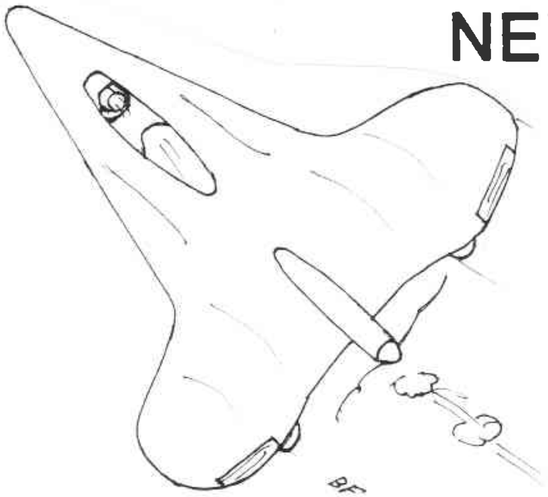
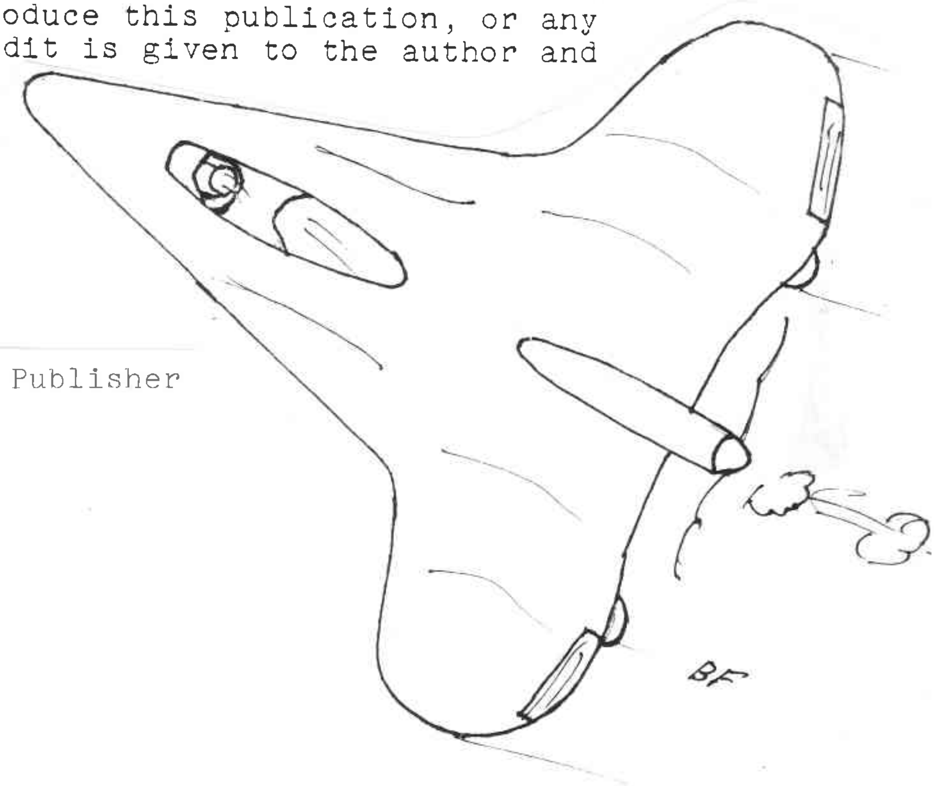
NO. 19, JANUARY 1988

TWITT
NEWSLETTER





TWITT
(The Wing Is The Thing)
PO Box 20430
El Cajon, CA 92021

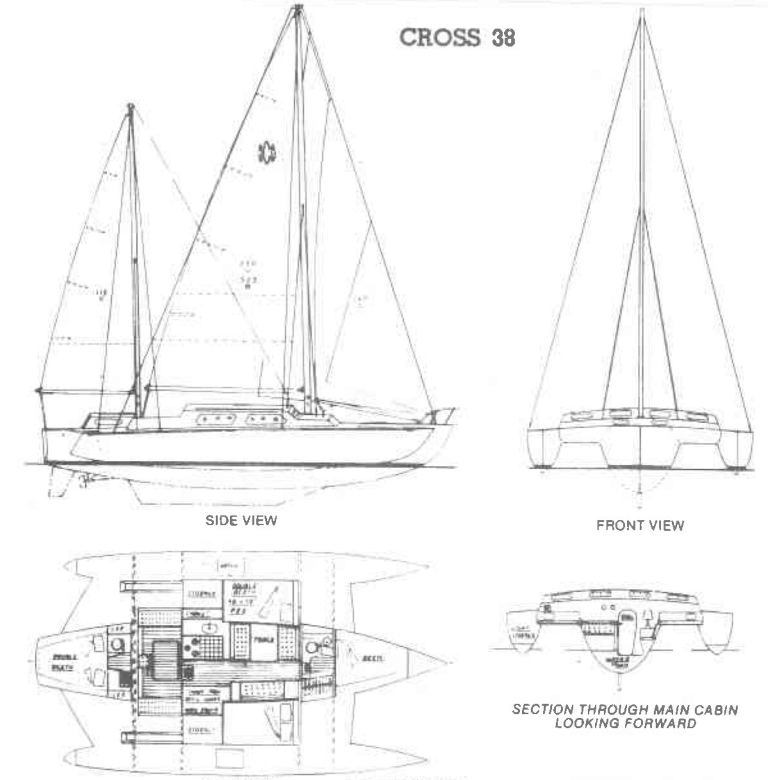
F. Marc de Piolenc, Editor and Publisher

Next Meeting: Saturday
16 January 1988 1330 hrs.
Hangar A-4, Gillispie Field

Telephone: (619) 224-1497 before 10 AM or after 10 PM

JANUARY MEETING

TWITT's January meeting will take place on the 16th at 1:30 pm at hangar A-4, Gillespie Field, El Cajon, CA. Our speaker will be Norm Cross. Mr. Cross is probably best known, even to inveterate TWITTs, for his work with multihull sailboats, which began in the mid-Fifties. He has 1300 boats either sailing or under construction worldwide. In 1980 the Crusader, a 55 ft racing trimaran of his design, set a new record in the Transpacific race. But despite Mr. Cross' celebrity in yachting circles, waterborne vehicles were not his first love. In 1939-40, while employed by Ford Motor Company in Detroit, he researched and attempted to patent a double-delta flying wing of his own design. Plans for a free-flight model, rubber powered, of 33" span, sold for a quarter each through Air Trails magazine. His interest in low aspect-ratio flying wings led him to Bill Stout, who referred him to a certain Lieutenant Colonel at Wright Field. The Army's Air Materiel Command never bought his design, but he learned a good deal about designing aircraft from the experience. A vacation trip in the early Fifties led to employment by Convair as a salaried engineer--the first employed by Convair who did not have a college degree in engineering. Mr. Cross stayed with Convair sixteen years, working successively in fuselage design, liaison, hydrodynamic design (including the R3Y flying boat project), and finally model design for the wind tunnel. His career as a yacht designer developed parallel to his career as an aeronautical engineer and began with his purchase of a 16 foot catamaran in 1954. Mr. Cross is an interesting speaker and his talk will be liberally illustrated with drawings, photographs and film of his work.

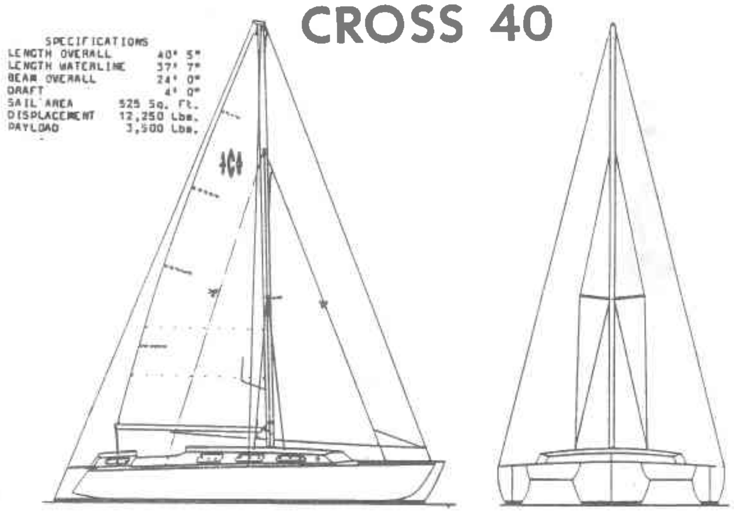


SPECIFICATIONS

Length Overall	38' 5"
Length Waterline	35' 4"
Beam	21' 0"
Draft	3' 8"
Sail Area	525 Sq. Ft.
Displacement	10,300 Lbs.
Auxiliary Power	15 - 25 h.p.
Berths	6 - 7
Headroom	6' 3"

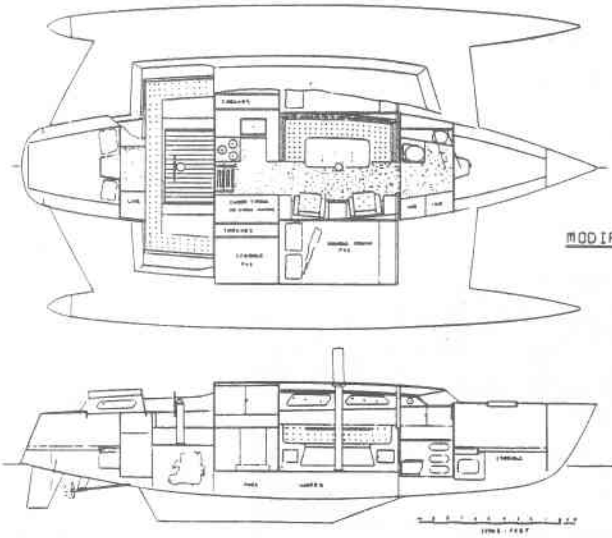
Hulls: Round bottom, double diagonal ply.
Hard Chine — Sheet Ply (optional)

NOTE: FULL SIZE PATTERNS FOR FRAMES AND STEMS (Round Bottom Only)



SPECIFICATIONS

LENGTH OVERALL	40' 5"
LENGTH WATERLINE	37' 7"
BEAM OVERALL	24' 0"
DRAFT	4' 0"
SAIL AREA	525 Sq. Ft.
DISPLACEMENT	12,250 Lbs.
PAYLOAD	3,500 Lbs.



MODIFIED CROSS 38

CROSS FLYING WING - 34" SPAN

DESIGNED BY NORMAN A CROSS

GENERAL INSTRUCTIONS

A - STUDY ALL DRAWINGS CAREFULLY BEFORE STARTING CONSTRUCTION. PARTS ARE NUMBERED ACCORDING TO ORDER OF ASSEMBLY.

B - MAKE ACCURATE (CARDBOARD) TEMPLATES FOR ALL PIECES TO BE CUT FROM SHEET BALSA. $\frac{3}{32}$ SHEET BALSA TO BE USED THROUGHOUT UNLESS OTHERWISE SPECIFIED. 3" WIDTHS PREFERABLE.

C - CONSTRUCT RIBS (2 EACH) AND SPARS (1 EACH) DIRECTLY ON DRAWINGS - USE STRIP SIZES SPECIFIED.

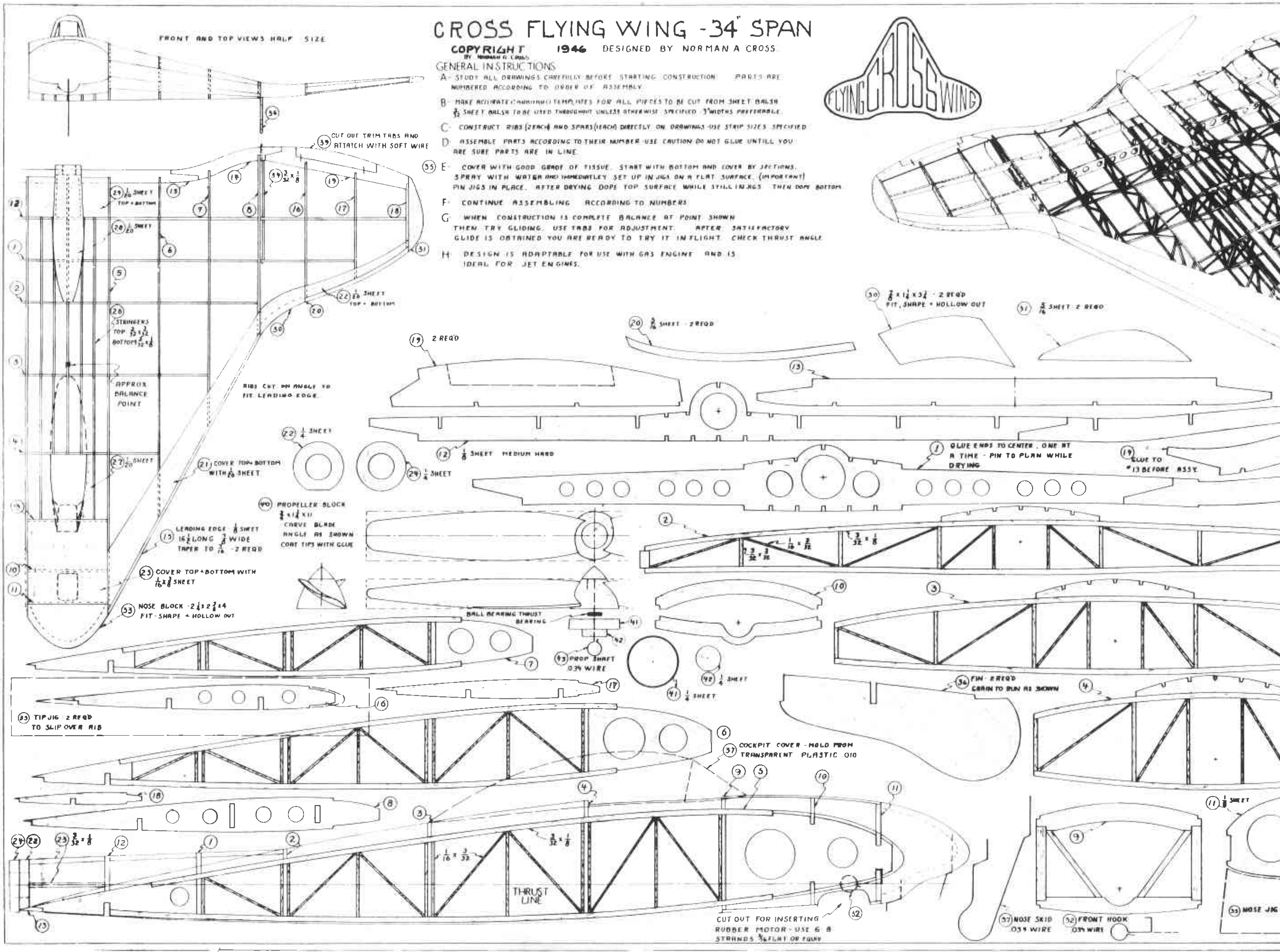
D - ASSEMBLE PARTS ACCORDING TO THEIR NUMBER - USE CAUTION - DO NOT GLUE UNTILL YOU ARE SURE PARTS ARE IN LINE.

(35) E - COVER WITH GOOD GRADE OF TISSUE. START WITH BOTTOM AND COVER BY SECTIONS. SPRAY WITH WATER AND IMMEDIATLEY SET UP IN JIGS ON A FLAT SURFACE. (IMPORTANT) PIN JIGS IN PLACE. AFTER DRYING DOPE TOP SURFACE WHILE STILL IN JIGS. THEN DOPE BOTTOM.

F - CONTINUE ASSEMBLING ACCORDING TO NUMBERS.

G - WHEN CONSTRUCTION IS COMPLETE BALANCE AT POINT SHOWN. THEN TRY GLIDING. USE TABS FOR ADJUSTMENT. AFTER SATISFACTORY GLIDE IS OBTAINED YOU ARE READY TO TRY IT IN FLIGHT. CHECK THRUST ANGLE.

H - DESIGN IS ADAPTABLE FOR USE WITH GAS ENGINE AND IS IDEAL FOR JET ENGINES.



flypaper THE JOURNAL OF FOLDED PAPER FLIGHT
P.O. Box 47186 / Wichita, Kansas 67201

11/13/87

T.W.I.T.T. ers;

Enclosed find the pre-publication "flyer" for the upcoming newsletter. I hope that some of you will want to gain your subscription by contributing clippings, articles or designs. At any rate, TWITT will receive a few "comp" issues.

I have enjoyed the dozen newsletters you sent. Though much of the aerodynamics is beyond me, they are still very interesting to this lay-person.

Bill Hannan kindly provided me with the name of the designer of the joined-wing configuration that I asked about earlier. Meanwhile, I came across a work in the WSU library that you might like to see.

PERFORMANCE ANALYSIS OF THE HORTEN IV FLYING WING
by Dezso Gyorgyfalvy - Pres. at the VIII Congress of O.S.T.I.V.
Koln - June, 1960. Aerophysics Dept., Miss. St. Univ.

The photocopy machines are only a nickel in this library, so making a copy is no problem. I seem to recall it was not more than 30 or 40 pages in length. If you would like it for the TWITT library, let me know; I would gladly provide this for a newsletter or two.

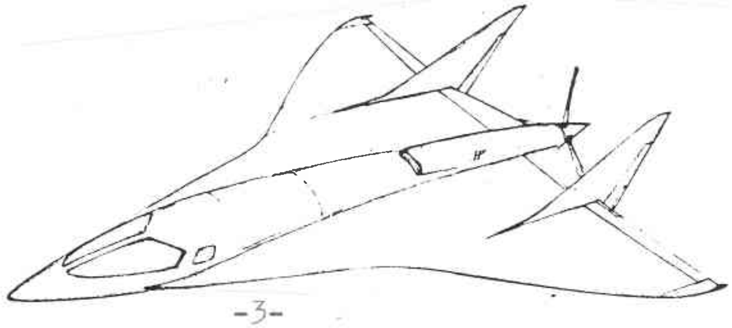
The libraries in this area do have some fairly obscure works of aviation and I will keep an eye out for other works relevant to your project.

Let me know if you are still interested in showing The Gallant Journey. Hope to get out your way now and again. Meanwhile, look for vol 1 # 1!

Regards,

Wwk

Wink
Charles E. Peck
Managing Editor



THE STALLING BEHAVIOUR OF THE WINGS IS OF CONSIDERABLE IMPORTANCE WHEN DESIGNING TAILLESS AIRPLANES. SINCE THS STALL DUE TO FLOW SEPARATION NOT ONLY DETERMINES THE LOSS OF LIFT AND CHANGES IN PITCH MOMENT AS IN CONVENTIONAL DESIGNS, BUT ALSO EFFECTS THE BEHAVIOUR OF PITCH AND ROLL CONTROL SYSTEMS OF THE TAILESS AIRCRAFT, IN THE FOLLOWING TWITT ISSUES WE WILL REPRINT A SERIES OF ARTICLES DEALING WITH THIS IMPORTANT SUBJECT THAT HAS BEEN OF MAIN CONCERN TO THE FLYING WING DESIGNERS AND OF COURSE OF ALL TWITT MEMBERS AS WELL.

THIS ARTICLES WERE PUBLISHED IN 1947 IN THE MAGAZINE "AERONAUTICAL ENGINEERING" AND WERE WRITTEN BY A.R. WEYL. IT IS ADVISED TO THE TWITTER THAT THE AGE OF THIS ARTICLE SHOULD NOT GIVE ANY SECOND THOUGHTS ABOUT THE VALIDITY OF ITS STATEMENTS.

Stalling Phenomena and the Tailless Aeroplane—I

By A. R. Weyl, A.F.R.Ae.S.

The tailless layout was one of the earliest adopted for aircraft and from time to time in the past, designs have been produced with varying degrees of success. Now, with the advent of very high-speed aircraft, much more attention is being paid to the tailless arrangement and to the associated aerodynamic problems which are being closely investigated. By no means the least of the problems to be examined is the very vital question of the behaviour of these aircraft at the stall with all the attendant stability and control problems under such flight conditions as indicated in Sqdn. Ldr. Kronfeld's article on test-flying tailless aircraft (April 11). With this in mind, we feel that a detailed account of the stalling phenomena, with particular reference to their relation to the tailless aircraft, would prove both timely and instructive. We present here the first part of a comprehensive article on this very important subject.

IN A BROAD SENSE, stall means the breakdown of the lift-producing air flow over the wing of an aeroplane. Generally, with tailless aircraft, a breakdown of the orderly flow over the wing has far greater consequences for stability, control and trim than those brought about by stalling phenomena on conventional aeroplanes. Moreover, common forms of tailless aeroplanes are more prone to exhibit certain types of flow separation than normal aircraft.

There are two kinds of such breakdown phenomena known as the "high incidence" stall and the "compressibility stall." Of these, the former occurs at high angles of incidence when the boundary layer is unable to follow the aerofoil contour to the trailing edge; it separates from the wing surface and causes a disruption of the circulatory flow about the wing. The latter type of stall occurs at very high speeds of flight when compressibility (shock) waves are formed at the wing. They, too, cause separation of the boundary layer from the wing surface, with subsequent breakdown of the orderly lift-generating flow.

Contrary to a frequent erroneous belief, the high-incidence stall may take place at any speed of flight. The compressibility stall is restricted to air speeds which exceed the critical Mach Number, i.e., to a particular speed appropriate to the wing system and to the temperature of the atmosphere in which the aeroplane flies (minor influences of the air, such as moisture, etc., are neglected).

The following discussion of stalling phenomena treats both categories of stall separately, although aerodynamically, they have a number of characteristics, both causes and consequences, in common.

The High Incidence Stall

Not every separation of the boundary layer from parts of a wing surface can be classified among the stalling phenomena defined above. So, for instance, the boundary layer may separate from heavily reflexed (stable) aerofoils at very small incidences, especially at low Reynolds Numbers. Though such a separation can have a profound influence on stability and control when flying at such incidences, it is not connected with what is understood by the pilot under "stall." Most probably it is the result of a laminar boundary layer flowing along the concave surface on the underside.

Another phenomenon of a similar nature is provided by a partial separation which may take place at medium incidences far below the critical angle of incidence. This transient "front" stall, too, is probably due to the separation of a laminar boundary layer which has become tired before transition to fully turbulent state is reached. Some way farther downstream, the laminar sub-layer which has separated from the surface forms a "transition vortex," and full turbulence develops throughout the boundary layer; particles with full flow energy are taken in from the outer fluid strata, and the energized boundary layer adheres to the wing surface again.

The phenomenon expresses itself in a discontinuous decrease of the slope of the lift curve ($dC_L/d\alpha$), or in a bend of the lift curve, both at medium incidences. From the point of stability and control of tailless aeroplanes, this transient "front" stall may be deemed inocuous.

Clearly shown, however, is the importance which the state or mode of the boundary layer has for all phenomena of flow separation from surfaces. Hence, for the stall, decisive factors are the flow energy and the thickness of the boundary layer, with the flow energy being paramount. The exigencies for safe stalling behaviour may, moreover, not be identical with those for minimum expense in drag. This leads to intricate problems for designers of tailless aircraft.

When a boundary layer is vigorous, it will adhere to a wing surface longer when flowing against an adverse pressure gradient. A less energetic boundary layer becomes easily stagnant and thickens, due to subsequent layers overlapping each other. The adverse pressure gradient induces backflow, a free vortex sheet is then formed in the boundary layer, and, finally, the whole layer breaks away from the surface into the undisturbed air stream, forming individual eddies. That is the picture of the stall.

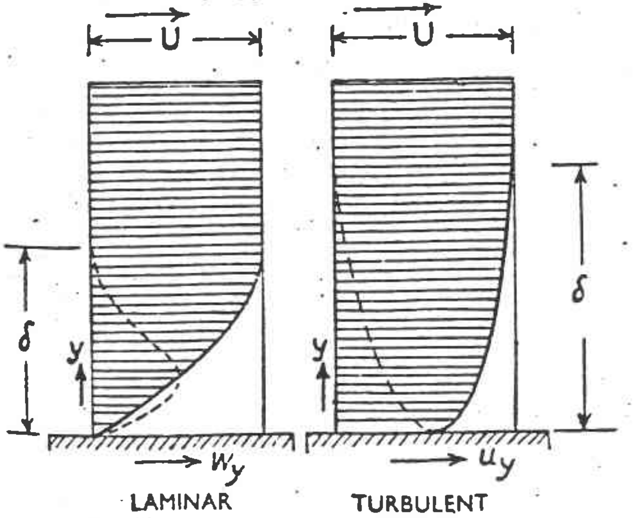


Fig. 1.—Velocity profiles of a laminar and of a turbulent boundary layer. The broken curves give the momentum loss in the boundary layer; the scales of the two figures are so adjusted that their total loss of momentum is the same (according to B. M. Jones).

The formation of eddies indicates that the phenomenon is fluctuating. Every eddy shed means a corresponding temporary reduction of the circulation, i.e., of the lift. There is no steady separation taking part at a defined chord station or region of the wing. Consequently, the disturbance of the regular flow and the forces produced by the latter are no longer independent from time. It is this which makes the observation and recording of stalling phenomena difficult.

The boundary layer is that layer of fluid nearest to the wall, in which viscous forces are acting between the fluid and the wall, and between the fluid particles themselves. These viscous forces, the surface friction and the inner friction of the flow, dissipate the kinetic energy of the flow particles in the form of frictional heat due to shear. In a laminar boundary layer, this energy loss is least, hence the low profile drag associated with it. On the other hand, a laminar boundary layer keeps distinct from the flow stratum of undisturbed air beyond it. Thus it does not exchange flow energy with this, by its nature, more vigorous stratum, except to a minute extent, which is due to action of viscosity. Thus a laminar boundary layer tires easily, because its original flow energy is not replenished. It is, therefore, very apt to separation, and, hence, prone to stall.

A turbulent state in the boundary layer entails a constant interchange (intermingling) of flow particles with the outer stratum of undisturbed air. Hence flow energy is continuously transferred to such a boundary layer by transportation of momentum. Thus, although a turbulent boundary layer dissipates far more energy in internal friction (higher profile drag), it keeps more vigorous. It adheres, therefore, better to wing (or body) surfaces; a turbulent boundary layer is less liable to produce stalling phenomena when an adverse pressure gradient is reached in the flow over a lifting wing. On the other hand, when flowing along a surface, the thickness of a turbulent boundary layer grows with the 0.8 power of the chord-wise distance from the leading edge, while the thickness of a laminar boundary layer grows with the 0.5 power only.

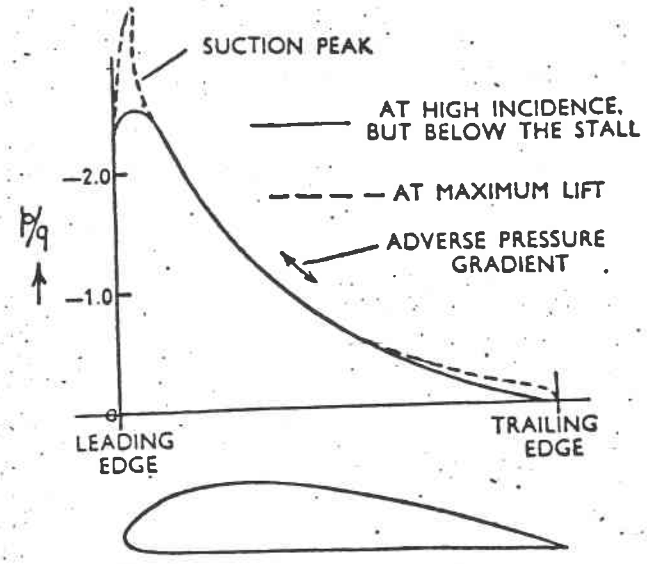


Fig. 2.—Distribution of negative pressure over the upper surface of an aerofoil at high lift co-efficients.

This is only a somewhat simplified, though true and experimentally verified, conception. In reality, there is no fully turbulent boundary layer. As Sir Thomas Stanton found (as long ago as 1911), a minute sub-layer of the boundary layer will always retain laminar state, whatever the mode of flow in the rest of the boundary layer. This sub-layer is nearest to the surface. Apparently, it can be upset by surface roughness, but it tries to re-form again.

There is not yet a satisfactory explanation why in one case a laminar boundary layer thickens and then separates from the surface, whilst still being in the laminar state of flow, when an adverse pressure gradient is encountered (i.e., when the local velocity of flow is decelerated); while, in another case, the thickened laminar boundary layer breaks down into turbulence before separating from the surface.

From experimental evidence, it is not easily seen if, and in which way, the laminar sub-stratum of the boundary layer is connected with these phenomena, since the relative surface roughness is apparently without influence. The behaviour might more likely be due to the stability of the velocity distribution (velocity " profiles ") within a thickening and slowing-down boundary layer.

When the boundary layer retains its laminar state, strata of boundary-layer material seem to overlap each other in a well-ordered way, so that a velocity profile across the boundary layer is formed in which the velocity continuously increases from the surface to the upper limit of the boundary layer, i.e., to the velocity of the potential flow. In the second case, parallel strata with higher velocity may become interspersed between such of lower velocity. Such a velocity distribution through the boundary layer is unstable, and is necessarily followed by breakdown into turbulence, after formation of a vortex (the " transition vortex ") in the boundary layer. When the boundary layer as a whole is decelerating, the tendency to damp out such unstable velocity distributions without breakdown of laminar flow is but small.

The stall of a wing may assume a variety of appearances, and this variety results in great differences for tailless aeroplanes in particular. First of all, one may distinguish between the incipient stall with its development in time or in incidence, and the fully developed, complete stall.

In practice, the development of the incipient stall is vital for the stability problems of normal flight. Upon it, the safety depends. It also marks the extent to which the aerodynamic qualities of the wing at high incidences can be utilized for practical flying, which is linked up with the manner in which the stall begins to spread over a wing.

The characteristics displayed by the aeroplane after a state of complete stall has been reached are essential for the stability of the flight path in stalled attitude. They decide upon the spinning (autorotation) properties. Also, they are of fundamental importance for aeroplanes designed to fly controlled when stalled, i.e., the so-called " Safety " aeroplanes.

The Incipient Stall

There is no doubt that the development of the stall when the incidence is slowly increased up to and beyond the critical angle of incidence affects the tailless aeroplane far more than any other category of winged aircraft. With the conventional (tailed) aeroplane, a separation of the flow which sets in at the wing tips leads only to a loss of roll damping and to impaired control in roll. In general, it is the spanwise spreading of the stall at slowly increasing incidence which affects the conventional aeroplane. With the tailless aeroplane, the chordwise development of the flow separation is also important, and longitudinal stability, trim and control are affected by the incipient stall.

From this is seen that the following characteristics of stall development over the wing system with slowly increasing incidence will have to be taken into consideration:—

- (I) Span-wise spreading of the flow separation.
  - (a) Origin of separation (inception of stalling phenomena, locally);
  - (b) Direction of the spreading of the stall (inboard; outboard);
  - (c) Rate of the spreading of the flow separation in relation to the incidence increase (incidence range of the stall development from its inception to its travel over the entire span);
  - (d) Span regions remaining unaffected by flow separation even after the critical incidence has been substantially exceeded;
  - (e) Variations in the affected span regions when the incidence is retained (stall development with time).
- (II) Chord-wise spreading of the flow separation.
  - (a) " Front " stall;
  - (b) " Rear " stall;
  - (c) Rate of chord-wise progress of the flow separation when the incidence is slowly increased (incidence range of the chord-wise stall development from the stall inception to its fully developed form);
  - (d) Loss of lift associated with the flow separation during and after full development of the stall.

Unfortunately, experimental research has not yet progressed very far into investigating all these characteristics of the incipient stall. This is certainly not due to lack of interest in the matter, but is caused by the difficulties which are besetting the way of the experimenter into non-steady flow phenomena.

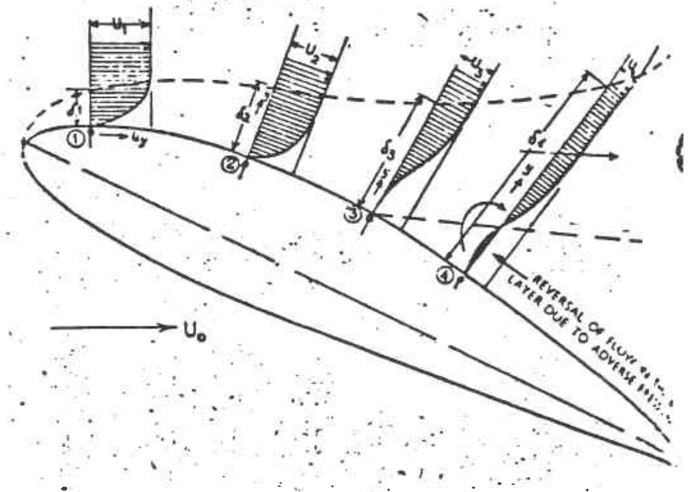


Fig. 3.—SEPARATION OF A LAMINAR BOUNDARY LAYER AT THE STALL.—Four velocity profiles are indicated. The dimensions of the boundary layer are grossly exaggerated for the sake of clearness.

U_0=undisturbed flow velocity.
U_1. U_2.. etc.=local flow velocities of the potential flow at the aerofoil.
δ=total thickness of the boundary layer.
U_y=velocity in the boundary layer at a distance y from the aerofoil surface.

The somewhat general expressions "front" stall and "rear" stall are introduced here for a short characterization of the chord-wise development of the stall. Formerly it was assumed that a separation setting in not far behind the leading edge was always due to laminar state in the boundary layer and abrupt, while inception of the separation near the trailing edge and spreading forward with increase of incidence, was due to a turbulent boundary layer and resulted in a gentle stall with moderate loss of lift.

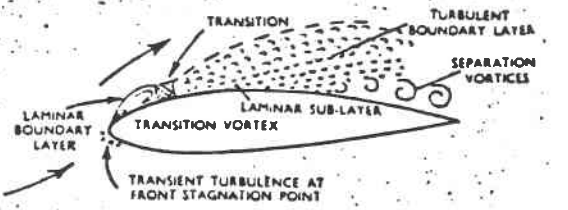


Fig. 4.—The transition vortex at maximum lift.

To-day, experimental evidence has modified this simple conception, and the existence of other forms of the stall has become established. In order to simplify the variety, it seems best to adopt E. J. Richard's (Ref. 80)* differentiation between three distinct main forms of stall:—

"A."—Gentle stall at relatively low values of the maximum lift coefficient, due to laminar front separation followed by re-adherence of the boundary layer farther along the chord. Consequently, no great loss of lift is experienced beyond the stall.

"B."—Abrupt stall accompanied by a sharp drop in lift, due to the complete separation of a turbulent boundary layer not far downstream of the transition point.

"C."—Gentle stall with the point of turbulent boundary-layer separation shifting slowly towards the leading edge; the loss of lift beyond the incidence of maximum lift is gradual

The stall forms "A" and "B" correspond to the expression "front" stall used here, while form "C" is the "rear" stall.

The difference in the stall forms "B" and "C" is, in two-dimensional flow, mainly due to the aerofoil section shape, and apparently greatly affected by the ratio between surface friction drag and form drag of the aerofoil. The section thickness is, hence, of great influence: thin aerofoil sections tend to be afflicted by the sudden turbulent form "B," while thick sections give the gentle turbulent separation form "C." The flow mechanics governing these stall differences are not yet explored; the degree to which the boundary layer breaks down into the turbulent state and the damping-out of turbulence at the stagnation point may be possible causes. For the stall forms "A" and "B," at otherwise equal conditions, the curvature of the aerofoil nose seems to be a major influence: thus aerofoils with sharp leading edges preferably give the gentle laminar stall form, and sharp-nosed thick aerofoil sections are practically free from autorotation, because of the small loss of lift beyond the stall (Ref. 81).

At low Reynolds Numbers, another mixed type of very gradual stall has been observed at cambered aerofoil sections of medium thickness (Ref. 1, p. 9): a local separation of a laminar boundary layer near the leading edge simultaneously occurring with that of a turbulent boundary layer near the trailing edge; i.e., a combination of stall form "A" with form "C," at the inception of the stall. The separated laminar boundary layer breaks down into turbulence and re-adheres in the turbulent state farther downstream.

This stall form gives, chord-wise, two regions of flow separation, and, as a result, a complete change in the pressure distribution during the stall development. For experiments with tailless models and gliders, the consequences of this stall form are of interest.

The Spreading of the Flow Separation

When considering the particular problem of the tailless aeroplane, i.e., of a self-contained wing system, in stall, in connection with the span-wise spreading of flow separation from the wing surface, it would seem worth while investigating what a simultaneous complete stall all along the span at a particular incidence (true critical incidence) will imply.†

Flow separation means a decrease of lift over the wing region concerned; the magnitude of this decrease depends upon the chord-wise station at which the flow separates. Flow separation existing at parts of the span only, necessarily results in a distorted span-wise lift distribution, as compared with that of normal flight. With stable wing systems incorporating sweep, this distorted span-wise lift distribution greatly affects the longitudinal stability. A simultaneously occurring flow-separation all along the span will, however, not result in a span-wise lift distribution which would differ essentially from that of the unstalled normal flight.

Theoretically, the condition of simultaneous flow separation is met by a wing system of minimum induced drag; i.e., by a plain elliptical wing having the same aerofoil section and equal effective incidence all along the span. Such a wing, too, would derive the greatest value for the maximum lift. This would be the simplest wing meeting the condition of simultaneous stall.

The condition may, however also be satisfied by more complicated wing systems evolved from a span-wise lift distribution where the effective incidence of maximum section lift is reached simultaneous at one defined attitude of the wing. For other than plain elliptical wings, this entails a wing twist or a corresponding variation of the aerofoil sections along the span. In such cases, however, the induced drag is invariably increased, and it does not become zero when the wing as a whole is at incidence of zero lift. Moreover, there is always a torsional load on the wing structure.

For any such wing system, the lift distribution remaining when the stall has simultaneously occurred all along the span depends on the progress of the flow separation in the chord-wise direction. The extent and the rate of this progress greatly depends on the qualities of the aerofoil sections employed. When the wing embodies a change in the aerofoil sections along the span, these qualities will not be uniform at all span-wise stations. Hence, although the critical incidences of the section lifts will be reached all along the span at the same wing incidence, it does not necessarily follow that the lift distribution at the stall will be similar in shape (though reduced in magnitude) to that at incidences below the stall.

(To be continued)

Stalling Phenomena and the Tailless Aeroplane—II

By A. R. Weyl, A.F.R.Ae.S.

The first part of this article appeared on page 427 April 25 Issue.

FROM INVESTIGATIONS of B. M. Jones and W. S. Farren it is established that, in two-dimensional flow, the stall may set in chord-wise in two distinct manners. The flow may separate first at a chord-wise station not far from the maximum section camber at the upper win surface, and progress from there slowly or at a great rate towards the trailing edge ("front" stall). Alternatively, the separation of the boundary layer may originate near to the trailing edge and spread from there, at a lesser rate, towards the leading edge ("rear" stall).

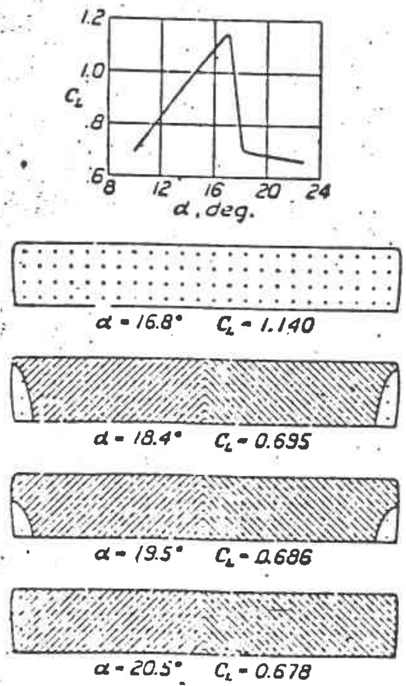
In respect to the rate of this chord-wise spreading, the results of pressure-distribution tests made by R. M. Pinkerton on an N.A.C.A. 2412 aerofoil at different Reynolds numbers (Ref. 1), is instructive, though the tests refer to an aerofoil section which had very gradual stalling qualities. At low Reynolds numbers (R.N. $= 0.45 \times 10^6$), the chord-wise spreading of the flow separation covers an incidence range of 4.5 degrees. At higher Reynolds numbers, the rate of progress seems to become more abrupt, but still rather gradual and without a fundamental change in the shape of the lift distribution. This would indicate that a simultaneous span-wise stall of a wing composed of such aerofoil sections would not adversely affect the stability of a tailless aeroplane of the "Flying Plank" type.

With many commonly employed aerofoil sections and at the high Reynolds numbers of practical flight, the forward separation of the flow wins in the contest between laminar front stall and turbulent rear stall (Ref. 2). In the lift curves (lift versus incidence), this is characterized by an abrupt loss of lift at the critical incidence. Lift discontinuities beyond the critical incidence indicate that the two forms of chord-wise stall development may occur alternatively.

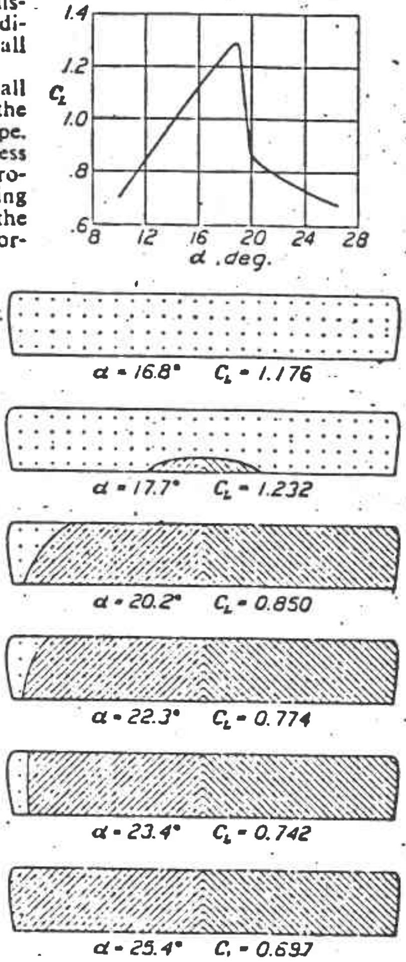
For the tailless aircraft, the incipient rear stall will cause a progressive loss of control, the control surfaces being generally of the flap type. Hence there will be a warning felt by sloppiness in the controls when, with such a tailless aeroplane, the critical wing incidence is being reached. With the "Flying Plank" type, the aerodynamic centre of the wing will shift forward, resulting in a decrease of the longitudinal static stabili A change in the trim will also become apparent. Its sen depends on the reflex in the aerofoil section camber.

The incipient front stall is not likely to give warning b affecting the control feel. Though it may entail less variati in the static stability, the rapid development of the stall form "B" must be deemed a dangerous feature. With tailless aero planes, tendencies to "whip" stall are catastrophic and oug to be excluded by appropriate design measures.

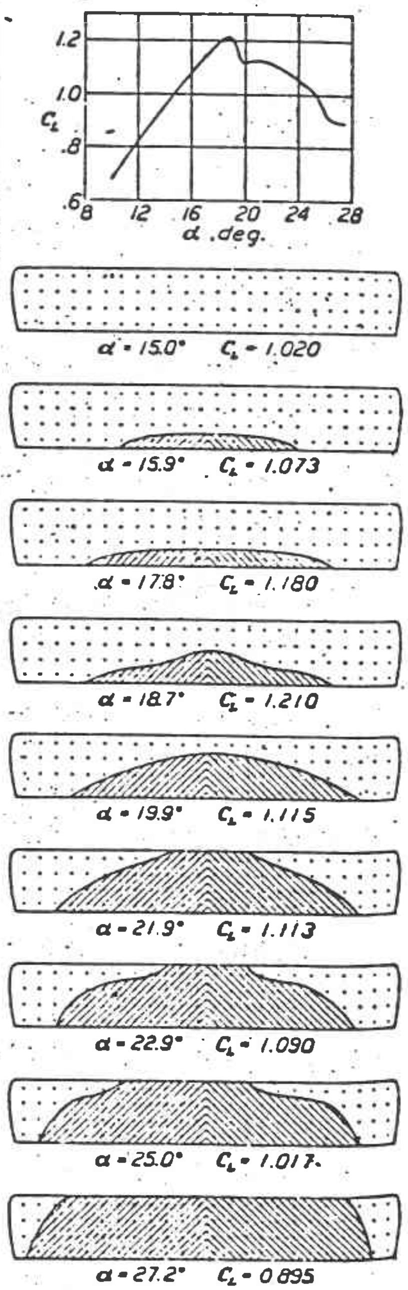
But even a simultaneous "rear" stall of form "C" all alon the span may be undesirable for a tailless aeroplane. Besid the roll damping and the control in roll, the control in pitch is lost as well, and brake rudders may even accentuate the spreading of the stall chord-wise, when operated. At the same time, the trim in pitch is seriously disturbed, and, as we shall see again later, often enough not in a sense which



The N.A.C.A. 0009 aerofoil.



The N.A.C.A. 0012 aerofoil.



The N.A.C.A. 0018 aerofoil.

Fig. 5.—Stalling contours of three N.A.C.A. aerofoils with rounded tips. Approximate test velocity, 84 f.p.s. Cross-hatched areas indicate stalled region.

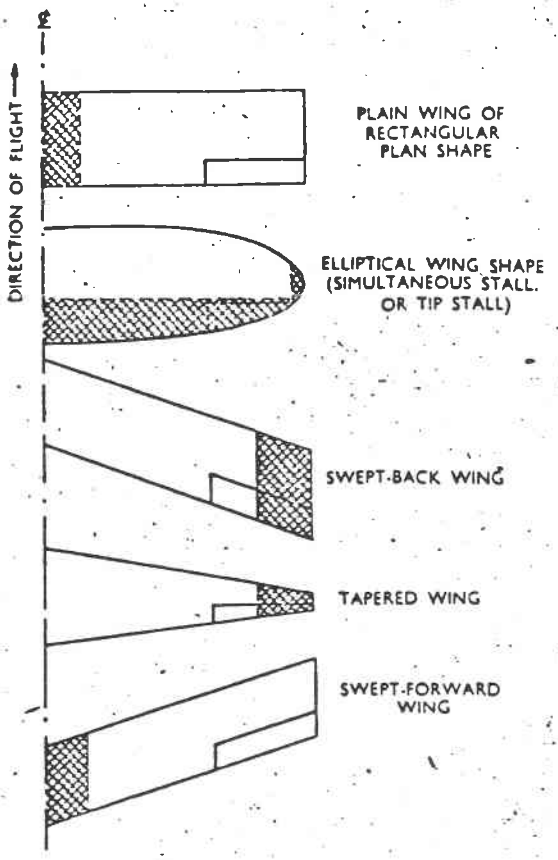


Fig. 6.—Influence of the plan shape on the incipient stall of untwisted wing systems. The shaded area indicates the region at which the stall is most likely to occur first.

would tend to bring the aeroplane back to smaller incidences.

It seems that simultaneous stalling all along the span is, for a tailless aeroplane, only admissible for the case when the critical incidence is reached otherwise than by elevator action, e.g., not in a straight stall, or by displacement of the centre of gravity.

To obtain a stall in straight, not otherwise disturbed flight, the pilot has to produce positive pitching moments by a displacement of elevator flaps. The angular displacement of such flaps affects the distribution of the effective section incidences along the span. Consequently, in the span region of the elevator flaps, the effective section incidences are decreased, and the stall will develop over these span parts later than at the rest of the span, provided the wing is designed for simultaneous stalling all along the span, with the elevator flaps in their neutral position.

It follows that simultaneous stall over the span—if desirable or not—cannot become a feature of tailless aeroplanes for all flying conditions under which an high-incidence stall may occur. If the wing system is designed to exhibit simultaneous stall with the elevator adjusted for trim at the critical incidence, the stall will originate at isolated parts of the span, when the stall is induced by other than elevator action (say, by a gust, or in circling flight). This will not lead to satisfactory solutions. Moreover, with sweep-back, for instance, it would imply premature tip stall, when such condition is adhered to for the choice of wing twist and of aerofoil selection along the span.

The incipient stall is connected with changes in the flow pattern which are of a rapid, unstable character. This flow instability expresses itself in fluctuations of the pressures and forces experienced. Within a narrow range of incidences, changes from sound flow to complete separation have been observed, while the incidence was not changed. With such alternating flow patterns, no symmetry in the reduced lift distribution over the span can be expected. Even a very minor disturbance or dissymmetry at the wing, moreover, will make one wing stall earlier than the other one, with consequent disturbance of the attitude of the aeroplane (Ref. 4). Very slight differences in the nose radius of local aerofoil sections have been found to cause one wing to stall first. The stall originated at the span-wise station where the nose radius was smallest (Ref. 70). Hence the fairly common experience of wing dropping in wing systems which ought to exhibit simultaneous stall all along the span.

Stalling tests in glides with a twin-jet fighter of elliptical wing shape and laminar-flow aerofoil section, proved that the rate-of-incidence change can greatly modify the character of a near-simultaneous stall. With slow operation of the elevator, the aeroplane dropped one wing abruptly and lost considerable altitude before it could be brought under control again; the same happened when the incidence at which the wing began to drop (due to a minute inaccuracy in manufacture), was maintained. But when the elevator was pulled back quickly so as to pass through the critical range of incidence quickly, the aeroplane could be brought into an easily controlled stalled flight.

Concluding, it would seem that simultaneous stalling all along the span is, for a tailless aeroplane, neither desirable nor practically achievable.

This has one serious consequence: it implies that, in respect of the maximum-lift coefficient, the tailless aeroplane will remain below the optimum value which can be realized with equal span, equal aspect ratio and equal aerofoil section. It also means that the tailless aeroplane will not have a wing system of minimum induced drag, although, in practice, the difference may become negligibly small. In all probability, this inherent aerodynamic deficiency should be more than balanced by other advantages pertaining to tailless aeroplanes in general.

L. Prandtl (Ref. 5) has most probably been the first to investigate the phenomena of the span-wise spreading of the incipient stall and the factors influencing it. He pointed out the difference between a stall originating at the wing root and a tip stall, and he related these phenomena to the wing plan shape, the Reynolds number and the wing twist. Since this work, which was done in 1920, various research workers have studied theoretically and experimentally how and why the incipient stall spreads over the span. The British experimenters W. E. Gray and H. B. Irving (Ref. 6) were probably the first to describe the flow mechanics responsible for the influence of the plan shape; from this, further fruitful research has developed.

The behaviour of a wing in respect of span-wise development of separation from the incipient to the complete stall seems to be governed by:—(a) Aspect ratio of the wing; (b) Angle of sweep of the leading edge and of the trailing edge of the wing; (c) Taper of the wing in plan; (d) Twist of the wing; (e) Thickness ratio of the aerofoil sections constituting the wing; (f) Shape of the aerofoil sections (especially nose radius, camber, and chord position of maximum section thickness), and its variation along the span; (g) Reynolds number (and its variation along the span); (h) Local interference phenomena (including the effect of slipstream), local surface irregularities and surface roughness; (i) Dihedral effect; and (k) Shape of the wing tips.

When discussing these points, it is necessary to realize that the manner in which the stall is being brought about will, in general, have a bearing on the character and on the spreading of the stall, since it is, for instance, possible to produce over one and the same aerofoil and at the same Reynolds number, alternatively " front " stall as well as " rear " stall, simply by varying the condition under which the stalled condition is brought into existence.

As mentioned, it cannot even be safely assumed that the least harmful stall is induced by a gradual increase of the incidence in straight flight, as, for instance, during a landing manœuvre. And the stall caused in circling flight may, again, have a quite different character. Power-on and power-off conditions will also affect the spreading of the flow separation as well as the region of its inception. The provision and setting of flap will vary the character of the stall to a large extent. There is some indication that the worst stalling character is often displayed under the influence of gusts, especially when they affect the wing partially only.

M. A. Garbell mentions (Ref. 7) " the dangerous characteristics of certain tailless designs which assume negative values of damping in pitch through trailing-edge airflow separation and wing-tip stall during violent nose-up pitching movements with the airplane trimmed for high C_L's . . .", and suggests shifting the centre of gravity forward in order to increase the static longitudinal stability. This is clearly a matter of stability at the incipient stall which is of great importance for the rational design of tailless aeroplanes.

For reasons of practical design, the discussion of stalling characteristics relating to tailless aeroplanes is best based on the comparative comparison of the different wing plan shapes and of the influence of the aerofoils chosen.

In theory, an aerofoil of elliptical plan shape, of constant aerofoil section and with no twist which retains an elliptic lift grading over the span at all incidences of lift, stalls simultaneously along its entire span. In reality, this is is not quite so: wind-tunnel tests prove that such an elliptic aerofoil usually has an incipient stall at the wing tips. The reason is that the Reynolds number decreases towards the tips, since it is based on the local aerofoil chord. Hence, for simultaneous stall and for maximum possible lift coefficient, twisted rectangular wings will satisfy the condition.

In the next part of this article, the flow mechanics of the spreading of the stall in a span-wise direction will be discussed in detail.

(To be continued.)

Clockwise from left:Hernan Posnansky, Don Webb, Stewart Cochran, Ladislao Pazmany, Bill McCaffrey, Billy Gray, Greg Kendall and Paul MacCready.