\frac{N}{n^2-1}} \\ \sec\phi &= n \\ C_L &= \frac{n}{N}C_{L\,max} \end{aligned}\right\} \qquad \ldots \qquad (1)$$

Now let θ be the angle of climb in the spiral and θ_0 the angle of straight climb at the same forward speed. Then if the profile drag coefficient is $C_{D0} + kC_L^2$ and if the loading is elliptic, the aspect ratio being A, we have

$$\begin{aligned} \Delta\theta &= \theta_0 - \theta \\ &= \left(\frac{1}{\pi A} + k\right)\frac{n^2-1}{N}C_{L\,max} \qquad \ldots \qquad (2) \end{aligned}$$

This is a convenient first approximation to the increase in drag at a given speed. It is optimistic near the stall. *See* R. & M. 1502[2] for a fuller discussion.

6. *Diagram of Turning Performance.*—Using the above equations, a compact diagram of turning performance can be constructed, using N as abscissa and $\Delta\theta$ as ordinate. This is filled with curves specifying constant values of n, R and T. It is bounded on the left by the stalling curve ($n = N$), and completed by the basic curve of angle of straight climb. R_{min} occurs on the asymptote to the stalling curve. Consider for instance Fig. 1. The turning performance at twice the stalling speed ($N = 4$) with a normal acceleration of $2\cdot5g$ ($n = 2\cdot5$) is given by the point P. The radius is about 480 ft. The time of turn, obtained from the right-hand scale, is 16·3 secs. The angle of descent is given by the distance of P above the basic performance curve; it is 5 deg., corresponding to a rate of descent of 1,000 ft./min.

The diagram is particularly convenient because the level turn condition is $\Delta\theta = \theta_0$, and so the level turn performance is defined by the basic curve (the black line) giving the angle of straight climb.

Concentric attack occurs near the stalling boundary ($n = N$) to the left of the diagram. The optimum for concentric attack at constant height occurs at X, the intersection of the basic performance curve with the stalling boundary, and at this point we have

$$R/R_{min} = 1 \cdot 28,\ R = 350 \text{ ft.},\ n = N = 1 \cdot 6,\ \phi = 52 \text{ deg.},\ V = 82 \text{ m.p.h.},\ T = 18\tfrac{1}{2} \text{ secs.}$$

Concentric attack, to be successful, must clearly be confined to a narrow speed range represented for instance by the small portion XY of the basic curve. At Y, where the speed is about 110 m.p.h., the radius of level turn has increased to 470 ft., and if this is reduced to 350 ft., the angle of descent is 8 deg., with a rate of descent of about 1,250 ft./min.

On the other hand the conditions of breakaway occur to the right of the diagram, near V_{max}. A breakaway at a blackout value of $n = 6$ at V_{max} is represented by the point Z, where $\Delta\theta$ is 25 deg. and the radius is 660 ft. The horizontal deceleration at the beginning of the breakaway is $25g/57 \cdot 3$ or $0 \cdot 43g$, but if the speed and the normal acceleration are held at the initial values and a steady spiral at this radius is developed, the angle of descent will be 25 deg. and the rate of descent about 9,000 ft./min.

7. *Effect of Wing Loading and Power on Concentric Attack.*—It is clear that wing loading and power are the dominant factors in concentric attack, since wing loading governs the stalling speed and power the vertical motion. The effects of these quantities have been illustrated by starting with measured performance figures for the Spitfire with constant-speed airscrew at 12,000 ft., the standard condition being :—

Wing loading 25	V_s 86 m.p.h.
B.H.P. 960	$C_{L\,max}$ 1·75

(*a*) *Effect of wing loading.*—The Spitfire wings are supposed to be decreased and increased by 30 per cent. at the same aspect ratio, nothing else being changed. This gives the straight performance curves of Fig. 4, the wing drag coefficient being taken as $0 \cdot 01 + 0 \cdot 07C_L^2$. The turning performance for the three cases is summarised in Fig. 2, and the radius of level turn is plotted against speed in Fig. 3.

The results may be summarised as follows :—

				Optima for level concentric attack			
Wing Loading	V_{max}	V_s	R_{min}	R	V	T	n
32·5	348	98	640	720	146	23	2·2
25	331	86	495	560	127	18½	2·2
17·5	315	72	345	400	102	15½	2·0

(*b*) *Effect of power.*—When the power is changed by $\pm$ 10 per cent., weight and $C_{L\,max}$ being unchanged, we get the straight performance curves of Fig. 7, the turning performance diagram of Fig. 5, and the radius of level turn of Fig. 6.

In this case the principal results are:—

				Optima for level concentric attack			
B.H.P.	V_{max}	V_s	R_{min}	R	V	T	n
1,060	341	86	495	540	133	17·3	2·5
960	331	86	495	560	125	18·5	2·2
860	320	86	495	580	118	21	2·0

8. *Other Examples of Turning Performance.*—The turning performance of the Blenheim (Fig. 1) has already been referred to in explaining the method of analysis. The Blenheim is of interest in having a considerably higher $C_{L\,max}$ at full throttle (about 2·5) than the Spitfire (about 1·75) owing to its twin slipstream; its optimum radius at the same loading would therefore be less.* The Spitfire would no doubt beat the Blenheim in a dog-fight, in spite of its greater radius of level turn, because of its greater speed, rate of climb and manœuvrability. Nevertheless, the extra lift obtained from the slipstream might turn the balance, in a dog-fight between a single-engine and twin-engine fighter of equal size, wing loading and power loading, in favour of the twin.

The turning performance of an old-type biplane, very lightly loaded (about 8 lb./ft.^{2}) and of small speed range, is shown in Fig. 8. By comparing this with the Spitfire (Figs. 2, 5) we get an idea of the difference between the dog-fights of 1914 and 1940; in the interval the typical radius has been multiplied by three and the typical speed by two. It is also apparent that an argument based solely on the evil effects of high wing loading is misleading. An S.E.5 would no doubt beat a Spitfire in concentric attack if the Spitfire accepted this tactic. But, in fact, the Spitfire would decline it and shoot the S.E.5 down by virtue of its immensely greater speed and climb.

9. *Conclusions.*—Analysable aspects of the dog-fight are:—

(1) The breakaway, which is a high-speed manœuvre in which everything depends upon a high rate of roll and a high blackout figure. The response in roll deteriorates critically with increase in span unless the ailerons are specially designed for lightness.

(2) The concentric attack, which is essentially a low-speed manœuvre, flown as close to the stall as possible, with acceleration well below the blackout. Factors which favour the concentric attack are:—

(i) low wing-loading,

(ii) low power-loading, which may compensate for high wing-loading,

(iii) high $C_{L\,max}$ at full throttle (twin engine probably better than single engine, other things being equal),

(iv) good control at the stall,

(v) high aspect ratio.

REFERENCES

No	*Author*	*Title, etc.*
1	Gates and Irving	An Analysis of Aileron Performance. R.A.E. Report B.A. 1624. A.R.C. 4652. July, 1940.
2	Gates	A Study of Aircraft Turning Performance. R. & M. 1502. August, 1932.

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* It should be noted that the $C_{L\,max}$ values quoted refer to straight flight. The difference will be considerably less at the higher speed of concentric attack, say $\sqrt{2}V_s$.

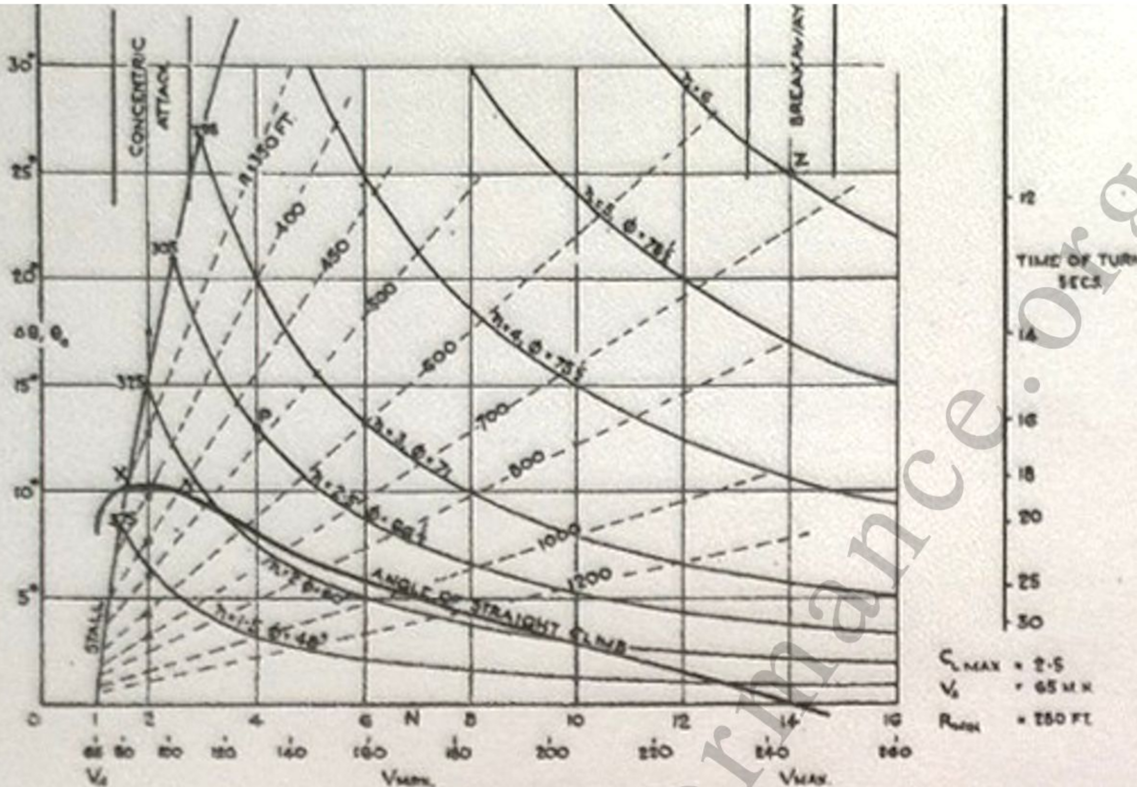

FIG. 1. Blenheim at Ground Level.

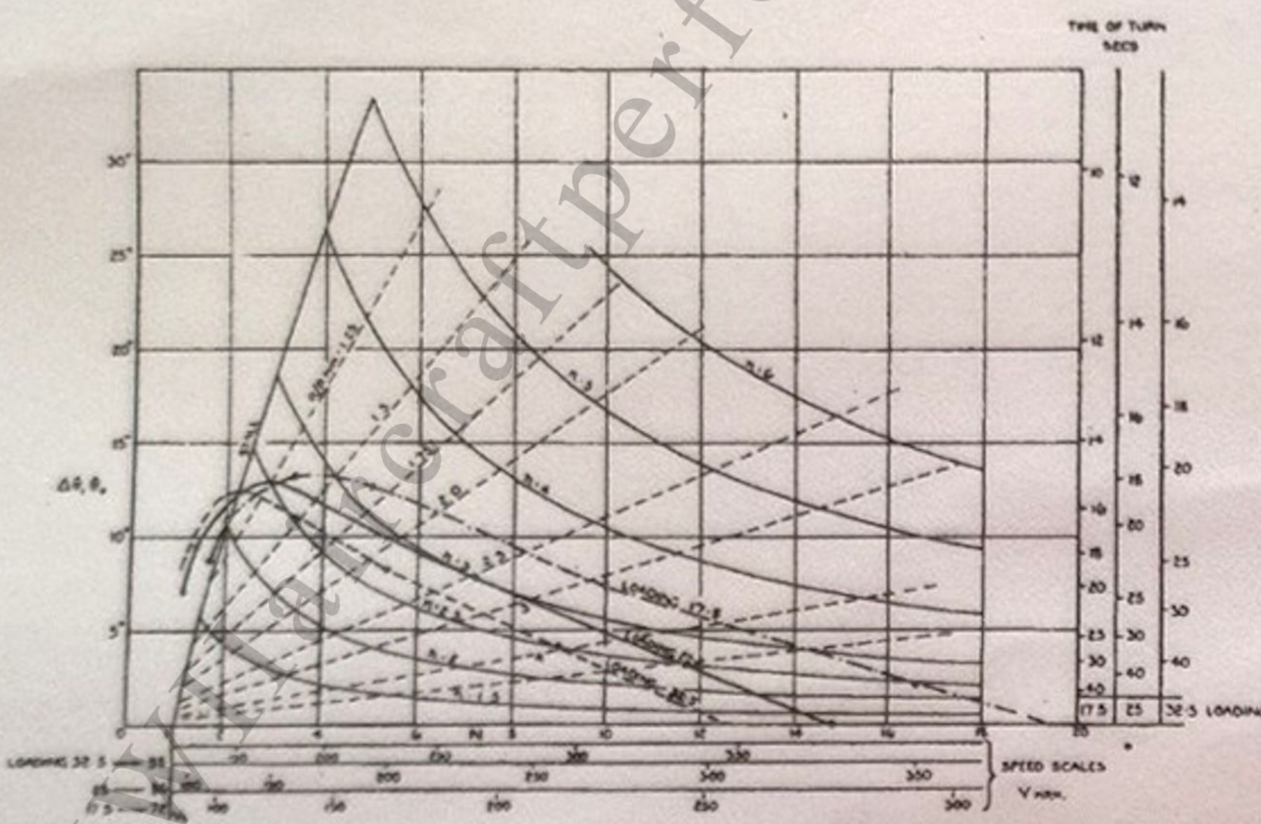

FIG. 2 Effect of 30 per cent. Variation of Loading by Changing Wing Area.—Spitfire at 12,000 ft.

Loading	V_s m.p.h.	V_{max}	R_{min} ft.	$C_{L\,max}$
32·5	98	348	640	1·75
25	86	331	495	1·75
17·5	72	315	345	1·75

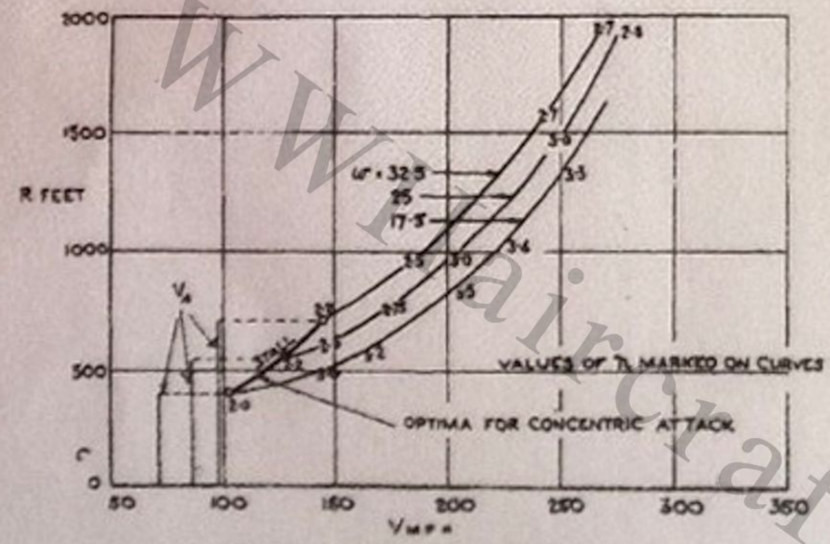

FIG. 3. Radius of Level Turn.

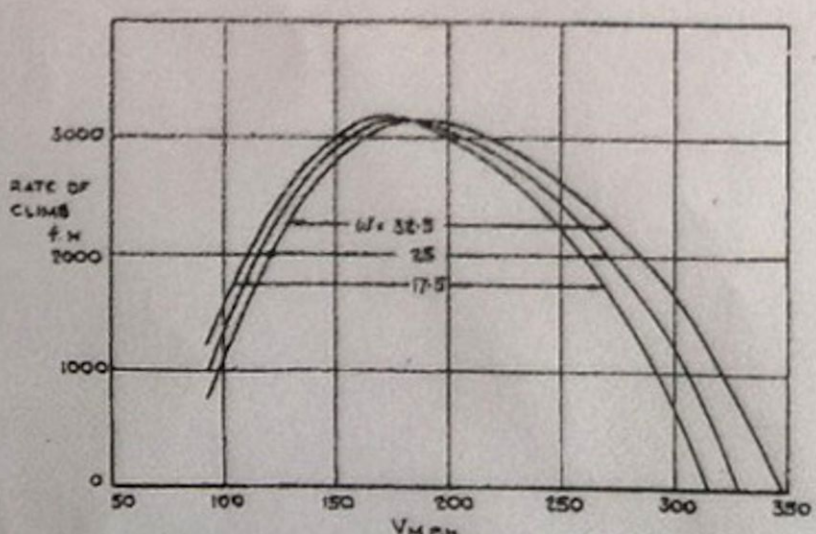

FIG. 4. Rate of Climb—Straight Flight.
Effect of Wing Loading on Level Turns—Spitfire at 12,000 ft.

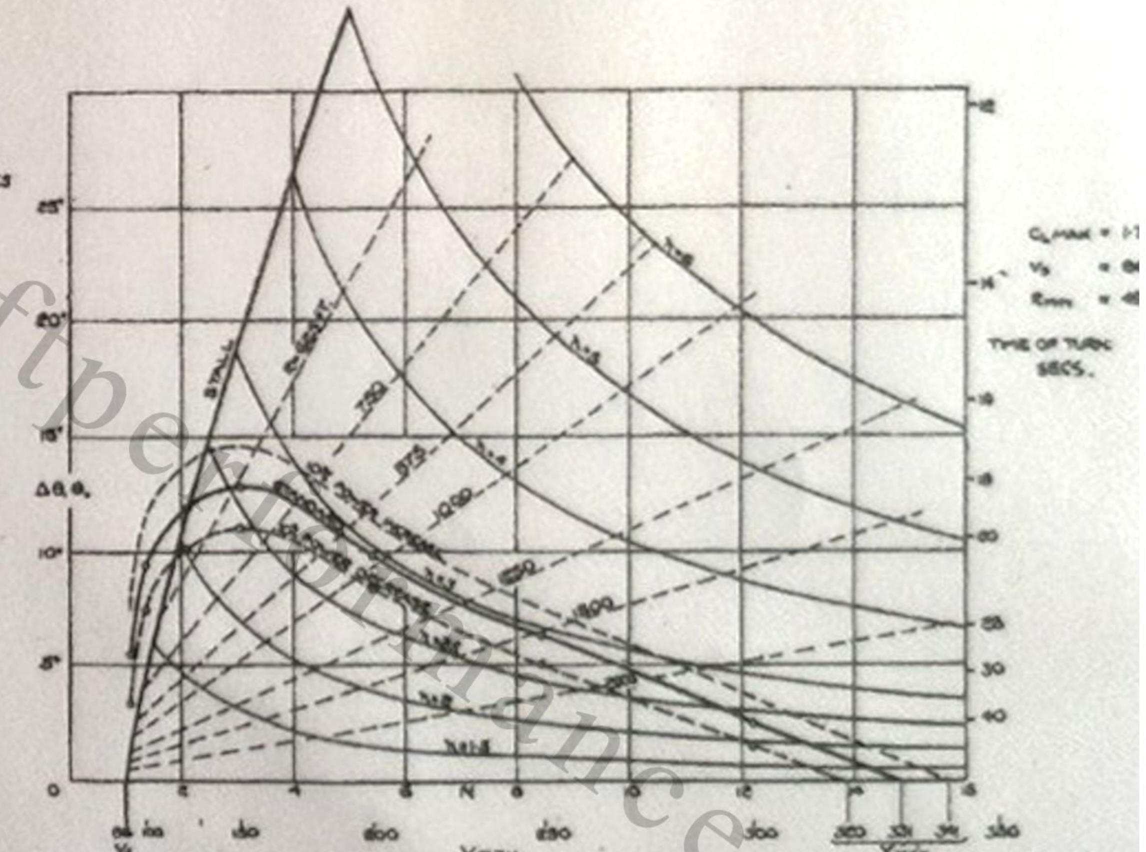

FIG. 5. Effect of 10 per cent. Variation in Power.—Spitfire at 12,000 ft.

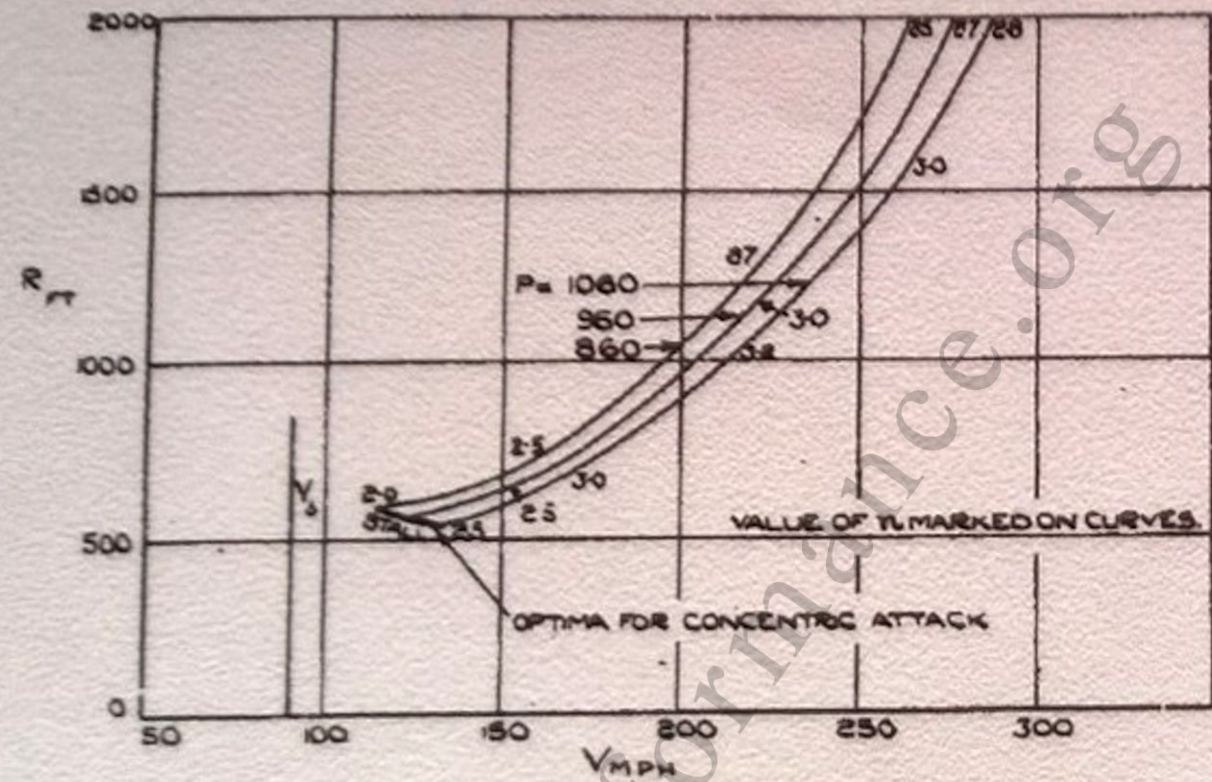

FIG. 6. Radius of Level Turn.

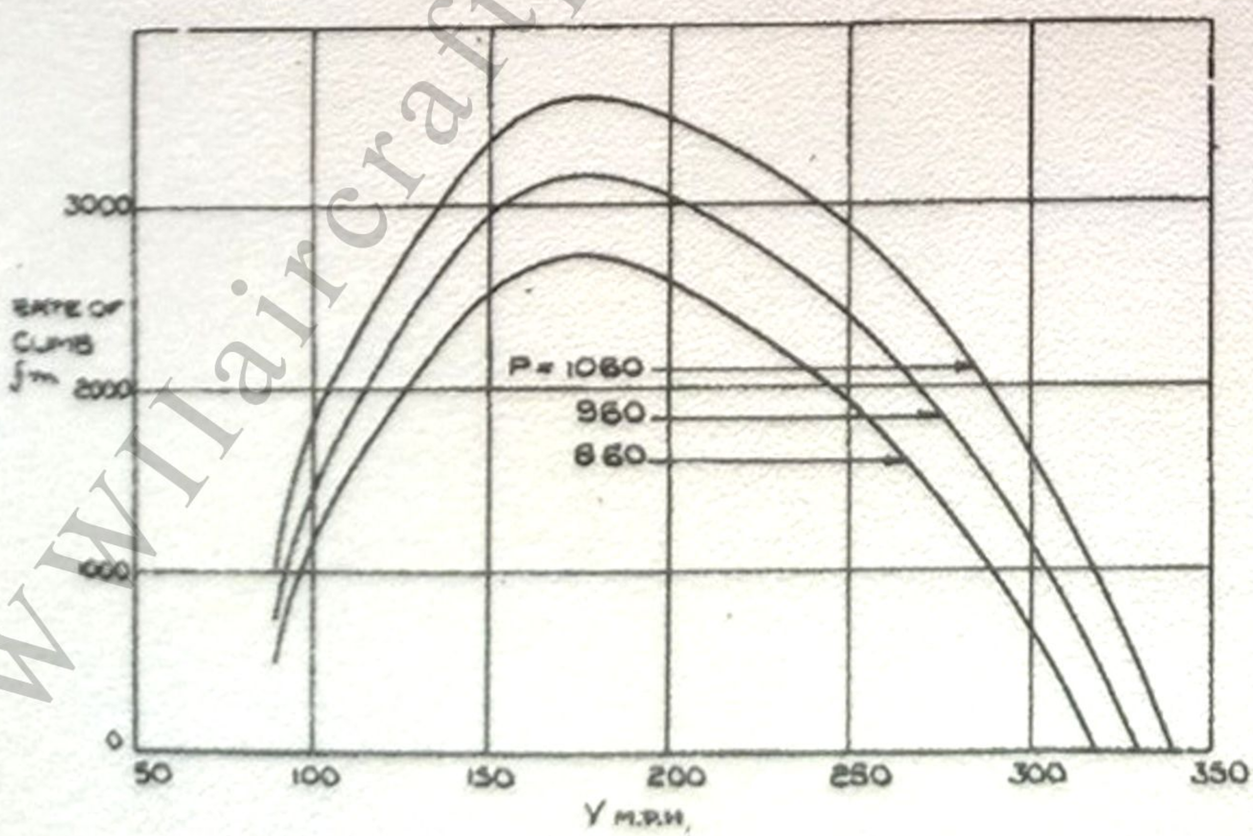

FIG. 7. Rate of Climb—Straight Flight.

(89848) Wt. 13/806 K5 2/50 H.W.
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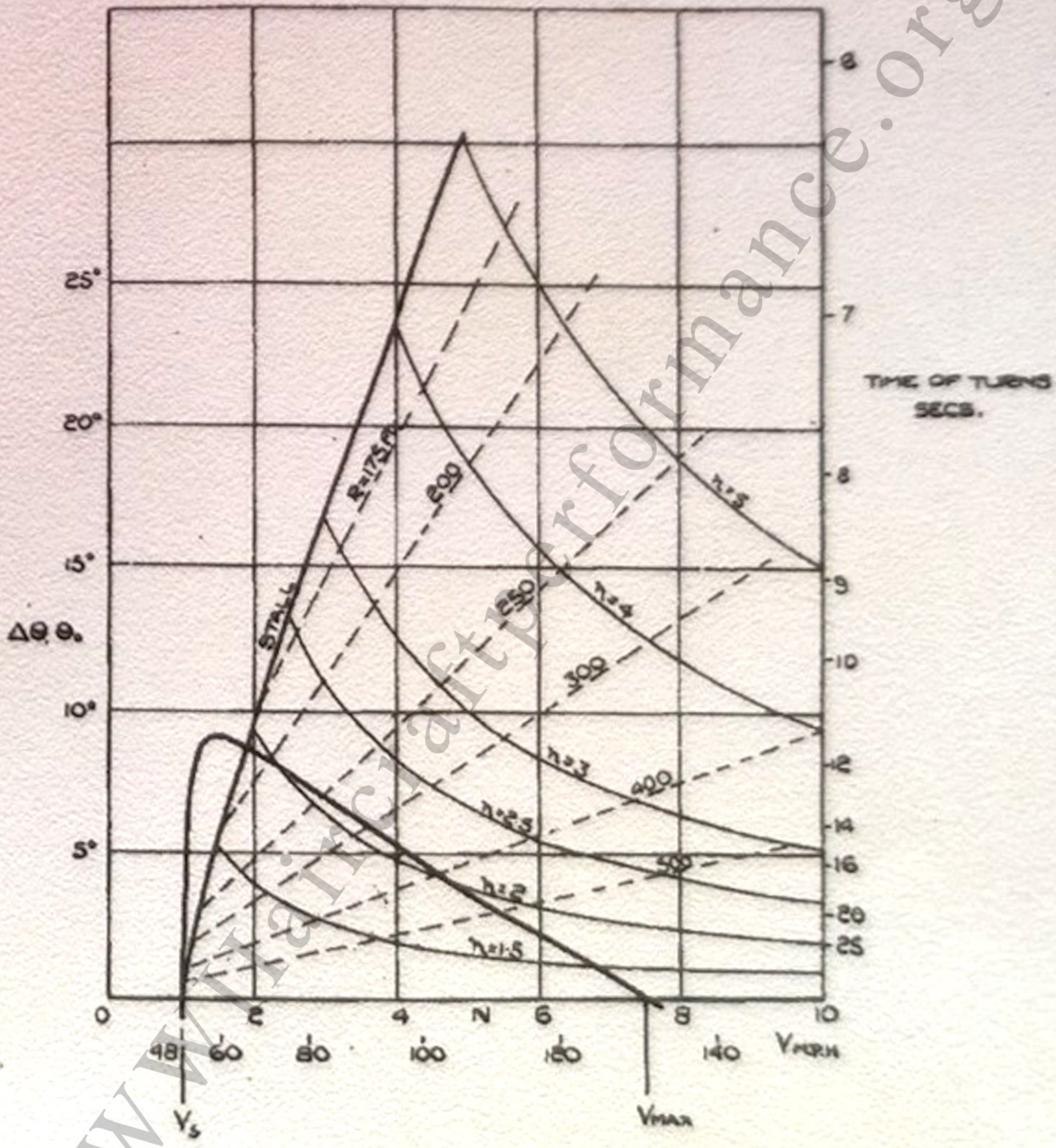

C_L MAX.	1·1
V_S	48 M.P.H.
R MIN	153 FT.

FIG. 8. Old Biplane at Ground Level.