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A Review of Some Stalling Research

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With an Appendix on

Wing Sections and their Stalling Characteristics

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Summary.—Over a period of years a considerable amount of stalling research on various aeroplanes was completed at the Royal Aircraft Establishment and it was considered desirable that the main results should be summarised and reviewed. The report includes a general discussion of the effect on stalling behaviour of wing section, plan form, washout, flaps, nacelles, gills, slipstream, automatic wing-tip slots and Hudson-type slits. The important part that is played by the longitudinal trim and stability at incidences near the stall is emphasised. The relation between wing sections and their stalling characteristics is discussed and it is shown that the stalling characteristics can be broadly predicted from an examination of the form of the wing-section upper-surface pressure distribution at high incidences.

The results indicate that vicious stalling behaviour can be avoided by the use of wing sections towards the tip of fairly high camber (3 to 4 per cent.) and moderate thickness (>12 per cent.). For some types of aeroplanes there are, however, serious objections to the use of high camber towards the tips; the designer is then advised to avoid wing sections which experiments and theory indicate have particularly bad stalling characteristics. The worst tip thickness for stalling appears to be in the region of 9 per cent. High taper tends to worsen the stalling behaviour and it is advisable to consider taper ratios greater than 2:1 only in conjunction with wing-tip sections having good stalling characteristics. The use of part-span flaps does not appear to cause any marked deterioration in stalling behaviour, and frequently it improves the behaviour; but there is some evidence, though not yet conclusive, that the use of full-span flaps may be accompanied by an appreciable worsening in stalling behaviour. Attention is drawn to the advisability of examining the flow at high incidences in the neighbourhood of the tail-plane of an aeroplane in the design stage, with a view to assessing its probable stalling behaviour; in particular, the possibilities of designing for some stall warning can then be examined.

1. *Introduction.*—In 1938 Gates[1] issued an extremely valuable resumé and analysis of the wing-dropping problem in which he outlined and discussed, in the light of the then existing knowledge, the main factors which might be expected to determine the stalling behaviour of aeroplanes. Since then a considerable amount of stalling research was completed, mainly at the R.A.E., in order to investigate in detail these various factors and to establish their relative importance. It cannot be claimed that the complexities of the stalling problem were all completely unravelled; nevertheless, as a result of this work our ideas on this important subject have been considerably clarified, and it is fair to claim that some of the more important queries were answered. The problem turned out to be somewhat simpler than was at first anticipated, since

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it appeared that the main factors act to some extent independently of each other, and their effects can be to that extent separately assessed. The bulk of the work has already been reported in detail, but in a number of scattered reports; it was felt, therefore, that a summary and digest of the considerable body of data available would be of value and interest to designers. At the same time this summary provides an opportunity of collecting and placing on record the results of some work on which reports have not been issued.

2. *Stalling. Some Preliminary Remarks.*—When referring to the stalling behaviour of an aeroplane we generally imply its behaviour at incidences in the neighbourhood of that corresponding to its maximum lift coefficient. At such incidences separation of the air flow from parts of the wings has begun and consequently more or less rapid changes in lateral and longitudinal stability and trim result.

The lateral instability and consequent wing dropping, which is the most serious feature of the stall, is characteristic of almost all wings. It generally appears at some incidence in the neighbourhood of that corresponding to the maximum lift coefficient, or stalling incidence, and persists over a considerable range of incidence above that incidence. It is easy to see why this lateral instability occurs. Consider, first, a simple wing, *i.e.* a wing without fuselage, nacelles, etc. Any asymmetric disturbance tending to start a roll will increase the incidence over the downgoing wing and reduce that of the up-going wing. Consequently, if the incidence has already reached a point where the flow has begun to break away and the lift over an appreciable part of the wing has begun to decrease with increase of incidence, a rolling moment in the direction of the initial roll can develop. The magnitude of this rolling moment will obviously depend on the rate at which lift is lost with increase of incidence and the distance from the rolling axis of the parts of the wings from which the flow has already separated. These factors are themselves dependent on the wing sections used and the spanwise distribution of lift at stalling incidences, and the latter in turn depends on the section, taper, plan form and washout of the wings. We can conclude, therefore, that the rolling instability of a plain wing will be a function of the wing section used, the section over the outer parts of the wing being most important, and the geometry of the wing.

The considerable influence the wing section has on the rolling instability and the rate at which the flow breaks away from the wing surface has not always been fully appreciated. Attempts have at various times been made to derive rules for avoiding severe rolling instability based only on theoretical considerations of the effect of wing geometry on the spanwise lift distribution[31,32]. The results are of great value in indicating qualitatively the relative effect on stalling behaviour of such factors as taper, washout, etc., but their usefulness ends there. The picture is then far from complete, for the effect of the wing geometry may be profoundly modified by the wing section used.

When we consider a complete aeroplane, we find additional factors which influence the spread of breakaway and the stalling behaviour. Wing-nacelle and wing-fuselage junctions are often ready sources of early separation and compete with the geometry of the wing in determining the origin and spread of the flow breakaway. For example, we find that whilst theory would predict a stall starting outboard of the mid-span position for wings of taper ratio greater than about 2, in practice such a stall is uncommon even on aeroplanes with wings of much higher taper. Further, we find that the longitudinal stability, control and trim at stalling incidences have an important bearing on the lateral stability characteristics. It can be stated that, in general, any aeroplane will be laterally unstable if its incidence can be raised to a high enough value, but this brings into question the ability of the elevators to raise the aeroplane to the required incidence. The thickened wake due to an early breakaway from the wing-fuselage junction may influence the elevator and reduce its efficiency. This may result in a fairly sudden nose-down pitching moment which would be reinforced by the nose-down pitching moment on the wing due to the stalling of the centre-section. This change of trim may be large and sudden enough for the pilot to interpret it as the stall, although in point of fact the main parts of the wings may be unstalled. By pulling the stick further back the pilot may succeed in stalling the wings completely so that the aeroplane becomes laterally unstable. On the other hand, the elevator efficiency may be so reduced as to make it impossible to bring the outer parts of the wings to their stalling incidence. Engine gills, slipstream and flaps may be expected to modify the intensity and direction of the centre-section wake and hence affect the stalling behaviour. Wing-tip slots will affect the stalling behaviour by considerably increasing the stalling incidence over the outer parts of the wings. Thus, it appears that in addition to being influenced by wing section, plan form and washout, the stalling behaviour of an aeroplane will be affected by the cleanness of the wing-fuselage and nacelle junctions, the relative positions of the wing and tail-plane, the elevator efficiency and range, the settings of the throttle, gills and flaps and the presence and efficiency of wing-tip slots. The main object of the stalling research at the R.A.E. has been to analyse as far as possible the mechanism of the complicated interplay of these various factors and to determine their relative importance in influencing the stalling behaviour.

3. *Experimental Technique.*—In assessing the stalling behaviour of an aeroplane the points of main interest to the pilot are:—

(1) Is there an adequate warning of the stall ?

(2) Does a wing or nose drop first at the stall and how far and fast does it drop ? (A pilot's assessment of the viciousness of a wing drop will be to some extent influenced by the degree of warning.)

(3) How effective are the controls at and beyond the stall in preventing a wing from dropping or in raising a wing once it has fallen ?

(4) Is there any tendency to enter a spin after the stall ?

The procedure laid down in A.D.M.293 (Test 3) for testing the straight stall was designed in the main with these queries in mind, and hence this procedure was adopted as far as possible during all the tests. In addition, for most of the tests the behaviour of the flow over the upper surfaces of the wings was studied by observing and photographing the behaviour of wool tufts attached at various heights to light posts (about 1 ft high) fixed at a number of points on the wing surface. It is worth noting here that in the early tests it was thought sufficient to attach the wool tufts only to the surface of the wing. It appeared, however, that whilst these surface tufts reflected in a most interesting manner the movements and cross flows of air in the boundary layer, their behaviour could not be correlated simply and directly with the behaviour of the aeroplane. Thus, the surface tufts frequently appeared quite agitated before any breakaway of flow occurred and hence before there was any significant change in the behaviour of the aeroplane. It was found that the flow breakaway which can be directly related to the behaviour of the aeroplane could only be properly studied by means of wool tufts placed at various heights above the wing surface, for they reflected the violent turbulent-motion characteristic of the separated flow.

4. *Summary of Results.*—4.1. *General.*—The results of fairly detailed stalling tests of a number of single-engined aeroplanes are summarised in Tables 1A to J and detailed tests of some twin-engined aeroplanes are similarly summarised in Tables 2A to D. In Tables 3A to L and 4A to C will be found similar summaries of somewhat less exhaustive stalling tests made on various aeroplanes as part of routine handling tests.

The stalls have been roughly graded according to the following system of classification:—

(1) So good that A.S.I. reading or warning from longitudinal motion are required to indicate when stalled.

(2) Stall is marked by a gentle nose drop, any wing dropping being confined to a few degrees. No considerable wing dropping even with the stick hard back.

(3) Initial partial stall where nose drops gently a few degrees. At complete stall a wing drops, but not violently, and can be prevented from falling by use of ailerons and rudder.

(4) Initial partial stall where nose drops a few degrees. At complete stall a wing drops violently and cannot be prevented from falling by use of aileron and rudder.

(5) No initial partial stall but the wing drop at the complete stall is not violent and can be prevented or delayed by the use of ailerons and/or rudder.

(6) No initial partial stall, the wing drops violently and cannot be checked by use of ailerons and rudder.

In addition, the warning of the stall has been classified as follows:—

A—The warning is good.
B—The warning is adequate.
C—The warning is poor.

The above classification provides in the main a scale of increasingly unpleasant stalls, but it is admittedly rough. It is readily conceivable, for instance, that a particular stall classified under (5) might be considered less unpleasant than another stall classified under (4). In addition, the degree of warning present will considerably modify the danger of a stall, thus, a stall classified as 6A may well be preferable to a stall classified as 5C.

In the column to be found in the Tables headed "tail-plane position, etc." the angle quoted for the tail-plane position is the angle between the wing chord line and the line joining the wing root leading edge and the tail-plane root leading edge. In most cases these angles have been derived from small-scale reproductions of 3-view general arrangements and must be considered as approximate.

4.2. *Single-engined Aeroplanes* (*Table* 1).—4.2.1. *Falcon* (*Table* 1A *and* B).—The stalling tests made on the Falcon provide valuable data on the effect of wing section, taper, flaps and wing-tip slots and are worth discussing in some detail under these headings.

Wing section.—The importance of the wing section towards the tips is clearly brought out. Thus, we see that with the standard low-taper wing the stalling behaviour with the NACA 4415 wing section at the tip was considered very good, with the Clark YH section the stall was moderate or poor, whilst with the NACA 23009 section or RAF 28 section the stalling behaviour was bad. With the high-taper wing we again note a considerable improvement in the stalling behaviour when the wing-tip section was changed from Clark YH to either the NACA 4415 section or the Gött. 387 section. These results are in general agreement with the conclusions drawn in Refs. 1, 5, 33, 34, that increase of camber or thickness towards the tips improves the stalling behaviour. This point will be amplified later, but it is worth noting at this stage that the spread of breakaway both spanwise and forwards was much slower and less complete with the tip sections giving good stalling behaviour than with the other sections.

Taper.—Comparing the results in Tables 1A and B it will be seen that, other things being equal, the increase in taper from 1·8 : 1 to 4·5 : 1 worsened the stalling behaviour. With the low-taper wing separation of flow started from the root and spread outwards for all tip sections tested; with the high-taper wing separations started at the tip and spread inwards when the tip section was Clark YH, but started at the root when the tip section was either NACA 4415 or Gött. 387. Theory[1, 32] would predict a stall starting very near the tip on the high-taper wings; we have here an example, therefore, of the modifying influence of the wing-tip section and presumably wing-root interference on the spread of separation. Although a stall starting from the tip may be expected to be more violent than one starting from the root, the importance of the position from which it starts can be exaggerated. The tests of the low-taper wing with RAF 28 wing-tip section illustrates, for example, a vicious stall originating at the root. It would appear that the rate of spread of flow breakaway when it reaches the outer parts of the wings is of greater importance than the position from which it starts; and increase in wing taper worsens the stall in so far as it increases this rate of spread of breakaway Perhaps the main advantage of a stall starting at the root lies in the fact that it usually induces an adequate stall warning.

Flaps.—Theory[31] predicts that partial span flaps should worsen the stall since they increase the incidence over the unflapped outer parts of the wings and so cause then to stall relatively earlier. In many cases, however, this effect appears to be masked by the less direct effect on the stalling behaviour of the flap wake. We find that the stalling behaviour of the Falcon was, in fact, improved when the flaps were put down; the increased nose-down pitching moment and the reduced elevator efficiency due to the flap wake combined to make it difficult or impossible to bring the outer parts of the wings to their stalling incidence. The characteristic feature of the stall with flaps down was a pitching motion accompanied by a flow breakaway more or less confined to the centre-section. As the elevator entered the wake of the flap and centre-section its efficiency dropped, the nose consequently dropped into a dive and the speed rose. The centre-section then unstalled, the elevator came out of the wake and the nose then rose again to repeat the pitching cycle. This pitching was reinforced by the changes in the pitching moment on the wing as the centre-section stalled and unstalled. If the pitching was allowed to develop it sometimes became violent enough to cause a dynamic stall, in which case a wing dropped. Sometimes the elevator still retained sufficient power to stall the outer parts of the wings and so cause a complete stall and a wing drop. This behaviour with flaps down is characteristic of many low-wing monoplanes.

Slots.—On both the high and low-taper wings the automatic slots were successful in producing very good stalling behaviour. Their success was due to the fact that they considerably raised the stalling incidence of the slotted outer parts of the wings and the elevator was incapable of bringing these parts of the wings to stall; separation of flow was more or less confined to the unslotted parts of the wings. It follows that slots may not be an absolute guarantee against vicious wing dropping if the elevator is sufficiently powerful to cause a complete stall.

4.2.2. *Courier* (*Table* 1C).—The interesting feature of the Courier tests lies in the fact that with flaps down the stalling behaviour was worse than with flaps up, unlike the Falcon; and it became progressively worse with increase of span of flap set down. The effect of the flap wake on the tail-plane characteristics appeared to be comparatively small in this case. This may have been partly due to the fact that the main flaps were slotted and therefore had a less intense wake than split flaps. It is interesting to note that the combination of comparatively high taper and flaps and ailerons set down was sufficient to cause a flow breakaway beginning at the tip, although with flaps up the breakaway spread from the root.

4.2.3. *Master* (*Table* 1D).—The stalling characteristics of the Master, which had an NACA 23008 section at the tip, were poor with flaps up and worse with flaps down, a bad feature being the lack of warning. When the tip section was changed to NACA 2415 there was a marked improvement in the stalling behaviour with flaps up, rather less improvement was found with flaps down. It is interesting to note that with this modified wing tip, flaps up, separation of flow did not develop normally beyond the centre section even with the stick hard back, but opening the throttle (about one-third) made a complete stall with a sharp wing drop possible. The slipstream then presumably delayed the root stall and cleaned up the flow over the tail-plane so that the whole of the wing could eventually be completely stalled. Changing the whole of the wing to NACA 2415 section improved the stalling behaviour a little more, although it was again found that opening the throttle caused some deterioration. When the standard wing was equipped with fixed slits of the Lockheed-Hudson type the stalling behaviour was improved about as much as it was when the wing-tip section was changed to the NACA 2415 section.

4.2.4. *Magister* (*Table* 1E).—The Magister tested in its original state had a bad stall with flaps up; with flaps down the pitching motion characteristic of the Falcon with flaps down was in evidence and the stalling behaviour was somewhat better than with flaps up. The main interest of these tests lies in the improvement obtained by putting sharpened wedges over the leading edge of the inboard parts of the wings and rounding the leading edge of the outer parts of the wings. An early root stall was provoked by the wedges, whilst the rounded leading edge over the outer parts of the wings raised the local stalling incidence. As a result the difference in stalling incidence between the inner and outer parts of the wings was increased whilst the wake from the centre-section was intensified so that it was impossible to stall the outer parts of the wings. It must be noted that improving the stalling behaviour of an aeroplane by spoiling the root section has the disadvantage that frequently the stalling speed is raised as a result (3 m.p.h in the case of the Magister). From the point of view of safety the consequent increase in the landing and take-off speeds may in some cases outweigh the advantage of improved stalling behaviour.

4.2.5. *Tipsy* (*Table* 1F).—The Tipsy is another example of a low-wing monoplane with fixed Hudson-type slits. The slits appeared to cause some improvement in the stalling characteristics which were, however, never bad with the slits sealed. The flow separation began at the tip in every case and spread inwards, and with the slits sealed there was some evidence of an initial transient separation over the forward half of the wing tip. Front separation is a phenomenon that has not otherwise been recorded outside a wind tunnel and is believed to be associated with transient separation of the laminar boundary layer which will only occur on thin wings at low Reynolds numbers.* The low Reynolds numbers and wing loading of the Tipsy make it difficult to draw conclusions from these tests of Hudson-type slits that could safely be generalised to a typical monoplane with a high wing loading.

4.2.6. *Skua* (*Table* 1G).—The Skua in its original standard form showed a mild initial stall associated in the usual way with a centre-section breakaway followed by a fairly vicious complete stall. With the C.G. on its aft limit there was a tendency to self-stall beginning at an incidence below that of the initial stall owing to the high position of the C.G. This longitudinal instability combined with the lack of warning to make the stalling behaviour rather unpleasant. However, when sharpened wedges were put on the leading edge of the root section the root stall was provoked at an earlier stage and was intensified. The resulting change in the wing pitching moment and the effect of the thickened and earlier root wake on the tail plane combined to eliminate to a large extent the tendency to longitudinal instability before the stall, and so made it considerably safer even though a complete stall was eventually attained. We see here how important an influence the longitudinal stability of an aeroplane can have on the degree of danger associated with its stalling behaviour.

4.2.7. *Battle* (*Table* 1H).—The stalling behaviour of the Battle is fairly good because it has a gentle initial stall produced by a breakaway from the centre-section well ahead of the breakaway from the rest of the wing.

4.2.8. *Spitfire* (*Table* 1K).—The interest of the Spitfire tests lies in the fact that after an initial root stall, deep separation on the outer wings appeared first at the tips and yet the stall remained gentle. With the engine on, the stall was still gentle, even though the initial root stall was suppressed. The Spitfire has exceptionally thin wings towards the tips (NACA 2205); wing sections of thickness below about 6 to 7 per cent. are known to have flat-topped lift curves even at full-scale Reynolds numbers*. It is possible, therefore, that the stalling at the tips of the Spitfire was not associated with any sudden large loss of lift and therefore the lateral instability was mild.

4.3. *Twin-engined Aeroplanes. Table* 2.—4.3.1. *Blenheim* (*Table* 2A).—The results of the stalling tests of the Blenheim illustrate very clearly how the stalling behaviour of an aeroplane may be profoundly modified, on the one hand, by opening the gills and so spoiling the flow over the inner parts of the wings and, on the other, by opening the throttles and so cleaning up the flow there. These effects may be expected to be more marked on a twin-engined aeroplane than on a single-engined aeroplane since a larger part of the wing surface is affected. The stalling behaviour of the Blenheim with flaps up, gills and throttles closed was fairly vicious; it is to be noted that the wing section was RAF 28, a section which has shown bad stalling characteristics in the Falcon tests. Opening the gills, however, produced a marked stall over the inner parts of the wings, a consequent increase in the nose-down pitching moment and longitudinal stability and an early reduction in elevator efficiency. These effects combined to make it very difficult to stall the outer parts of the wings and the stall was therefore very mild. Opening up the engines largely counteracted the effect of the gills, and the stalling behaviour then became poor again.

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* This point is discussed in more detail in Section 5.2 and the Appendix.

Note added 1951. Front separation has in recent years been noted in flight at normal Reynolds numbers when thin low-drag sections have been used.

With flaps down, gills open or closed and engines throttled back, the stall was mild and characterised, as on the Falcon, by considerable pitching and little separation of flow beyond the centre section. Opening up the engines, however, increased the downwash and efficiency of the tailplane, largely suppressed any warning and rendered the stall vicious.

4.3.2. *Monospar* (*Table* 2B).—The Monospar had a peculiar root section which made it " dirty " from a stalling point of view. The main parts of the wings beyond the nacelles were more or less in a mid-wing position relative to the fuselage, but the centre-sections sloped down sharply from the nacelles to the bottom of the fuselage, whilst the front spar member carried straight on above the centre section through the fuselage. Consequently, for any throttle setting, and in spite of the high taper, separation always started at the root and thoroughly covered it before spreading to the outer parts of the wings. In addition, the wing section towards the tips had $3\frac{1}{2}$ per cent. camber and was 16 per cent. thick and therefore had good stalling characteristics. These factors combined to make the stalling behaviour very good under all conditions tested.

4.3.3. *Hudson* (*Table* 2C).—The interesting feature of the Hudson is its fixed wing-tip slits. With the slits sealed it is an aeroplane whose stalling properties one might with some confidence have anticipated would be poor. It has a poor stalling section at the tip (NACA 23009), high taper (4·3 : 1), large tail and elevator volume, sweepback, high wing loading and is fairly clean in design; as a result the stall is fairly vicious with flaps up or down, engines on or off, and there is practically no warning With the slits open and flaps up, the stall is improved a little, the aileron control is somewhat better at the stall and the wing drop is not quite so violent. With flaps down the slits improve the stall considerably; the evidence then suggests a root stall which cannot spread over the outer parts of the wings. When the throttles are opened, however, this root stall is partially suppressed whilst the downwash and efficiency of the elevators are increased, and we again get a fairly sudden wing drop. On the whole, the fixed slits appeared to have made a fair improvement to the stalling properties of this aeroplane.

4.3.4. *Hampden and Hereford* (*Tables* 2D *and* E).—The Hampden has automatic wing-tip slots. A number of combinations of flap, gill and throttle settings were tried and in every case but one the breakaway could not be induced to spread beyond the unslotted parts of the wings, so that the stall was marked by mild pitching without appreciable wing dropping. However, with the throttles open about two-thirds and the flaps down about one-third of their travel (20 deg.), the breakaway did eventually spread to behind the slotted parts of the wings and a wing dropped fairly gently. With this setting of the slotted flaps their wake was not very intense, but the lift increment and hence the downwash due to the flap was probably considerable; this effect combined with the increased downwash, increased tail-plane efficiency and cleaning up effect due to the slipstream so that it was just possible to stall the outer parts of the wings.

A few, though not comprehensive, stalling tests were also made with the slots sealed and these indicated that, apart from a reduction in aileron effectiveness near the stall, the behaviour was remarkably good and little worse than with the slots free. The early stalling over the inner parts of the wings and consequent loss in elevator efficiency was, even with the slots sealed, enough to make it impossible to stall the outer parts of the wings; this suggested that on this aeroplane the slots were not exercised to any great extent and were therefore unnecessary.

Later, stalling tests were made on a Hereford, which is identical with the Hampden except that it has Dagger instead of Pegasus engines and oil-cooler entry ducts in the root leading edge. With the slots free, the behaviour was much the same as that of the Hampden, but the root stall and general warning were rather more marked owing to the disturbing effect of the oil-cooler inlets. With the slots sealed and throttle closed, separation remained largely confined to the inner parts of the wings and the stalling behaviour was still very gentle. With the throttles partly open, flaps up, the flow breakaway did eventually spread over the whole wing and the wing dropped fairly quickly but not viciously. With the throttles partly open and flaps down, separation was persuaded to start about two-thirds of the span out along the trailing edge before it spread over the root, and again the wing dropped fairly quickly but not viciously. The general impression was that, although the slots ensured that the outer parts of the wings did not stall, the stalling behaviour of this aeroplane with the slots sealed was too good to warrant the slots. This is rather surprising, since the taper is high (3·7 : 1) and the wing section towards the tips (NACA 2311) would not be expected to have exceptionally good stalling properties.

4.3.5. *Beaufort* (*Table* 2F).—The tests on the Beaufort[53] showed that with flaps up there was an appreciable region of breakaway behind the nacelles at gliding speeds as high as 200 m.p.h. I.A.S.; at 100 m.p.h. I.A.S. this region covered most of the root section and inner parts of the wings. With the flaps set down this breakaway was partially suppressed and delayed. The breakaway appeared to be due to the disturbing effect on the flow of an air intake and petrol vent above each nacelle; in addition, there was a radiator for cabin heating above the starboard nacelle. The " touchiness " of the flow over the upper surface of large nacelles could not be more clearly illustrated; and it follows that from the point of view of performance, excrescences in such positions should, if possible, be avoided. The intense and early root stall was obviously the main cause of the very mild stalling characteristics of this aeroplane. With flaps up and gills closed or open, and with flaps down, gills open, it was impossible to stall the aeroplane completely. With flaps down, gills closed, there was a marked initial pitch, any subsequent wing drop that occurred being in the nature of a dynamic stall due to the violent pitching and wallowing. A complete stall in the usual sense was only attained with the throttles open about a third and the flaps down, when a sharp wing drop followed an initial stall.

4.4. *Miscellaneous Brief Stalling Tests. Tables* 3 *and* 4.—The results summarised in Tables 3 and 4 will not each be discussed in detail but there are particular points of interest that are worth noting.

Lysander (*Table* 3A).—This aeroplane was so effectively slotted that it was only with the throttle almost fully open that any degree of stalling occurred, when the gentle wing drop and effective controls indicated that the stalling was partial and, in the main, confined to the root.

*Me.*109 (*Table* 3C).—This aeroplane was made to stall thoroughly and drop a wing in spite of its slots, but a considerable warning and a preliminary stall combined to make the behaviour unobjectionable.

Hurricane (*Table* 3E).—The standard Hurricane dropped a wing sharply but with fair warning. The smaller automatic slots ($0 \cdot 38b$) were partially successful in improving the stall by introducing an initial gentle stall; the larger slots ($0 \cdot 5b$) were much more successful although they did not entirely prevent the complete stall and final wing drop.

Hendy Heck (*Table* 3D).—The results on this aeroplane provide an interesting illustration of a case where automatic tip slots provided an initial gentle root stall but failed to prevent a vicious main stall. The high position of the tailplane might be partially the reason for its ability to bring the wing to the high incidence needed to stall the slotted parts of the wings.

*Fairey P.*4/34 (*Table* 3K).—This aeroplane is very similar to the Battle in general design yet its stall is worse in so far as it shows no sign of a preliminary stall. This difference may be due to the fact that it has rather cleaner lines and the root stall was consequently delayed and less intense.

5. *Discussion.*—5.1. *General.*—In the light of these experimental results we can now discuss in greater detail the manner in which the various factors noted in the preliminary remarks of Section 2 influence stalling behaviour. The first point that is immediately evident is that the stall can only become dangerous when the flow breakaway succeeds in becoming widespread quickly over the outer parts of the wings. A rapid spread of breakaway with a small change of incidence at the stall indicates a rapid breakdown of circulation and consequently a rapid loss of lift and hence a large rolling instability. The inference from this is that good stalling behaviour can be obtained in one of two ways:—

(1) The section used over the outer parts of the wings is such that it does not lose lift rapidly with increase of incidence at and beyond the stall.

(2) The stalling incidence of the outer parts of the wings are arranged to be beyond the capabilities of the elevator.

In practice, the degree of warning plays an important part, so that a vicious stall may be acceptable if there is fair warning either in the form of buffeting, general vibration, falling off in effectiveness of controls, rapid change of trim, etc., or in a preliminary gentle stall. Further, the viciousness of a stall is intensified if the longitudinal stability is poor, and large changes of incidence occur for small stick movements.

5.2. *Wing Section.*—The relation between wing sections and their stalling behaviour is discussed in detail in the Appendix, but a brief review of the main points will not be out of place here. The pressure distribution around an aerofoil in two dimensions is determined by the shape of the aerofoil section and to a small extent by the Reynolds number. At high incidences near the stall the pressure on the upper surface generally rises rapidly from a high-suction peak near the leading edge to a small positive pressure at the trailing edge, and separation of flow at the trailing edge begins when the positive pressure gradient there becomes so large that the boundary layer can no longer cope with it. If the positive pressure gradient increases in magnitude from the trailing edge forwards then it may be expected that the breakaway of flow will spread rapidly forwards and become complete with a relatively small increase of incidence. On the other hand, if the positive pressure gradient decreases from the trailing edge forwards then we may expect the rate of forward spread of breakaway with incidence to be comparatively slow. It follows that a section with the former type of pressure distribution will show a large and rapid fall of lift with a small increase of incidence at the stall, but a section with the latter type of pressure distribution will have a fairly gentle fall of lift with increasing incidence at the stall. It is found that the characteristic shape of the pressure distribution of a wing section is well in evidence at lift coefficients of the order of $1 \cdot 0$. Hence, by obtaining the pressure distribution for a given section at this lift coefficient, either theoretically or experimentally, one can rapidly assess the probable stalling properties of that section. Fig. 7 illustrates the close correlation existing between the lift-incidence curves of a number of aerofoils and their calculated pressure distributions at a C_L of $1 \cdot 0$. It is assumed that the stalling properties of a section in two-dimensional flow are a good guide to its stalling properties in the complicated three-dimensional flow round wings at high incidences. This assumption appears to be well borne out in practice and can be supported by the argument that separation of flow may be expected to be "contagious"; a rapid forward spread of breakaway will help to make the spanwise spread rapid.

This theoretical approach confirms what has already been observed experimentally, namely, that increase in camber or in thickness (above about 7 to 8 per cent.) towards the tips is accompanied by an improvement in the stalling behaviour. It also confirms that the 230 sections and the RAF 28 section have poorer stalling properties than most other sections of the same thickness and camber.

In the above it is implied that stalling always begins with separation of the turbulent boundary layer at the trailing edge. This is true of all wing sections of thickness above a certain value depending on the Reynolds number (probably about 6 to 7 per cent. at normal flight Reynolds numbers).* On sections of thickness below that value the positive pressure gradients immediately aft of the leading edge are so intense at even moderate incidences that it appears that an early front separation of the laminar boundary layer occurs, followed by the re-attachment of a somewhat weakened turbulent boundary layer which separates in its turn at a higher incidence. Once this process begins the growth of circulation with incidence is effectively stunted and the lift incidence curve is flat topped (*cf.* that of a flat plate). The lateral stability of aeroplanes with wing sections of this order of thinness over an appreciable part of their outer wings might therefore be expected to be good although the maximum lift coefficient attained may be low. The results of the Spitfire tests appear to confirm this, but further experimental confirmation and research is desirable.

5.3. *Wing Taper, Washout and Sweepback.*—Theory[1, 32] demonstrates that at a given lift coefficient the higher the taper the higher is the incidence over the outer parts of the wings relative to the incidence over the inner parts. For example, the maximum incidence occurs at

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* Note added 1950. For low-drag wings at normal flight Reynolds numbers the critical thickness is in the region of 9 to 11 per cent.

the root for a plain wing with a taper ratio of 1 : 1, at about 0·5 of the semi-span for a taper ratio of 2 : 1, and at about 0·8 of the semi-span for a taper ratio of 5 : 1. Hence, it is not surprising to find an increase in taper accompanied by a worsening of the stalling behaviour, as on the Falcon, since it encourages an earlier breakaway of flow from the outer parts of the wings. Similarly, washout may be expected to improve the stalling behaviour since it decreases the incidence towards the tips whilst washin will worsen the stall. A disadvantage of using washout to improve stalling behaviour is the fact that a considerable amount is generally required to have a marked effect, and this implies in general an appreciable increase in induced drag. A detailed discussion of the relative magnitude of these effects is given in Ref. 32; as already pointed out, however, the effect of taper or washout on stalling may be considerably modified by the wing section used and the effect of slipstream, nacelles, etc.

There is some experimental evidence[36, 37] to show that sweepback encourages early tip stalling and sweepforward encourages early root stalling. There appears to be a tendency for a secondary flow to be set up in the boundary layer towards the wing root due to the lateral pressure gradients which become greater with decrease of sweepback. The slow moving air, moving in towards the root, increases the tendency to separation there, and it follows that decrease of sweepback will encourage root stalling.

5.4. *Flaps.*—The flight results indicate the number of conflicting ways in which partial span flaps can affect the stalling behaviour. We find in fact, about as many cases in which they improve the stalling behaviour as cases in which they worsen it. There are four main effects:—

(1) They increase the upwash over the outer unflapped part of the wings and therefore the incidence there.

(2) They tend to clean up any " dirtiness " of the root.

(3) They increase the downwash at the tail-plane

(4) Their wake may envelope the tail-plane at incidences in the neighbourhood of the stall, reducing its efficiency and causing a change in trim. This is generally accompanied by tail buffeting and pitching which increase the stall warning.

Effects (1), (2) and (3) operate to worsen the stall, examples where they tend to dominate are the Master (Table 1D), Hotspur (Table 3G), Courier (Table 1C) and some of the slotted aeroplanes such as the Taifun (Table 3B), Hendy Heck (Table 3D) and Hurricane (Table 3E). Effect (4) operates to improve the stall; the Falcon (Tables 1A and B), Magister (Table 1E) and Blenheim (Table 2A) provide good examples where it plays the dominant part. For any given design the position intensity and width of the wake and the downwash at the tail plane can be estimated from the comprehensive charts and data given in Refs. 38, 39; hence, it should be possible to gauge how important effect (4) will be.

The deterioration of stalling behaviour with increase in span of flaps set down, as noted on the Courier, raises the question whether aeroplanes using full-span flaps may be expected to have bad stalling characteristics. The effect (1) then does not arise but an additional factor arises which may strongly reinforce the tendencies worsening the stall. It is known that however round-topped and gentle the lift and incidence of an unflapped wing section may be, when that wing section is flapped the lift-incidence curve becomes sharp and a considerable and sudden loss of lift may occur at the stall. It follows that with full-span flaps the section of the flapped outer parts of the wings will have poor stalling properties. Some tests on a Parasol monoplane[40] with a retractable-arc flap, which could be put down in spanwise stages, showed a very considerable worsening in the behaviour at the stall when the span of the flap set down was increased from part to full span. When the same aeroplane was equipped with a full-span Zap flap[41], however, the stalling behaviour was quite gentle with flaps up or down. This may have been due to the fact that the Zap flaps, unlike the retractable-arc flaps, had a fairly large chord, and the considerable masking effect and pitching moment due to them may have made it impossible to stall the aeroplane completely. Some National Physical Laboratory model tests on tapered wings with flaps of various span[36] indicated that, with moderate taper, flaps of span as great as

70 per cent. of the wing span could be used without serious effect on the lateral stability at the stall. As the flap span was increased from 70 to 100 per cent. of the wing span, however, the instability at the stall increased very rapidly. Further experimental evidence on this point is desirable as designers of high-lift aeroplanes tend to the use of flaps approaching the full wing span in size.

5.5. *Nacelles, Gills and Slipstream.*—The effects of nacelles, gills and slipstream are amply illustrated by the experimental results reviewed. We see that nacelles frequently introduce centres of early separation which being located over the inner parts of the wings help to improve the stalling behaviour. Their effect is two-fold. Firstly, the wake from the disturbed regions may reduce the efficiency of the elevator and introduce buffeting as a stall warning. Secondly, when the flow separates from the inner parts of the wings the nose-down pitching moment and longitudinal stability increase. Opening the gills generally intensifies these effects considerably as do also excrescences on the upper surfaces of the nacelles. Slipstream acts in the opposite way by cleaning up the flow round the nacelles and over the root section; in addition, the slipstream may increase the efficiency and downwash of the tail plane. The importance of including in routine stalling tests some tests with throttles open will be realised from these remarks; an aeroplane which may be safe at the stall with engines off may be dangerous with engines on.

5.6. *Automatic Wing-Tip Slots and Hudson-Type Slits.*—It is evident that if automatic wing-tip slots are efficiently designed and of adequate span they are very effective in producing good stalling properties; but it is worth emphasising that their effectiveness is always subject to the elevators being unable to raise the slotted parts of the wings to their stalling incidence. The Hendy Heck provides an instance where the elevators were capable of stalling the slotted parts of the wings and the resultant wing drop was vicious. However, the design of an aeroplane would have to be most unusual if in reaching those incidences a considerable degree of warning was not given by buffeting and vibration induced by the wake of the thoroughly stalled centre-section.

For some high-lift designs the use of full-span slots is being considered. With uniform full-span slots of efficient design the difference between the stalling incidences of the inner and outer parts of the wings can be little more than the difference when the wing is unslotted. Since slotted sections generally have sharp-topped lift curves, we can anticipate that an aeroplane with such slots may have poor stalling characteristics. This possibility can to a large extent be avoided by splitting the slot into inner and outer portions and designing the outer portion to have a higher stalling incidence than the inner portion.

Hudson-type slits also help the stalling behaviour by raising the local stalling incidence; but they are not so effective as wing-tip slots, and the extra drag caused by them at high speeds prohibits their use over more than a small part of the span on aeroplanes whose speed is of any importance. It is estimated that they double the local wing profile drag; consequently, their usefulness is limited. Nevertheless, on the Hudson and Master they apparently succeeded in changing the stalling behaviour from bad to borderline or even passable.

It will be noted that, because they delay the stall over the outer parts of the wings, slots (automatic or fixed), generally improve the effectiveness of the ailerons at high incidences.

5.7. *Stall Warning.*—As already noted a pilot will generally tolerate an aeroplane with vicious stalling characteristics if he is given adequate warning of the approach of the stall. The importance of the stall warning cannot, therefore, be too strongly emphasised. Unfortunately the conditions which promote a bad stall are generally those which provide little warning; conversely, a good stall is generally accompanied by ample warning. Thus, the warning usually takes the form of vibration, pitching, tail buffeting or rapid change of trim which are evidence of an early root stall. A reduction in the effectiveness of the controls sometimes provides a warning but is frequently difficult to separate from the usual reduction in effectiveness due to the reduction in speed.

A case can be made out, therefore, for the installation of some artificial stall warning device on aeroplanes which have a bad stall with inadequate warning and (a) are likely to be flown by unskilled pilots, *e.g. ab initio* trainers, (b) may be involved in manoeuvres where the pilot may wish to fly as close to the stall as possible, *e.g.* fighters in combat doing tight turns, (c) are used at night and are liable to be brought in to land at too great a speed owing to the pilots' fear of stalling. Some of the work that has been proceeding both in America and here on the development of stall warning devices is described in detail in Ref. 42. It appears that the problem of providing the warning at the right moment for most manoeuvres for which it is required is largely solved, but the form the warning should take still presents difficulties.

6. *Concluding Remarks.*—What advice can be culled from the foregoing for the designer who wishes to avoid bad stalling properties in a new design ? The advice can be fairly definite for the designer of an aeroplane for which the top speed is of no great importance but which must be reasonably free from vice at low speeds, *e.g.* an *ab initio* trainer or a long-range patrol aeroplane. For such aeroplanes a section over the outer parts of the wings of fairly high camber (3 to 4 per cent.) and a moderate thickness at the tips ($>$ 12 per cent.) would ensure a non-vicious stall and is unlikely to be seriously objected to on other grounds.

The designer of a high-speed aeroplane is faced, however, with a more difficult problem. The conditions that ensure good stalling properties are nearly always in conflict with those required by high performance. The designer will naturally try to keep his fuselage and nacelle junctions as clean as possible, and he will in general be reluctant to use high camber at the wing tips, large washout or fixed wing-tip slits because of the extra drag involved. An additional objection can be raised to high-camber wing sections over the outer parts of the wings on account of the large pitching moments involved; they may necessitate large tail loads in high-speed dives for which the designer must provide extra strength.* Automatic wing-tip slots involve extra weight and some complication of design. On the other hand, the designer is attracted by the reduction in structure weight offered him by the use of high-wing taper. Nevertheless, so far as multi-engined aeroplanes are concerned, some consolation can be extracted from the fact that the modern tendency to increase power and wing loading is necessarily accompanied by an increase in nacelle and fuselage sizes relative to the wing area. Consequently, it is becoming increasingly difficult to keep the nacelles and fuselage junctions clean, even at cruising incidences, and this would suggest that the chances of a multi-engined aeroplane having a vicious stall without warning are decreasing.†

However, the designer of a high-speed aeroplane is advised to avoid if possible the use of a section over the outer parts of the wings which experiment and theory indicate have particularly bad stalling properties; there are generally other sections of the same thickness and camber with far better stalling properties. In this connection the discussion of section 5.2, the Appendix, Table 5 and Fig. 7 should be of some help. He should try to keep the wing-tip thickness as high as possible, the worst thickness for stalling is in the region of 9 per cent.‡ There is a possibility, however, that if he adopts an extremely thin wing-tip section ($<$6 to 7 per cent. thick) the stalling behaviour will be satisfactory, but this requires further investigation. It is advisable to consider taper ratios greater than about 2 : 1 only in conjunction with tip sections having good stalling characteristics.

The important part played by the tail-plane position, elevator power and range in determining the stall warning, longitudinal trim and stability characteristics near the stall cannot be too strongly emphasised. In the preliminary model tests of a new design it would probably pay the designer to examine carefully the position, extent and intensity of the wake and its relation to the tail plane at incidences approaching the stalling incidence of the outer parts of the wings. Such

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* It may be possible to reduce the pitching moment by the use of reflex, *e.g.* by rigging up the ailerons, without impairing the good stalling qualities, but this requires further investigation.

† These remarks were made with piston engines in mind. The clearness and relatively small size of jet engine installations will make them less likely to induce a root stall, and so the tendency for a vicious stall will be greater.

‡ For low drag sections the worst thickness is likely to be in the region of 11 to 12 per cent.

an investigation should help in assessing the probable stalling behaviour of the aeroplane, in particular it should indicate possible arrangements for which a stall warning should be present. Scale effect will undoubtedly affect the results of such tests, but for this purpose it is felt that the scale effect should not be serious; the results can and should be checked, however, by means of the data and charts of Refs. 38, 39. It is worth noting that the region in which buffeting is felt is wider than the wake proper, which is normally defined as the region in which the total head is less than the main stream value. The results of R. & M. 1457[54] suggest that the "buffeting wake" is about twice as wide as the actual width of the wake. We may expect, for example, that if the wake is situated at about a third of its width below the tail-plane at an incidence below the stalling incidence of the outer wings some tail buffeting, and hence a stall warning, will occur.

APPENDIX

Wing Sections and their Stalling Characteristics

By

H. B. Squire, M.A. and A. D. Young, B.A.

1. *Stalling of Thin Sections.*—For most sections at present in use at flight Reynolds numbers, stalling arises from the separation of the turbulent boundary layer at the trailing edge, but very thin sections provide an important exception to this rule. Jones[43] introduced the distinction between "front" and "rear" stalls by examination of the results of pressure plotting and lift measurements made at a Reynolds number of 10^5; he noted that increase of Reynolds number is favourable to rear separation but unfavourable to front separation. It now appears from an examination of the available data, particularly that given in Ref. 44, that this front stall does not occur at a Reynolds number greater than 10^6 except on very thin sections (less than about 7 per cent. thick)* with small leading-edge radius. The front separation, when it occurs, appears to be a separation of the laminar boundary layer which is generally followed for $R > 10^6$ by the re-attachment of a turbulent boundary layer, which separates in its turn from the trailing edge at a higher incidence.

The important feature of the behaviour of thin aerofoils with small leading-edge radius arises from the fact that, owing to the stunting effect on the growth of circulation of this early front separation, the lift coefficient remains approximately constant with increasing incidence once the separation starts. The lift curve of NACA 2306 (leading-edge radius $0 \cdot 004c$) for $R = 3 \times 10^6$ is shown in Fig. 1 and is typical of the lift curves found for all thin sections of the same or smaller leading-edge radius, provided that the camber is not more than 4 per cent. Tests of flat plates show similar results[45]. As explained in the body of this report, if wing sections having such flat-topped lift curves are used over the outer portions of the wings of an aeroplane then severe lateral instability at the stall will not occur.

It is probable that for thin wing sections the radius of curvature of the leading edge is the most important parameter determining whether the lift curve will be similar to Fig. 1; an examination of the data given in Ref. 46 suggests that the leading-edge radius should be not greater than $0 \cdot 5$ per cent. of the wing chord.

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* Or low-drag sections less than about 9 per cent. thick.

2. *Stalling of Wings of Moderate Thickness.*—Separation of the turbulent boundary layer from the trailing edge is determined primarily by the local conditions there. It can be argued, on dimensional grounds, that the velocity distribution across the turbulent boundary layer and the conditions of separation are controlled by a parameter of the form

$$\Gamma = \frac{U'\delta}{U} f\left(\frac{U\delta}{\nu}\right),$$

where U is the velocity at the outer edge of the boundary layer, U' the velocity gradient at the edge of the boundary layer, and δ is the boundary-layer thickness.

The function $f\,(U\delta/\nu)$ cannot be specified exactly at present but it must be a function which increases very slowly with increase of $U\delta/\nu$. Since we are only concerned with the qualitative characteristics of separation it is sufficient to neglect this undetermined function, and take

$$\Gamma = U'\delta/U$$

as the parameter which determines the velocity distribution across the boundary layer. Separation will then occur when Γ falls to the value $-K$, some constant which need not at present be determined. We therefore take the condition for separation as

$$\frac{U'\delta}{U} = -K\,.$$

In support of the argument that the parameter Γ largely controls separation we find it enables us to explain the known variations of the maximum lift coefficients of aerofoils with Reynolds number and surface roughness as follows:—

(i) For aerofoils with fully turbulent boundary layers δ falls with increase of Reynolds number. Hence at separation, since $\Gamma = -K$, $|U'|$ increases with increase of Reynolds number, and the incidence at which the maximum lift coefficient occurs will therefore also increase. It follows that $C_{L\,\text{max.}}$ increases with increase of Reynolds number, as is experimentally observed[47].

(ii) On thick, highly-cambered aerofoils, such as Gött.387, the boundary layer is not fully turbulent at high incidences and low Reynolds numbers. Increase of Reynolds number, combined with the effect of stream turbulence, then increases δ at the trailing edge by causing the transition point to move forward. It follows that $C_{L\,\text{max.}}$ should decrease with increase of Reynolds number until the boundary layer is fully turbulent, after which it should increase with increase of Reynolds number as explained above. This result is also in accordance with experiment[47].

(iii) Surface roughness increases the boundary-layer thickness, δ, due to the increased surface friction. It follows that for $\Gamma = -K$, separation occurs for a smaller numerical value of U' at the trailing edge if the surface roughness is increased, *i.e.* at a smaller value of the incidence. This corresponds to the experimentally observed fall in $C_{L\,\text{max.}}$ due to roughness[47].

Assuming, therefore, that the parameter Γ controls the separation of the boundary layer, we can proceed to relate the stalling behaviour with the wing-section shape by considering the pressure distribution and its relation to the Γ distribution over the upper surface at stalling incidences. Since δ increases steadily from the transition point to the trailing edge for all aerofoils, and $\partial p/\partial X$ or U' are the quantities which differ most between different sections, it follows that the pressure distribution on the upper surface is the major factor which determines the characteristic features of the Γ distribution of a section. For example, consider the upper-surface pressure distributions of two aerofoils A and B near their stalling incidence shown in Fig. 2(a), 2(b). The corresponding Γ distributions for the incidences $\alpha_1, < \alpha_2 < \alpha_3$, where α_3 is approximately the stalling incidence, are shown in Fig. 3(a) and 3(b), and it will be seen that these differ considerably.

For aerofoil A, due to the convexity of the pressure distribution*, Γ increases roughly linearly from zero at the point of maximum suction to its value at the trailing edge. It follows that, as the incidence increases through the stalling incidence, the region over which Γ has reached its critical value increases relatively slowly, and the boundary-layer separation will therefore move forward slowly. Hence the lift curve will be round topped as shown in Fig. 4(a). For aerofoil B on the other hand, the convexity of the pressure distribution causes Γ initially to increase rapidly from zero at the point of maximum suction and then flatten out so that its gradient over the rear half of the aerofoil is small. It follows that Γ quickly reaches its critical value over a large part of the aerofoil as the incidence passes through the stalling incidence. Consequently, separation moves forward rapidly, once it has started, and the stall is sudden, so that the lift curve may be expected to have a sharp peak as shown in Fig. 4(b).

The effect of section shape on the upper-surface Γ distributions was confirmed by analysing experimental pressure distribution for the sections NACA 4412[46] and NACA 23012[48] for a Reynolds number of about 3×10^6. The results obtained are shown in Figs. 5, 6. Unfortunately, the experimental data are not accurate enough to define Γ satisfactorily over the rear $0{\cdot}2c$ of the aerofoils and the measurements with the section NACA 23012 did not extend up to stalling incidence. The difference in character of the curves for the two sections is, however, apparent, and indicates that forward spread of separation will be far more rapid on the NACA 23012 section than on the NACA 4412 section.

The above discussion leads to the conclusion that the pressure distribution on the upper surface of an aerofoil at a fairly high incidence, which may be determined either by calculation or by experiment, is a good guide to the stalling characteristics of the section, since it controls the distribution of the quantity Γ, and therefore determines the rate of spread of separation forward from the trailing edge. Before this argument can be accepted, however, it is obviously necessary to be satisfied that the pressure gradients over the unstalled parts of the wing are not greatly modified by the stalled region near the trailing edge. This, however, is borne out by the results of a complete investigation of wing section NACA 4412[44], from which it appears that the form of the calculated distribution remains a good guide to that of the actual distribution over the unstalled forward part of the wing, provided that the Reynolds number is greater than about 10^6.

We can conclude, therefore, that the stalling behaviour of an aerofoil will be indicated by the degree of concavity of the upper-surface pressure distribution at high incidences. Since it is only the characteristic form of the pressure distribution with which we are concerned it is sufficient to consider the pressure distribution at any reasonably high incidence; in comparing different wing sections it has been found convenient to consider the pressure distributions at $C_L = 1{\cdot}0$. Various methods of gauging the concavity of the upper-surface pressure distributions suggest themselves. The considerations that (a) the pressure distributions all apply to the same lift coefficient, (b) the lower-surface pressure distributions are much the same for all aerofoils, (c) the pressure coefficient at the trailing edge is, in practice, small and positive and much the same for all aerofoils, lead to the conclusion that a very simple, though somewhat rough, guide, to the concavity of the upper-surface pressure distribution is the magnitude of the suction peak. In Fig. 7 the theoretical pressure distributions[52] at $C_L = 1{\cdot}0$ and lift curves for a number of aerofoils are shown. The aerofoils are arranged in the order of magnitude of their suction peaks. The close correlation between the pressure distributions and lift curves suggested by the above reasoning will be at once apparent. An exception appears to be the reflexed aerofoil NACA M6, for which the suction peak suggests a stall much worse than is indicated by the lift curve. The suction peak is, however, only an approximate guide to the curvature of the pressure distribution, and is here followed by a kink in the pressure curve convex upwards, which tends to improve the stall; the prediction of the stalling behaviour by means of the suction peak is therefore pessimistic. Such cases are, however, unusual.

The main characteristics and magnitudes at the suction peaks of the aerofoils considered are given in Table 5. It will be seen that, in agreement with the experimental results already described, RAF 28 and NACA 23012 sections would be expected to have bad stalling qualities

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* The convention is here adopted that negative pressures are denoted by positive ordinates.

whilst Gött. 387, NACA 4412 would be expected to have good stalling qualities. In addition, general deductions are possible as to the effect of various parameters such as camber, thickness, etc. on the stalling properties. The following conclusions, which, in the main have already been arrived at empirically[1, 5, 33] immediately suggest themselves:—

(a) Increase in camber improves the stall (*cf.* the aerofoils NACA 0012, 2412, 4412).

(b) Increase in thickness above 9 per cent. improves the stall (*cf.* the aerofoils NACA 2409, 2412, 2415).

(c) Bringing the maximum camber forward, as in the NACA 230 sections, appears to have a bad effect on the stall.

The need for a classification of aerofoils according to their stalling qualities has already been pointed out in Ref. 1. Since it is a comparatively simple matter to calculate the pressure distribution for a given wing section, the classification of aerofoils according to the magnitude of their upper-surface suction peaks at $C_L = 1 \cdot 0$ as indicated in Table 5 can easily be extended to include all the aerofoils in common use today and any aerofoils (except thin ones) that may be introduced in the future. Such a classification, broad as it must be, would nevertheless enable a designer to obtain quickly a rough idea of the stalling qualities of any aerofoil in which he may be interested.

REFERENCES

No.	*Authors*	*Title, etc.*
1	Gates	Notes on the Wing Dropping Problem. A.R.C. 3441. February, 1938. (Unpublished).
2	Francis	Full Scale Tests of the Effect of Flaps on Lateral Stability and Control. Part I. Tests of Falcon with Standard Wing Plan Form. R. & M. 1961. 1939.
3	Francis and Pringle	Tests of the Effect of Wing Tip Section on Stalling Properties. Part II. Low Taper Wing. R. & M. 2061. June, 1941.
4	Francis	Full Scale Tests of the Effect of Flaps on Lateral Stability and Control. Part II. Tests of Falcon with High Taper Wing. R. & M. 1961. 1939.
5	Francis and Birch	Tests of the Effect of Wing Tip Section on Stalling Properties. Part I. High Taper Wing with NACA 4415 Tip. R. & M. 2061. June, 1941.
6	Francis	Full Scale Tests of Slotted Flaps and Ailerons on a Courier. R. & M. 1819. April, 1937.
7	—	A.A.E.E. M/719. August, 1939.
8	Birch	Note on the Improvement of the Stalling Characteristics of the Magister. R. & M. 2061. June, 1941.
9	Birch	Stalling Tests on Tipsy G-AFGF with Wing Tip Slits. A.R.C. 4657. April, 1940. (Unpublished).
10	Francis and Pringle	Note on Flight Tests of the Blackburn Skua Prototype. A.R.C. 3536. March, 1938. (Unpublished).
11	Morgan and Pringle	Research Handling Tests on Battle I. K.7555. A.R.C. 4045. March, 1939. (Unpublished).
12	Morgan	Research Handling Tests on Spitfire Prototype K.5054. A.R.C. 4533. January, 1940. (Unpublished).

REFERENCES—*contd.*

No.	*Authors*	*Title, etc.*
13	Francis and Pringle	Note on Flight Tests of Stability and Control at Low Speeds on a Blenheim. A.R.C. 3680. July, 1938. (Unpublished).
14	Pringle	Further Stalling Tests on a Blenheim. R. & M. 1966. December, 1939.
15	—	Effect of Built-in Slots on Hudson Aeroplanes from Aspects of Stall, Landing and Top Speed. A.R.C. 4233. July, 1939.
16	Young	Stalling Tests on a Hampden. A.R.C. 4701. May, 1940. (Unpublished).
17	Morgan and Birch	Research Handling Tests on Lysander K.6127 (prototype). A.R.C. 3866. November, 1939. (Unpublished).
18	Morris	Research Handling Tests on the Messerschmidt "Taifun" G-AFRN. A.R.C. 4892. October, 1940.
19	Morgan and Morris	Messerschmidt Me.109. Handling and Manoeuvrability Tests. A.R.C. 4920. September, 1940.
20	Woodward, Nutt and Hufton	Full Scale Tests of the Hendy Heck. (With an Appendix giving pilot's notes). R. & M. 1719. January, 1936.
21	Morgan	Research Handling Tests on Hurricane K.5083 (prototype). A.R.C. 3696. August, 1938. (Unpublished).
22	Morgan	Research Handling Tests on Gloster F.5/34 K.8089. A.R.C. 4018. February, 1939. (Unpublished).
23	Morris	Research Handling Tests on Hotspur (prototype) K.8309. A.R.C. 4651. April, 1940. (Unpublished).
24	Morgan and Morris	Handling Tests on a Curtis H–75. R. & M. 2379. April, 1940.
25	Morgan	Research Handling Tests on a Fairey P.4/34. K.5099. A.R.C. 4020. March, 1939. (Unpublished).
26	Serby and Shone	Full Scale Tests of Landing Flaps on a Miles Hawk Major. A.R.C. 1807. January, 1935.
27	Morgan	Full Scale Tests on the Handley Page C.26/31. J.9833. A.R.C. 3597. May, 1938. (Unpublished).
28	Alston	Tests for Stability and Control at the Stall (A.D.M. 293 revised). R.A.E. Report No. B.A. 1419. August, 1937.
29	Morgan	Research Handling Tests on Anson (prototype) K.4771. A.R.C. 4290. October, 1939. (Unpublished).
30	Morgan and Birch	Research Handling Tests on Lockheed 12 AG-AENZ. A.R.C. 3856. September, 1938. (Unpublished).
31	Hollingdale	Aerodynamic Characteristics of Tapered Wings with Flaps and Slots. R. & M. 1774. 1936.
32	Soulé and Anderson	Design Charts Relating to Stalling of Tapered Wings. N.A.C.A. Tech. Rept. 703. 1940.
33	Relf	Note on the Nature of the Stall in its Relation to Rolling Stability. A.R.C. 2488. June, 1936.
34	Francis	Note on Evidence from Flight Tests on the Influence of Wing Thickness on Stalling. A.R.C. 2704. September, 1936. (Unpublished).
35	Anderson	Determination of the Characteristics of Tapered Wings. N.A.C.A. Tech. Rept. 572. 1936.
36	Irving, Batson, Warsap and Gummer	Some Aerodynamic Characteristics of Tapered Wings Fitted with Flaps of Various Spans. A.R.C. 2871. February, 1939.

REFERENCES—*contd.*

No.	*Authors*	*Title, etc.*
37	Hartwig	Beobachtung des Einflussen von Flugelanbautung und Klappen auf den Abreizverlauf der Tragflügelströmung. Luftfahrtforschung. March, 1941.
38	Silverstein, Katzoff and Bullivant	Downwash and Wake Behind Plain and Flapped Airfoils. N.A.C.A. Tech. Rept. No. 651. 1939.
39	Silverstein and Katzoff	Design Charts for Providing Downwash Angles and Wake Characteristics Behind Plain and Flapped Wings. N.A.C.A. Tech. Rept. No. 648. 1939.
40	Serby and Hufton	Full Scale Tests of a Retractable Arc Flap on a RAF 48 Wing Fitted to a Parasol Monoplane. A.R.C. 2581. July, 1936. (Unpublished).
41	Jones, Cohen and Hufton	Full Scale Lift, Drag and Landing Measurements of a Monoplane Fitted with a Zap Flap. R. & M. 1741. October, 1936.
42	Pringle	Stall Warning Devices. A.R.C. 5049. January, 1941.
43	Aeronautics Laboratory, Cambridge	An Experimental Study of the Stalling of Wings. R. & M. 1588. December, 1933.
44	Pinkerton	The Variation with Reynolds Number of the Pressure Distribution over an Airfoil Section. N.A.C.A. Tech. Rept. No. 613. 1938.
45	Flachsbart	Ergebnisse der Aerodynamischen Versuchsanstalt zü Gottingen. Vol. IV. 1932.
46	Jacobs, Ward and Pinkerton	The Characteristics of 78 Related Airfoil Sections from Tests in the Variable Density Tunnel. N.A.C.A. Tech. Rept. No. 460. 1933.
47	Fluid Motion Panel	Modern Developments in Fluid Dynamics. Vol. II. pp. 442–447.
48	Wenzinger	Pressure Distribution over a NACA 23012 Airfoil with a NACA 23012 external flap. N.A.C.A. Tech. Rept. No. 614. 1938.
49	Pinkerton and Greenberg	Aerodynamic Characteristics of a Large Number of Aerofoils Tested in the Variable Density Wind Tunnel. N.A.C.A. Tech. Rept. No. 628. 1938.
50	Jacobs, Pinkerton and Greenberg	Tests of Related Forward Camber Airfoils in the Variable Density Tunnel. N.A.C.A. Tech. Rept. No. 610. 1937.
51	The Aerodynamic Staff, R.A.E.	Flight Tests on Wing Sections using the Parasol Monoplane. R. & M. 1844. December, 1936.
52	Garrick	Determination of the Theoretical Pressure Distribution for Twenty Airfoils. N.A.C.A. Tech. Rept. No. 465. 1933.
53	Morris and Morgan	Handling Tests on Beaufort L.4478. A.R.C. 5425. August, 1941.
54	Duncan, Ellis and Scruton Aerodynamics Staff of N.P.L.	Two Reports on Tail Buffeting. R. & M. 1457. February, 1932.

TABLE 1

Summary of Detailed Stalling Tests. Single-engined Aeroplanes

TABLE 1A. Falcon [Low-taper]

Ref. No.	Description, etc.	Slots	Flaps	Tail plane position and volume, elevator range and volume	Wing Sections		Stall Warning	Behaviour at and beyond stall	Spread of flow breakaway	Stall grade [*see* § 4]
					Root	Tip				
2	Low Wing Taper = 1·8:1 Sweepback = $1\frac{1}{2}^\circ$ Dihedral = 5° w = 13 lb./sq. ft.	Plaster Type Automatic Span 0·4b	Split $0\cdot15\bar{c}\times$ $0\cdot58b$	$11\frac{1}{4}^\circ$ 0·39 $\pm28^\circ$ 0·15	C.Y.H. $t/c = 0\cdot19$	Section $t/c = 0\cdot08$	*Slots closed, flaps up*.—Slight lateral instability.	*Slots closed, flaps up*.—Lateral stability good down to stall, at stall wing drops fairly gently to steep spin. Wing cannot be raised by controls.	[Only surface tufts used. ‘ Deep ’ turbulence not observed]. *Slots closed, flaps up*.—‘ Shallow ’ turbulence starts at root and spreads outwards and forwards over wing as it drops.	5C
							Slots closed, flaps down.—Pitching oscillation.	*Slots closed, flaps down*.—Severe pitching oscillation begins near stall. No tendency to drop a wing or spin. Lateral control good down to stall.	*Slots closed, flaps down*.—‘ Shallow ’ turbulence eventually covers most of wing and fluctuates with pitching.	2A
							Slots open, flaps up.—None.	*Slots free, flaps up*.—Lateral stability good up to highest incidences attainable. Lateral control good.	*Slots free, flaps up*.—‘ Shallow ’ turbulence does not spread much beyond unslotted parts of wing.	1C
							Slots open, flaps down.—Pitching oscillation.	*Slots free, flaps down*.—Severe pitching oscillation. Wing may drop slowly into spiral. Lateral control good.	*Slots free, flaps down*.—Similar to slots closed, flaps down.	2A
3	Low Wing. Taper = 1·8:1 Sweepback = $1\frac{1}{2}^\circ$ Dihedral = 5° w = 13 lb./sq. ft.	—	Split $0\cdot15\bar{c}\times$ $0\cdot58b$	$11\frac{1}{4}^\circ$ 0·39 $\pm28^\circ$ 0·15	C.Y.H. $t/c = 0\cdot18$	NACA 4415	*Flaps up*.—Slight unsteadiness and lateral instability.	*Flaps up*.—Change in longitudinal trim, wing drops gently 15°–20° into mild falling leaf. Stalled glides possible with use of rudder and ailerons.	*Flaps up*.—‘ Deep ’ turbulence starts at root and spreads slowly spanwise along rear half of wing. Front part of wing rarely affected appreciably.	3C
							Flaps down.—Very slight.	*Flaps down*.—Nose pitches and wing drops gently a few degrees; pitching oscillation sets in. Stalled glides possible.	*Flaps down*.—Similar to flaps up but modified by pitching motion.	2C
					C.Y.H. $t/c = 0\cdot18$	C.Y.H. $t/c = 0\cdot09$	*Flaps up*.—Slight lateral instability.	*Flaps up*.—Wing drops fairly quickly into spiral or spin. Not violent.	*Flaps up*.—Starts at root and spreads spanwise along rear half of wing; foremost tufts rarely affected.	5C
							Flaps down.–Pitching and reduction in aileron effectiveness.	*Flaps down*.—Wing drops and then violent pitching motion obscures the lateral behaviour.	*Flaps down*.—Similar to flaps up but modified by pitching motion.	5A
					C.Y.H. $t/c = 0\cdot18$	NACA 23009	*Flaps up*.—Very slight pitching oscillation.	*Flaps up*.—After initial roll, nose and wing drop fairly quickly into falling leaf or steep spiral. Stalled unsteady glides occasionally possible.	*Flaps up*.—Starts at root and spreads outwards and forwards quickly to cover complete outer wing.	5C

TABLE 1—*contd.*

TABLE 1A. Falcon [Low-taper]—*contd.*

Ref. No.	Description, etc.	Slots	Flaps	Tail plane position and volume, elevator range and volume	Wing Sections		Stall Warning	Behaviour at and beyond stall	Spread of flow breakaway	Stall grade [*see* § 4]
					Root	Tip				
					C.Y.H. $t/c = 0\cdot18$	NACA 23009	*Flaps down.*—Slight pitching.	*Flaps down.*—After initial mild wing drop, nose pitches up violently and wing drops viciously into spiral. Stalled glides occasionally possible.	*Flaps down.*—Similar to flaps up; wing wholly turbulent in stalled glide.	4B
					C.Y.H.	RAF 28	*Flaps up.*—Slight lateral oscillation and loss of feel.	*Flaps up.*—Behaviour is variable; usually after large rolling oscillation wing drops sharply into spin or spiral.	*Flaps up.*—Starts at root and spreads outwards and forwards quickly to cover complete wing.	6B
							Flaps down.—Slight lateral unsteadiness and change of trim.	*Flaps down.*—Wing drops during each pitching oscillation and rises again.	*Flaps down.*—Similar to flaps up, modified by pitching motion.	4B

TABLE 1B. Falcon [High-taper]

Ref. No.	Description, etc.	Slots	Flaps	Tail plane position and volume, elevator range and volume	Wing Sections: Root	Wing Sections: Tip	Stall Warning	Behaviour at and beyond stall	Spread of flow breakaway	Stall grade [*see* § 4]
4	Low Wing. Taper $\left[\frac{\text{Root chord}}{\text{Tip chord}}\right] = 4\cdot5:1$ Sweepback $= 2°$ Dihedral $= 4\cdot5°$ $w = 12\cdot85$ lb./sq. ft.	Plaster Type Automatic Span 0·5b	Split $0\cdot15\bar{c} \times 0\cdot58b$	$11\frac{1}{4}°$, $0\cdot39$ $\pm28°$ $0\cdot15$	C.Y.H. $t/c = 0\cdot18$	Section $t/c = 0\cdot08$	*Slots closed, flaps up.*—Very slight.	*Slots closed, flaps up.*—Wing drops quickly to steep angle, followed by nose. Cannot be controlled after stall.	*Slots closed, flaps up.*—Spreads inboard from tip T.E., first along T.E. and then inboard along front tufts from tip.	6C
							Slots closed, flaps down. Very slight.	*Slots closed, flaps down.*—Similar to flaps up. Pitching starts after wing drops.	*Slots closed, flaps down.*—Similar to flaps up.	6C
							Slots free, flaps up.—Slow lateral and slight pitching oscillation.	*Slots free, flaps up.*—Slight pitching and slow lateral oscillation. No tendency to spiral or spin. Aileron control good and glides easy even with stick hard back.	*Slots free, flaps up.*—Apart from rear outboard tufts, no sign of deep turbulence elsewhere, even with stick hard back.	2B
							Slots free, flaps down. Slow lateral oscillation.	*Slots free, flaps down.*—Strong pitching oscillation; wing drops slightly followed by irregular spiral.	*Slots free, flaps down.*—Similar to flaps up.	2A
5	Low Wing. Taper $\left[\frac{\text{Root chord}}{\text{Tip chord}}\right] = 4\cdot5:1$ Sweepback $= 2°$ Dihedral $= 4\cdot5°$ $w = 12\cdot85$ lb./sq. ft.	—	Split $0\cdot15\bar{c} \times 0\cdot58b$	$11\frac{1}{4}°$ $0\cdot39$ $\pm28°$ $0\cdot15$	C.Y.H. $t/c = 0\cdot18$	NACA 4415	*Flaps up.*—Slight lateral oscillation.	*Flaps up.*—Nose drops a little; some mild lateral instability and gentle falling leaf; build up slowly. Stalled glides, stick hard back, can be maintained by coarse use of the controls.	*Flaps up.*—Spreads slowly outwards from root along T.E. Only rear tufts out to two thirds along span affected at stall. Tip tufts become affected only if falling leaf allowed to become violent.	2C
							Flaps down.—Slightly lateral and pitching oscillation.	*Flaps down.*—Mild lateral instability on which is superimposed a fairly violent pitching oscillation.	*Flaps down.*—Similar to flaps up but modified by pitching.	

TABLE 1—*contd.*

TABLE 1B. Falcon [High-taper]—*contd.*

Ref. No.	Description, etc.	Slots	Flaps	Tail plane position and volume, elevator range and volume	Wing Sections		Stall Warning	Behaviour at and beyond stall	Spread of flow breakaway	Stall grade [*See* § 4]
					Root	Tip				
Not Yet published	Low Wing. Taper $\left[\frac{\text{Root chord}}{\text{Tip chord}}\right]$ = 4·5:1 Sweepback = 2° Dihedral = 4·5° w = 12·85 lb./sq. ft.	—	Split $0\cdot15\bar{c}\times$ $0\cdot58b$	11¼° 0·39 ±28° 0·15	C.Y.H. $t/c = 0\cdot18$	Gött. 387 $t/c = 0\cdot15$	*Flaps up*.—None. *Flaps down*.—None.	*Flaps up, engine off*.—Initial increase in longitudinal stability and mild rolling oscillation. As stick comes back rolling oscillation increases and falling leaf of increasing violence begins. Controlled glides are possible. *Flaps up, engine on*.—Some tail buffeting at stall when a wing dropped gently. *Flaps down*.—Similar to flaps up except that pitching motion is superimposed.	*Flaps up, engine off*.—Starts at root and spreads slowly outwards along T.E. to two-thirds of span. As falling leaf becomes violent deep turbulence spreads over major part of wing. *Flaps down*.—Similar to flaps up.	3c 2c
TABLE 1C. Courier										
6 & 1	Low Wing. Taper = 2·7:1 Sweepback = 2° Dihedral = 4·5° w = 13·7 lb./sq. ft. A = 7·7:1	—	Slotted $0\cdot25\bar{c}\times$ $0\cdot275b$ Split $0\cdot13\bar{c}\times$ $0\cdot22b$ Slotted Ailerons (23°) $0\cdot2\bar{c}\times$ $0\cdot435b$	+11½° 0·42 ±23° 0·19	NACA 2219	NACA 2212	(1) *Flaps and ailerons up*.—Slight vibration. (2) *Flaps and ailerons down*.—Slight tail buffeting. (3) *Slotted flaps and ailerons down, split flaps up*.—Slight tail buffeting. (4) *All flaps down, ailerons up*.—Slight vibration.	(1) *Flaps and ailerons up*.—Wing drops fairly slowly. Stalled glides possible. (2) *Flaps and ailerons down*.—Wing drops very sharply at stall; stalled glides impossible. (3) *Slotted flaps and ailerons down, split flaps up*.—Wing dropping milder than with all flaps and ailerons down, but stalled glides impossible. (4) *All flaps down, ailerons up*.—Similar to case (3) above.	(1) *Flaps and ailerons up*.—Spreads slowly along T.E. from root and returns quickly along front half of wing as wing drops. (2) *Flaps and ailerons down*.—Spreads inwards from T.E. near wing tip fairly quickly and forwards as wing drops. (3) Not recorded. (4) Not recorded.	5c 6c 5c 5c
TABLE 1D. Master										
7 & unpublished data	Low Wing. Taper = 1·8:1 Sweepback = 0° Dihedral = 6° w = 21lb./ sq. ft. A = 6:1	—	Split $0\cdot13\bar{c}\times$ $0\cdot51b$	+9½° 0·415 0·135	NACA 23024	NACA 23008	*Flaps up*.—None. *Flaps down*.—None.	*Flaps up*.—Either nose or wing or both drop fairly sharply but not violently. Stalled glides have been known but are very difficult. *Flaps down*.—Wing and nose drop quite sharply to a steep angle.	*Flaps up*.—Not observed. *Flaps down*.—Not observed.	5c 6c

TABLE 1—*contd.*

TABLE 1D. Master—*contd.*

Ref. No.	Description, etc.	Slots	Flaps	Tail plane position and volume, elevator range and volume	Wing Sections		Stall Warning	Behaviour at and beyond stall	Spread of flow breakaway	Stall grade [*see* § 4]
					Root	Tip				
	With modified wing tips.		Split $0{\cdot}13\bar{c}\times$ $0{\cdot}51b$	$+9\frac{1}{2}°$ $0{\cdot}415$ $0{\cdot}135$	NACA 23024	NACA 2415	*Flaps up.*—Mild pitching oscillation.	*Flaps up, engine off.*—An initial stall in which nose pitches mildly and wing rolls slowly through a few degrees. No further wing dropping as stick comes right back; stalled glides easy.	*Flaps up, engine off.*—Spread from root section along T.E. to two thirds span. Forward spread of turbulence remained largely confined to root section. No separation at tip.	2B
								Flaps up, ⅓ throttle.—Initial stall similar to case with engine off. Beyond initial stall there was some pitching and eventually a wing dropped about 40° followed by nose into dive.	*Flaps up ⅓ throttle.*—Up to final stall turbulence pattern was similar to case with engine off; at second stall turbulence spread quickly over rest of wing.	4B
	With modified wings.		Split $0{\cdot}13\bar{c}\times$ $0{\cdot}51b$	$+9\frac{1}{2}°$ $0{\cdot}415$ $0{\cdot}135$	NACA 2415	NACA 2415	*Flaps up, engine off.*—None prior to initial stall.	*Flaps up, engine off.*—Initial stall in which nose pitched 50°. A wing dropped mildly about 30°, pitching then set in but disappeared as stick came back, stalled glides with stick hard back possible with full use of controls.	*Flaps up, engine off.*—Spread from root trailing edge forwards and outwards but never extended much beyond inner half of wing or over leading edge.	3C
							Flaps up, engine on ⅓.—Mild oscillation.	*Flaps up, ⅓ throttle.*—Initial stall similar to engine off. Eventually a wing dropped suddenly 45° in main stall, but stalled glides were just possible.	*Flaps up, ⅓ throttle.*—Similar to engine off case but at main stall turbulence spread over most of remainder of wing.	3B
							Flaps down, engine off.—Slight oscillation.	*Flaps down, engine off.*—Very similar to flaps up, engine on. Stalled glides with stick hard back not possible.	*Flaps down, engine off.*—Very similar to flaps up, engine on, but initial root turbulence is more marked.	3C
							Flaps down, engine on ⅓.—Some wallowing and oscillation.	*Flaps down, ⅓ throttle.*—Mild initial wing drop; at main stall the wing drop is sharp and sudden. Stalled glides with stick hard back not possible.	*Flaps down, ⅓ throttle.*—Similar to flaps up, engine on.	4B
	With Lockheed type slits.	Similar to slits on the Hudson	Split $0{\cdot}13\bar{c}\times$ $0{\cdot}51b$	$+9\frac{1}{2}°$ $0{\cdot}415$ $0{\cdot}135$	NACA 23024	NACA 23008	*Flaps up.*—None.	*Flaps up.*—Very similar to behaviour with NACA 2415 tips both engine off and on.	*Flaps up.*—Not observed.	2C [engine off] 4C [engine on]
							Flaps down.—None.	*Flaps down.*—A sharp wing and nose drop which is made worse with engine on.	*Flaps down.*—Not observed.	6C

TABLE 1—*contd.*

TABLE 1E. Magister

Ref. No.	Description, etc.	Slots	Flaps	Tail plane position and volume, elevator range and volume	Wing Sections		Stall Warning	Behaviour at and beyond stall	Spread of flow breakaway	Stall grade [*See* § 4]
					Root	Tip				
8	Low Wing. Taper = 1·55:1 Sweepback = 0·6° Dihedral = 5° $w = 10{\cdot}2$ lb./sq. ft. $A = 6{\cdot}35$		Split $0{\cdot}14\bar{c}\times$ $0{\cdot}47b/_{2}$	$+9\tfrac{1}{4}^\circ$ $+0{\cdot}41^5$ $\left.\begin{array}{l}+23^\circ\\-32^\circ\end{array}\right\}$ $0{\cdot}15$	Clark 0·19	YH 0·10	*Flaps up.*—Slight warning given by steep attitude, 'feel' and vibration. *Flaps down.*—Some pitching oscillation.	*Flaps up.*—Wing drops fairly sharply to about 40°, then other wing flicks over into violent falling leaf. *Flaps down.*—Similar to flaps up but with a pitching motion superimposed and starting earlier than the wing drop.	*Flaps up.*—Spreads outwards and forwards from root T.E. very rapidly covering whole wing as wing flicks over the second time. *Flaps down.*—Similar to flaps up.	6B 4B
	With sharp edged wedges each 0·1b in span along inboard L.E.		Split $0{\cdot}14\bar{c}\times$ $0{\cdot}47b/_{2}$	$+9\tfrac{1}{4}^\circ$ $+0{\cdot}41^5$ $\left.\begin{array}{l}+23^\circ\\-32^\circ\end{array}\right\}$ $0{\cdot}15$	Clark 0·19	YH 0·10	*Flaps up.*—Slight lateral instability. Change of trim. *Flaps down.*—Similar to flaps up.	*Flaps up.*—Nose pitched down and wing dropped into pitching falling leaf or spiral. Stalled glides with stick hard back were possible. *Flaps down.*—Similar to flaps up but lateral instability was worse. Stalled glides with stick hard back were possible.	*Flaps up.*—Turbulence spread fairly completely over the root before spreading outwards over wing as wing dropped. *Flaps down.*—Similar to flaps up.	3B 3B
	Rounded fairings over outboard leading edge in addition to above wedges.		Split $0{\cdot}14\bar{c}\times$ $0{\cdot}47b/_{2}$	$+9\tfrac{1}{4}^\circ$ $+0{\cdot}41^5$ $\left.\begin{array}{l}+23^\circ\\-32^\circ\end{array}\right\}$ $0{\cdot}15$	Clark 0·19	YH 0·10	*Flaps up.*—Similar to above. *Flaps down.*—Similar to above.	*Flaps up.*—Nose pitched down initially but wings kept fairly level even with the stick hard back. *Flaps down.*—Lateral stability worse than with flaps up but still mild and otherwise similar with a pitching motion superimposed. Stalled glides with stick hard back fairly easy.	*Flaps up.*—Spread fairly completely over the root but did not spread much outboard of root. *Flaps down.*—Similar to flaps up.	2B 3B

TABLE 1F. Tipsy

9	Low Wing. Taper = 2·66:1 Sweepback = 0° Dihedral = 6° Washout = 6·5° $w = 8$ lb./sq. ft. $A = 6{\cdot}7{:}1$	Fixed Lockheed type Net span =0·1b	Split $0{\cdot}1\bar{c}\times$ $0{\cdot}17b$	$+11\tfrac{3}{4}^\circ$ $0{\cdot}38$ $\left.\begin{array}{l}+24^\circ\\-15^\circ\end{array}\right\}$ $0{\cdot}12^5$	RAF 0·16	28 0·08	*Slits sealed, flaps up or down.*—Slight vibration and longitudinal oscillation. *Slits open, flaps up or down.*—Slight vibration and longitudinal vibration	*Slits sealed flaps up or down.*—Wing drops fairly quickly followed by nose into steep spiral. Stalled glides with stick hard back are possible. *Slits open, flaps up or down.*—Fairly mild wing drop followed by nose into steep spiral. Stalled glides with stick hard back impossible.	*Slits sealed, flaps up or down.*—Front separation at tip spreading inwards. *Slits open, flaps up or down.*—Separation started at T.E. near tip and spread inwards.	5B 5B

TABLE 1—*contd.*

TABLE 1G Skua [Prototype]

Ref. No.	Description, etc.	Slots	Flaps	Tail plane position and volume, elevator range and volume	Wing Sections		Stall Warning	Behaviour at and beyond stall	Spread of flow breakaway	Stall grade [*see* § 4]
					Root	Tip				
10	Low Wing. Taper = 1·8:1 Sweepback = 0° w = 22·6 lb/sq. ft.		Split 0·15$\bar{c}$ × 0·35b	$+8\frac{1}{2}$° 0·48	NACA 2416^5	NACA 2411^5	*Flaps up.*—None.	*Flaps up.*—Strong self-stalling tendency prior to initial stall. Wing and nose drop a few degrees and as stick comes back, a wing and nose flick over fairly sharply about 60°.	*Flaps up.*—Spreads over root when first stall occurs and then along T.E. and forward over tip as second stall occurs.	4c
							Flaps down.—None.	*Flaps down.*—Similar to but more violent than with flaps up.	*Flaps down.*—Similar to flaps up.	4c
	With pointed fairings each 0·145$b/_2$ in span along root L.E.		Split 0·15c × 0·35b	$+8\frac{1}{2}$° 0·48	NACA 2416^5	NACA 2411^5	*Flaps up.*—Increasing nose heaviness. Slight pitching and vibration.	*Flaps up.*—Wing drops into fairly gentle falling leaf. Self-stalling tendency largely eliminated.	*Flaps up.*—Similar to standard case but forward spread of root turbulence is earlier and more gradual.	5B
							Flaps down.—None.	*Flaps down.*—Similar to behaviour without pointed fairings.	*Flaps down.*—Similar to behaviour without fairings.	4c

TABLE 1H. Battle

Ref. No.	Description, etc.	Slots	Flaps	Tail plane position and volume, elevator range and volume	Root	Tip	Stall Warning	Behaviour at and beyond stall	Spread of flow breakaway	Stall grade [*see* § 4]
11	Low Wing. Taper = 2·3:1 Sweepback = 1° Dihedral = 2·5° Wing Twist = 3·5° w = 20·5 lb/sq. ft. A = 6·48:1		Split 0·29$\bar{c}$ × 0·45b [47°]	+8° 0·49 ±24·5° 0·22	NACA 2418	N.A.C.A. 2409	*Flaps up.*—Very slight vibration.	*Flaps up.*—One wing drops slowly a few degrees in initial stall and then pitching begins; as stick is pulled further back a fairly sharp wing drop into a falling leaf results.	*Flaps up.*—Turbulence does not extend much beyond centre section during initial stall, but spreads rapidly over most of wing at final stall.	3c
							Flaps down.—Vibration less marked than with flaps up.	*Flaps down.*—Similar to flaps up.	*Flaps down.*—Similar to flaps up.	3c

TABLE 1K. Spitfire [Prototype]

Ref. No.	Description, etc.	Slots	Flaps	Tail plane position and volume, elevator range and volume	Root	Tip	Stall Warning	Behaviour at and beyond stall	Spread of flow breakaway	Stall grade [*see* § 4]
12 and unpublished data	Low Wing. Elliptic plan form Sweepback = 0° Dihedral = 6° w = 21·5 lb/sq. ft. A = 5·67:1		Split [57°] 0·15¯ × 0·445b	$+11\frac{1}{2}$° 0·375 ±28° 0·15	NACA 2213	NACA 2205	*Flaps up.*—None.	*Flaps up.*—The nose and wing drop slightly in initial stall, with stick further back the wing drops slowly to 45° stalled glides are easy, ailerons remaining effective after stall.	*Flaps up.*—Appears first over root T.E. for initial stall, then appears at tip but not over rest of wing until the wing drops, with engine on, 'deep' turbulence appears first at tip.	3c
							Flaps down.—None.	*Flaps down.*—Similar to flaps up, except that wing drops more quickly and general vibration is more marked.	*Flaps down.*—Similar to flaps up.	3c

TABLE 2

Summary of Detailed Stalling Tests. Twin-engined Aeroplanes

TABLE 2A. Blenheim

Ref. No.	Description, etc.	Slots	Flaps	Tail plane position and volume, elevator range and volume	Wing Sections		Stall Warning	Behaviour at and beyond stall	Spread of flow breakaway	Stall grade [*see* § 4]
					Root	Tip				
13, 14	Mid-wing Taper = 2·8:1 ~~Sweepback = 25°~~ Dihedral = 6·5° w = 24·1 lb./sq. ft. A = 6·71:1		Split (58°) $0\cdot2\bar{c}\times$ $0\cdot54b$	+6½° 0·466 +24° / −37·5° 0·186	RAF 0·18	28 $0\cdot10^5$	*Flaps up, gills closed.*—Slight pitching considerable vibration change in trim.	*Flaps up, gills closed.*—A wing drops suddenly followed by the nose with a tendency to spin.	*Flaps up, gills closed.*—Appears at root T.E. and spreads forwards and outwards, spreading rapidly as wing drops.	6B
							Flaps up, gills open.—General unsteadiness is more marked.	*Flaps up, gills open.*—Aeroplane is brought to the stall with greater difficulty than with gills closed and wing dropping is milder. Stalled glides with stick hard back are possible.	*Flaps up, gills open.*—Outward spread is slow, 'deep' turbulence remains largely confined to root section and behind nacelles.	3A
							Flaps up, ⅓ throttle.—Warning is much less marked than with engine off, gills open or closed.	*Flaps up, ⅓ throttle.*—Similar to behaviour engine off, but wing dropping is more violent.	*Flaps up, ⅓ throttle.*—With gills closed, the root section remains only partially stalled and the turbulence spreads rapidly over outer wings. With gills open, the turbulence again spreads over root and then outwards.	6C [Gills closed] 6B [Gills open]
							Flaps down, gills closed.—Increasing pitching.	*Flaps down, Gills closed.*—Pitching oscillation buildsup, but any wing drop is very mild.	*Flaps down, gills closed.*—Spreads over root and remains largely confined to inner parts of wing.	2B
							Flaps down, gills open.—Warning is more marked.	*Flaps down, gills open.*—Similar to behaviour with gills closed.	*Flaps down, gills open.*—Similar to behaviour with gills closed.	2A
							Flaps down, gills closed, ⅓ throttle.—Warning largely suppressed.	*Flaps down, gills closed, ⅓ throttle.*—Wing drops violently and suddenly.	*Flaps down, gills closed, ⅓ throttle.*—Not observed.	6C
							Flaps down, gills open, ⅓ throttle.—More marked than with gills closed.	*Flaps down, gills open, ⅓ throttle.*—Wing drops very gently.	*Flaps down, gills open, ⅓ throttle.*—Not observed.	5B

TABLE 2—*contd.*

TABLE 2B. Monospar

Ref. No.	Description, etc.	Slots	Flaps	Tail plane position and volume, elevator range and volume	Wing Sections Root	Wing Sections Tip	Stall Warning	Behaviour at and beyond stall	Spread of flow breakaway	Stall grade [*see* § 4]
Not yet issued	Low Wing. Taper = 3·35:1 Sweepback = −1° Washout = 1·8° Dihedral = 9° $A = 7 \cdot 28:1$ $w = 12 \cdot 0$ lb/sq. ft. [Upper spar member runs above wing surface over centre section]			? 0·495 +20·5° } −33·0° } 0·188	Stieger series, $3\frac{1}{2}$% camber with some reflex. 0·18 [This is the thickness just outside the nacelle]	0·16	*Engines off.*—Slight vibration and lateral instability. $\frac{1}{4}$ *throttle.*—Same as throttles closed.	*Engines off.*—Wing and nose fall very gently together into spiral. Stalled glides with stick hard back were easy. $\frac{1}{4}$ *throttle.*—Same as throttles closed.	*Engines off.*—Spreads slowly forwards and outwards, from the root reaching the tip as the wing dropped. $\frac{1}{4}$ *throttle.*—Same as throttle closed.	5B 5B

TABLE 2C. Hudson

15	Mid-Wing. Taper = 4·3:1 Sweepback = 2·0° Dihedral = $6\frac{1}{4}$° $A = 6 \cdot 8:1$ $w = 32 \cdot 3$ lb/sq. ft.	Built-in slits Net span =0·2b	Fowler (35°) $0 \cdot 35\bar{c} \times 0 \cdot 5b$	$+10\frac{1}{4}$° 0·69 +15° } −35° } 0·298	NACA 23018	NACA 23009	*Slits sealed, flaps up.*—None.	*Slits sealed, flaps up.*—Wing dropped sharply followed by nose, could not be arrested.	No observations.	6C
							Slits sealed, flaps down.—Slight reduction in control effectiveness.	*Slits sealed, flaps down.*—Wing dropped sharply, could not be arrested.		6C
							Slits sealed, flaps down, throttle open.—None.	*Slits sealed, flaps down, throttle open.*—Wing drop is more vicious than with throttle closed.		6C
							Slits open, flaps up—Slight snatching of ailerons.	*Slits open, flaps up.*—Wing drop can be arrested at first, but as stick comes back the wing drops rapidly.		5B
							Slits open, flaps down.—Similar to warning with slits sealed.	*Slits open, flaps down.*—Violent pitching oscillation and some instability, but stalled glides are possible even with the stick hard back.		3C
							Slits open, flaps down throttle open.—Slight.	*Slits open, flaps down, throttle open.*—A wing drops, but less violently than with slits sealed.		5C

TABLE 2—*contd.*

TABLE 2D. Hampden

Ref. No.	Description, etc.	Slots	Flaps	Tail plane position and volume, elevator range and volume	Wing Sections		Stall Warning	Behaviour at and beyond stall	Spread of flow breakaway	Stall grade [*See* § 4]
					Root	Tip				
16	Mid-wing. Taper = 3·69:1 Sweepback = 2·3° Dihedral = 6·5° w = 9·1 lb/sq. ft. A = 6·58:1	Automatic HP Type Net span = 0·47b	Slotted HP Type 0·29$\bar{c}$ × 0·438b	5·1° 0·53 ±23° 0·194	NACA 2317	NACA 2311	*Flaps up, engines on or off.*—Slight with gills closed, but marked vibration with gills open.	*Flaps up.*—The nose pitched gently and the aeroplane went into a right hand spiral as the stick came back with 'engines on,' there was a pitching motion superimposed. Stalled glides with stick hard back were easy.	*Flaps up, engines on or off.*—Spreads slowly from just outboard of nacelles forwards and inwards, no sign of turbulence behind the slots.	2C [Gills closed] 2A [Gills open]
							Flaps down.—Moderate vibration with gills closed, marked vibration with gills open.	*Flaps down.*—Various flap and engine combinations were tried and in every case but one, behaviour was similar to flaps up case.	*Flaps down.*—Except for case of flaps down 20°, ⅔ throttle, turbulence spread was similar to flaps up case.	2B [Gills closed] 2A [Gills open]
								Flaps down 20°, throttle open ⅔.—After some vibration wing dropped fairly gently to 45°, followed by nose into dive.	*Flaps down 20°, throttle open ⅔.*—Spreads forwards and outwards from just outboard of nacelle, covering wing as it dropped.	3B [Gills closed] 3A [Gills open]
unpublished data	With Slots sealed. (These tests were not very comprehensive).						*Flaps up.*—Slight deterioration in aileron control.	*Flaps up.*—Behaviour is much the same as with the slots open.	No observations with slots sealed.	2C
							Flaps up, ½ throttle.—Slight.	*Flaps up, ½ throttle.*—Nose and wing drop mildly a few degrees, as stick comes back aircraft tends to wallow.		2C
							Flaps down.—Some change in trim.	*Flaps down.*—Behaviour is much the same as with the slots open.		2C

TABLE 2E. Hereford

Ref. No.	Description, etc.	Slots	Flaps	Tail plane position and volume, elevator range and volume	Root	Tip	Stall Warning	Behaviour at and beyond stall	Spread of flow breakaway	Stall grade
unpublished data	This aeroplane is the same as the Hampden except that it is powered with Dagger and not Pegasus engines. There are oil cooling ducts in the L.E. of the root section.	Same as Hampden (*see* Table 2D). Slots open					*Flaps up.*—Early tail buffeting, pitching and wallowing.	*Flaps up.*—Behaviour is similar to that of Hampden, with stick hard back there is a mild root stall and no tendency for wing to drop.	*Flaps up.*—Starts fairly early at root and spreads slowly forwards and outwards but never gets beyond unslotted parts of wings.	2A
							Flaps up, ⅓ throttle.—Same as with throttle closed.	*Flaps up, ⅓ throttle.*—Pitching and wallowing become more marked at and after stall. At top of pitch a wing may drop gently and rise again.	*Flaps up, ⅓ throttle.*—Much the same as with throttle closed.	2A

TABLE 2—*contd.*

TABLE 2E. Hereford—*contd.*

Ref. No.	Description, etc.	Slots	Flaps	Tail plane position and volume, elevator range and volume	Wing Sections		Stall Warning	Behaviour at and beyond stall	Spread of flow breakaway	Stall grade [*see* § 4]
					Root	Tip				
	Slots open.						*Flaps down, throttle closed or $\frac{1}{3}$ open.*—Mild vibration decreased by throttle being opened.	*Flaps down, throttle closed or $\frac{1}{3}$ open.*—Nose pitches 10°–15° at stall, and then aircraft continues to pitch but remains on even keel as stick comes back	*Flaps down, throttle closed or $\frac{1}{3}$ open.*—Much the same as with flaps up.	2A [throttle closed] 2B [throttle open]
	With Slots sealed.						*Flaps up, throttle closed.*—Same as with slots open.	*Flaps up, throttle closed.*—Same as with slots open.	*Flaps up, throttle closed.*—Same as with slots open.	2A
							Flaps up, throttle $\frac{1}{3}$.—Slight vibration and pitching oscillation.	*Flaps up, throttle $\frac{1}{3}$.*—Pitching and wallowing increased and one wing dropped fairly quickly to 35°, aileron control disappearing, wing came up as speed increased; but a sharper wing drop resulted if stick was pulled further back.	*Flaps up, throttle $\frac{1}{3}$.*—Turbulence spread slowly forwards and outwards from root and extended over outer parts of wing as it dropped.	3B
							Flaps down, throttle closed.—Slight pitching.	*Flaps down, throttle closed.*—Pitching and wallowing increase and wing may drop gently from top of pitch into spiral, lateral control disappearing till speed rises.	*Flaps down, throttle closed.*—Spreads slowly forwards and outwards but only occasionally extends beyond inner parts of wing when it drops from top of pitch.	2B
							Flaps down, throttle $\frac{1}{3}$.—Slight.	*Flaps down, throttle $\frac{1}{3}$.*—Mild but sudden wing drop. Controlled glides with the stick hard back are possible but a wing is liable to drop from the glide.	*Flaps down, throttle $\frac{1}{3}$.*—Starts at T.E. about two-thirds out along wing span and spreads inwards joining up with root turbulence as wing drops.	5C

TABLE 2F. Beaufort

Ref. No.	Description, etc.	Slots	Flaps	Tail plane position and volume, elevator range and volume	Wing Sections Root	Wing Sections Tip	Stall Warning	Behaviour at and beyond stall	Spread of flow breakaway	Stall grade
53	Mid-wing. Taper = 2·1:1 Sweepback = 1° Dihedral 0° (inner) 6·5° (outer) $w = 32\cdot5$ lb/sq. ft. $A = 6\cdot72:1$	—	Split $0\cdot23\bar{c}\times$ $0\cdot57b$	4½° 0·485 +23° −33° 0·194	RAF 0·18	28 0·10	*Flaps up, gills closed.*—Oscillations in roll and pitch.	*Flaps up, gills closed.*—Oscillations increase and there is considerable wallowing; no wing drop occured even with the stick hard back.	*Flaps up, gills closed.*—There was a region of pronounced breakaway well above the stall just behind the nacelles. This covers the root and then spreads slowly outwards to cover about $\frac{2}{3}$ of the wing.	1A
							Flaps up, gills open.—Marked vibration.	*Flaps up, gills open.*—Similar to behaviour with gills closed.	*Flaps up, gills open.*—Similar to behaviour with gills closed.	1A

TABLE 2—*contd.*

TABLE 2F. Beaufort—*contd.*

Ref. No.	Description, etc.	Slots	Flaps	Tail plane position and volume, elevator range and volume	Wing Sections		Stall Warning	Behaviour at and beyond stall	Spread of flow breakaway	Stall grade [*see* § 4]
					Root	Tip				
							Flaps down, gills closed.—As with flaps up.	*Flaps down, gills closed.*—Oscillations increase with marked pitching of the nose. Occasionally wing dropped during pitch. Unsteady stalled glides with stick hard back were possible.	*Flaps down, gills closed.*—Initial region of breakaway behind nacelles occurred at lower speed than with flaps up and was less intense. Breakaway spreads rather more rapidly over most of the wing.	3A
							Flaps down, gills open.—Similar to flaps up, gills open.	*Flaps down, gills open.*—Similar to behaviour with flaps up.	*Flaps down, gills open.*—Initial region more marked than with gills closed. Spread of breakaway similar to flaps up.	1A
							Flaps down, throttle $\frac{1}{3}$.—Oscillation in roll and pitch start at the stall.	*Flaps down, throttle* $\frac{1}{3}$.—Initial pitch (10°) of nose and then wing dropped 90° and would not be raised by the controls. Stick could not be eased back beyond stall position because of violent pitching.	*Flaps down, throttle* $\frac{1}{3}$.—Not observed.	4C

TABLE 3

Summary of Stalling Behaviour of Some Single-engined Aeroplanes as indicated by General-handling Tests

TABLE 3A. Lysander

Ref. No.	Description, etc.	Slots	Flaps	Tail position and volume elevator range and volume	Wing Sections		Stall Warning	Behaviour at and beyond stall	Stall grade [*See* § 4]
					Root (t/c)	Tip (t/c)			
17	High Wing. Taper (inner half) = 0·75:1 (outer half) = 4·1:1 Sweepback (inner half) = −8° (outer half) = −4° Dihedral = 2° $A = 9{\cdot}6{:}1$ $w = 22{\cdot}3$ lb/sq. ft.	Outer slots are automatic of span $= 0{\cdot}574b$ inner slots are coupled with flaps and of span $= 0{\cdot}349b$	Slotted (93°) $0{\cdot}28\bar{c} \times 0{\cdot}426b$	−7° 0·635 $\left.\begin{array}{l}+16{\cdot}5^\circ \\ -19^\circ\end{array}\right\}$ 0·355	RAF 34 (Mod.)		Warning given by steep attitude and low air-speed.	*Flaps up or down, engine off.*—It was impossible to stall the aeroplane (C.G. at $h = 0{\cdot}29\bar{c}$, permissible range in $h = 0{\cdot}23 - 0{\cdot}33\bar{c}$). *Flaps up or down, engine r.p.m.* >2500.—A wing and nose drop very gently at the stall; the wings can be held level by use of the controls.	1 2A

TABLE 3—*contd.*

TABLE 3B. Me. Taifun

Ref. No.	Description, etc.	Slots	Flaps	Tail position and volume elevator range and volume	Wing Sections		Stall Warning	Behaviour at and beyond stall	Stall grade [*See* § 4]
					Root (t/c)	Tip (t/c)			
18	Low Wing. Taper = 2·15:1 Sweepback = 2·5° Dihedral = 5·0° A = 6·65:1 w = 15·6 lb/sq. ft.	Automatic Tip slots Span = 0·515b	Slotted (43°) 0·272$\bar{c}$ × 0·435b	10° 0·495 +27° } −24° } 0·22			*Flaps up.*—Very slight vibration. *Flaps down.*—Same as with flaps up.	*Flaps up.*—Nose drops about 5°; stalled glide with stick hard back is very easy as rudder and ailerons remain effective. *Flaps down.*—Nose drops about 5° and aeroplane begins to pitch, as stick comes back a wing and nose slowly drop into spiral dive. Wing can be raised by rudder but not by ailerons.	2c 3c

TABLE 3C. Me 109

19	Low Wing. Taper = 2·00:1 Sweepback = 2·5° Dihedral = 5·75° A = 6·05:1 w = 32·1 lb/sq. ft.	Automatic Tip slots Span = 0·462b	Slotted (42°) 0·275$\bar{c}$ × 0·518b	16$\frac{3}{4}$° 0·454 +19° } −30·5° } 0·17	2% Camber Section with max. thickness at 0·3c 0·15	0·10^5	*Flaps up.*—Increasing lateral unsteadiness and aileron buffeting. *Flaps down.*—None.	*Flaps up.*—A wing drops gently through 10° in an initial stall, and aeroplane goes into gentle spiral; ailerons alone will then lift the wing, unsteadiness increases and vigorous use of controls is required to get to main stall when a wing drops and cannot be raised by controls. *Flaps down.*—A wing drops about 10° and nose follows into spiral; wing cannot be raised by the controls which are ineffective at the stall.	3A 5C

TABLE 3D. Hendy Heck

20	Low Wing. Taper = 2·5:1 A = 5·9:1 w = 16·2 lb/sq. ft.	Automatic tip slots Span = 0·5b	Slotted (36°) 0·27^5 $\bar{c}$ × 0·375b and slotted ailerons coming down 14$\frac{1}{2}$°	13° 0·42°	Probably NACA 23 series 0·15		*Slots free, flaps up.*—Buffeting. *Slots free, flaps down.*—None. *Slots locked, flaps up.*—None. *Slots locked, flaps down.*—Buffeting and pitching just prior to stall.	*Slots free, flaps up.*—A wing drops a few degrees in preliminary stall but is controllable. Buffeting then increases and at proper stall a wing drops viciously, usually into a spin. *Slots free, flaps down.*—Nose goes down several degrees in preliminary stall, pitching and buffeting gradually ceases as main stall which is vicious is approached. *Slots locked, flaps up.*—Wing drops very viciously into falling leaf. *Slots locked, flaps down.*—After initial drop of one wing, other wing flicks over very viciously, so that aeroplane is on its back and then into spin.	4A 4C 6C 6A

TABLE 3—*contd.*

TABLE 3E. Hurricane

Ref. No.	Description, etc.	Slots	Flaps	Tail position and volume elevator range and volume	Wing Sections		Stall Warning	Behaviour at and beyond stall	Stall grade [*See* § 4]
					Root (t/c)	Tip (t/c)			
21 and unpublished data	Low Wing. Taper = 2·0:1 Sweepback = −1·7° A = 6·2 w = 22·4 lb/sq. ft.	—	Split $0{\cdot}2\bar{c}\times$ $0{\cdot}5b$	+9° 0·371 $\left.\begin{array}{l}+24\tfrac{1}{2}^\circ\\-30\tfrac{1}{2}^\circ\end{array}\right\}$ 0·15	Clark Y.H. 0·19	0·12	*Flaps up.*—Pitching.	*Flaps up.*—Wing drops suddenly and cannot be checked by ailerons or rudder.	6A
							Flaps down.—Pitching and slight shaking.	*Flaps down.*—A wing drops suddenly, but using both ailerons and rudder a stalled glide with the stick hard back is possible.	6A
		Automatic tip slots Span = $0{\cdot}38b$					*Flaps up.*—Slight pitching.	*Flaps up.*—A wing drops slowly through 10° in preliminary stall and lateral oscillation begins ; as stick comes back wing drops suddenly and cannot be raised. Coarse use of controls will maintain a stalled glide with stick hard back.	3B
							Flaps down.—None.	*Flaps down.*—A wing drops slowly a few degrees in preliminary stall, then a wing flicks over violently and nose follows, using both ailerons and rudder a stalled glide with stick hard back is only just possible.	4C
		Automatic tip slots Span = $0{\cdot}5b$	Split $0{\cdot}2\bar{c}\times$ $0{\cdot}5b$	+9° 0·371 $\left.\begin{array}{l}+24\tfrac{1}{2}^\circ\\-30\tfrac{1}{2}^\circ\end{array}\right\}$ 0·15	Clark Y.H. 0·19	0·12	*Flaps up.*—None.	*Flaps up.*—A wing and nose drop slowly a few degrees in preliminary stall ; then pitching and general oscillation set in but stalled glides with stick hard back are easy, there being no sign of violent wing dropping.	2B
							Flaps down.—Slight change of trim.	*Flaps down.*—There is a slight initial sink of the nose followed by a wing drop which is gentle but may be steep (50°), and then the nose drops to about (40°), the behaviour beyond this point was not examined.	

TABLE 3F. Gloster F.5/34

Ref. No.	Description, etc.	Slots	Flaps	Tail position and volume elevator range and volume	Root (t/c)	Tip (t/c)	Stall Warning	Behaviour at and beyond stall	Stall grade
22	Low Wing. Taper = 2:1 Sweepback = 0° A = 5·53:1 w = 18·7 lb/sq. ft.		Split (90°) $0{\cdot}17^{5}\bar{c}\times$ $0{\cdot}412b$	$+4\tfrac{1}{2}^\circ$ 0·412 $+25\tfrac{1}{2}^\circ$ -23° $0{\cdot}16^{5}$	NACA 2218	NACA 2209	*Flaps up.*—None.	*Flaps up.*—A wing drops suddenly, it can be kept up by use of ailerons but not by use of rudder alone.	5c
							Flaps down.—None.	*Flaps down.*—Behaviour is similar to that with flaps up but wing drops more quickly.	5c

TABLE 3G. Hotspur

Ref. No.	Description, etc.	Slots	Flaps	Tail position and volume elevator range and volume	Root (t/c)	Tip (t/c)	Stall Warning	Behaviour at and beyond stall	Stall grade
23	Low Wing. Taper = 1·78:1 Sweepback = 5·0° Dihedral = 3·5° A = 6·2:1 w = 24·9 lb/sq. ft.		Split (78°) $0{\cdot}18\bar{c}\times$ $0{\cdot}54b$	$10\tfrac{1}{2}^\circ$ 0·473 $\left.\begin{array}{l}+30^\circ\\-30^\circ\end{array}\right\}$ 0·17	0·20	0·12	*Flaps up.*—None.	*Flaps up.*—A wing drops slightly, following by the other wing and finally the first wing flicks over sharply followed by the nose.	4c
							Flaps down.—None.	*Flaps down.*—A wing drops sharply followed by the nose.	6c

TABLE 3—*contd.*

TABLE 3H. Curtiss

Ref. No.	Description, etc.	Slots	Flaps	Tail position and volume elevator range and volume	Wing Sections		Stall Warning	Behaviour at and beyond stall.	Stall grade [*See* § 4]
					Root (t/c)	Tip (t/c)			
24	Low Wing. Taper = 2·2:1 Sweepback = −2·0° Dihedral = 6° $A = 5·9$ $w = 22·5$ lb/sq. ft.		Split (50°) 0·3$\bar{c}$ × 0·53b	11½° 0·48 +19° } −30·5° } 0·197	NACA 2215	NACA 2209	*Flaps up.*—Slight buffeting. *Flaps down.*—The nose attitude is high.	*Flaps up.*—A wing and nose drop fairly suddenly and cannot be checked by the controls; there is a tendency to spin. *Flaps down.*—Behaviour is similar to that with flaps up, but the wing drop is more violent.	6B 6B

TABLE 3K. Fairey P.4/34

25	Low Wing. Taper = 2·18:1 Sweepback = 4° Dihedral = 4° Washout = 3½° $A = 5·9$ $w = 21·3$ lb/sq. ft.		Split (45°) 0·2$\bar{c}$ × 0·43b	8½° 0·45 +27° } −27° } 0·170	NACA 2418	NACA 2409	*Flaps up.*—Slight vibration. *Flaps down.*—Very slight vibration.	*Flaps up.*—Wing suddenly drops to about 50° with tendency to spin, rudder alone or rudder and ailerons will raise the wing after the stall. *Flaps down.*—A wing suddenly drops about 50° and a falling leaf develops. Full rudder will raise a wing after the stall.	5C 5C

TABLE 3L. Hawk Major

26	Low Wing. Taper = 1·56:1 Sweepback = 0° $A = 6·4:1$ $w = 11·5$ lb/sq. ft.		Split 0·14$\bar{c}$ × 0·425b	7¼° 0·56	Clark Y.H.		*Flaps up.*—Pitching oscillation. *Flaps down.*—Marked pitching oscillation.	*Flaps up.*—After some pitching a wing drops sharply and cannot be raised by the ailerons without inducing a spin. *Flaps down.*—Similar to behaviour with flaps up.	4B 4A

TABLE 4

Summary of Stalling Behaviour of some twin-engined aeroplanes as indicated by general handling tests

TABLE 4A. H.P.C. 26/31

Ref. No.	Description, etc.	Slots	Flaps	Tail position and volume elevator range and volume	Wing Sections		Stall Warning	Behaviour at and beyond stall.	Stall grade [*See* § 4]
					Root (t/c)	Tip (t/c)			
27 and 28	High Wing. Taper = $3{\cdot}78{:}1$ $A = 7{\cdot}2{:}1$ $w = 16{\cdot}0$	Automatic tip slots Span = $0{\cdot}52b$	Slotted $0{\cdot}2\bar{c}\times$ $0{\cdot}46b$	$0{\cdot}607$			*Flaps up.*—None. *Flaps down.*—Not noted.	*Flaps up.*—Aeroplane pitches gently and goes into spiral. *Flaps down.*—Nose and wing drop gently through small angle, pitching more severe than with flaps up.	2c 2

TABLE 4B. Anson

Ref. No.	Description, etc.	Slots	Flaps	Tail position and volume elevator range and volume	Root (t/c)	Tip (t/c)	Stall Warning	Behaviour at and beyond stall.	Stall grade
29	Low Wing. Taper = $1{\cdot}67{:}1$ Sweepback = 0° Dihedral = 4° $A = 6{\cdot}9$ $w = 15{\cdot}1$ lb/sq. ft.		Split $0{\cdot}19c\times$ $0{\cdot}372b$	$6\frac{1}{4}°$ $0{\cdot}63$ $\left.\begin{array}{l}+17°\\-29°\end{array}\right\}$ $0{\cdot}155$	NACA 2218	NACA 2209	*Flaps up.*—Slight oscillation in pitch. *Flaps down.*—Same as with flaps up.	*Flaps up.*—The right wing and nose drop slowly and gently; can be checked by aileron but not rudder. At this stall (probably preliminary) the stick is practically hard back. *Flaps down.*—Same as with flaps up.	5B 5B

TABLE 4C. Lockheed 12A

Ref. No.	Description, etc.	Slots	Flaps	Tail position and volume elevator range and volume	Root (t/c)	Tip (t/c)	Stall Warning	Behaviour at and beyond stall.	Stall grade
30	Low Wing. Taper = $2{\cdot}64{:}1$ Sweepback = 0° Dihedral = 6° $A = 6{\cdot}97{:}1$ $w = 22{\cdot}4$ lb/sq. ft.		Split $0{\cdot}32\bar{c}\times$ $0{\cdot}48b$	$10\frac{1}{4}°$ $0{\cdot}775$ $\left.\begin{array}{l}+24°\\-25{\cdot}3°\end{array}\right\}$ $0{\cdot}30$	Probably NACA 23016	NACA 23010	*Flaps up.*—None. *Flaps down.*—None.	*Flaps up.*—A wing drops suddenly to 45°, followed by the nose; the wing drop cannot be checked by the controls. *Flaps down.*—The wing drop is more violent than with flaps up and shows a tendency to enter a spin.	6c 6c

TABLE 5

Aerofoil	T/c	Camber (c/o Chord)	(p/q) Min. $C_L = 1 \cdot 0$	Ref. No.
NACA 6512	0·120	6·0	—1·06	46
NACA 4412	0·120	4·0	—1·30	46
C.72	0·117	4·0	—1·38	49
Gött 387	0·149	5·9	—1·44	49
Gött 398	0·138	4·9	—1·44	49
U.S.A. 27	0·111	5·6	—1·44	49
U.S.A. 35B	0·116	4·6	—1·49	49
Clark Y	0·117	3·9	—1·52	49
C.Y.H.	0·117	3·1	—1·82	49
Boeing 103A	0·104	3·2	—1·82	49
NACA 2415	0·15	2·0	—2·00	46
NACA 2412	0·12	2·0	—2·16	46
NACA 2212	0·12	2·0	—2·27	46
RAF 28	0·12	2·0	—2·58	51
NACA M.6	0·12	2·4	—2·75	46
NACA 2409	0·09	2·0	—2·75	46
NACA 23012	0·12	2·0	—2·83	50
NACA 0012	0·12	0	—3·79	46

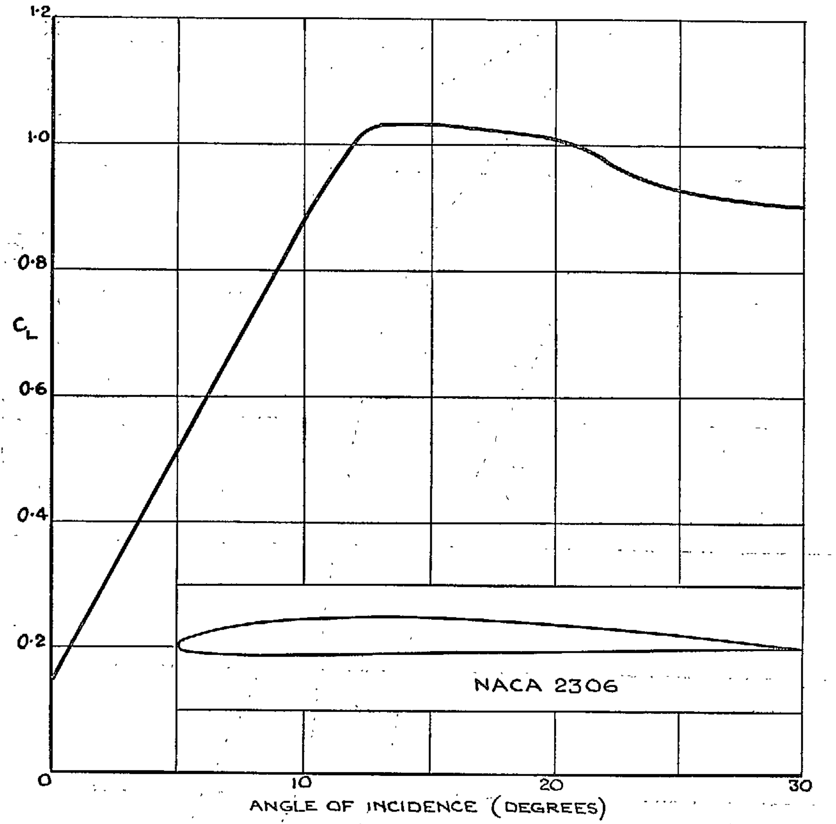

FIG. 1. Lift Curve of Aerofoil NACA 2306 as Measured in the V.D.T. at $R = 3 \times 10^6$

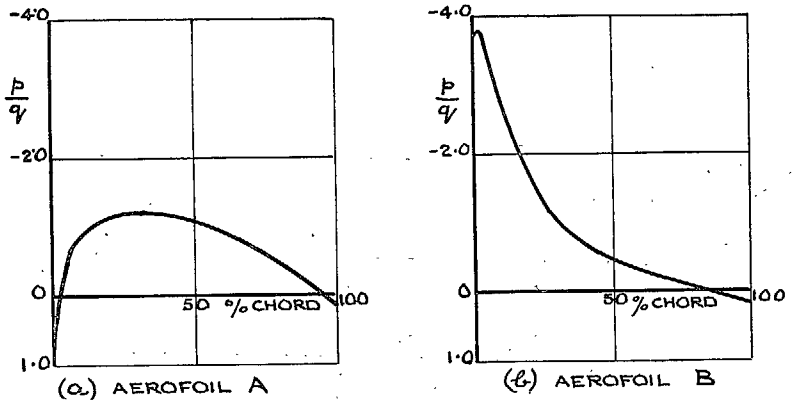

FIG. 2. Pressure Distribution on Upper Surface of Two Aerofoils near Stalling Incidence.

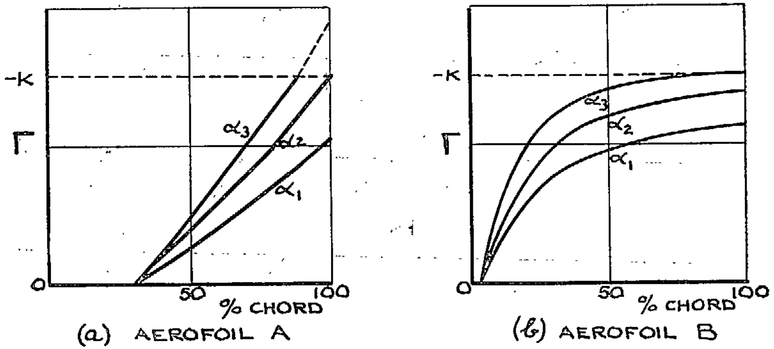

FIG. 3. Γ Distributions on Upper Surface of Two Aerofoils A and B near Stalling Incidence

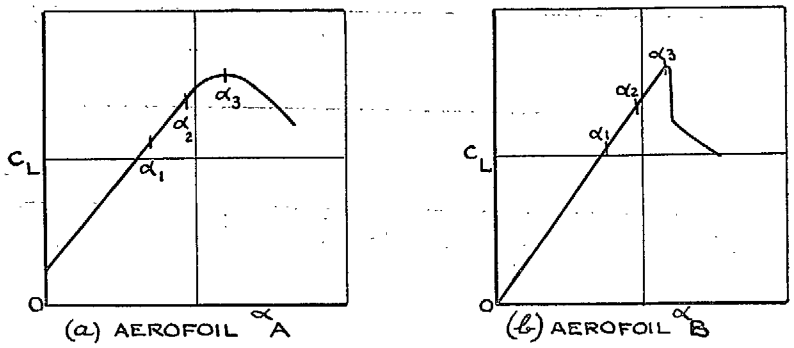

FIG. 4. Probable Lift Curves for Aerofoils A and B

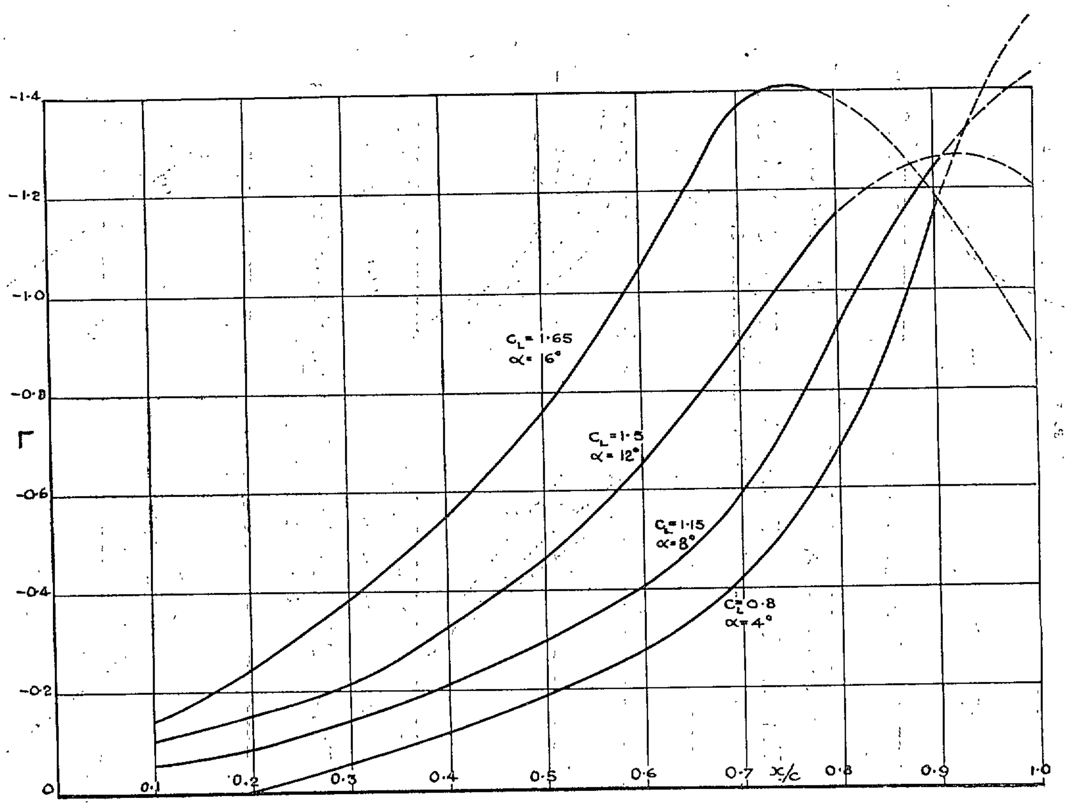

FIG. 5. Γ Distribution on Upper Surface of Section NACA 4412 at $R = 3 \times 10^6$
$C_{L\,\max} = 1\cdot65$ Arbitrary Scale for Γ

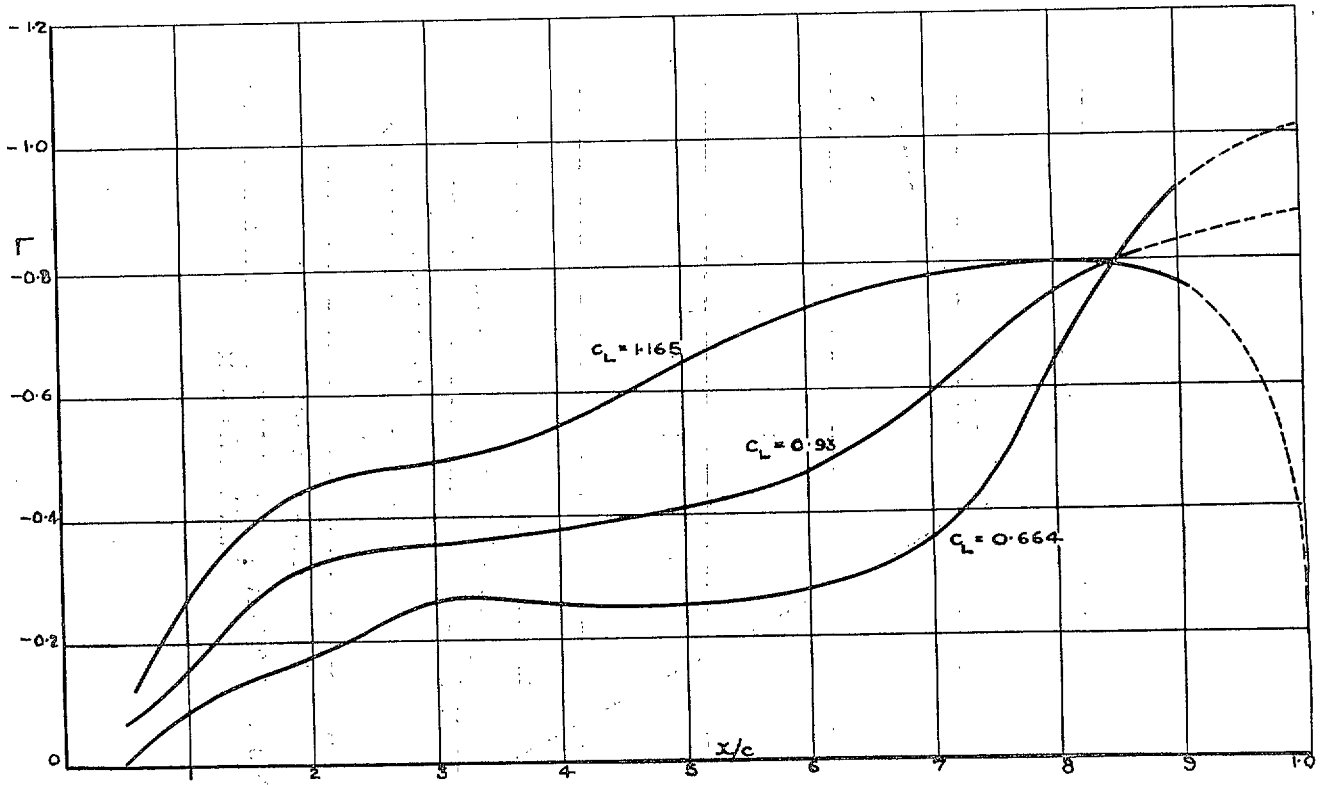

FIG. 6. Γ Distribution on Upper Surface of Section NACA 23012 at $R = 3 \times 10^6$
$C_{L\,\max} = 1\cdot55$ Arbitrary scale for Γ

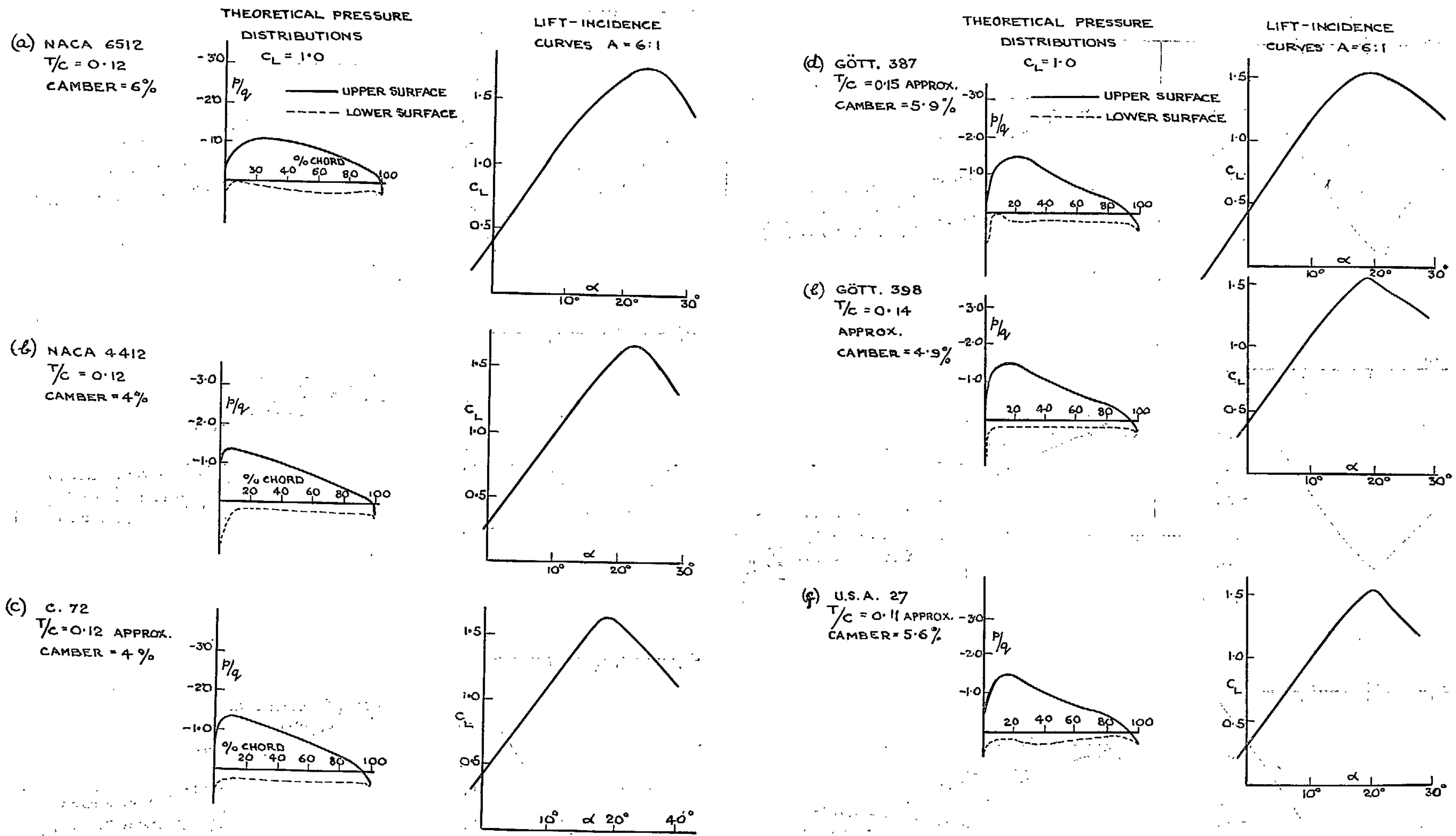

FIG. 7. Pressure Distributions ($C_L = 1 \cdot 0$) and Lift Curves of a Number of Aerofoils

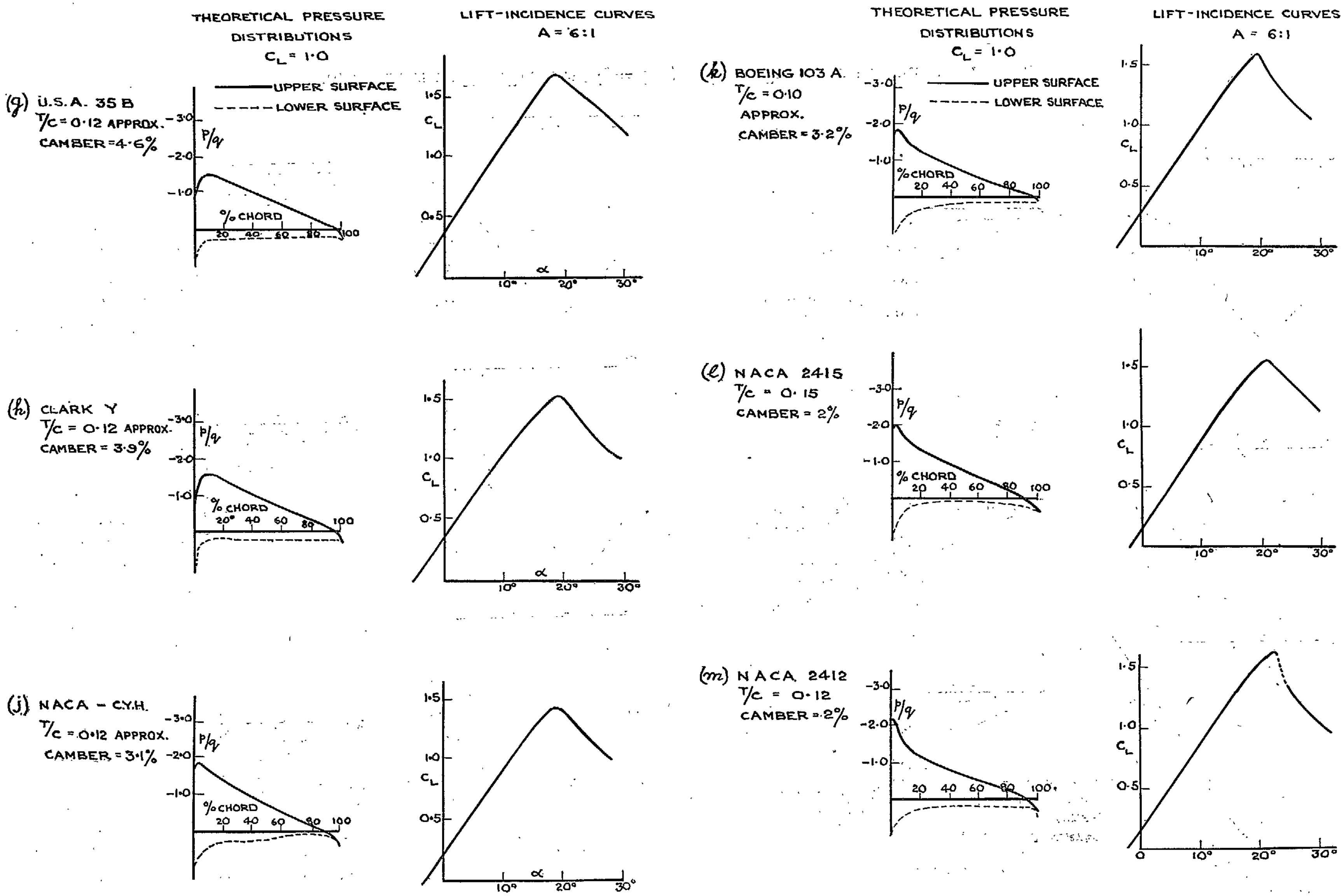
THEORETICAL PRESSURE DISTRIBUTIONS
C_L = 1·0
LIFT-INCIDENCE CURVES
A = 6:1
UPPER SURFACE
LOWER SURFACE
(g) U.S.A. 35 B
T/c = 0·12 APPROX.
CAMBER = 4·6%
(h) CLARK Y
T/c = 0·12 APPROX.
CAMBER = 3·9%
(j) NACA – C.Y.H.
T/c = 0·12 APPROX.
CAMBER = 3·1%
(k) BOEING 103 A.
T/c = 0·10
APPROX.
CAMBER = 3·2%
(l) NACA 2415
T/c = 0·15
CAMBER = 2%
(m) NACA 2412
T/c = 0·12
CAMBER = 2%
P/q
-3·0
-2·0
-1·0
% CHORD
20
40
60
80
100
C_L
0·5
1·0
1·5
α
0
10°
20°
30°

FIG. 7 (*contd.*)

(96557) Wt. 14/655 K.5 12/51 Hw.

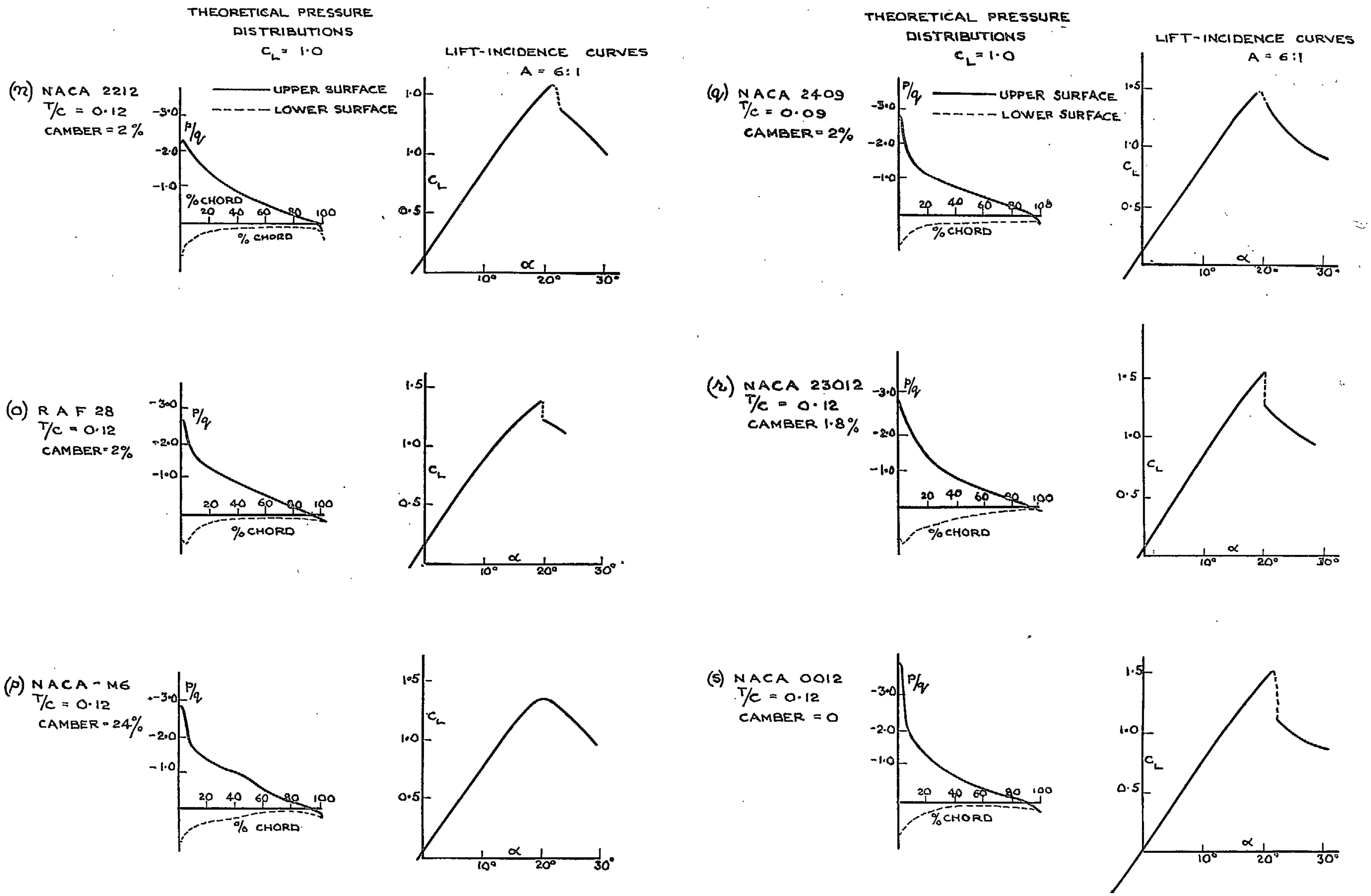

FIG. 7 (*contd.*)

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