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A CONCEPT OF STALL WARNING SYSTEM

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Abstract

The present work deals with a stall warning system that senses the total head within the boundary layer near the trailing edge of the wing. The ratio of this value to that of the total head in the free stream gives an indication of the state of the boundary layer regarding the proximity of the separation of the flow. When the flow is far from reaching the critical point the value of this ratio is about 0.9 to 1.0 . As the incidence increases towards higher values of the lift coefficient,C_L, this pressure ratio starts to decrease and finally drops to a value of about 0.3 to 0.5, depending on the shape of the basic airfoil, flaps position and the roughness conditions of the wing upper surface. These pressures are detected through a pair of diaphragm manometers which apply their respective forces to a system of levers whose equilibrium has been adjusted at a pre-assigned value of the pressure ratio. If the ratio of the applied pressures is lower than the pre-assigned value, un umbalance results which produces the displacement of the lever system actuating a relay that activates the alarm in the cockpit.

If the ratio is higher, the levers are displaced to block the system in the opposite direction, thus disactivating the alarm.

A device to do this is described in the text.

I. Introduction

At present the majority of the Stall Warning Systems (SWS) available in the market are those of the leading edge type, which operate by sensing the position of the stagnation point at the leading edge. This point changes position slightly according to the angle of attack, and in doing so operates a small movable tongue which sends an electric signal to the alarm device in the cockpit when the angle of attack is approaching the stall.

Airworthiness regulations require the stall warning device to supply a clear signal with flaps and landing gear in any normal position and in straight and turning flight; it follows from this that the tongue type device must be in a fixed position of compromise to satisfy all these requirements.

The boundary layer type of SWS, instead, senses the real flow conditions that causes the stall; therefore - it is hoped- its indications are true for whatever configuration of the aircraft, roughness of the wing skin or type of flight.

II. Laboratories and studies results

Many reliable authors have conducted researches and studies on the boundary layer in connection with flow separation and stall. A limited list of the works consulted is given in the references at the end of this paper.

There are no doubts that "the first indication of the approaching stall is the formation of a thick region of low total head over the upper surface near the trailing edge. The formation of this region is associated with the progressive fall of the rate of increase of C_L with the incidence" (Goldstein[1]) which had previously been increasing linearly.

Measurements made by Dianat and Castro[4] also show a noticeable decrease in the total head preceding the separation of the flow.

One of the most complete experimental works on the separation was made by Doenhoff and Tetervin[3]. They devised a method for predicting the separation trough a step by step integration , which is still used in engineering offi

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ces. Much of the numerical results of the cited reference[3] has been used in this paper to obtain further numerical values necessary for this work.

The magnitude of the shape parameter H has been taken as indication of the approaching stall defined as the ratio of the "displacement thickeness" to the "Momentum thickeness", $H = \delta_1/\delta_2$ where:

$$\delta_1 = \int_0^\infty (1 - u/U)\,dy \qquad \text{displacement th.}$$

$$\delta_2 = \int_0^\infty (u/U)(1 - u/U)\,dy \qquad \text{momentum thick.}$$

where u is the velocity within the boundary layer and U is the velocity in the free flow.

No separation has ocurred for value of H lower than 1.8 and definitively it has occurred for values of H higher than 2.6 [3].

III. The shape parameter and the total head in the boundary layer

In order to apply these concepts of the shape parameter as an indicator of appraching stall it must be directly related to a value easy to be detected in flight. The parameter chosen is the ratio of the total head in the boundary layer (p_t) to the total head in the free stream.

The total head within the boundary layer has been calculated by taking u from ref.3 (Fig.3a and 4a) and assuming the static pressure is constant throuh the whole heigh of the BL and equal to the local static pressure just outside the BL. Applying Bernouilli's equation to the free flow and to the flow within the BL, the following relation is obtained:

$$\frac{p_t - p_e}{p_0 - p_e} = 1 - (U/U_0)^2 + (u/U_0)^2$$

U is the potential velocity of the flow just outside the BL at the station considered. U_0 is the velocity in the general flow; u is the velocity in the BL at a distance y over the surface of the wing. The calculated values of

$$\frac{p_t - p_e}{p_0 - p_e} = q_t/q_0$$

and the values of $H = F(x/c)$ obtained from Table I of ref.3, are shown in fig.1 in which it is possible to appreciate very clearly the complete fall of q_t/q_0 occurring at approximate the same abscissa x/c for which H increases rapidly throuh the reference value of 2.6 in x/c = 0.5 to 0.6 .

Thus the drop in the total head in the boundary layer is equivalent to the increasing of the shape parameter, H, in announcing the coming stall.

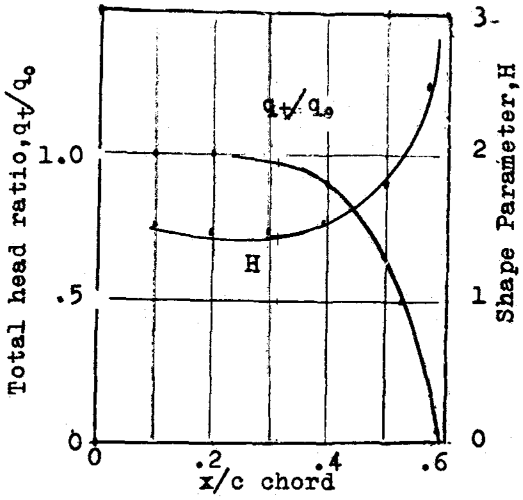

Fig.1 - Values of q_t/q_0 calculated, and H from Ref.3. y/c=0.014

IV. Principle of operation

The stalling speed of an aircraft depends on the maximum value attainable for the lift coefficient and the load on the wing. For a given aircraft the load on the wing is a function of the type of flight (stationary or in manoeuvre); the maximum lift coefficient depends on the flaps position and the roughness conditions of the upper surface of the wing, and in general of whichever cause that deteriorates the behaviour of the boundary layer leading to the separation of the flow and the stall.

Therefore a signal indicating the onset of the boundary layer separation is a good warning about the coming stall, and can be used to trigger the alarm in the cockpit.

The dynamic pressure ($\rho V^2/2$) at stall is of the order of a few millimeters of water (about 20 mm at 60 km/h and 50 mm at 100 km/h) which settles the threshold of the stalling speed to activate the manometer (or pressure transducer) of the stall warning alarm.

The signal that activates the alarm is not a pressure, but the ratio of two pressures, q_t/q_0 , adimensional; the formation of this quotient is achieved through a system of levers on which two independent sensitive diaphragm manometers one of them sensing q_t the other q_o, supply their respective forces to establish an equilibrium of the system at a pre-adjusted value of the ratio q_t/q_o in such a manner that when the applied pressure forces give a ratio lower than the pre-adjusted value, the levers are displaced in one direction to actuate a relay which activates the alarm. When the ratio is higher than the pre-adjusted value the levers are displaced to block the system in the opposite direction thus disactivating the alarm.

V. Description of a feasible instrument (+)

The general arrangement is shown in Fig.2 which is a cross section through the centerline. Both diaphragms act on the system of levers whose sketch is shown in Fig.3. Lever a-b receives the load of q_o at point D and transfers a part to lever c-d at F. Lever a-b is articulated at A and can be slid along z. in order to adjust the ratio q_t/q_o for equilibrium. This condition is:

$$q_t/q_o = \frac{(a-z).(d-z)}{(c+d).(a+b)}$$

adopting a=b=c=d= 20 mm, the condition of equilibrium results in:

$$q_t/q_o = 0.25 - (z/40 - z^2/1600)$$

the values of the distances z are counted from point A which represents z = 0, when the lever is slid to the right and negative to the left.

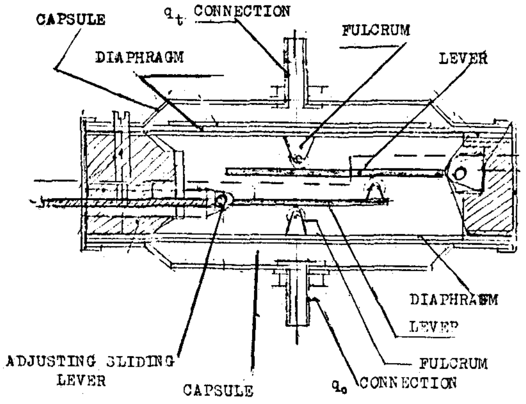

Fig.2 Pressure Ratio Manometer General Arrangement

The calculation of the total head within the boundary layer shown in Fig.1 was based on the experimental results over an airfoil NACA 65(216)222 which was exhaustively tested at different Reynolds Numers and various incidences.

An angle of incidence of 10.1 degrees (Reynolds N° 0.92×10^6, $C_L \sim 1.2$), representative of a high angle of incidence, was chosen for the calculations.

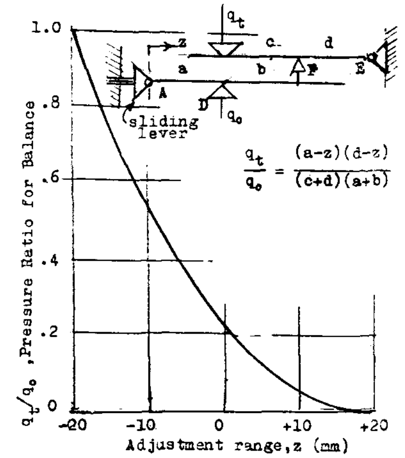

Fig.3 Adjustable Lever System

A tentative set of ordinates for the location of the mouth of the total head tube to sense the boundary layer in such an airfoil, would be x/c = 0.5 and y/c = 0.014 as the starting point for a possible flight calibration.

Displacement of the total head tube mouth upward or forward increases the anticipation time to the stall.

VI. Conclusions

1. Owing to the fact that a prototype of this device has not been flight or wind tunnel tested yet, all conclusions and results of this work must be regarded as provisional.

2. Notwithstanding, it seems to present some potential and intrinsic advantages over other types:

-Installation: it can be installed anywhere in the airplane, subject only to the lenght of the necessary tubing.

-Sensitivity: it senses directly the intimate behavior of the boundary layer responsible for the separation of the flow which leads to stall, which means that consideration is given to the state of roughness of the wing upper surface; and to the flap position, provided the total head tube is placed in a section affected by the flap.

(+) Patent Pending .

VII. References

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