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Stalling Tests on a Blenheim

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Summary.—Reasons for Enquiry.—In extension of earlier flight tests[2] it was required to investigate how accidental stalling and spinning of a Blenheim is affected by the setting of flaps, engine gills and throttles.

Range of Investigation.—The behaviour of the aircraft was tested at low speeds, both in straight stalls and also when one engine was cut in the climb. The tests included an investigation of some modifications to the wing.

Conclusions.—All of the above settings affect the behaviour of the Blenheim at and near the stall; closing the gills and opening the throttles usually both have an adverse effect, either by reducing the warning of imminent stalling or by making the stall more violent. With gills closed and throttles partly open the stall is violent with flaps and undercarriage either up or down.

In the engine-cutting tests the aircraft drops the corresponding wing suddenly, and at the lower speeds the falling wing partially stalls.

The experiments with modified wing-section and wing-tip plan-form resulted in some improvement in stalling and behaviour after engine-cutting.

1. *Introduction.*—Previous tests at Martlesham[1] and at the R.A.E.[2] had shown that the Blenheim, when stalled with flaps and undercarriage up, usually drops a wing sharply, though not necessarily without warning. Important changes in behaviour are caused by lowering the flaps, opening the engine-cowling gills or opening the throttles.

As the previous tests had shown no important effect of C.G. position on stalling behaviour, the present tests were done with the C.G. at 1 in. in front of the aft limit only ($37\frac{1}{2}$ in. aft of root leading edge with undercarriage down; $h = 0{\cdot}27$). The aircraft was flown at a total weight of 11,400 lb. Flaps and undercarriage were either fully up or fully down together, except where the contrary is stated, and, in the tests with engine on, the throttles were generally about $\frac{1}{3}$ open. The airflow was studied by visual observation of wool-tufts and by ciné-photography.

The wing plan is shown in Fig. 1.

During the handling tests[3] there was an investigation of flying with one engine. If one engine is suddenly throttled back in the climb at full throttle, a wing may drop sharply. For test purposes the pilot acted as though the engine had cut unexpectedly. In the worst cases, at the lower climbing speeds, there is a stalling phenomenon, and observations were taken with flaps and undercarriage up, and with flaps 30 deg. down and undercarriage down.

The effect of making the nose of the wing section blunt was also investigated. This change made it more difficult to stall the section thoroughly, but the improvement in behaviour of the aircraft was not great. A more noticeable improvement was gained by the further modification of removing a part of the wing tips.

In describing the turbulence by diagrams there is an elaboration of previous practice, in that a turbulence which only affects the two lowest tufts on the same post is defined as "partial" and denoted by simple shading. Thorough turbulence is denoted by cross-hatching. The depth of turbulence is thus indicated by two contours instead of one. The milder disturbance,

* R.A.E. Report B.A. 1566, received 9th February, 1940.

provoked by opening the gills, is classed as " partial " to distinguish it from the more severe disturbance, often amounting to reversed flow, that " deep " turbulence usually involves.

The present report is intended mainly to show how complex are the problems of stalling and wing-dropping with twin-engined aircraft.

2. *Behaviour in Straight Stalls.*—2.1. *General.*—Some details of the tests are set out in Table 1 and the corresponding diagrams in Figs. 2–9. Speeds are stated throughout as A.S.I.R.

It was noted that, even in those stalls from which recovery is immediate, the aircraft remains in a partly stalled condition during the resulting dive until the speed has risen about 10 m.p.h. above stalling speed. This feature is not affected by any of the modifications of para. 4.

2.2. *Behaviour in Straight Stalls, Flaps Up, Figs. 2–5.*—In the ordinary condition of gliding flight with flaps up and gills closed, the stall has the following features :—

(i) There is a warning unsteadiness at 70 m.p.h., with slight pitching oscillation and considerable vibration.

(ii) The aircraft becomes nose-heavy at about the same speed, and from this point the stick has to be pulled back considerably to prevent the speed from rising.

(iii) The stick becomes progressively heavier.

(iv) The wing gradually becomes more stalled, though usually the A.S.I. reading changes very little and still indicates about 70 m.p.h. when the right wing drops suddenly and rather quickly with slight snatch on the control column. The nose drops into a steep attitude from which a spin would probably develop if the stick were not eased forward.

This is not a pleasant stall but it is preceded by warnings that a pilot would not normally ignore. These warning features are evidently due to one cause : the development of early root turbulence. The resulting wake causes buffeting, unsteadiness and pitching oscillation, and the collapse of local downwash produces a change of trim that is felt by the pilot as nose-heavi ness. The severity of the ultimate stall is due to the rapid spreading of turbulence, ultimately covering the whole of the falling wing. These points find some expression in Fig. 2.

The remaining tests, with each of the various combinations of flaps, gills and throttles, seem to point to one principal conclusion, namely that, so long as the root stalls well in advance of the extension wing, the stall is not unduly violent and is preceded by reasonable warning.

With engine on at about $\frac{1}{3}$ throttle there is a repression of root turbulence due to slipstream and this has the effect that—

(i) the downwash at the tail is preserved to higher incidences, so that the aircraft undergoes no sudden change of longitudinal trim, and stalls with stick more nearly central, and with very light load (trimmed to 100–120 m.p.h.) ;

(ii) the warning unsteadiness is wholly or partly suppressed ;

(iii) the wing usually drops faster and further, though sometimes less violently, than with engine off. On one occasion with controls fixed the aircraft recovered from the incipient spin. Though there is some degree of alternative warning from the lower speed and steeper attitude, the stall with engine partly on is worse, both because there is less warning and because the movement may be more violent.

These effects are attributed to the root of the wing, the outer wing being in fact much less affected by opening the throttles. So far as turbulence at the outer wing is concerned, the same effects occur, though at a lower speed. At about 62 m.p.h. deep turbulence appears beyond the nacelles and there is more pronounced turbulence at the root of the left wing than at the root of the right wing, resulting in a slight tendency of the aircraft to turn right. Below this speed the right extension wing stalls progressively and quickly, and the root does not keep pace. The difference from the engine-off condition shows in Fig. 3.

A contrary effect is noticed when the gills are opened (Fig. 4). Root turbulence is provoked mildly at quite high gliding speeds, about 120 m.p.h., and the aeroplane vibrates considerably. This vibration develops as speed is reduced and below 86 m.p.h. the aircraft becomes very unsteady, pitching slightly. In consequence of the root condition—

(i) the stick position to stall is hard back, because the tail is ineffective in the turbulent wake or because of deficient downwash. The stick load is very heavy at the stall;

(ii) the warning unsteadiness is considerably increased;

(iii) the wing drops more gently at the stall. The aircraft becomes laterally unstable at about 66 m.p.h. and this effect increases as the stick is eased right back, the speed meanwhile not changing much. Finally, there is a pause before the wing drops, usually not very fast, the nose falling with it. The airflow over the wing does not become wholly turbulent until the latter is actually dropping.

In the approach to the stall in this condition, gills open, the aircraft has a strong tendency to turn right, and requires nearly ¾ left rudder and about ½ full aileron to keep straight and level; this is probably another wake effect. The aerodynamic warning of the impending stall consists chiefly of the oscillation that begins at about 10–20 m.p.h. above the stalling speed and the progressive increase of stick force. One pilot did not regard these warnings as satisfactory, but the effects, however regarded, are evidently those of root turbulence.

If the gills are open and the engine is partly on then there are conflicting influences on the root. The result is a better stall than with engine on, gills closed, but a worse stall than with engine off, gills open. Slipstream has some visible effect towards suppressing root turbulence, though less obviously than in the previous case (gills closed). The aircraft is, however, less unsteady than with engine off. Apart from this, the chief differences are an increase of elevator effectiveness as with slipstream in flight at lower incidences, a tendency to turn right even stronger than without engine, and a lower stalling speed. The wing drops further at the stall before recovery. The stick heaviness, noticeable with engine off, is delayed and so develops suddenly.

2.3. *Behaviour in Straight Stalls, Flaps Down, Figs.* 6–9.—The aircraft behaves quite differently with flaps down. Root turbulence begins at 70 m.p.h. (gills closed), and extends beyond the nacelle at 59–60 m.p.h., at which speed a slight pitching oscillation begins. The wing may drop gently, but does not always drop even with the stick further back. The oscillation builds up rapidly and after about two cycles the turbulence is more extensive but still does not reach the leading edge. It is probable that the pitching would become dangerous before the wing could be thoroughly stalled.

The use of engines again suppresses root turbulence. It is not certain whether the flap alone has an adverse effect though it might be expected to improve the flow at the root; it is noticeable that flaps alone and engine (⅓ throttle) alone produce about the same change of stalling speed, of which change probably position error accounts for only a small part, but that the root turbulence with flaps down starts at a lower speed (Table 1). With engine on, too, there is very little turbulence anywhere down to 50 m.p.h., the aircraft remaining steady. A slight pitching oscillation then begins and as the stick is pulled further back the aircraft stalls very violently, the right wing falling beyond the vertical. This is the clearest case of the adverse effect of slipstream. Possibly the slipstream exerts a different effect with flaps down from that which it exerts with flaps up, and the adverse effect with flaps down may be partly due to the suppression of the pitching tendency. The longitudinal behaviour cannot be dissociated from the problem of lateral control at the stall, and in this case the changes at the tail may be more important than any direct effect of slipstream on the lateral stability.

The effect of slipstream is also felt with flaps down and gills open. Both stalls are mild and with engine off a wing usually does not drop at all. With engine on the aircraft may spiral gently, but sometimes drops a wing, though not violently.

3. *Effect of Cutting One Engine.*—If one engine is suddenly throttled back at low speeds in a straight climb at full throttle, the Blenheim drops a wing rather quickly. Before control is regained there is a considerable loss of height, of which measurements have been given[3]. At the lowest climbing speeds there is a danger of accidental spinning. Tests were done with flaps up and gills closed, flaps up and gills open, and flaps down 30 deg. and gills open. The pilot was attempting to effect recovery as if taken by surprise without preparatory control movements. The starboard engine was cut because the result was worse than with the port engine cut[3].

In most conditions of climb the results of the tests were similar. After the throttle was closed there was a short pause of a second or two while the aircraft yawed slightly to the right. Then a wing dropped without further warning. In the test at 100 m.p.h. (flaps up, gills closed) the airflow over the falling wing became slightly turbulent at the root. At 90 and 80 m.p.h. the area of turbulence became progressively greater (Fig. 10). At 70 m.p.h. the attitude of the aircraft was very steep in the climb. On one occasion, when wool tufts were being observed, turbulence spread over the whole of the falling wing, and the aircraft started to spin from a nearly vertical attitude. The resulting loss of height, including the dive to recover, was about 2,000 feet. Usually a skilled pilot checks the incipient spin, and the loss of height is then about 800 feet. At none of these speeds is there turbulence during the climb. With flaps up and gills open, however, there is a fairly well-developed turbulence at the root at 90 and 80 m.p.h., which extends further along the trailing edge as the wing drops (Fig. 11). On lowering the flaps 30 deg. (gills open) there is again no turbulence in the climb. In tests at speeds between 100 and 80 m.p.h. there is a small turbulent area at the root of the falling wing (Fig. 12).

4. *Modification of Wing Section and Plan Form.*—A blunt nose-fairing was built on the extension wing as shown in Fig. 1. The modified radius of curvature was as given by the formula—

$$\frac{\varrho}{c} = 2\left(\frac{t}{c}\right)^2,$$

instead of the value for thickened R.A.F. 28 :—

$$\frac{\varrho}{c} = 0{\cdot}77\left(\frac{t}{c}\right)^2.$$

Afterwards the tips of the wings were removed to the rib XX in Fig. 1.

The resulting behaviour is summarised in Tables 2 and 3.

In the opinion of the pilots, the fairings effected a little improvement, by giving a slightly better warning of the stall and by making the wing drop slightly less viciously. A greater improvement was gained when, in addition, the wing tips were removed. The stall was then milder and recovery easier, and these improvements were obtained with no noticeable increase of stalling speed. Turbulence spreads more slowly over the extension wing than without the blunt fairings, and diagrams of its growth are given in Figs. 13 and 14 for the case with flaps up, gills closed, engine on. The forward spreading, as at the tip in Fig. 13 and at the next row of tufts in Fig. 14, does not seem to affect the behaviour of the aircraft adversely. With gills closed, engine off, there is now a warning interval of speed between the first signs of stalling and the stall proper, as well as the warning given by the original stick movement. With engine on, the original right-turning tendency disappears at 60 m.p.h., before the aircraft reaches the stall, which is now milder. With flaps down and gills closed, the tip and root still stall almost together and the stall remains rather a bad one, although not quite so bad as for the unmodified aircraft.

In all conditions of the modified aircraft it is noticeable that the extension wing stalls in a similar manner. With fairings only, the tip row of tufts on the falling wing shows turbulence spreading forwards before the inboard rows (except the root), and with the wing-tips removed the next row is affected instead. This consistent effect may be connected with the general improvement of the stall on removing the tips.

In the tests of cutting one engine, there was a marked improvement in what was formerly the worst case, gills closed, flaps up. Turbulence did not spread nearly so far. In other cases the behaviour was not much improved, and in all those tested there was a considerable loss of height.

5. *Discussion.*—On the whole the behaviour of this particular Blenheim agreed with that of the Blenheim subjected to the previous tests[2], so far as those tests extended, apart from unimportant details that could be attributed to differences of manufacture. The present tests revealed the bad stall flaps down, gills closed, engine on.

It is confirmed that the bad stalls are those in which the flow breaks away rapidly from the outer wing. The milder stalls are those that result when the turbulence first develops strongly at the root. The opening of engine gills provokes this development and causes a milder stall. Slipstream retards it and aggravates the stall. The lowering of flaps, like the opening of the throttles, probably causes a local decrease of incidence relative to local stalling angle, and both have the same adverse effect, except where it is obscured by changes of longitudinal stability; both settings together result in a specially vicious stall.

The modifications to the outer wing may be regarded as an attempt to keep pace with the root changes by increasing the local stalling angle, and their relative ineffectiveness as being due to the inadequate amount of such increase.

The rapid spreading of deep turbulence also accounts for the worst case of loss of control when one engine cuts unexpectedly.

The adverse effect of slipstream in removing warnings of the stall is readily explained by its effect on root turbulence at high incidence, whether the warning is a vibration due to tail buffeting or a loss of effectiveness of the elevator as the tail enters the wing wake. The contrary effects follow from opening the gills.

6. *Conclusions.*—The worst stalling conditions of the Blenheim are indicated in Table 4.

These features are correlated with the rapid spreading of deep turbulence over the wing. The effect of slipstream on straight stalls is due to its suppression of the normal root turbulence. The favourable effect of opening the engine gills is due to their increasing the root turbulence. The effect of flaps, engine off, is favourable, but engine on, adverse, and is inseparable from their influence on longitudinal stability.

The study of turbulence also throws some light on the difference in behaviour of the original and modified wing sections and of the original and modified tips. The modified wing section does appear to retard the spreading of turbulence, but not enough.

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No.	*Author*	*Title, etc.*
1		Performance and Handling Trials of Blenheim K.7033. Martlesham Report M.707, May, 1937. (Unpublished.)
2	R. H. Francis and G. E. Pringle ..	Note on Flight Tests of Stability and Control at Low Speeds on Blenheim. R.A.E. Report No. B.A.1485 (3680), July, 1938. (Unpublished.)
3	M. B. Morgan	Research Handling Tests on Blenheim L.6595. R.A.E. Report No. B.A.1567 (4404), December, 1939. (Unpublished.)

TABLE 1.

	Flaps up				Flaps down			
	Gills closed		Gills open		Gills closed		Gills open	
		$\frac{1}{3}$ throttle		$\frac{1}{3}$ throttle		$\frac{1}{3}$ throttle		$\frac{1}{3}$ throttle
Turbulence starts at rear of wing root.	80	85	120	120	70	70	80	70
Turbulence spreads to extension wing.	75–70	65–62	80	75	62	<55	69	<50
Stalling speed W = 11,400 lb.	70	60	66	60	~ 60	~ 50	62	50
Stick position to stall	half back	central to half back	right back	nearly right back	quarter to half back	quarter back	right back	nearly right back
Stick force to stall (trimmed to —)	fairly heavy (100)	light (120)	very heavy (100)	very heavy (110)				
Warning of stall ..	pitching oscillation, stick movement and force	reduced or nil	unsteadiness, lateral instability, stick force		pitching oscillation	slight pitching oscillation	unsteadiness	unsteadiness, slight pitching oscillation
Wing drop (controls fixed).	fairly fast	faster and further than engine off	usually fairly slow	faster and further than engine off	does not always drop—not violent	very violent	does not drop	fairly fast but not violent—may only spiral
Time for turbulence to spread over extension wing.	7 sec.	3 sec.	40 sec.	7 sec.	16 sec.		22 sec.	
Diagrams in fig. :—	2	3	4	5	6	7	8	9

At W = 11,400 lb., $V_s = 84\frac{1}{2}$ m.p.h., $C_L$max. = 1·34 } with gills half open, flaps up.

TABLE 2.

Blunt Nose.

	Flaps up				Flaps down	
	Gills closed		Gills open		Gills closed	
		1/3 throttle		1/3 throttle		1/3 throttle
Turbulence starts at rear of wing root.	75	70	120	120	59	40–45
Turbulence spreads to extension wing.	72	70	85	75	59	40–45
Stalling speed W = 11,400 lb.	68	59	69	63	59	40–45
Stick position to stall.	half back	quarter back	half to full back*	half back or more*	right back	
Stick force to stall	heavy	light	fairly heavy	fairly heavy		
Warning of stall.	pitching oscillation, stick movement and force	reduced lateral unsteadiness	unsteady slight pitching oscillation, stick force	less unsteady	unsteadiness	none
Wing drop (controls fixed).	slow	slow or fairly fast	slow or fairly fast*	slow or fairly fast*	fairly fast but not violent	very violent if corrected
Time for turbulence to spread over extension wing.	25 sec.	31 sec.	26 sec.	23 sec.		0·8 sec.
Diagrams in fig. :—	31					

* According to degree of correction beforehand.

TABLE 3.

Blunt Nose, Reduced Span.

	Flaps up				Flaps down*			
	Gills closed		Gills open		Gills closed		Gills open	
		1/3 throttle		1/3 throttle		1/3 throttle		1/3 throttle
Turbulence starts at rear of wing root.	>75	>65			~ 80	~ 60	75	~ 60
Turbulence spreads to extension wing.	70	70	>85	85	~ 60	58		<60
Stalling speed, W = 11,400 lb.	66	58	69	59	58	54	60	56
Stick position to stall	$\frac{1}{2}$ back	$\frac{1}{4}$ back	$\frac{3}{4}$ back	$\frac{1}{2}$ back	$\frac{1}{4}$ to $\frac{3}{4}$ back**	central to $\frac{1}{4}$ back	$\frac{1}{2}$ to $\frac{3}{4}$ back	$\frac{1}{4}$ back
Stick force to stall ..	heavy	light	heavy	heavy	fairly heavy	light	fairly heavy	
Warning of stall ..	pitching oscillation, stick movement and force	reduced	vibration, lateral unsteadiness, stick force	less vibration, stick force		none	unsteadiness	
Wing drop (controls fixed).	slow	fairly fast	slow or fairly fast**	fairly fast	slow or none***	fairly fast	slow or none***	slow
Time for turbulence to spread over extension wing.		18 sec.	24 sec.	23 sec.		$2\frac{1}{2}$ sec.		$1\frac{1}{2}$ sec.
Diagrams in fig. :—	14							

* In these tests the undercarriage was up and the C.G. therefore 1 in. further aft than in the other tests with flaps down.

** According to degree of correction beforehand.

*** According to stick position.

TABLE 4.

Worst Stalls of the Blenheim.

Flaps	Gills	Undercarriage	Throttles	Remarks
Up	Closed	Up	Partly open	Little or no warning; wing often drops sharply.
Up	Open	Up	Partly open	Some warning; wing may drop sharply if correction is applied at the stall and stick then pulled back.
Down	Closed	Down	Partly open	Little warning; flicks over violently if falling wing is corrected.
Up	Closed	Up	Fully open	If starboard engine cuts in the climb at 70 m.p.h., the wing stalls and drops viciously.

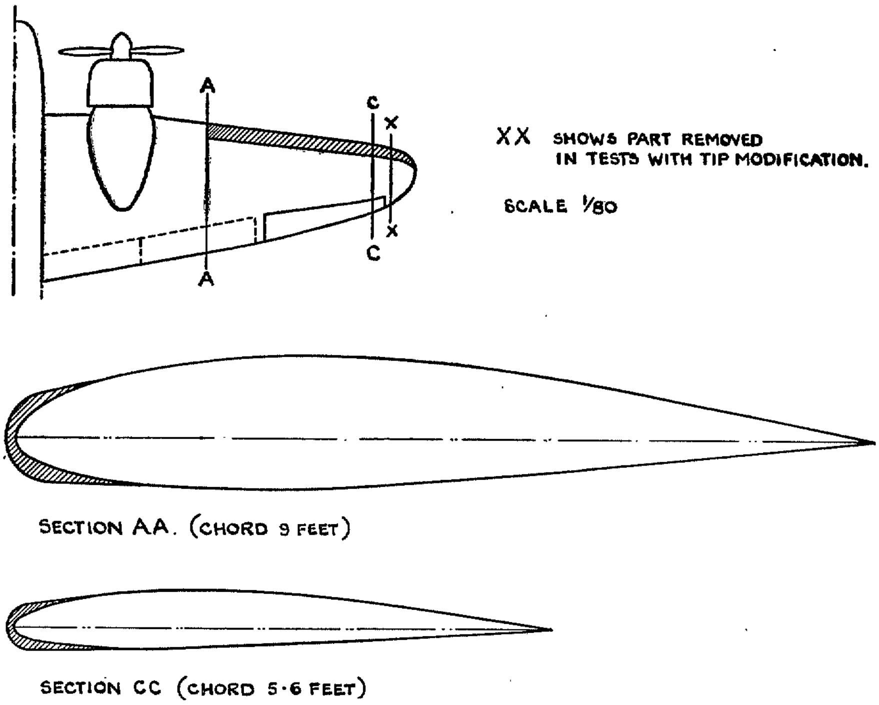

FIG. 1.—Details of Blenheim Wing and Modifications.

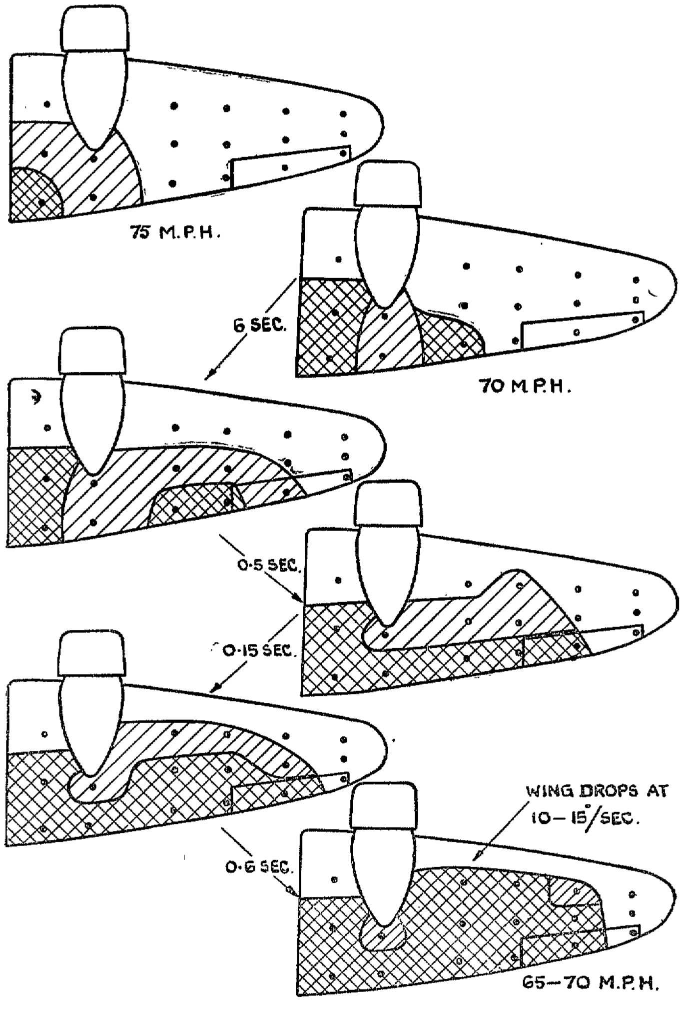

FIG. 2.—Straight Stall; flaps up, gills closed, engine off.

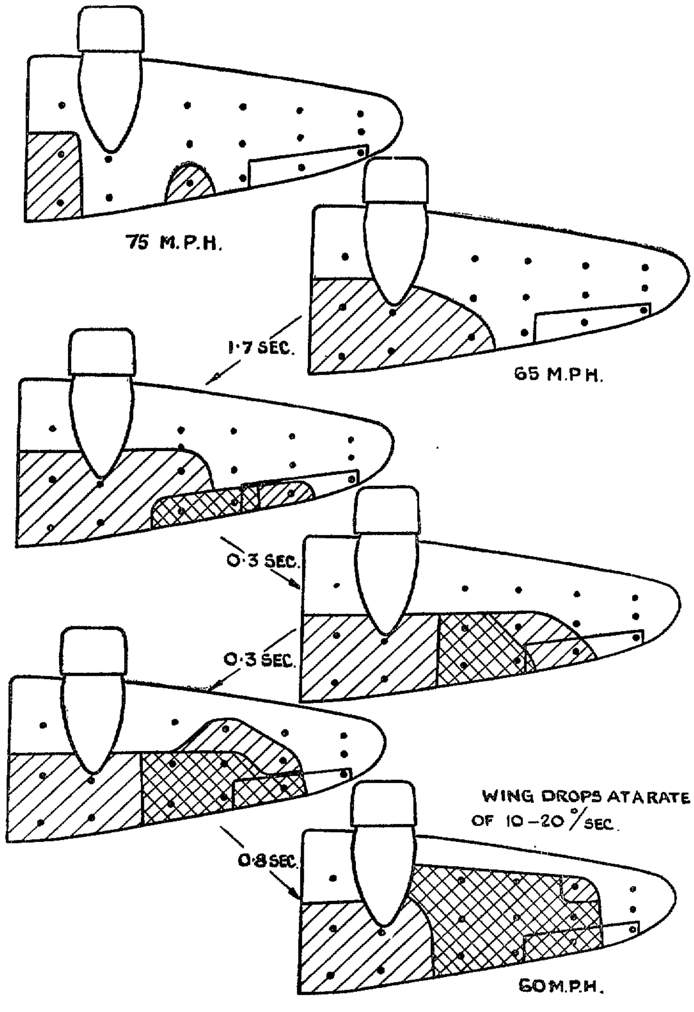

FIG. 3.—Straight Stall; flaps up, gills closed, throttles 1/3 open.

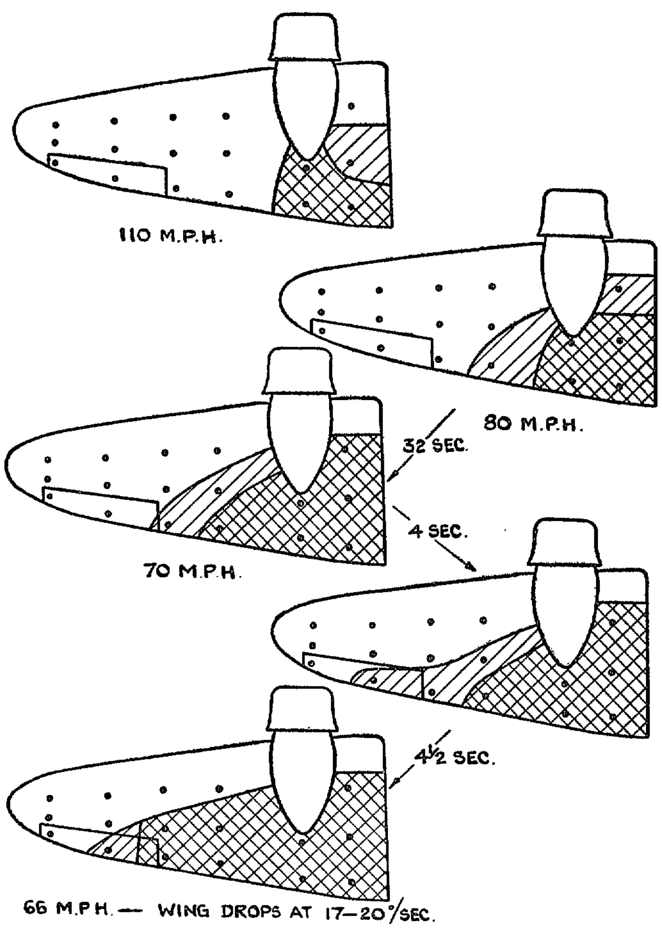

Fig. 4.—Straight Stall; flaps up, gills open, engines off.

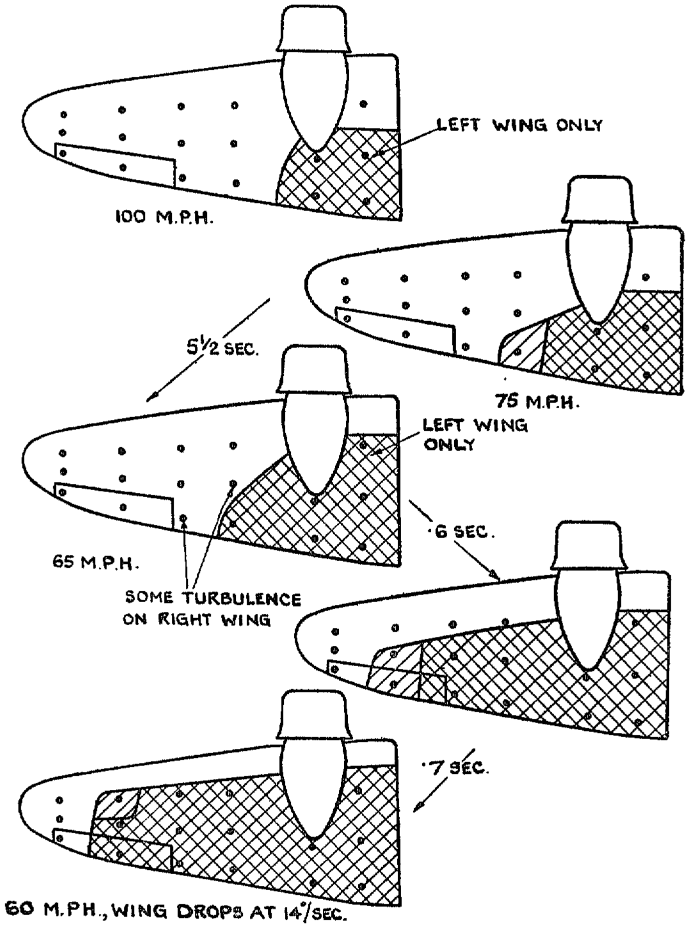

Fig. 5.—Straight Stall; flaps up, gills open, throttles, 1/3 open.

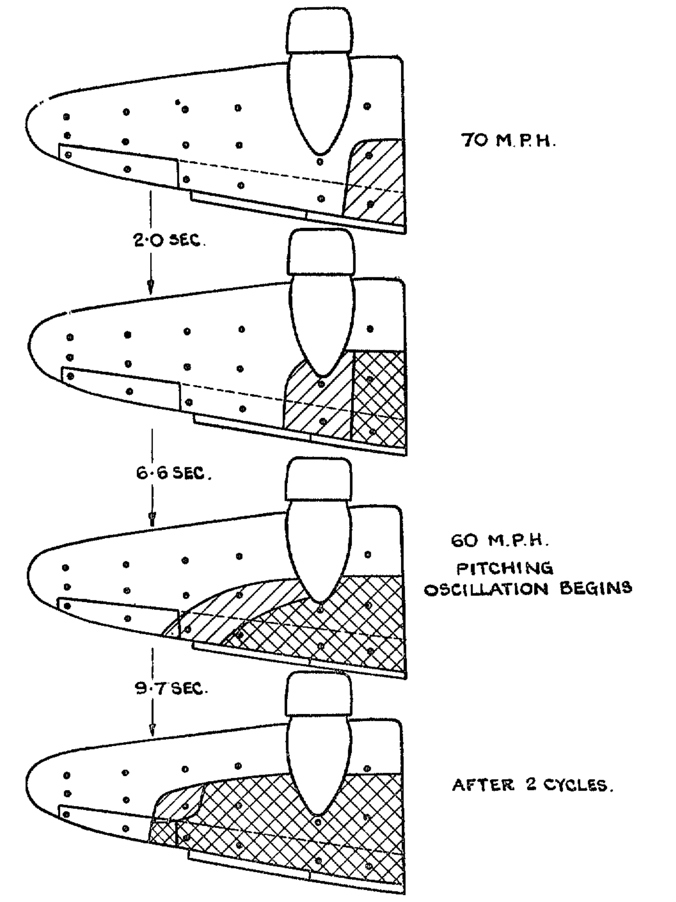

Fig. 6.—Straight Stall; flaps down, gills closed, engines off.

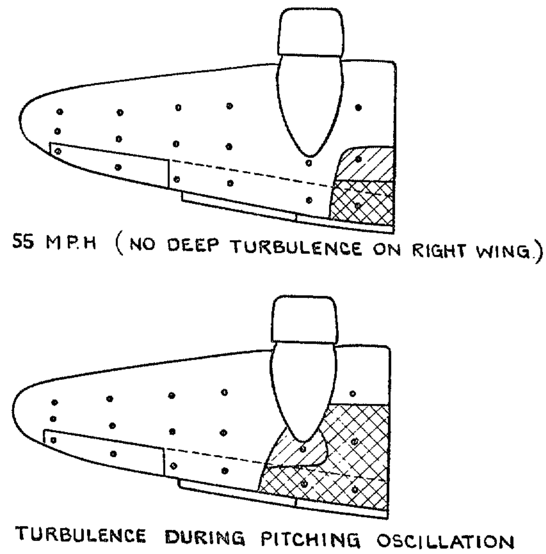

Fig. 7.—Turbulence in Semi-Stalled Glide, flaps down, gills closed, throttles, 1/3 open.

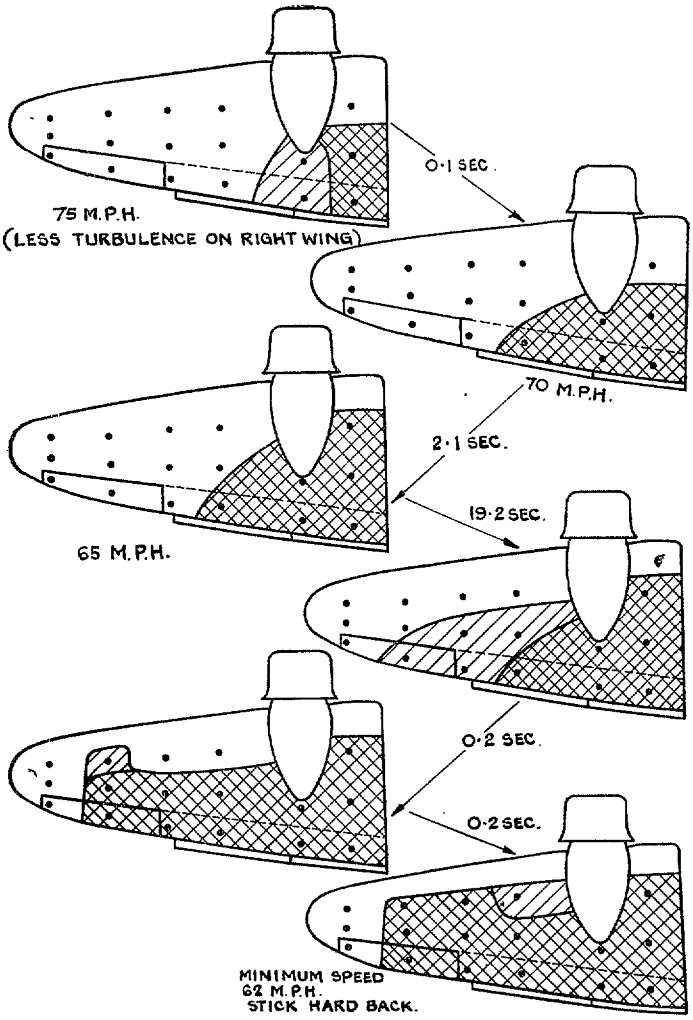

FIG. 8.—Straight Stall; flaps down, gills open, engines off.

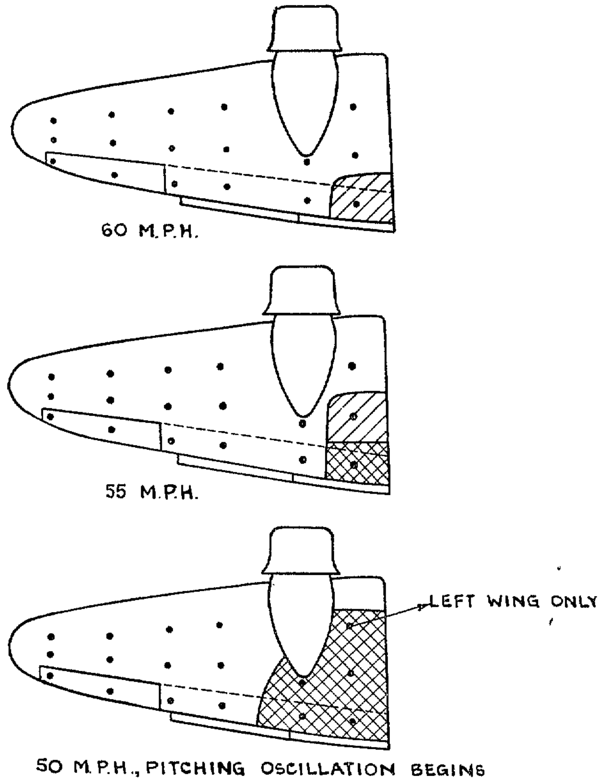

FIG. 9.—Straight Stall; flaps down, gills open, throttles, 1/3 open.

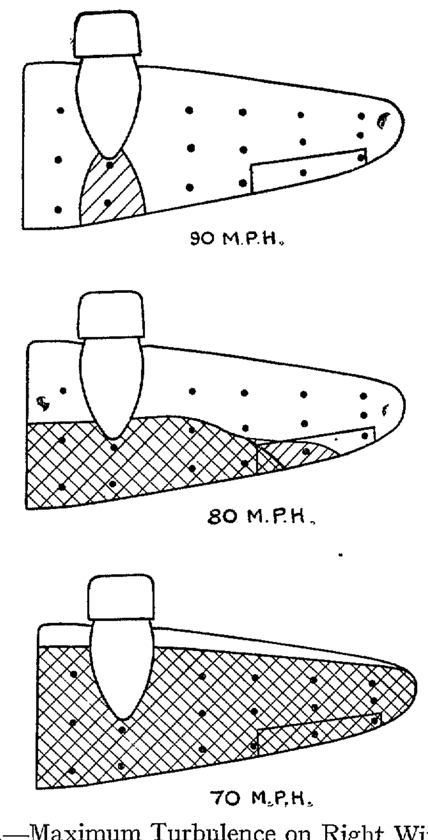

FIG. 10.—Maximum Turbulence on Right Wing After Cutting Right Engine in Climbs at Various Speeds; flaps up, gills closed.

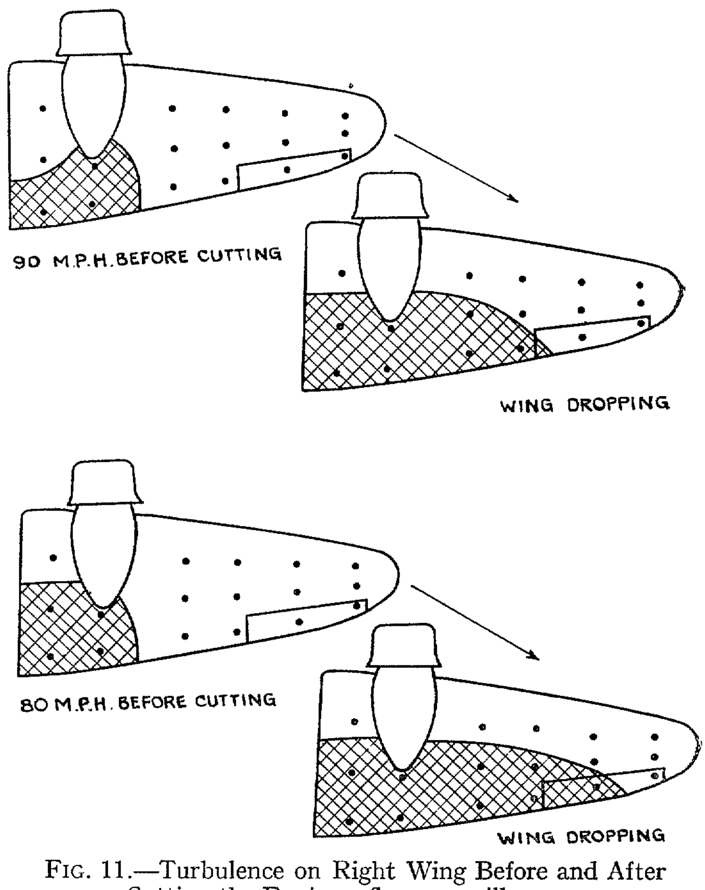

FIG. 11.—Turbulence on Right Wing Before and After Cutting the Engine; flaps up, gills open.

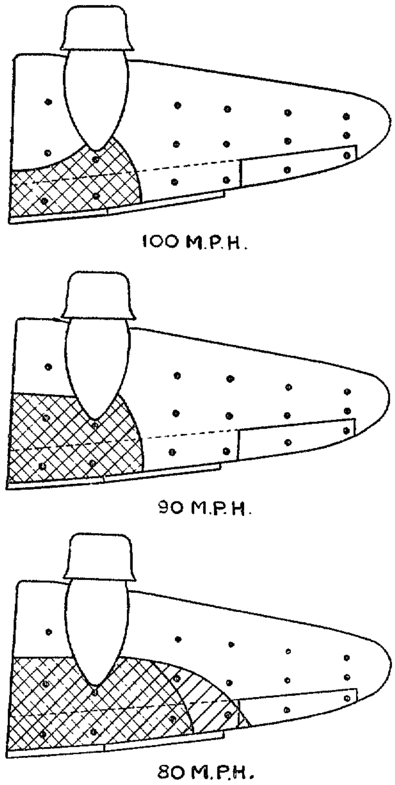

FIG. 12.—Maximum Turbulence on Right Wing After Cutting the Engine in Climbs at Various Speeds; flaps down 30°, undercarriage down, gills open.

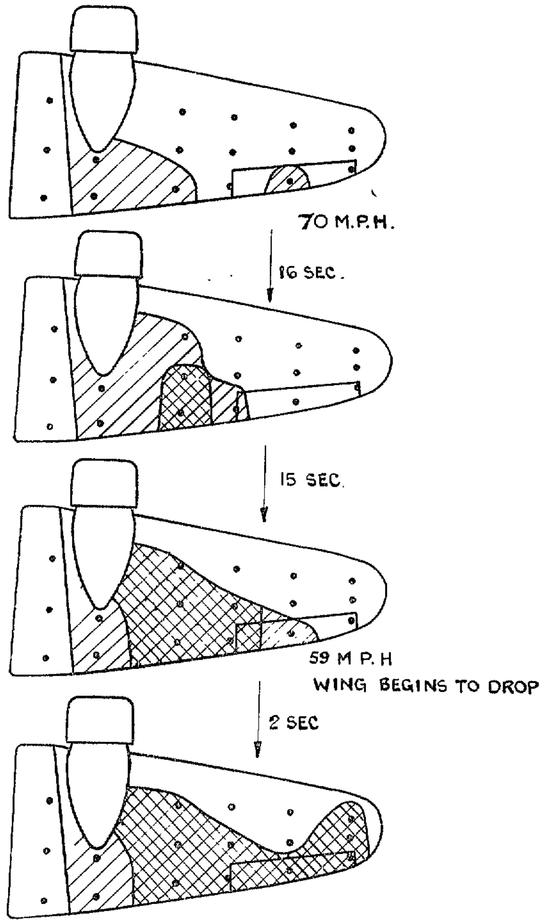

FIG. 13.—Straight Stall; modified wing-section, flaps up, gills closed, throttles 1/3 open.

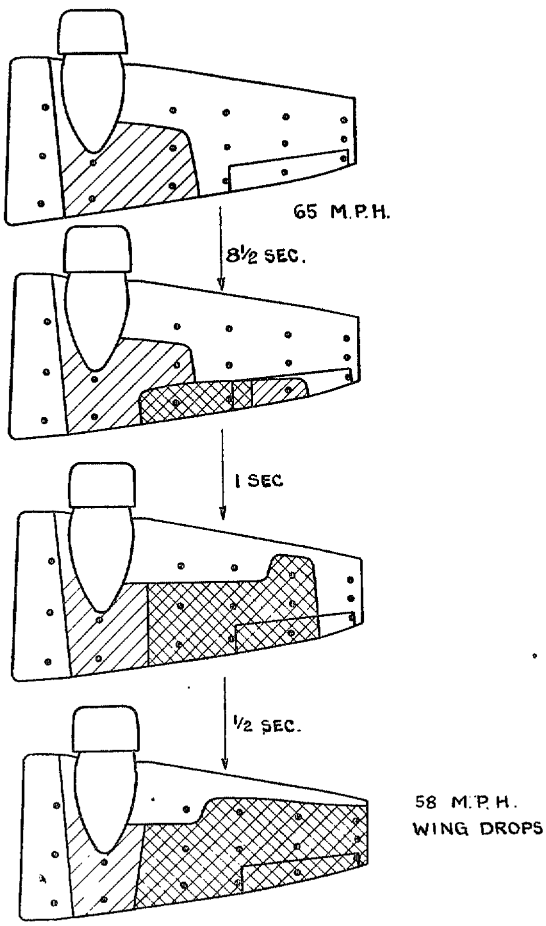

FIG. 14.—Straight Stall; modified wing-section and tips, flaps up, gills closed, throttles 1/3 open.

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