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Notes on research into some aspects of
stall-warning devices.

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SUMMARY

The problems of detecting and indicating an approaching stall have been investigated in flight on an "Anson" aircraft. A lower-surface flap near the leading-edge of the wing detects the approaching stall at a speed which depends critically on the length of the flap and on its location, but the margin of warning speed over stalling-speed is reasonably independent of landing-flap position and throttle setting. A trailing-edge flap is being developed as a stall detector. A "stick-shaker" is the most acceptable form of stall indicator, and ground tests show that a frequency of shake of about 6 cycles/second is desirable. A practical "stick-shaker" of this frequency has been satisfactorily flight-tested on the "Anson". Further development work is in progress.

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SUMMARY

The problems of detecting and indicating an approaching stall have been investigated in flight on an "Anson" aircraft. A lower-surface flap near the leading-edge of the wing detects the approaching stall at a speed which depends critically on the length of the flap and on its location, but the margin of warning speed over stalling-speed is necessarily independent of landing-flap position and throttle setting. A trailing-edge flap is being developed as a stall detector. A "stick-shaker" is the most acceptable form of stall indicator, and ground tests show that a frequency of about 6 cycles/second is desirable. A practical "stick-shaker" of this frequency has been satisfactorily flight-tested on the "Anson". Further development work is in progress.

1. INTRODUCTION

Throughout the history of flight the inadvertent stall, with the possibility of subsequent loss of control, has presented one of the chief hazards and accident statistics show that experienced pilots and beginners alike are affected. Fortunately, in most conventional types of aeroplane the stall is heralded by a warning in the form of buffetting or loss of effectiveness of the controls, produced by the premature breakdown of the airflow over some part of the wing usually over the root section. With improved aerodynamic design, however, this warning does not exist on some contemporary types of aircraft, and it has become urgent to consider the possibilities of artificial stall-warning.

An investigation into certain aspects of the problem is in progress at the College of Aeronautics. Initially it was proposed to investigate only the method of warning the pilot of a stall, but the programme has been extended to cover also the method of detection of an approaching stall. This work was initiated as second year student research and is being continued under a research contract placed by the Ministry of Supply. The results already obtained are discussed in this interim report and future developments are suggested.

2. DETECTION OF AN APPROACHING STALL

If the pilot is to have sufficient time to avert an oncoming stall the warning must occur at a speed of, say, 10 miles per hour above stalling speed, or, otherwise expressed, at an angle of incidence of about 3 degrees below stalling incidence in a typical case. Several methods of detecting the stall have been suggested, based on changes in the airflow or associated static pressure around the wing as the stall is approached. These are described in (refs. 1-7) and, for the most part, will not be discussed in this report.

2.1 LEADING EDGE FLAP.

As the angle of incidence of an aerofoil is increased the stagnation point moves round the leading-edge towards the lower surface, as illustrated in fig.1. This property is used in the stall detector developed by the Safe Flight Instrument Corporation of New York. The stall detector illustrated in fig.2. is similar to the "Safe Flight" device. A small metal flap is free to rotate against the plunger of a micro-switch; continuity is broken when the plunger is depressed. The unit is mounted with the flap protruding from the leading-edge of an "Anson" in the spanwise location normally occupied by the landing-lamp, since this is outside the slipstream and gives convenient access (fig.3.) At low angles of

/incidence....

incidence the local airflow presses the flap backward, depressing the plunger. As incidence is increased the stagnation point moves behind the flap which is pushed forward, releasing the plunger, and continuity is made in the switch. The spring-loading of the plunger helps to push the flap forward, whereas if a conventional "make" switch is used, the flap has to be pushed forward against the spring-loading. For the early tests, the micro-switch was included in the circuit of a warning-light in the cockpit, but it is now used together with a relay to switch the electric motor of the "Stick-shaker" discussed later. The effects of locating the flap at different positions around the leading-edge and also of the actual size of the flap are discussed.

2.2 UPPER SURFACE TRAILING-EDGE FLAP

The leading-edge flap may be criticised on the grounds that it is undesirable to have protruberances on the leading-edge of a high-performance aircraft. A trailing-edge position offers less drag penalty. A detector flap protruding from the upper surface of the wing near the trailing-edge is moved forward at high incidences by the reversal of airflow normally occurring at the trailing-edge just before the stall. Fig.4 shows the trailing-edge flap mounted on the "Anson" in a spanwise position where wool tufts had indicated a reversal of flow just before the stall.

3. WARNING THE PILOT OF AN APPROACHING STALL

A warning to the pilot that his aircraft is about to stall must be clear and definite, incapable of being overlooked or misconstrued, and, having due regard to the psychological aspects of the problem, should be associated with the pilot's preconceptions of an approaching stall. It may be visual, aural or ~~tactual~~, but in a modern aircraft many of the signals are visual, (e.g. undercarriage lights, oil pressure warning lights) or aural (undercarriage horns, radio-communication) and it is felt that a stall-warning appealing to the sense of touch is preferable. Bearing in mind these requirements, the most satisfactory kind of artificial stall-warning device seems to be one which simulates the elevator buffet already associated with the onset of the stall on many types of aircraft. Such a device has become known as a "stick-shaker".

3.1 REQUIREMENTS FOR FREQUENCY AND AMPLITUDE OF A "STICK-SHAKER"

A test rig to investigate the degree of "stick-shake" desirable from the pilot's point of view is illustrated in fig.5. A wheel-type control column is pivoted about its lower end and can be vibrated in a fore-and-aft direction by an arm connected close to the pivotal-point. The other end of this arm is connected to an adjustable eccentric mounted on the outer spindle of the gear-box of an electric motor. By using different gear-ratios in the gear-box and different settings of the eccentric it is possible to vibrate the control column over a wide range of frequencies and amplitudes. Using the rig, about twenty-five pilots, covering a wide range of flying experience, have selected the most desirable values of frequency and amplitude. It is apparent from fig.6 that the most desirable frequency is about 6 cycles per second. The general opinion is that lower frequencies do not give a sufficiently clear warning and higher frequencies may be associated with phenomena quite apart from stalling (e.g. engine vibration).

Clearly there is some minimum value of amplitude which will give a sufficiently obvious warning and it is pointless and, indeed, may be undesirable, to exceed this. The investigation shows that the value of this minimum amplitude is of the order of ± 0.25 , measured at the top of the control column.

3.2 DEVELOPMENT OF A PRACTICAL "STICK-SHAKER"

With these requirements for frequency and amplitude in mind, an experimental stick-shaker has been developed and satisfactorily flight-tested on the "Anson". In this installation an electric motor supplies the power though the use of either hydraulic or pneumatic power may have certain advantages.

A 24-volt electric motor with a built-in reduction gear enclosed in a cylindrical case is mounted in front of the control column, as shown in fig.7. The unit is pivoted about an axis close to its lower end and the shaft of the motor, protruding from the upper end, carries an eccentric circular cam. By means of rubber "bungee" round the motor and control column this cam is held in contact with a hardened block attached to the control column. Thus, when the motor is energised it rocks to and fro imparting a sympathetic vibration to the control column. The amplitude of vibration depends on the weight of the motor and the distance through which it rocks, or the size and shape of the cam. The effect of using cams of different shape has been investigated, but the simple eccentric circular cam gives the most desirable characteristics. The entire unit is considerably larger than is desirable, but this is because the only motor readily available in the College with a suitable reduction gear is larger and more powerful than necessary. For the purpose of this experiment, however, it has proved satisfactory. A metal cover is provided, partly for neatness, and also to ensure that the actual movement of the motor does not contribute visually to the warning.

4. FLIGHT TRIALS OF STALL-WARNING SYSTEM.

The "stick-shaker" is mounted in an "Anson" (fig.8) using the second-pilot's control column since this provides greater clearance than the first-pilot's position. The effect is equally apparent on both control columns. The motor is connected in series with the micro-switch of one of the stall detectors previously described, an ordinary relay and the aircraft batteries. A separate isolating switch is also included in case it is desired to stall the aircraft without the device in operation.

The normal stalling characteristics of the "Anson" are very mild, there being only slight natural stall-warning one or two miles per hour before the stall.

4.1 TESTS OF LEADING-EDGE FLAP.

The effects of the location of the detector-flap on the leading-edge and of the length of flap protruding outside the wing have been investigated. The results are plotted in fig.9 and 10, for several configurations of landing-flaps and throttle setting. As expected, the stall-warning speed is reduced as the detector is moved further behind the leading-edge of the wing and, in the case of the "Anson", a satisfactory stall-warning margin is obtained with the flap located at approximately 6% of the local wing chord aft of the leading-edge. (Stall-warning margin is defined as the excess of warning speed over stalling-speed). Fig.9 shows that the margin is reasonably independent of both landing flap position and engine-power. Furthermore, the margin is not very critically dependent on the chordwise location of the stall-detector, a change in location of 1% of wing chord causing only about 2 - 3 m.p.h. change in the stall-warning speed. When the stall is approached under "g" from a sharp "pull-out" the warning speed is correspondingly increased, but it is not possible on the "Anson" to do stalling tests under controlled "g". It is desirable to extend the tests to an aircraft which can be stalled in a tight turn.

For any given chordwise location of the stall-detector, a reduction in the length of flap protruding outside the wing causes a considerable increase in stall-warning speed, as shown in fig.10. Thus, in a typical case, reducing the length of flap protruding outside the wing from $1\frac{3}{8}$ inches to 1 inch causes an increase in stall-warning speed of about 10 m.p.h.

The results apply only to the "Anson", of course, though it is expected that similar results would be obtained for any conventional aerofoil section. No attempt has been made so far to investigate the effect of reducing the width of the stall-detector flap.

4.2 TESTS OF TRAILING-EDGE FLAP

This device has not yet been investigated as completely as the leading-edge flap. With the stall-detector flap protruding 0.75 inches above the wing-surface at a chordwise location of 25 inches forward of the trailing-edge (this is approximately 75% of the local chord from the leading-edge) the following values of stall-warning speed V_w have been measured.

Condition	V_w m.p.h.	V_s m.p.h.	Margin m.p.h.
Flaps up, Cruising Power	66	49	17
Flaps up, Throttles closed	69	57	12
Flaps down, Cruising Power	55	46	9
Flaps down, Throttles closed	57	51	6

These figures are based on a limited number of tests, but they do indicate that the margin is roughly halved when the landing flaps are lowered. This is not unexpected since the sparwise location of the stall-detector is immediately ahead of the flapped portion of the trailing-edge, and future tests will include the search for a more satisfactory spanwise location. Clearly any trailing-edge device may be affected by controls or landing flaps.

One unexpected advantage of the trailing-edge detector has emerged from the limited experience so far obtained. When tested in conjunction with the "stick-shaker", the leading-edge device is very definite in its action; that is to say, when a well-defined warning-speed is reached, the "stick-shaker" is suddenly energised. In the case of the trailing-edge detector, the onset of the shake is more gradual; there is a small range of speed (about 3 m.p.h.) during which the shake is spasmodic, after which it builds up to a consistent level. This is because the trailing-edge device depends on a breakdown of flow which is itself spasmodic, whereas the movement of the stagnation point which operates the leading-edge flap is continuous. The pilots who have compared the two devices all prefer the gradual build-up of stick-shake obtained with the trailing-edge detector.

4.3 FLIGHT TESTS OF "STICK-SHAKER"

The "Anson" fitted with the stick-shaker" previously described has been flown by various pilots, including test pilots from the Royal Aircraft Establishment, the Air Registration Board, and the aircraft industry, several of whom have considerable experience of the problems involved. As a stall-warning they have praised it unanimously. The only criticism has been of a tendency for the shake to come into operation during the final hold-off before touchdown. This is a criticism of the speed at which the

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particular detector operates rather than of the "stick-shaker" itself. Although no serious difficulty is presented in the case of the "Anson" it is, however, a point worthy of note. If any stall-warning system is to be effective, it must be set to operate at a speed clearly above the stall, and this speed may then be reached during hold-off, particularly in the case of a tail-wheel aircraft on a glide approach. Whereas a warning light or horn would not worry the pilot at all in these circumstances, it may be disconcerting to have the control column suddenly shaken just before touch-down. The insertion of a pilot-operated isolating switch is not considered acceptable, since this would be subject to misuse. Any automatically operated isolating device (e.g. a ground-proximity switch) would unacceptably increase the complication and unreliability of the stall-warning system.

5. GENERAL CONCLUSIONS

As a stall detector, a leading-edge flap, which is pushed forward as the stagnation point moves round the leading-edge at high incidence, performs satisfactorily. The speed at which the detector operates is not very critically dependent on the location of the flap on the leading-edge, and it seems that, for any conventional aerofoil section, it should be fairly simple to find a location giving a satisfactory warning speed. The warning speed, however, is considerably increased by reducing the length of flap protruding outside the wing. The leading-edge location suffers from two disadvantages; it is undesirable to have any excrescence on the leading-edge of a high performance aeroplane and also the operation of such a flap would be seriously affected by ice accretion on the wing.

The first of these objections is overcome completely by using a trailing-edge detector. It is also considered that this type of device would be less seriously affected by wing-icing than a leading-edge flap. The fact that the trailing-edge flap gives a warning which gradually builds up to a steady pitch seems to be advantageous from the pilot's point of view. With a trailing-edge detector, however, it is clearly more difficult to obtain a stall-warning margin which is independent of landing flap position and slipstream, though further work is proceeding to show whether these difficulties can be overcome.

If, as seems probable, a "stick-shaker" is the best form of stall-warning indicator, then a frequency of about 6 cycles/second and an amplitude of about ± 0.25 inches gives the most favourable degree of stick-shaking. To produce this type of "stick-shaker" for a large aeroplane involves moving a fairly large out-of-balance weight, and since a moderately large and heavy electric motor is required, it is feasible to oscillate this, rather than the alternative of fixing the motor and using it to oscillate a separate weight. A "stick-shaker" based on this principle has been successfully built and flight-tested.

Research into the use of a trailing-edge flap as a stall-detector is continuing and an attempt is being made

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to reduce the size of the "stick-shaker" by choice of a more suitable electric motor. It is advisable to investigate the special problems of a "stick-shaker" of this frequency on an aeroplane with power-operated elevators, since, in this case, it is clearly essential to avoid the critical "judder" frequency. It is desirable to extend the flight tests to an aeroplane which is capable of being stalled in a tight turn.

It is recognised that the modern, high-speed aircraft with its thin, swept wings may require special investigation. On such wings the stalling characteristics tend to be complicated by leading-edge separation of the laminar boundary layer out towards the tips, by the spanwise flow in the boundary layer, and by tip vortex formations which normally play little part in the stalling of conventional unswept wings. The trailing-edge warning may then be unsuitable and for that reason it may be necessary to investigate some incidence-sensitive device which offers no protruberances or step in the wing surface to which objection could be taken.

A means for warning of incipient breakdown of smooth airflow over airfoil surfaces. R.A.A.F. Transactions 1942

R.D. KELLY 5

Brief outline of an artificial stall-warning device. R.A.A.F. R.G. No 113/1938

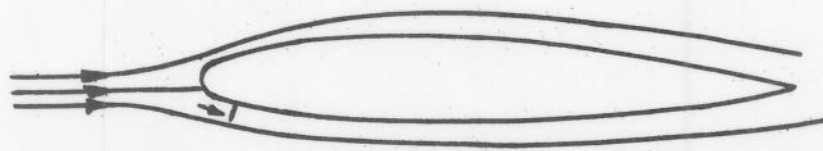
R.G. NEWMAN 6

Summary of stall warning devices. R.A.A.F. Tech. Note 2076

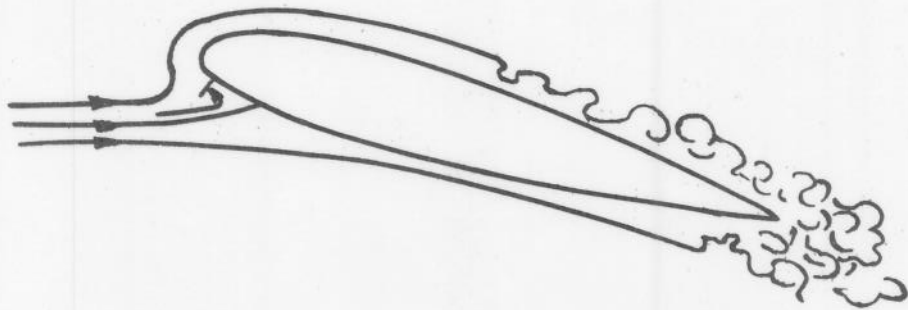
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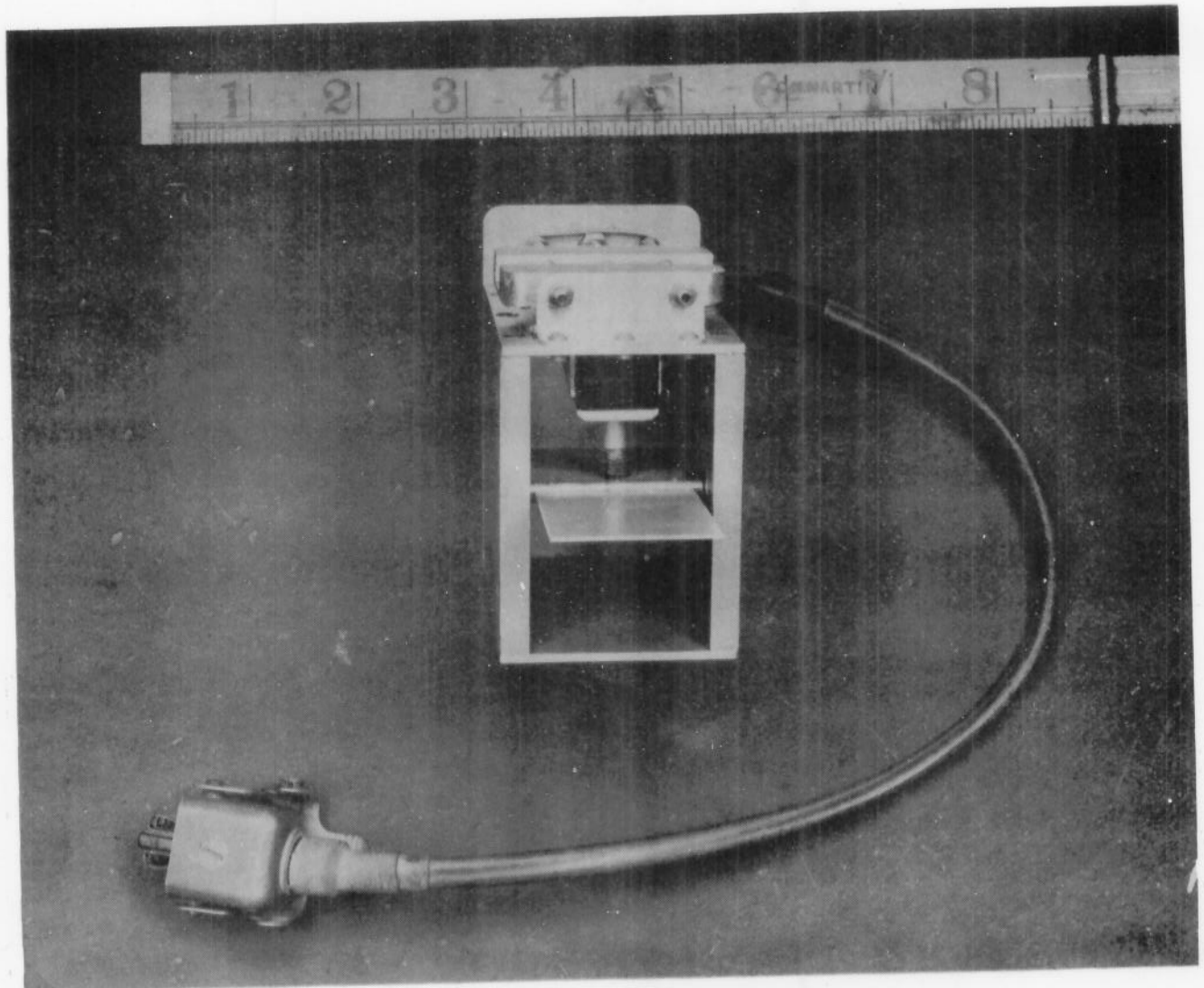
(a) LOW ANGLE OF INCIDENCE



(b) HIGH ANGLE OF INCIDENCE

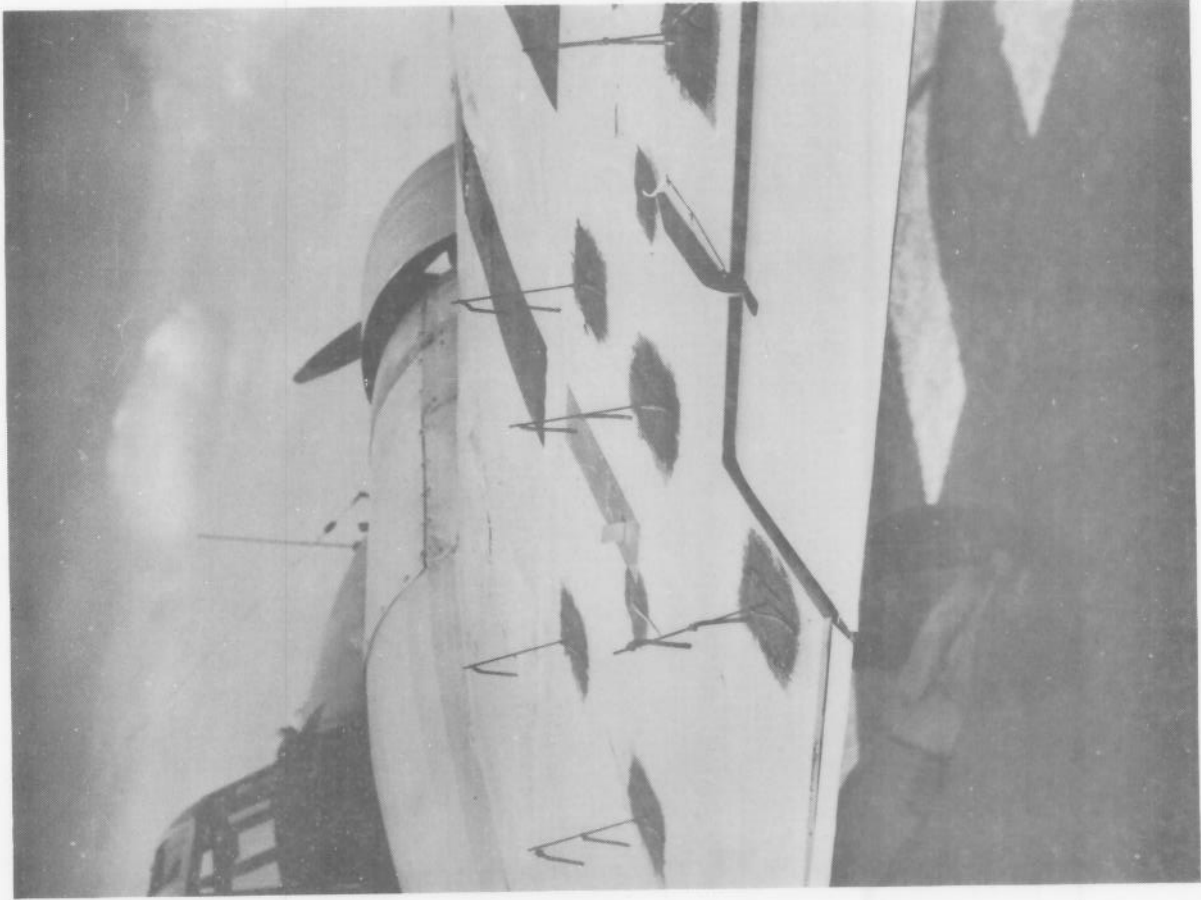
ILLUSTRATION OF THE PRINCIPLE OF A LEADING-EDGE
STALL DETECTOR

FIG. 1.

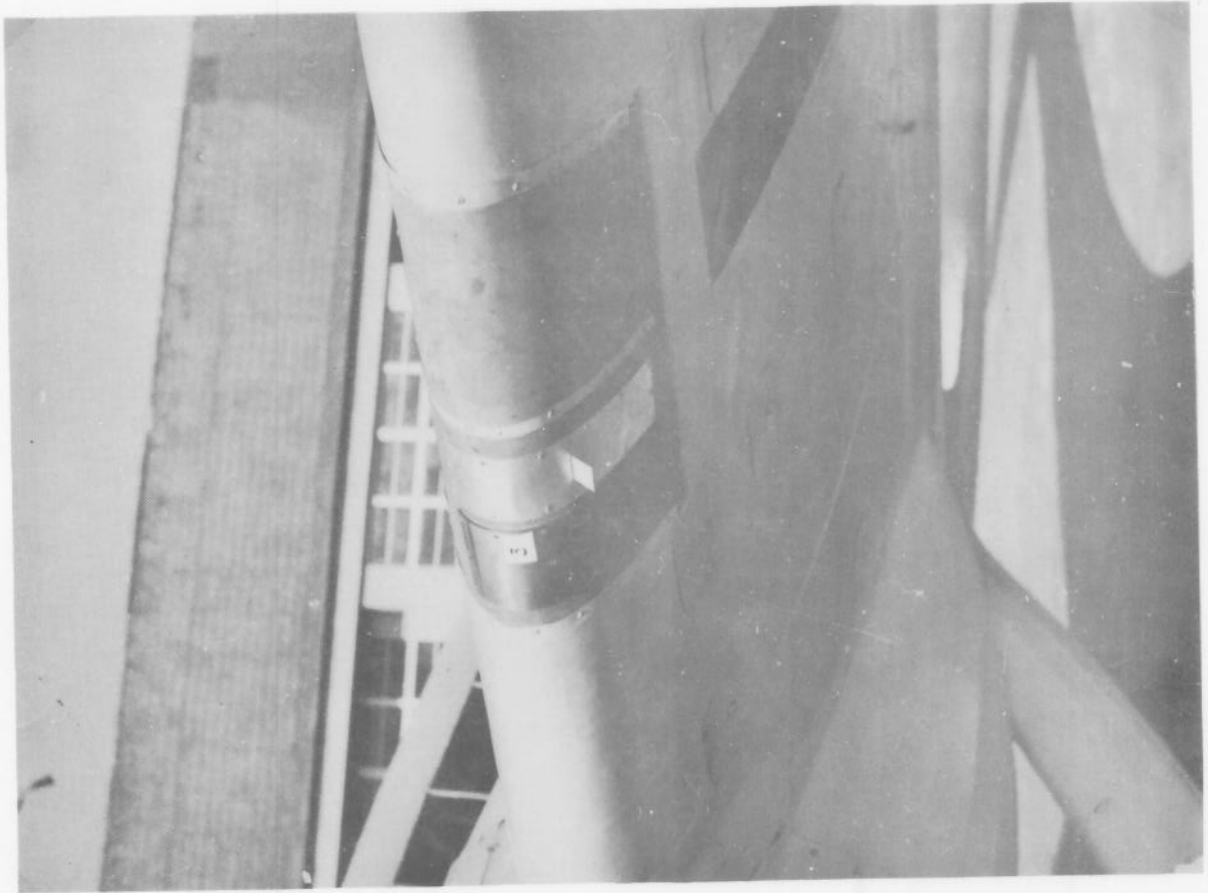


STALL DETECTOR UNIT

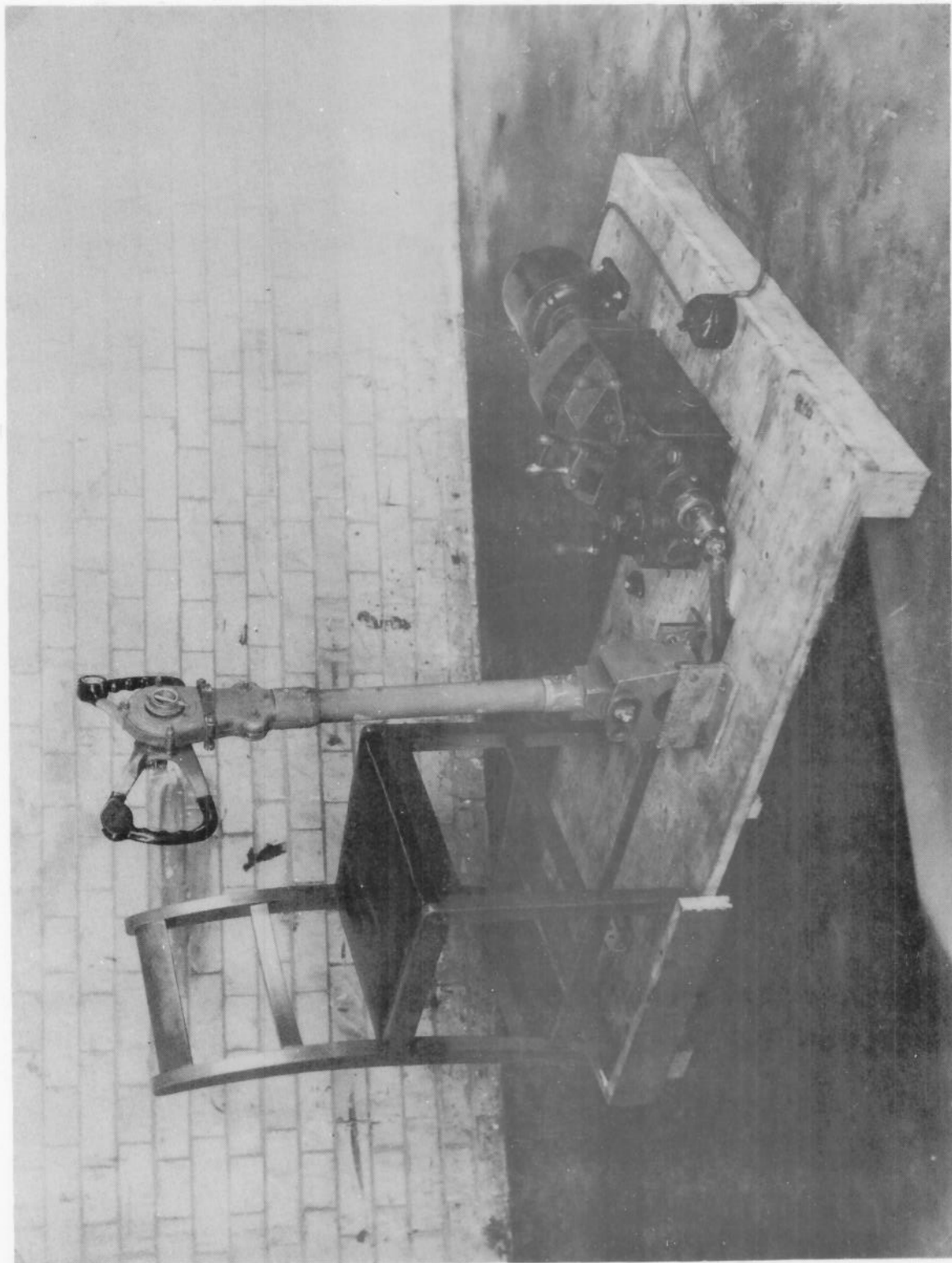
FIG 2



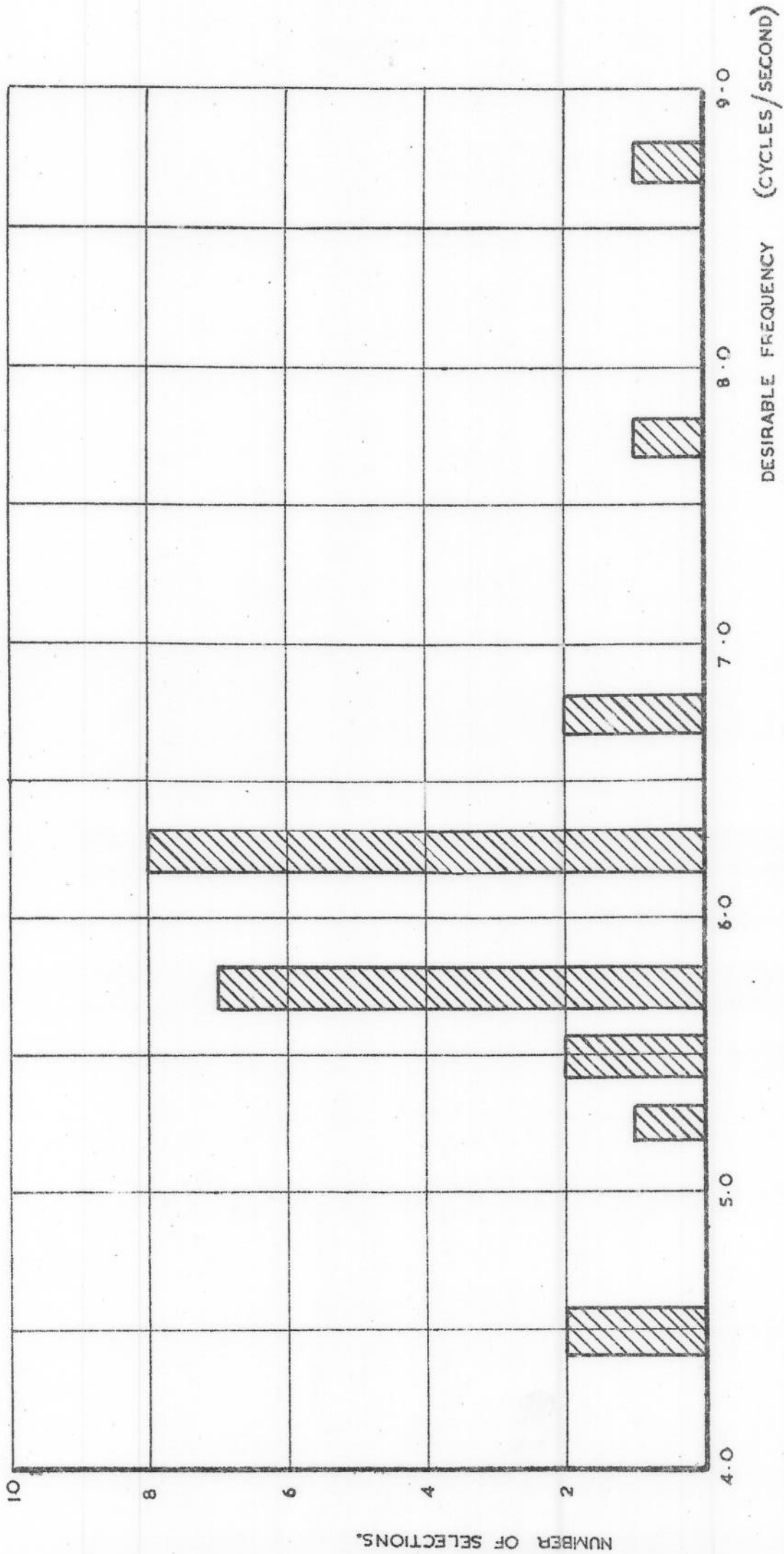
TRAILING-EDGE STALL DETECTOR FIG. 4.



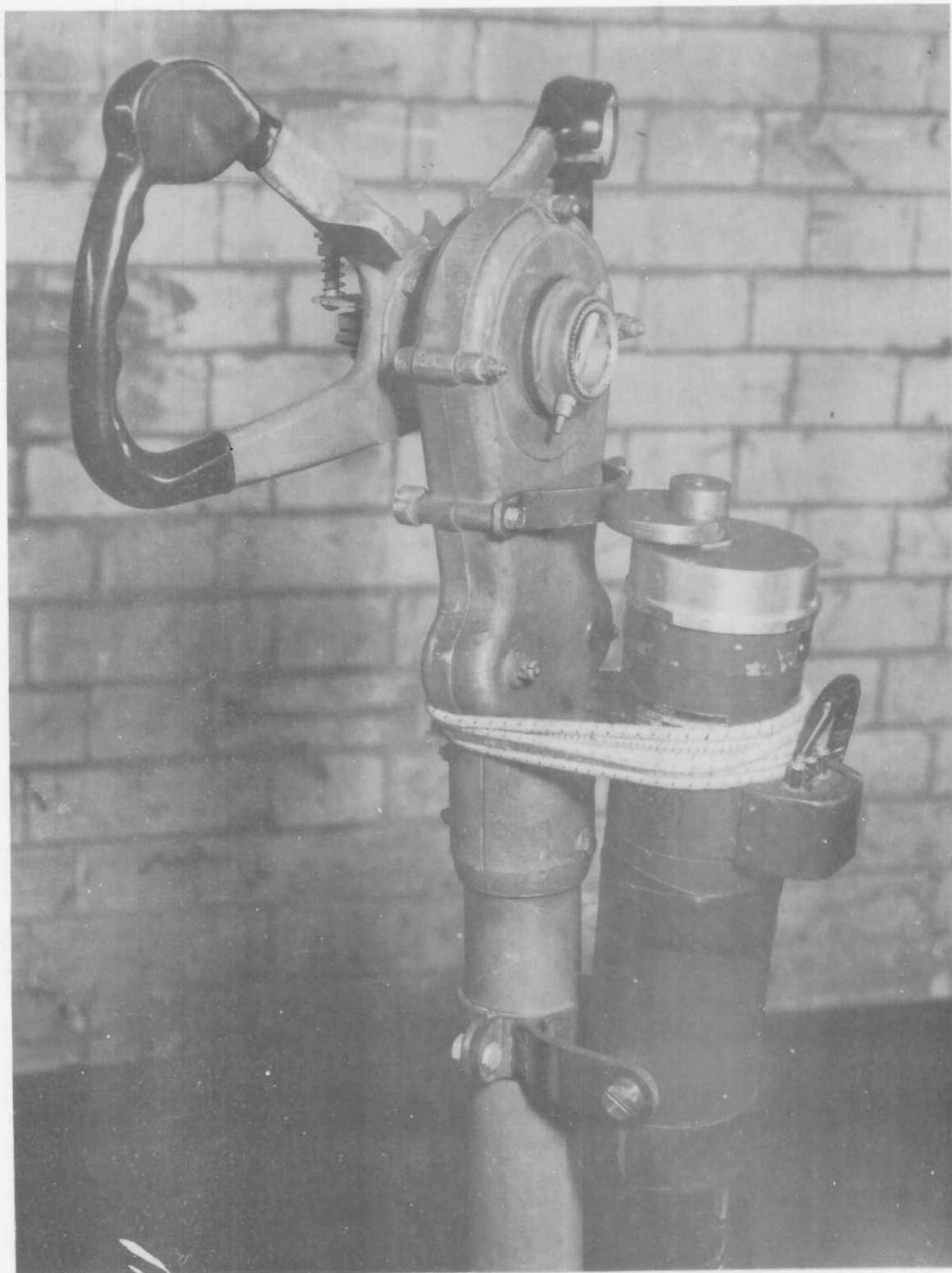
LEADING-EDGE STALL DETECTOR FIG. 3.



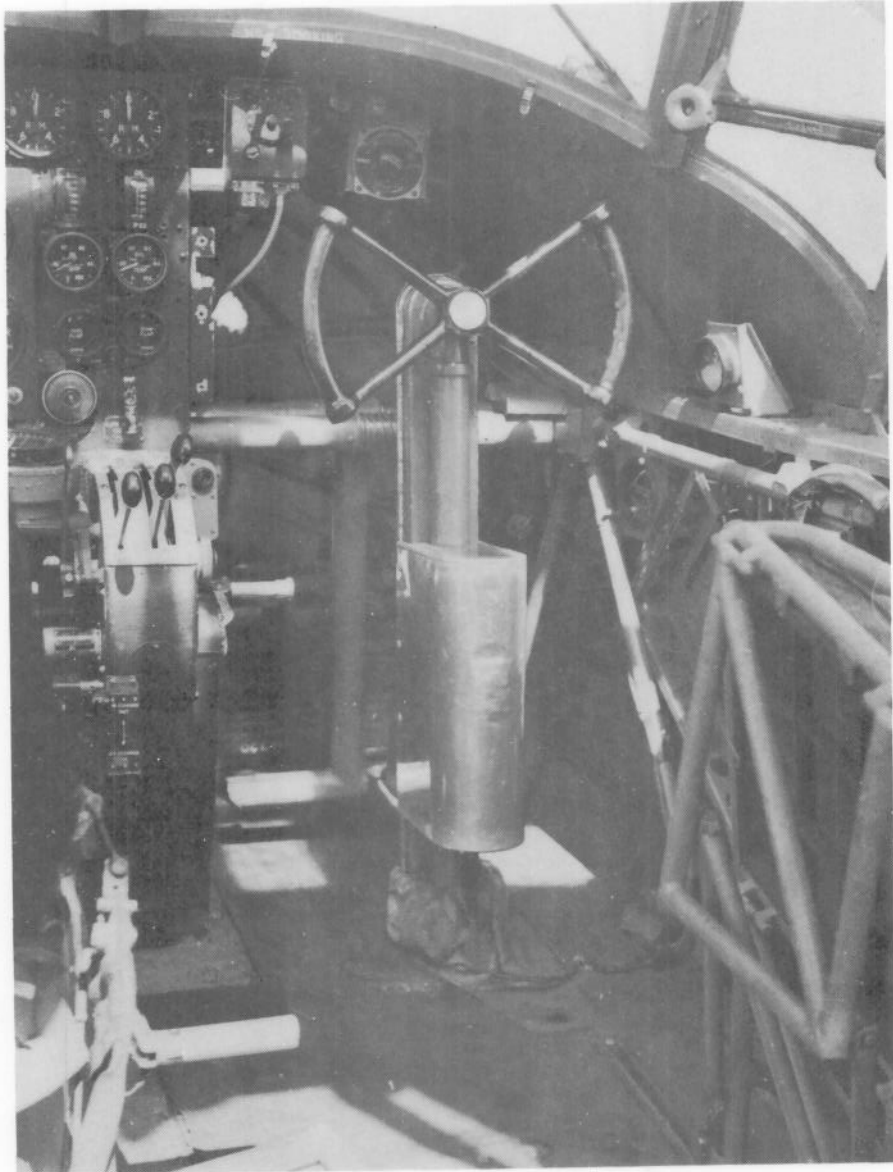
EXPERIMENTAL RIG FOR THE INVESTIGATION OF THE
DESIRABLE CHARACTERISTICS OF A "STICK - SHAKER".



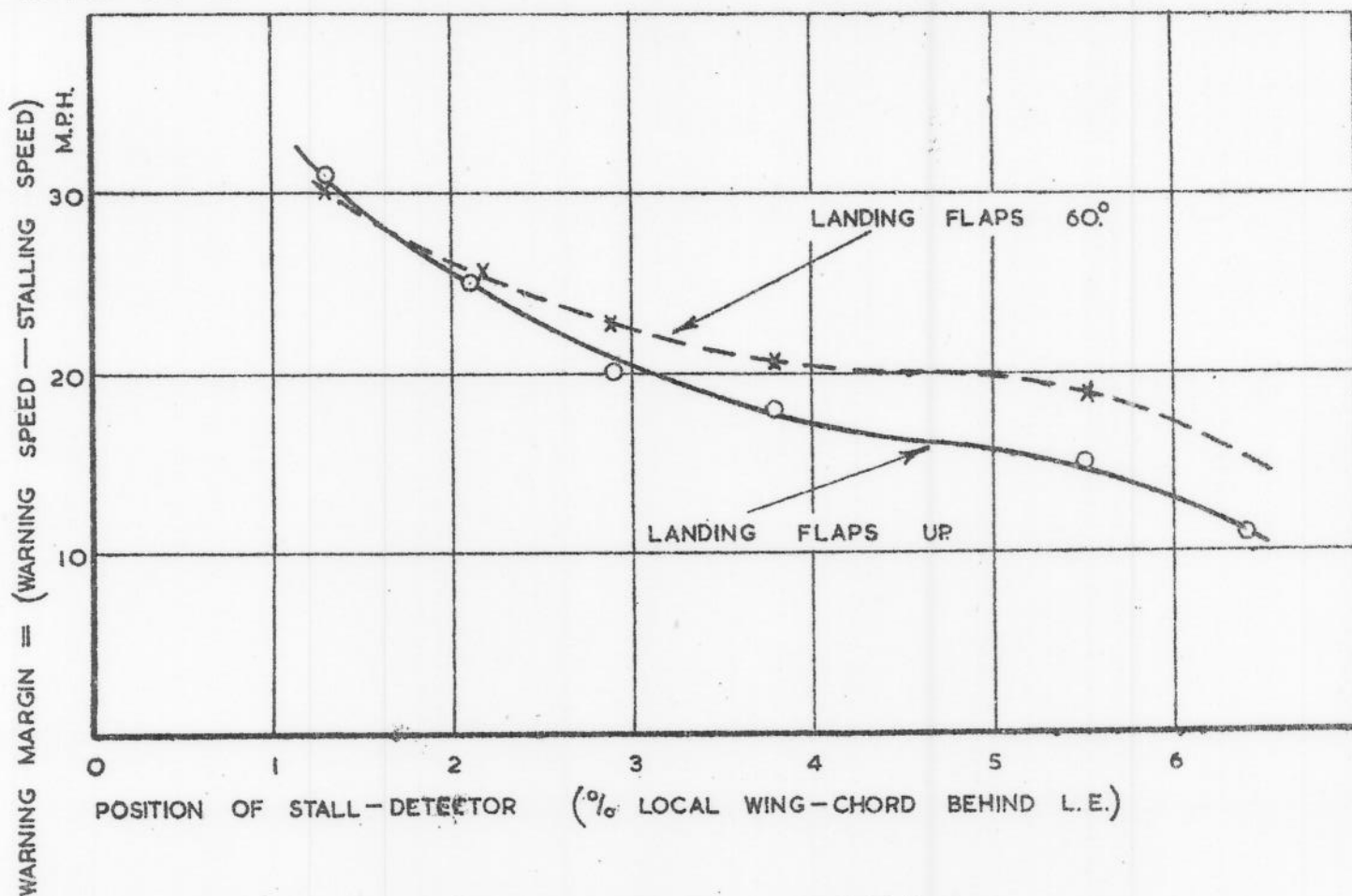
SUMMARY OF PILOTS' SELECTIONS OF DESIRABLE FREQUENCY OF A
STALL-WARNING STICK-SHAKER



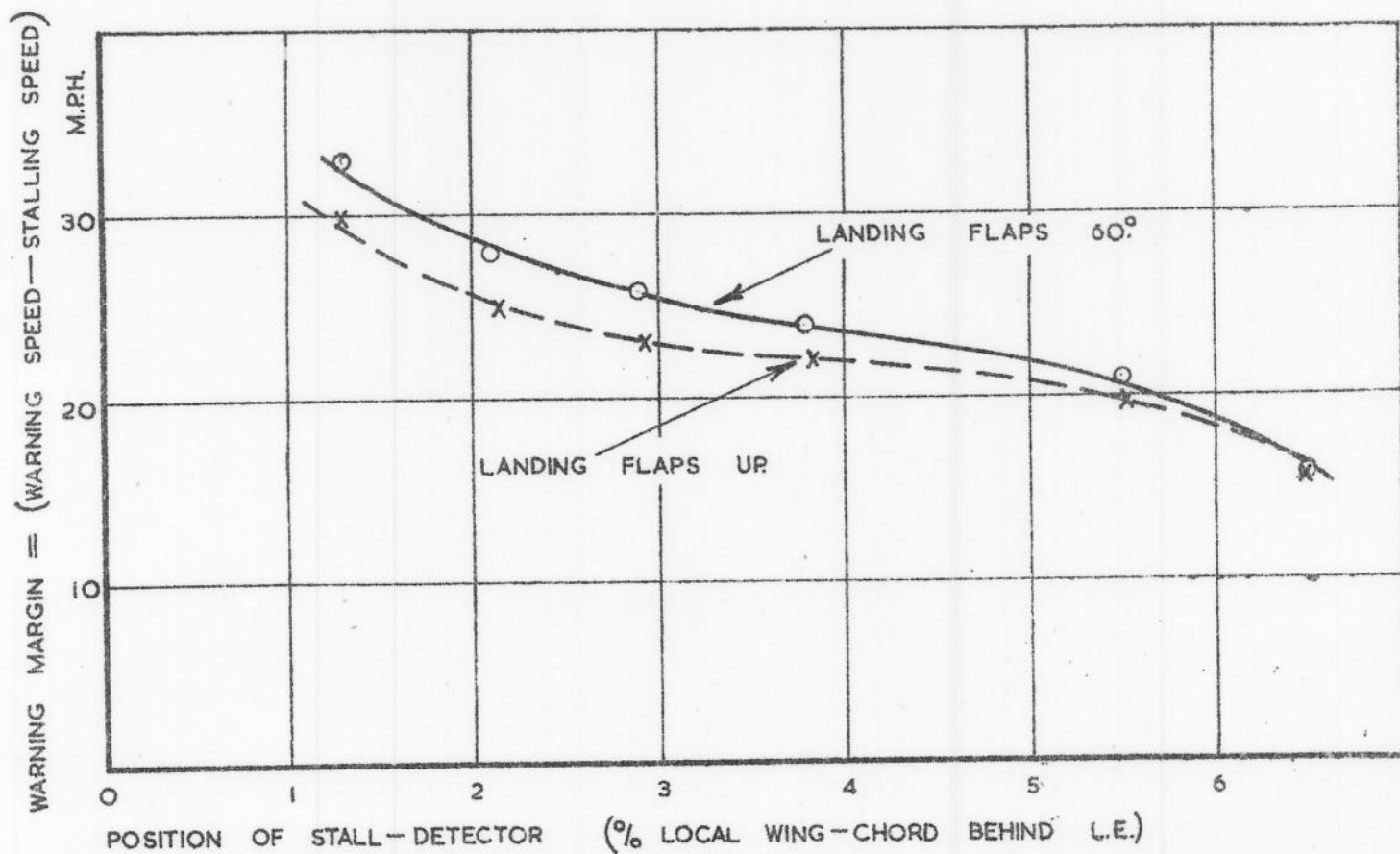
EXPERIMENTAL "STICK SHAKER"



EXPERIMENTAL "STICK-SHAKER" FITTED TO THE
CONTROL COLUMN OF AN ANSON

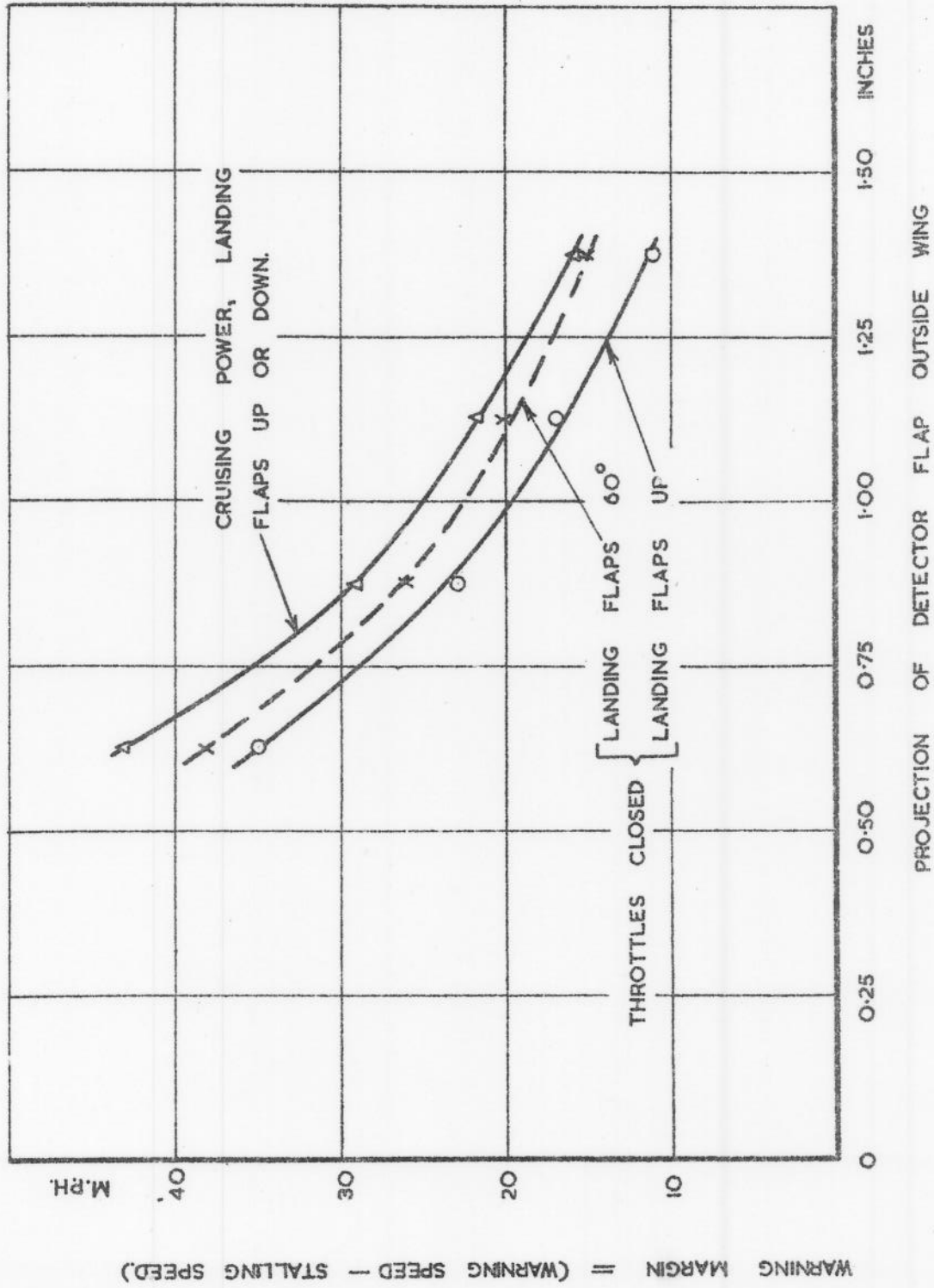


(a) THROTTLES CLOSED.



(b) CRUISING POWER.

VARIATION OF STALL-WARNING MARGIN WITH POSITION OF LEADING-EDGE DETECTOR FLAP.



VARIATION OF STALL-WARNING MARGIN WITH LENGTH OF DETECTOR FLAP PROJECTING OUTSIDE WING. (DETECTOR LOCATED AT 6.4% LOCAL WING CHORD BEHIND L.E.)