EVALUATION OF THE UPSON STALL WARNING INDICATOR

By
James H Hardıng
Flıght Operatıons Dıvısıon

Technıcal Development Report No 213

CIVIL AERONAUTICS ADMINISTRATION
TECHNICAL DEVELOPMENT AND
EVALUATION CENTER
INDIANAPOLIS, INDIANA
September 1953

U S DEPARTMENT OF COMMERCE

Sinclair Weeks, Secretary

CIVIL AERONAUTICS ADMINISTRATION

F B Lee, Administrator

D M Stuart, Director, Technical Development and Evaluation Center

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SUMMARY

This report describes the Upson stall warning indicator, the auxiliary equipment required for test purposes, the test procedure, and the results The flight testing program was performed in a Beechcraft C-45 airplane at the Technical Development and Evaluation Center of the Civil Aeronautics Administration, Indianapolis, Indiana A description of the method used to locate the optimum position of the pressure-measuring orifice on the wing is given

Test results show that this method of actuating a warning mechanism by differential pressures has considerable merit Adequate warning was realized in all stalls except those involving severe slipping and skidding attitudes Data taken during these tests gave evidence that the actuator, not the principle, was the cause of warning failure under these circumstances

INTRODUCTION

As a result of numerous deaths resulting from stall and spin accidents, the development of safe and practical stall warning indicators has received considerable impetus during recent years The need for a suitable device to indicate the approach to a stall prior to loss of control has also been indicated by various studies of pilot performance in recognizing stalls and approaches to stalls

In 1942, Mr Ralph Upson presented to the CAA a stall warning device for further development and evaluation A contract to build a production model of Upson's device was awarded to the Power Equipment Company of Detroit, Michigan Early laboratory work and flight testing were conducted at Detroit by Wayne University under the supervision of Mr Upson and Professor Arthur Locke The Upson indicator consists of a pressure actuator and a visual-aural signaling device for use in the cockpit The actuator is operated by a static pressure reversal which occurs at a point on the leading edge of the wing, depending on the angle of attack when an approach to a stall is encountered

A C-45 airplane was used in the flight testing, because it was found very adaptable for installation of the necessary equipment and because all of the tests performed on this airplane could apply to most single or multiengine aircraft with or without flaps or retractable gear

During the time required for installation of the test equipment, the stall warning system was bench-tested to determine its operational limits under ideal conditions This was also used to develop criteria for evaluating the performance obtained in actual flight testing A record of all flight testing was made on a 70-millimeter (mm) film by means of a special camera-instrument arrangement

This report is specifically an in-flight evaluation of the Upson stall warning indicator, which evaluation was conducted at the TDEC

DESCRIPTION OF APPARATUS

The Upson stall warning indicator consists of the following four basic parts, as shown in Fig 1

1 A pressure orifice located in the leading edge of the wing

2 A chamber divided into two sections by a flexible nonporous diaphragm, one side of the chamber being connected by a tube to the leading-edge pressure orifice and the other vented to atmospheric pressure

3 A microswitch actuated by a piston connected to the center of the diaphragm

4 An indicator consisting of a light and horn arrangement for both visual and aural indication and actuated by the afore-mentioned microswitch

In addition to the usual aircraft instruments, a panel was designed to hold nine test instruments including the Upson stall warning indicator

1 Air-speed indicator, Eclipse-Pioneer Division of Bendix Aviation Corporation, Type C-14, 0 to 300 miles per hour (mph)

2 Differential pressure gage, -30 inches of H_2O to +30 inches of H_2O

3 Sensitive altimeter, Kollsman Instrument Division of Square D Company, Type C-12

4 Differential pressure gage, -30 inches of H_2O to +30 inches of H_2O

5 Upson stall warning indicator

6 Free air temperature gage, Weston Electrical Instrument Corporation, Type AN 5790-6, -50° to +120° C

7 Angle-of-attack indicator, Kollsman Instrument Division of Square D Company, Type No 889-01

8 Clock, Waltham Watch Company, Type AN 5743T1A

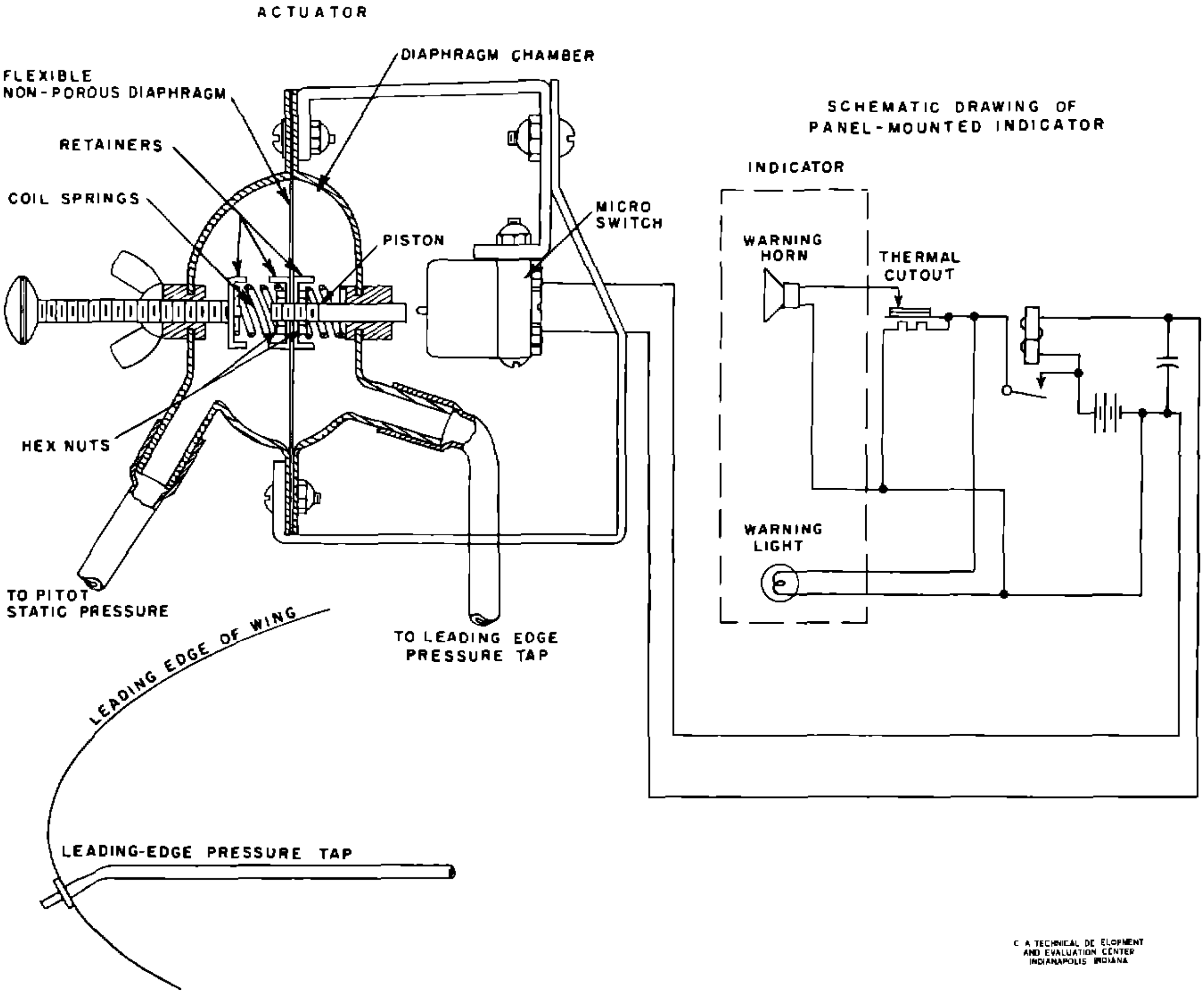

Fig 1 Diagram of Upson Stall Warning Indicator

9 Differential pressure gage, -30 inches of H_2O to +30 inches of H_2O

The test panel is illustrated in Fig 2, and a diagram of instrument connections is shown in Fig 3

The angle-of-attack transmitter (Kollsman Instrument Division of Square D Company, Type No 889T) was mounted at the end of a boom projecting 37 inches ahead of the door on the nose of the aircraft See Fig 4 The power for this transmitter and its indicator was supplied by the standard 26-volt, 400-cycle per second (cps) inverter of the airplane A special 70-mm camera was used to record the indications of the test instruments

Several variables had to be taken into consideration before any actual flight testing could be accomplished The chordwise location of the pressure orifices on the wing had to be determined with regard to a representative cross section of the airfoil Spanwise, the orifices had to be located outboard of all possible propeller slip-stream confusion The latter requirement had to be further considered for slipping and skidding attitudes (whereby the slip stream is diverted laterally), depending upon the direction and intensity of the slip or skid After examination of aerodynamic and structural factors a position on the left wing, Fig 5, was decided upon This position corresponds to that housing the red warning light, or passing light The warning-light shield was replaced with one of dural at the same location Two slots were cut in the aluminum shield, as shown in the figure, one for the lower sector of the leading edge and one for the upper

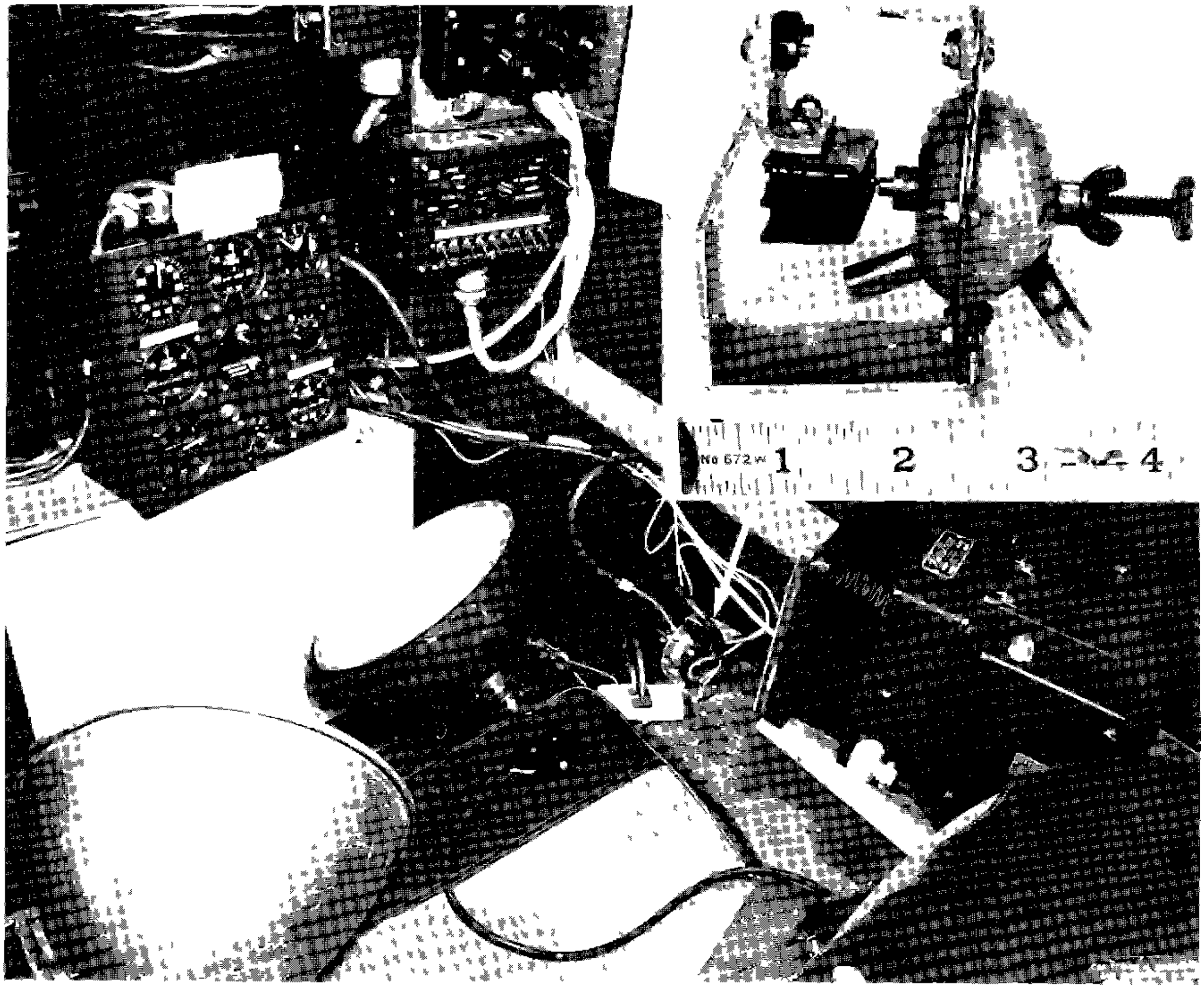

Fig 2 Evaluation Test Equipment

To make a complete evaluation of the stall warning device, it was necessary to explore the existing pressures over the entire leading edge in the predetermined vertical plane The slots were of such dimensions that the pressure orifices could extend through the openings and be adjustable up or down as desired In order that the air flow about the leading edge would not be affected by the slots in the wing, a piece of flexible aluminum was mounted with the pressure orifice behind each groove and was made movable by the use of guides The final result was a pair of pressure orifices which were independently adjustable without altering any of the aerodynamic characteristics of the wing in that immediate area The distance from the wing root to a line intersecting the lower pressure orifice and perpendicular to the main spar was 100 1/4 inches A like measurement placed the upper orifice at 103 inches

Two copper tubes with flexible hose at the ends were used to connect the pressure orifices with the stall warning actuator and the associated pressure gages Tubing was installed in a similar manner to provide the test instrument panel with Pitot static and impact pressures Differential pressure gages were used to measure the pressure at upper and lower leading-edge orifices This was done to eliminate the necessity of calculating absolute pressure from gage pressure, since the altimeter was the only means of registering atmospheric pressure

By venting the static connection of each differential pressure gage to Pitot static pressure and by venting the pressure connection to the test source, absolute pressure readings were obtained directly

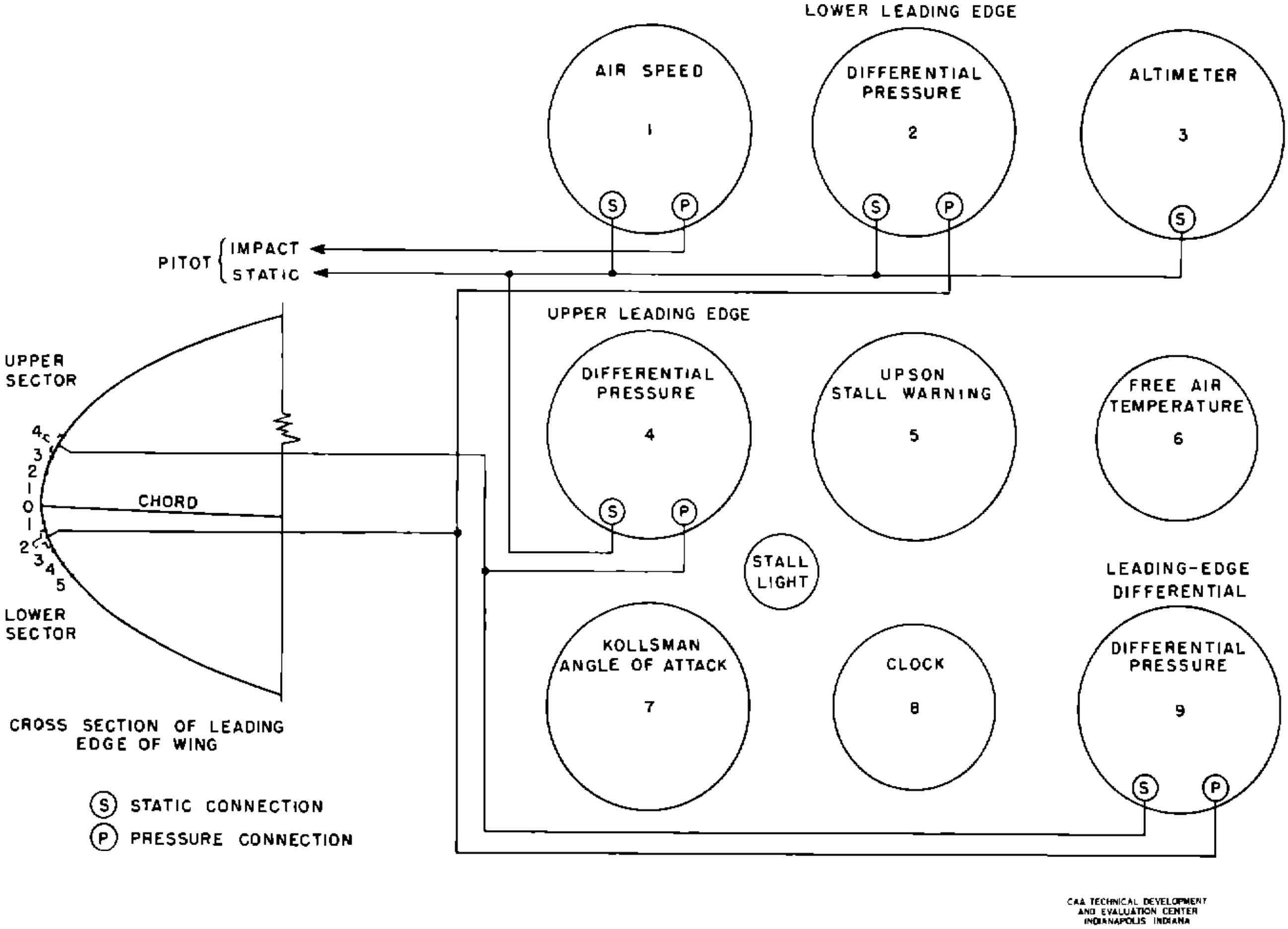

Fig 3 Diagram of Test Panel With Pressure Installation Shown Schematically

The remaining instruments were used to obtain information pertinent to the attitude of the aircraft and to the atmospheric conditions prevailing at the time of the tests

The stall warning actuating mechanism was mounted with the plane of the diaphragm vertical and with the diaphragm piston linkage of the microswitch parallel to the longitudinal axis of the aircraft, in order to minimize piston movement caused by gravity forces resulting from turbulent air

METHOD OF TESTING

A flight test procedure was formulated in order to cover comprehensively most of the attitudes which cause an aircraft to stall It was deemed necessary to stall the airplane by using (1) cruising power which was arbitrarily chosen as 22 inches of mercury and 1,900 revolutions per minute (rpm), (2) power off, (3) climbing and gliding attitudes, (4) turning with a 30° angle of bank, (5) straight lines of flight, (6) gear up and down, (7) flaps up and down (30°), and (8) all combinations of various power settings and lines of flight The following flight test outline was used to differentiate between the various stalls In this outline each stall was classified as to category, and each category was subdivided into flight configurations or lines of flight,

Flight Test Sequence

I Straight and level stalls, cruising power (22 inches of Hg and 1,900 rpm)
- A Climb, gear and flaps up
- B Climb, 30° flaps
- C Climb, 30° flaps, gear down

II Straight and level stalls, power off
- A Descent, gear and flaps up
- B Descent, 30° flaps
- C Descent, 30° flaps, gear down

III Left-turn stalls, cruising power
- A Climb, gear and flaps up
- B Climb, 30° flaps
- C Climb, 30° flaps, gear down

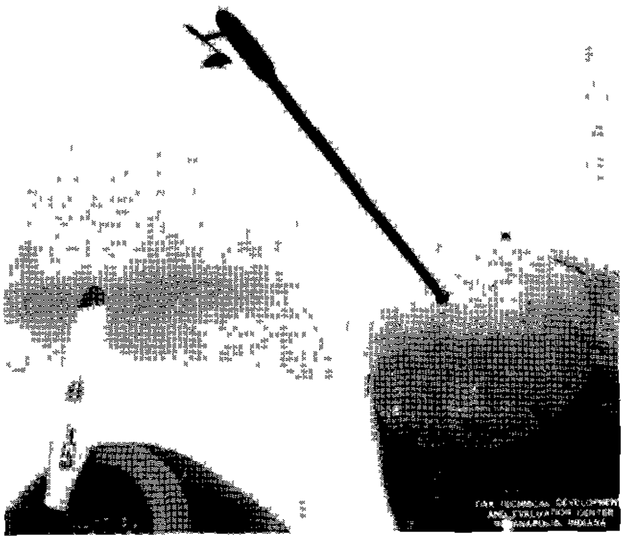

Fig 4 Kollsman Angle-of-Attack Installation

IV Right-turn stalls, power off
- A Descent, gear and flaps up
- B Descent, 30° flaps
- C Descent, 30° flaps, gear down

V *Right-turn stalls, cruising power*
- A Climb, gear and flaps up
- B Climb, 30° flaps
- C Climb, 30° flaps, gear down

VI Left-turn stalls, power off
- A Descent, gear and flaps up
- B Descent, 30° flaps
- C Descent, 30° flaps, gear down

VII Slipping-turn stalls, power on
- A Left-turn stall
- B Right-turn stall

VIII Skidding-turn stalls, power on
- A Left-turn stall
- B Right-turn stall

IX High-speed stalls, power on
- A Left-turn stall
- B Right-turn stall

Each picture taken of the test panel was titled accordingly

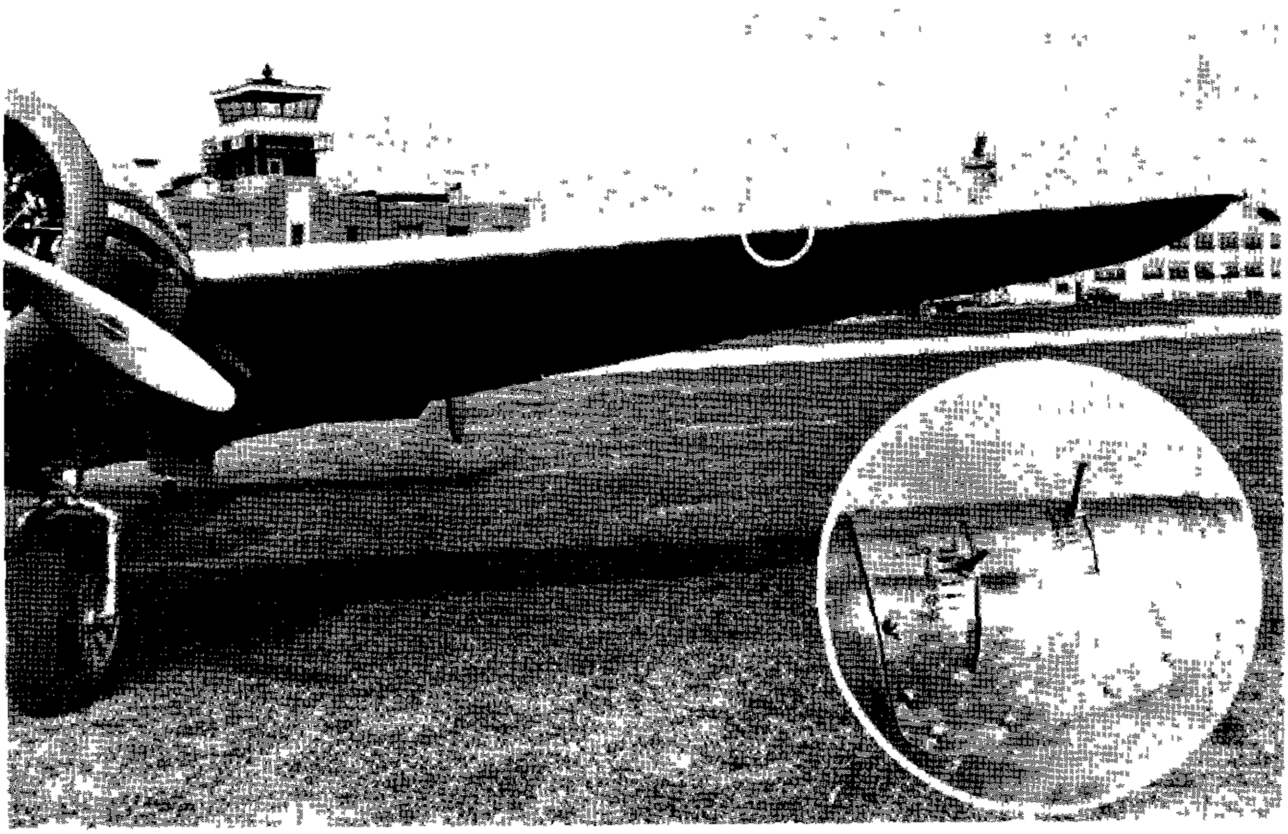

Fig 5 Pressure-Orifice Installation

The preliminary problems were to determine the optimum location for the pressure orifices and to determine whether a semiflush type or a tubular type of orifice would give the more accurate pressure information Graduations were marked on the leading edge of the shield adjacent to each pressure-orifice slot The zero or reference line (a projection of the chord plane on the leading-edge contour) was common to both, and graduations were measured in 1/4-inch increments up and down from this line for the upper and lower orifices respectively The lower sector was numbered 0 to 5 and the upper sector was numbered 0 to 4 Fig 3 shows the contour of the leading edge of the airfoil and shows the pressure opening locations which were explored Three possible locations of the pressure orifices can be described The lower sector had a dual application, as described in Nos 1 and 2 of the following

1 When placing the orifice in position 4 or 5, the pressure changed from negative to positive as the angle of attack increased

2 When placing the orifice in positions 0 through 3, the pressure changed from positive to negative as the angle of attack increased

3 The upper sector had only one application — that of registering a continuously increasing negative pressure as the angle of attack increased

The entire problem was based on the movement of the stagnation point and its associated pressure pattern about the leading edge of the wing with a change in the angle of attack A diagram of the pressure distribution around the leading edge of the wing is shown in Fig 6

With these applications in mind, flight testing was begun A flight was made for each pressure-orifice location with stalls I A and II C used in each flight Pictures were taken in order to have an accurate comparison of the results The method used in taking

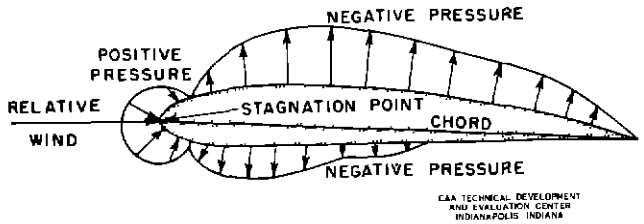

Fig 6 Cross Section of Airfoil in Flight and Showing Pressure Distribution Around Leading Edge

pictures was as follows As the approach to the stall was started the flood lights were turned on, and the observer watched the test panel to determine when to start the camera Pictures were taken at 120 mph, 110 mph, 105 mph, and every five miles per hour thereafter, until the stall warning light was actuated From this instant until the full stall was completed, the camera ran continuously taking pictures at the rate of one per second In instances where the warning did not appear at 81 mph or above, pictures were taken continuously from 80 mph until the stall occurred The actual stall was registered on the test panel by an improvised warning light which was connected to a microswitch located on the pilot's control wheel and which was actuated by him at the first indication of a complete stall Both the preliminary and the final testing were accomplished in this manner After the initial flight testing was completed, the films were developed and processed to determine the orifice design and location to be used in the final test

DISCUSSION OF DATA AND RESULTS

Laboratory tests showed that the diaphragm and its associated actuating mechanism had pressure operating limits ranging from 0 75 to 3 inches of water, depending upon the spring-tension adjustment As a result of poor workmanship in the manufacture of the actuator, excessive leakage occurred The device was reworked in order to seal the leaks Further laboratory testing showed that the device was operating within limits necessary to permit flight testing The warning-horn portion of the indicator failed early in the program and was disconnected Testing was continued with visual indication only

Several flights were made to determine whether the semiflush orifice or the tubular orifice provided better information After the in-flight performance was observed and the results were viewed on film, it was determined that the tubular orifice was in use when the most accurate results were obtained All further testing was accomplished with the tubular type of orifice

The actuator spring tension was adjusted in flight to give a consistent warning at an air speed 10 miles per hour greater than stalling air speed for a Type 1A stall A negative pressure of two inches of water proved to be the necessary actuating force After several different stalls were performed to insure that the operation was as desired, the formal test series was started Test results are given in Table I

TABLE I

RESULTS OF FLIGHT TESTS

Each stall is listed twice The first has information associated with V_w only and the second has V_s information only

Category	Air Speed V_w (mph)	Air Speed V_s (mph)	Lower Leading-Edge Pressure H_2O (inches)	Upper Leading-Edge Pressure H_2O (inches)	Leading-Edge Differential Pressure H_2O (inches)	Angle of Attack (degrees)	Stall Warning Indicator (On-Off)	Actual Stall Indicator (On-Off)	Altitude (feet)	Free Air Temperature (degrees C)	Ratio V_w/V_s
I A	70		-2	-14	12 5	14 5	On	Off	6840	12	1 17
I A		60	-3	-14 5	12 5	18	On	On	6940	11	1 17
I B	59		-2	-11	10	15	On	Off	7040	10	1 21
I B		49	-4 5	-15 5	12	22	On	On	7070	10	1 21
I C	60		-2	-12	11	16	On	Off	6920	10	1 20
I C		50	-5	-16 5	12 5	21 5	On	On	6940	10	1 20
II A	72		-2	-13 5	12	16	On	Off	6540	10	1 03
II A		70	-2	-13	12	16 5	On	On	6540	10	1 03
II B	62		-3	-15	13	19	On	Off	6000	11	1 05
II B		59	-1 5	- 9	8 5	16	On	On	5970	11	1 05
II C	69		-2	-12	11	15	On	Off	5450	11	1 08
II C		64	-2	-13	12 5	16	On	On	5420	12	1 08
III A	75		-2 5	-15 5	14	15	On	Off	5400	15	1 14
III A		66	-4	-18	15	18 5	On	On	5440	15	1 14
III B	62		-2	-12	10 5	15	On	Off	5410	15	1 15
III B		54	-5	-18	14	20	On	On	5430	15	1 15
III C	66		-2 5	-14	12	16	On	Off	5100	15	1 14
III C		58	-5	-19	15	21 5	On	On	5110	15	1 14
IV A	77		-2	-15	13 5	15	On	Off	3900	18	1 10
IV A		70	-2 5	-14	13	17	On	On	3900	18	1 10
IV B	70		-2 5	-15	13	16	On	Off	3290	19	1 08
IV B		65	-2	-12	11	16	On	On	3280	19	1 08
IV C	71		-1 5	-10	10	12	On	Off	3010	19	1 08
IV C		66	-2 5	-14 5	13	14	On	On	3000	20	1 08
V A	75		-2	-14 5	13	14 5	On	Off	3510	19	1 34
V A		56	-4 5	-17 5	14	22	On	On	3640	19	1 34
V B	63		-2	-12 5	11	12 5	On	Off	3540	19	1 24
V B		51	-6	-19	14	21 5	On	On	3580	19	1 24
V C	66		-2 5	-14	12	15	On	Off	3300	19	1 22
V C		54	-6	-18 5	14	21	On	On	3330	19	1 22
VI A	79		-2 5	-16 5	15	16 5	On	Off	4740	16	1 05
VI A		75	-2	-14	13	13 5	On	On	4740	16	1 05
VI B	75		-2	-14	13	14	On	Off	4340	17	1 09
VI B		69	-2 5	-14	12 5	16	On	On	4300	17	1 09
VI C	73		-2	-13 5	12	13 5	On	Off	3320	18	1 00
VI C		73	-1	-10 5	10	16	Off	On	3300	19	1 00
VII A		90	0	- 9 5	10 5	14	Off	On	3780	19	No Warning
VII A		79	0	- 5	6 5	Erratic	Off	On	4080	19	No Warning Repeated Test
VII B	76		-2 5	-14	12 5	16	On	Off	4000	19	1 17
VII B		65	-6	-19 5	14 5	21 5	On	On	4050	19	1 17
VIII A	83	83	-3	-16	14	16	On	On	4370	18	1 00
VIII B		80	-1	-13	13	15	Off	On	4430	17	No Warning
VIII B		85	-1	-13	13	19 5	Off	On	4590	18	No Warning Repeated Test
IX A	115		-3	-27 5	25 5	12	On	Off	4380	18	1 10
IX A		105	-6	-32	30	14 5	On	On	4370	18	1 10
IX B	105		-2 5	-24	22 5	18	On	Off	4430	18	1 13
IX B		93	-1 5	-15 5	15 5	18	On	On	4500	18	1 13

In this table V_w refers to the air speed at which the stall warning indicator was first actuated, and V_s refers to the air speed recorded at the time the aircraft actually stalled The column $\frac{V_w}{V_s}$ gives an index, or ratio, between these two factors Obviously, the greater this ratio, the greater the stall warning margin In cases where the margin ranges from unity to approximately 1 05, warning would be considered unsatisfactory With the foregoing as a basis for satisfactory operation, the listed stalls in Table II were not preceded by satisfactory warning

Two reasons for these unsatisfactory results can be deduced First, the flight conditions for the final test were not perfect, however, the weather conditions represented the average to be encountered rather than the exception The second, and probably the greatest reason for unsatisfactory results, was the poor workmanship in the actuating mechanism In every stall except No VII A, which was a violent slipping left turn, enough negative pressure was registered on the pressure gage to actuate the mechanism if it had been properly designed For instance, in stall No VIII A, a negative pressure of three inches of water was required to trigger the actuator It appears, then, that gravity forces were causing a cancelling effect in the actuator Gravity and inertia forces must be kept to an absolute minimum because an aircraft is subjected to abnormal attitudes, forces, and vibrations in stalls This is especially true when they tend to nullify the pressure forces In one instance, stall No VII A (where zero pressure was registered), leaks in the actuator housing were strongly suspected as the cause

It was very interesting to note that with the bottom pressure orifice in the No 2 position and the upper orifice in No 4 position, the leading-edge differential pressure gage (No 9 in Fig 3) gave angle-of-attack indications which were in very close agreement with the Kollsman vane type of indicator The differential pressure method gave oscillations and fluctuations of less magnitude and frequency but gave very quick response to any abrupt change in angle of attack

TABLE II*

UNSATISFACTORY RESULTS OF FLIGHT TESTS

Stall Category	V_w (mph)	V_s (mph)	$\frac{V_w}{V_s}$
II A	72	70	1 03
VI C	73	73	1 00
VII A	No warning	90	- --
VII A (repeated)	No warning	79	- --
VIII A	83	83	1 00
VIII B	No warning	80	- --
VIII B (repeated)	No warning	85	- --

*These results are given in greater detail in Table I

CONCLUSIONS

The results obtained from the various flight tests indicate that the pressure reversal method of actuating a stall warning device has considerable merit It was found that in severe slipping and skidding turns adequate warning was not obtained In spite of the inadequate warning, however, there was enough negative pressure registered to operate a properly designed actuator

It is reasonably certain that a more carefully designed pressure chamber (cast or machined of heavier metal, equipped with the pressure fittings attached in a more positive manner, or even made an integral part of the chamber) would have given much more reliable operation It also appears that better adjustment of the actuator pressure limits could be had if the microswitch were made movable parallel to the axis of the actuator piston Changing the spring tension against the diaphragm by means of a screw and wing-nut arrangement was unsatisfactory If the movement of the diaphragm were opposed only by a spring of known constant and if the piston clearance were adjustable in the suggested manner, the negative pressure that would be required to actuate the switch would be a direct function of the spring constant In this manner the pressure limits needed to actuate the microswitch could be increased, allowing a greater flexibility of installation

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