# THE DEEP STALL OF SAILPLANES

PART I

by

Henry Millicer
Principal Lecturer in Aeronautics at the
Royal Melbourne Institute of Technology

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## INTRODUCTION

Recently a couple of high performance sailplanes crashed in Australia. The cause of these crashes is suspected to be the *deep stall*, the malaise of every high "T" tail jet aircraft and a nightmare for every jet pilot, especially when flying an aircraft with an aft C.G. position. In the 1960's the *deep stall* was the cause of fatal crashes in the U.K. when the B.A.C. one eleven and the Trident prototypes crashed, killing large test crews. However, following various aerodynamic and electromechanical "fixes" such as stick shakers and automatic stick pushers, the problem was supposedly "put to bed" and conveniently forgotten. It was finally buttoned up by an excellent article by Peter Langford in 1965, the then assistant director general of D.C.A. Personally, I may not be able to explain the *deep stall* phenomenon as well as Mr. Langford, for the lack of time and space allotted to me with this article. Any reader wanting a deeper insight into this complex problem should refer to Mr. Langford's article in *Aircraft* (Ref. 1).

## CAUSES OF THE DEEP STALL

### Fuselage Vortices

There are two principal causes of the *deep stall* in "T" tailed aircraft, and a few more contributory ones. N.B. Low tailed aircraft seldom suffer from a deep stall (except in a flat spin) and probably this is the reason the problem never bothered the gliding community until now.

The first cause is the fuselage lift at high angles of incidence, when it exceeds about 20 degrees. This lift causes any fuselage to behave as an *independent* low aspect ratio *wing*, shedding tip vortices from its sides long after the main wing has stalled (Fig. 1).

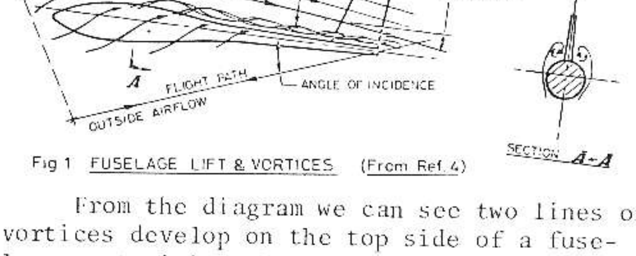


Fig 1 FUSELAGE LIFT & VORTICES (From Ref. 4)

From the diagram we can see two lines of vortices develop on the top side of a fuselage, entraining the outer airflow above the fuselage, and sweeping the top surface clean of any broken away flow. Thus, these two vortices entrain a high velocity, and a high dynamic pressure just above the fuselage, and in addition they create a strong downwash in the same region - about five to eight degrees local incidence. These two effects combined (a high velocity and a large angle of downwash) cause a strong, localized, *down* tail load in the center of any tailplane placed in that region. However, a tailplane placed low

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on the fin does, at the same time, receive a fresh blast of airflow from below the wing wake, on the outer parts of its span. The latter effect, counteracting the first one (downwash) causes an overall *upload* on the tailplane, creating a *nosedown* pitching moment. Thus, a *low* tailed aircraft will not proceed in to *deep stall* unless forced into it by centrifugal forces, i.e. in a flat spin, or by an extraordinarily powerful elevator, or by a nose strake.

On the other hand, a "T" tail, on a glider, placed high upon a fin, becomes enveloped by the wing main *wake* of very low velocity, about half of the free airflow. At the same time, the local tailplane angles of attack in the outer parts of span are very large (of the order of twenty five to thirty degrees), thus causing the majority of the tail and elevator area to be fully stalled and ineffective. Thus, the overall effect of fuselage vortices on the high "T" tail is a strong *download*, causing a *nose up*, unstable change of trim, which can be completely uncontrollable if the elevator is not powerful enough, and applied soon enough, to overcome this nose up tendency.

The resultant tailplane spanwise distribution is shown on Figure 2, showing the resultant download in its center.

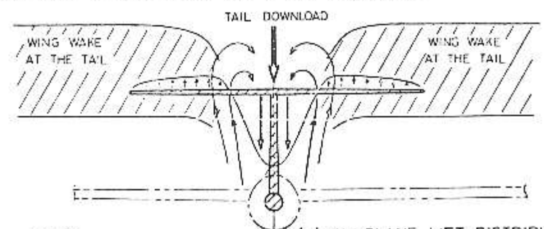
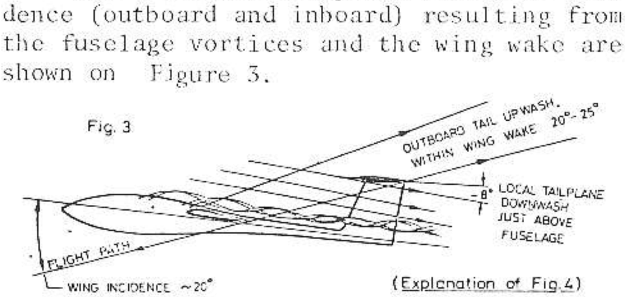



Fig. 2 'T' TAILPLANE LIFT DISTRIBUTION

## The Poor Tailplane Efficiency

As was mentioned before, the secondary cause of the *deep stall* is the poor efficiency of the high "T" tailplane in its *outboard* parts, which are placed *outside* the fuselage vortex flow. The main reason is the wing *wake*, the region of very turbulent airflow of very low, oscillatory velocity. As we well know, when any high aspect ratio wing becomes stalled, its downwash becomes lost, the wing wake widens and lifts up suddenly, its bottom edge becoming almost parallel with the outer airflow. Any tailplane immersed in the wide wake of a stalled wing, loses its stabilizing efficiency and may render the whole aircraft unstable. This is especially so if the given aeroplane or glider is already marginally stable with the C G in its aft limit.

The different tailplane angles of incidence (outboard and inboard) resulting from the fuselage vortices and the wing wake are shown on Figure 3.




'T' TAIL ANGLES OF ATTACK AT POST-STALL WING INCIDENCE

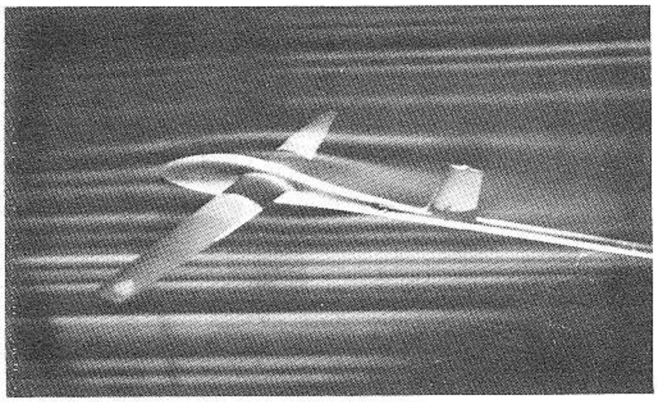


Figure 4a. Vortex at wing root. No tailplane. This is a model of a Cirrus sailplane in the RMIT wind tunnel.

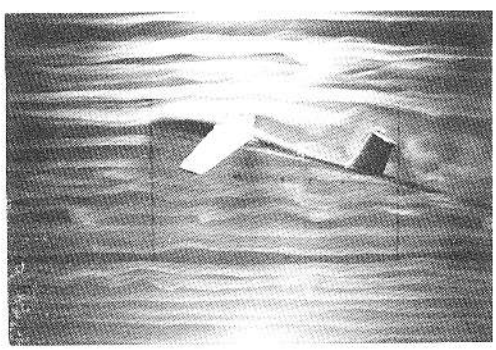


Figure 4b. Wing-fuselage vortex hitting tailplane.

## Effect of Wing Flaps

A third effect, contributing to a *deep stall* may be the wing flap angle. Sailplane wings, with their high aspect ratio, large camber, and low Reynold's numbers, stall at comparatively low $C_L$s and low angles of attack, especially with flaps down (Fig. 5).

We can see a sharp stall at some eight degrees incidence, with flaps down + ten degrees. We can see a very mild stall with a

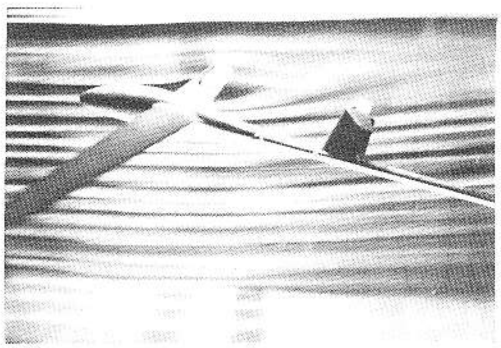


Figure 4c. Vortex at dive-brake.

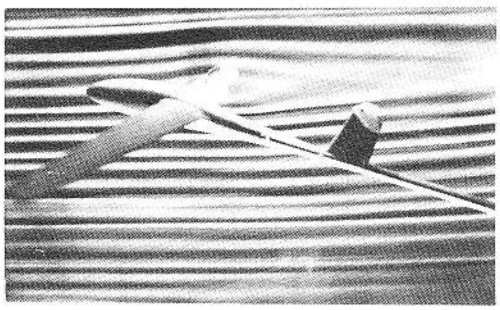


Figure 4d. Vortex behind dive-brake.

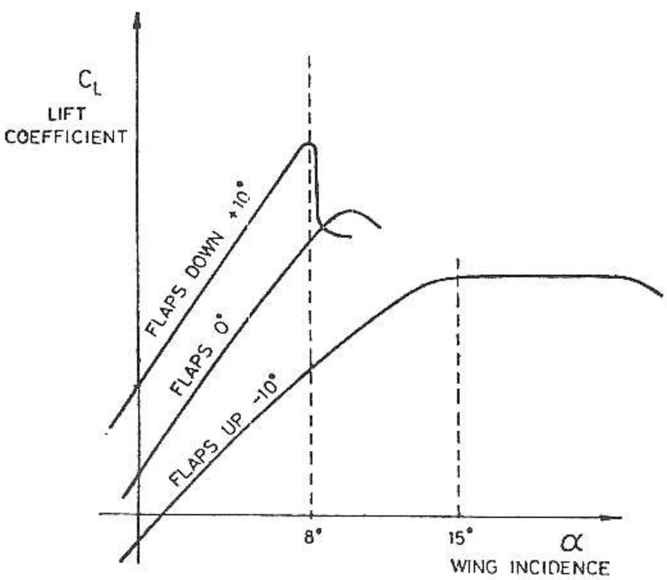



Fig. 5 LIFT COEFFICIENT VARIATION WITH ANGLE OF INCIDENCE FOR THREE FLAP ANGLES

negative flap angle — the lift lingers on from 15 - 20 degrees. When such a high angle of incidence is reached before the stall, the whole "T" tail becomes immersed in a very wide wake, where the dynamic pressure can drop to as little as one twelfth as the one for free air.

Poor Elevator Efficiency

Hence, the tailplane and elevator can become stalled and ineffective. They can be stalled because of their very large local angle of incidence, resulting from wing up-wash, and they can be ineffective because of a very low dynamic pressure in the wake.

It does not matter then if our sailplane has an all flying tailplane or just an elevator. At thirty degrees angle of incidence any *aerofoil* or *flap* attached to it are equally useless. If this situation is allowed to develop the pilot may become unable to do anything about it. Even though he may apply full down elevator after the stall, he may be too late, as the dotted line on Figure 6 shows.

If no external help is given to produce a sudden nose down pitching moment a larger and larger angle of incidence will develop. It will lead from point B, to point C, to point D, along the curves of the pitching moment coefficient versus the angle of incidence - as shown on Figure 6.

As the sailplane stalls deeper, it is a similar situation to an aircraft entraining and locking into a flat spin. As the nose of the sailplane rises and its angle of incidence increases, the tailplane suddenly emerges from the wing wake, and gets a blast of undisturbed air. Suddenly the aircraft becomes *stable* again, in pitch. The stable slope of pitching moment will continue from point C to point D, as on Figure 6, and the sailplane will become *trimmed* out and *stable*, thus *locked* in a deep stall at an estimated glide angle of 35 degrees, with a constant rate of descent of about 2000 feet per minute (10 m/s).

Needless to say, such a rate of descent is quite terminal to the human body, enclosed in the cockpit capsule, unless hitting very soft ground or water.

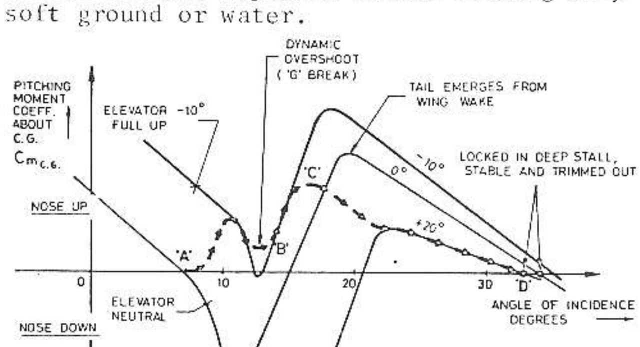



Fig. 6 DEEP STALL PROGRESS, SHOWN AS PITCHING MOMENT vs WING ANGLE OF INCIDENCE

Dive Brakes Effect

Another contributory cause towards the development of the *deep stall*, could be a pair of vortices shed from the inboard end of the dive-brakes and the wing junction (Fig. 7).

In Figure 7, an end-on-view of a sailplane is shown, with a pair of fully developed vortices, *and* a pair of dive brake vortices. Both pairs of vortices create *download* on the tailplane root and tips respectively, whilst its midsemispan is immersed in the wing wake, and therefore useless. This *could* become a contributory cause of the *deep stall* on sailplanes whose dive-brake roots are close to the tailplane tips, such as on the Kestrel, and on the IS29.

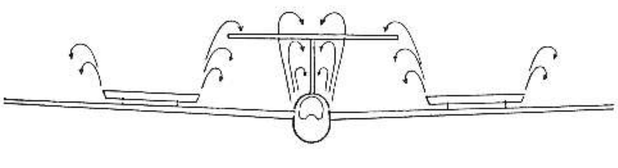


Fig 7 Vortices from the dive brakes could create downwash on tail and nose up change of trim, when used near the stall.... DON'T !

Possible Design Means of Improvement

Possible design improvements to prevent the deep stall from developing would be: an enlarged tailplane *sweepback* or dihedral or unhedral, to be distinctly different from the wing angles — in order to prevent the sudden and *total* loss of tailplane effectiveness as it enters the wing wake. If the tail or elevator *does* retain some of its effectiveness, then the pilot has the means at its disposal of preventing the deep stall from developing to its full conclusion.

Another very successful and simply way of providing an additional nose down pitching moment would be the addition of some lead in the nose of the sailplane, or a restriction on the aftmost CG position. A most successful method of control is the deployment of a tail parachute. None the less all the above changes would be quite unpopular if required to be introduced.

Means of Recovery — And Various Don'ts

On some "T" tail aircraft there would be no means of recovery from a fully developed deep stall except the deployment of the tail parachute, or the ejection of the cockpit canopy. When flying sailplanes known to have difficulties in recovery from a deep stall the pilots should observe the following *don'ts*:

1. Do not attempt to stall with a far aft CG position, especially don't attempt a dynamic stall.
2. Do not stall with flaps set at a negative angle.
3. Do not use dive brakes at the stall, *Nota Bene*, the recovery from a deep stall by attempting to roll out by means of either the full rudder and/or full aileron is impossible for rather complex aerodynamic reasons, given clearly in Reference 1.

Suggestions to Users

It is hereby suggested that every "T" tail sailplane should be tested and testified to have been tested — to establish the safe limits of the aft position of the center of gravity, at which the deep stall would be impossible, with various combinations of usable flap and divebrake positions.

This could become quite a severe and unpopular limitation on some existing high performance sailplanes, which rely considerably on their aft CG positions for their high speed performance achievements.

The tailplane induced drag, or the so-called trim drag due to the download, is quite a large percentage of the total profile drag at high speed (Ref. 5). Strangely enough, for the very same reason the aft CG positions are used on high performance jet aircraft (such as DC-9, B727, *Concorde*) to avoid high trim drag a high cruising Mach numbers, be it subsonic or supersonic.

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