STALL RECOGNITION IN A LIGHT AIRPLANE

by

P. J. RULON

A report on research conducted at the Educational Research Corporation, Cambridge, Massachusetts, under the auspices of the National Research Council Committee on Aviation Psychology, with funds provided by the Civil Aeronautics Administration.

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National Research Council

Committee on Aviation Psychology

Executive Subcommittee

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National Research Council

1949

LETTER OF TRANSMITTAL

NATIONAL RESEARCH COUNCIL

2101 Constitution Avenue, Washington, D. C.
Division of Anthropology and Psychology

Committee on Aviation Psychology

May 18, 1949

Dr. Dean R. Brimhall
Civil Aeronautics Administration
Room 5217, Commerce Building
Washington 25, D. C.

Dear Dr. Brimhall:

The attached report, entitled Stall Recognition in a Light Airplane, by P. J. Rulon, is submitted by the Committee on Aviation Psychology with the recommendation that it be included in the series of Technical Reports of the Division of Research, Civil Aeronautics Administration.

The present report, concerned with a study of the cues used by expert pilots in the recognition of the incipient stall, is the third in a series of reports on research in stall recognition and avoidance conducted by the Educational Research Corporation under the direction of Dr. P. J. Rulon. As a result of the first study, which revealed consistent failure on the part of student pilots, private pilots, and flight instructors in the detection of pre-stall conditions in light aircraft, the Committee on Aviation Psychology recommended that "regulations be formulated requiring the installation of approved stall warning devices in all private airplanes, providing field tests demonstrate that available instruments can be adequately maintained and function properly over an extended period."

The results of the present investigation support that recommendation and suggest additional steps which might be taken to render more adequate the indoctrination of civilian pilots with respect to the problem of stall recognition and avoidance.

Cordially yours,

M S Viteles

Morris S. Viteles, Chairman
Committee on Aviation Psychology
National Research Council

MSV:maf

EDITORIAL FOREWORD

Research on stall recognition and stall avoidance has represented a major activity of the Committee on Aviation Psychology for the past two years. Interest in this problem developed, in large part, from a survey of CAA accident reports and from systematic studies, by D. R. Brimhall and R. Fransen, which indicated that many accidents in light aircraft follow an inadvertent stall.[1]

The first study in the series revealed a marked inaccuracy among flight instructors, private pilots, and student pilots in recognizing the incipient stall.[2] Supplementary analysis of data showed that such accuracy in stall recognition as existed tended to be specific to the flight situation. In other words, pilots who can recognize the "edge of the stall" with relative accuracy in one maneuver or condition of flight fail to do so when flying under other conditions or when executing other maneuvers.[3]

The purpose of the present study was to determine the specific sensory cues employed by experienced pilots in recognizing the approach to the stall.[4] One important finding was that variation in the uniform rate of turn was used to a great extent by experts in "calling" the incipient stall in this maneuver. It was noted that this cue has received little attention in literature generally read by the private pilot.

As a result of earlier studies referred to above, the Committee on Aviation Psychology recommended to the Civil Aeronautics Administration that "regulations be formulated requiring the installation of approved stall-warning devices in all private airplanes, providing that field tests demonstrate that available instruments can be adequately maintained and function properly over an extended period." The results of the present study further support this early recommendation, and it is again specifically recommended that regulations be issued requiring the installation of some form of lift, stall, or angle-of-attack indicator in every licensed private airplane.

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[1] Fransen, Raymond, & Brimhall, Dean R. A study of serious and fatal accident records during 1939 and 1940. Washington, D.C.: CAA Division of Research, Report No. 77, May 1948.

[2] Rulon, P. J. A study of the accuracy of recognition of the incipient stall in familiar and unfamiliar planes. Washington, D.C.: CAA Division of Research, Report No. 74, November 1947.

[3] Rulon, P. J. The inconsistency of pilot performance in approaching the stall: relationship to flight conditions, experience, and age. Washington, D.C.: CAA Division of Research, Report No. 79, September 1948.

[4] Another experimental attack on this problem has been made through studies of flight performance under conditions in which the pilot is deprived of the use of certain sensory cues. The report on this investigation is in preparation.

Accompanying this primary recommendation is the suggestion that a regulation calling for the installation and maintenance of a ball-bank indicator, an airspeed indicator, a tachometer, and an altimeter may be considered as an alternative to the requirement that a stall-warning device be installed in all licensed private planes. However, this is definitely presented as a secondary recommendation, for consideration only if the situation makes it impossible to require the installation and maintenance of a stall-warning device. It is to be noted that, apart from the problems involved in maintaining four instruments, objections can be raised to the basic implication that the airspeed and ball-bank instruments be considered primary flying instruments to which major reference should be made as a source of stall cues.[5]

The import of the recommendations outlined above is that the human organism is an inadequate stall detector and that dependence should be placed upon an instrument rather than upon the human organism for the recognition of the incipient stall. However, so long as such regulations are not in effect, and dependence is placed upon the human organism, steps should be taken to better prepare the individual to recognise the incipient stall. Specific recommendations to cover this situation are that:

1. CAA bulletins be revised to include a more definite statement of the cues which can be utilized by experienced pilots in recognizing the incipient stall;

2. stress be placed during training upon the information that can be provided by instruments as a basis for understanding and appreciating the approach of stall conditions; and

3. the same emphasis be placed upon uniform rate of turn as is already placed upon uniform angle of bank, uniform rate of climb and the like in the primary flight curriculum.

The present investigation was conducted under the auspices of the Committee on Aviation Psychology by the Educational Research Corporation, under the direction of Dr. P. J. Rulon. Acknowledgment should also be made

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[5]Certain objections have been raised to the suggestion "that the airspeed and ball-bank indicator be considered primary flying instruments and continually 'watched' by a student." In this connection it has been pointed out that "The airspeed indicator in personal aircraft, when newly installed, has an allowable error of five miles per hour at stalling speed. After a year or two of normal wear and tear, this error is probably ten miles per hour. Since in addition to this error, the stalling speed of an aircraft varies with the gross loading, the angle of bank, and the acceleration induced by the application of 'up elevator,' the airspeed indicator must be considered a most unreliable stall-warning indicator. Further, serious hazard to other aircraft would be created by this practice in areas of traffic congestion. In other words, we feel that the airspeed and ball-bank indicator as used in flight training should remain in the category of reference instruments for the purpose of detecting errors and establishing sound basic flight techniques." (Memorandum to the Assistant to the Administrator for Research, CAA.)

to Mr. Leighton Collins and to Dr. David L. Webster who reviewed a preliminary draft of the report and made many helpful suggestions. A final study in the series, representing an evaluation of stall recovery procedures employed by expert pilots, is in progress.

May 18, 1949

Morris S. Viteles, Chairman
Committee on Aviation Psychology

CONTENTS

SUMMARY

The purpose of this study was to determine how experienced pilots recognize the stall approach conditions of light airplanes in each of ten practical maneuvers. The questions investigated were: (1) what physical cues does a capable, experienced pilot utilize in recognizing the approach of stall conditions, beginning with the first departure from normal flight to the entry of the plane into the stall? and (2) what implications do these findings have for the instruction of student pilots?

Civilian flight instructors employed regularly as full-time teachers at airfields in eastern Massachusetts were used as the "experienced and competent pilots." Since previous studies have revealed that there is considerable variation in the performance of flight instructors with respect to the evaluation of stall conditions in light airplanes, it was deemed necessary to utilize a group of instructors whose performance in recognizing and avoiding stall conditions was definitely of a superior character.[1] Consequently, 44 instructors were examined, and, of these, 22 with an above-average rating on the stall recognition test employed were selected for purposes of interview in flight and on the ground.

The first phase of the study involved testing the stall recognition performance of the 44 instructors. All instructors were asked to fly as close as possible to the stall, without actually stalling the airplane; and furthermore, they were told that they would be rated on the closeness with which they were able to approach the stall in each maneuver.[2] The performance of individual instructors was measured by an adaptation of a commercial stall-warning indicator, similar to that employed in previous stall studies conducted by the Educational Research Corporation and others. The results of this examination were taken as an indication of the abilities of the instructors to recognize the imminence of stall conditions, and performance on the test was used to select instructors who were particularly adept at recognizing these conditions.

The 22 instructors with above-average performance on the stall recognition test were interviewed under controlled flight conditions. The purpose of the interview was to secure the pilot's description of the physical cues which he used to recognize the approach of the stall in each of ten practical maneuvers.[3] During the interview, the pilot was asked to describe

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[1] Rulon, P. J. A study of the accuracy of recognition of the incipient stall in familiar and unfamiliar planes. Washington, D.C.: CAA Division of Research, Report No. 74, November 1947.

[2] The names of the nine maneuvers utilized in the testing procedure are listed on the check sheet, Exhibit III, page 13.

[3] These were: (1) straight ahead -- climbing power, (2) straight ahead -- cruising power, (3) straight ahead -- power off, (4) straight ahead -- slow flight, (5) left climbing turn at constant bank, (6) right climbing turn at constant bank, (7) left gliding turn at constant bank, (8) right gliding turn at constant bank, (9) steep left turn at altitude, and (10) steep right turn at altitude.

the method whereby he detected the departure from normal flight conditions and the approach to the stall. Each pilot performed the ten maneuvers, in each case with coordinated controls.[4]

During the aerial interview each subject was asked to describe and demonstrate the cues he used in stall detection. If the cue proved to be definitely recognizable and capable of transmission in teaching and demonstration to the interviewer, it was accepted. If, however, the expert was unable to describe definitely the cue or cues he was using or if the interviewer could not learn to sense the cue, the interviewer did not accept the explanation.[5]

All testing and interviewing were conducted in a Piper J-3 airplane. Since previous studies have revealed that pilots are more consistent and effective in recognizing stall conditions when flying a familiar airplane than when flying an unfamiliar plane, all instructors who were not acquainted with the Piper J-3 were instructed to familiarize themselves with it before being tested. Thus, the investigation used as subjects experienced pilots with above-average performance in recognizing stall conditions and who were flying a familiar plane.

The descriptions and demonstrations by the 22 experts were classified according to the physical sense used in the identification of the cues -- hearing, seeing, and touch. These are summarized in this report under the headings of vision, audition, and kinesthesia. Provision was also made for the description of composite evidence of stall approach. Stages from normal flight to the stall are described as they occur in a steady approach; and, at each stage, the air speed and the tachometer readings are presented.

It was found that at each successive stage of departure from normal flight conditions in the direction of the stall, certain physical cues -- visual, auditory, kinesthetic -- were utilized by the 22 subjects. In general, these cues are fairly definite in character and can be discerned by any capable student with some training and awareness. The cues listed in this report are definitely demonstrable. They can be described and demonstrated by a flight instructor to another pilot.

Perhaps the most striking finding of this study was the fact that the experts did not rely very much upon the information provided by the airspeed indicator and the tachometer, even in those maneuvers in which these instruments serve as accurate stall indicators. As visual cues, the pilots used instead the apparent attitude and behavior of the nose and wings as evidence of the departure of the plane from a normal flight attitude.

Another major finding was the distinction between straight-ahead stalls and stalls in turns. Apparently in straight-ahead maneuvers the most easily visible and the most easily teachable cue to the stall approach is the air

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[4]Otherwise an unreasonably large task would be involved in investigating all of the possible ways in which a stall could possibly occur.

[5]It is possible that the experts used cues they were not able to transmit to the interviewer, even with his assistance. Such cues would of course be of little value in training the private pilot.

speed and the engine speed, both easily determined by instruments available to the pilot. When the stall is approached in a turn, however, the air speed and tachometer settings are not the same as in the straight-ahead stall. However, another cue is available. The experts reported that the stall approach is signaled by "something going wrong with the turn." Sometimes this something was a faltering of the nose of the airplane in its swing around the horizon; sometimes the down wing would come up or go down. But the expected behavior of the airplane through the turn was disturbed, and this was used by the expert as a stall cue.

An examination of the published material on primary flight disclosed that neither of the available cues is emphasized in the instructional literature. As regards air speed, there are treatments of lift and drag with speed, and good expositions of stalling speeds under differing sets of conditions, but little or no suggestion that the airspeed indicator should be consulted when there is a question of pre-stall conditions in straight flight. As regards the turn, the "something going wrong" with it in the stall, there appears nothing in the standard instructional literature which even proposes that the nose of the airplane <u>should</u> progress uniformly around the horizon in still air. Much is said in this instructional literature about the desirability of uniform angle of bank, uniform rate of climb, uniform gliding speed, and so on, but nothing could be found by the investigators concerning, much less emphasizing, uniform rate of turn, or uniform sweep of the nose around the horizon.

It is believed that the findings of this study warrant the following recommendations:

1. That consideration be given to regulations requiring, in all licensed training and "private" airplanes:

    a. the installation of some form of lift, stall, or angle of attack indicator and, (or possibly alternatively[6]);

    b. installation and maintenance of a ball-bank indicator and proper maintenance of the airspeed indicator, tachometer, and altimeter;

2. That CAA bulletins be revised to include a more definite statement of the physical cues which can be utilized by experienced pilots in stall perception;

3. That in the training period, stress be placed upon the information that can be provided by instruments as a basis for understanding and appreciating the approach of stall conditions in straight-ahead flight and

4. That in the primary flight curriculum the same emphasis be placed upon uniform rate of turn (in still air) as is already placed upon uniform angle of bank, uniform rate of climb, and the like.

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[6]Particularly if it cannot be demonstrated that available stall warning instruments can be maintained and function properly over a period of time.

STALL RECOGNITION IN A LIGHT AIRPLANE

INTRODUCTION

This study was undertaken to answer the following questions: (1) What physical cues do capable, experienced pilots utilize in recognizing the approach of stall conditions? (2) What instruments of the light-plane panel are most effective and useful for assisting the pilot in recognizing these conditions? (3) What implications do these findings have for the instruction of student pilots?

Researches conducted under the auspices of the Civil Aeronautics Administration and under the auspices of the National Research Council Committee on Aviation Psychology have already shown that student pilots, private pilots, and flight instructors consistently fail to find the edge of the stall in light aircraft, in both familiar and unfamiliar planes. The present study sought, therefore, to inquire more deeply into the problem and to ascertain what recognizable cues experienced pilots used in recognizing the stall approach. It was believed that only the most capable and experienced pilots should be considered in this study, inasmuch as previous studies had revealed that performance in recognizing pre-stall conditions is highly variable and most unsatisfactory in the lower part of the range of performance. It was considered appropriate, also, to test and interview all subjects in a familiar plane, which had been equipped to provide instrument data to supplement information obtained in personal interview.

I. PRELIMINARY PROCEDURES

INSTRUMENTATION OF THE AIRPLANE

Before the present study could be undertaken, a preliminary investigation was carried out to determine whether an airplane could be instrumented in such a manner as to make possible a controlled study of the ability of pilots to recognize and avoid stalls. Experimental installations on a trainer airplane were tested in flight; and after refinements in the indicator mechanism were effected, a satisfactory stall-scoring system was developed.

The stall-warning device utilized in this investigation was similar to that described in detail in CAA Research Report No. 74.[1] However, important modifications were made. The original stall-warning device involved the use of five vanes, installed in one wing of the airplane. For purposes of this study, a sixth vane was adjusted to indicate the edge of the stall in a steep turn, and a set of six vanes was installed in each wing of the airplane. The corresponding vanes on each wing, for example vane #1 in each

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[1] Rulon, P. J. A study of the accuracy of recognition of the incipient stall in familiar and unfamiliar planes. Washington, D.C.: CAA Division of Research, Report No. 74, November 1947.

wing, were wired in series by pairs so that it was necessary for both of the corresponding vanes on the two wings to trigger before their lamp on the clip-board was lighted. This procedure was employed to reduce the possibility of a lamp coming on when one vane was triggered by purely local turbulence, as well as to render the instrumentation symmetrical with respect to behavior in turns.

The wiring diagram for the stall-warning device is presented in Figure 1.

The testing and interviewing reported in succeeding sections of this report were conducted in a Piper J-3 high wing, tandem monoplane, 65 H.P., CAA designation NC41302. This plane was equipped with a sensitive altimeter, reliable (but not accurately calibrated) airspeed indicator, tachometer, and the special stall-warning installation.

SELECTING THE SUBJECTS TO BE EXAMINED

No specific requirement was established for the flight experience of those who were to serve as subjects. However, it was believed for two reasons that all subjects should be instructors: (1) instructors as a group should be skillful in precision flying, and should also be in a position to explain accurately what they do in flight; and (2) the test performance would reveal the degree of skill[2] possessed by individual instructors and thus give some idea whether or not tuition and explanation were all they should be in such instructional personnel.

No attempt was made to select instructors for the purpose of the initial test on a random basis. A letter was sent to all civilian airfields in eastern Massachusetts inviting the management to cooperate in the investigation. A copy of this letter and the enclosed answer sheet are presented in Exhibit I. In Exhibit II is presented the reply made to those offering cooperation. Replies were received from the following locations:

Address	Airport	Manager
Ayer, Mass.	Ayer Municipal	Paul Buckingham
Bedford, Mass.	Lawrence G. Hanscom Field	Clinton H. Sperry
Beverly, Mass	Beverly	Daniel Ginty
Billerica, Mass.	Shawsheen Pines	Russell D. Totman
Brockton, Mass.	Brockton	Nat Treger
Dracut, Mass.	Richardson	Charles B. Reed, Jr.
Fitchburg, Mass.	Fitchburg	Joseph A. Lamothe
Hanover, Mass.	Clark	George Tillinghast
Lawrence, Mass.	Lawrence	Joseph Mahoney
Marlboro, Mass.	Marlboro	Donald V. Lacoupure
Millbury, Mass.	Windle	Robert Swenson
Newburyport, Mass.	Plum Island	Warren S. Frothingham
No. Grafton, Mass.	Grafton	Joseph A. Ruseckas
Norwood, Mass.	Norwood Municipal	John Phillips
Revere, Mass.	Revere	Julius Goldman
Worcester, Mass.	Worcester	Francis T. Fox

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[2]And judgment, since each subject was trying to get close to whatever he meant by the stall.

EXHIBIT I

EDUCATIONAL RESEARCH CORPORATION
40 Quincy Street
Cambridge, Massachusetts

5 April 1948

Dear__________:

We intend to carry out a series of tests in the air and on the ground for the purposes of research under the auspices of the National Research Council Committee on Aviation Psychology. We therefore need a number of first-rate instructors to be tested, who would be hired at their normal rates of fees.

Such tests would be carried out either at Bedford Airport or at your field or at some other airfield convenient for the pilots at times to be arranged to mutual advantage.

We should therefore be most grateful if you would kindly tell us the number of instructors at your field. An answer sheet is enclosed, as well as a self-addressed stamped envelope.

We shall look forward to hearing from you and contact you shortly afterwards.

Yours sincerely,

EDUCATIONAL RESEARCH CORPORATION

By____________________________

EXHIBIT I (Enclosure)

EDUCATIONAL RESEARCH CORPORATION
40 Quincy Street
Cambridge, Massachusetts

5 April 1948

ANSWER SHEET

An answer from . . . .

. . . .

. . . .

. . . .

There are _______ instructors working on this field.

I have checked here [ ] to indicate that I should like to have you send me more particulars about the research.

EXHIBIT II

EDUCATIONAL RESEARCH CORPORATION
40 Quincy Street
Cambridge, Massachusetts

17 April 1948

Dear Sir:

Thank you very much for your reply to our inquiry.

Our investigation seeks to determine how and why pilots are able to recognize the approach of a stall. Earlier studies show that there are appreciable differences between pilots' abilities to do this (ref. P. J. Rulon, A study of the accuracy of recognition of the incipient stall in familiar and unfamiliar planes, C. A. A., Report No. 74, November 1947). We therefore wish to discover why, and to find out how some pilots are able to do it.

Our plan is to test a number of instructors and determine their abilities to recognize stall characteristics and to fly as near to the stall as possible without actually stalling in a number of maneuvers. From these instructors, some will be selected for further employment, and will be interviewed to determine exactly how they accomplish this recognition.

We feel you realize the significance of our investigation and the contribution that it could make to the safety of flying in the future. We hope that we can bring this research to a successful conclusion and make suitable recommendations that will improve training programs and result in the eventual elimination of one of the dangers of private flying.

Thank you for your interest and cooperation.

Yours sincerely,

EDUCATIONAL RESEARCH CORPORATION

By Francis G. H. Sherman

CHARACTERISTICS OF SUBJECTS EXAMINED

The personal data pertaining to the age and flight experience of the instructors who volunteered for the investigation indicated definitely that the group as a whole was well qualified in terms of experience. All instructors were asked to state their age, the year in which their first solo flight occurred, the total number of flight hours, and the total number of flight hours logged in the 90-day period just previous to the examination. These data are summarized in the following paragraphs and in Tables 1, 2, and 3 following.

Age. With respect to age, the 44 instructors ranged from 21 to 46 years. The average age was 28 years; the median age, 28.5 years. Complete data on the age of the 44 instructors examined are presented in Table 1.

Flight Experience. With respect to flight experience in terms of total number of solo hours, there was considerable variation among the members of the group. At the lower extreme, three pilots had logged approximately 250 hours, while at the upper end of the range one pilot had logged a total of 8,200 solo hours. For the group as a whole, the average number of hours of flight experience was 2,987.5 hours; the median number, 2,750 hours. One pilot first soloed in 1928, and at the other extreme, another pilot soloed as recently as 1946.

Hours in Last 90 Days. The number of flying hours logged during the 90 days just preceding the examination was also determined. In each case, the instructor was asked to supply first, the total number of flying hours during this period in all types of planes, and secondly, the total number of flying hours in a plane of the same or similar model as that used during the examination. As shown in Table 3, the total number of flying hours during the past 90 days ranged from 1 to 350 in all types of aircraft and from 0 to 350 in a Piper J-3 trainer.

THE PRELIMINARY EXAMINATION

All subjects were told of the general purpose of the experiment and were asked to familiarize themselves with the Piper J-3 to be used during the examination. In certain instances this was done by the instructors actually flying the Piper trainer used in the experiment; in others, the subjects obtained a similar model plane from their own or nearby airport and practiced in advance of the examination. All of the subjects who had not had extensive flying experience during the last 90 days in a Piper trainer were anxious to practice before the examination and were encouraged to do so. The purpose of this procedure was to make as nearly comparable as possible the results for all subjects in the examination.

Method

The general purpose of the examination was to provide a basis for selecting a group of the most capable instructors with respect to the recognition of the stall conditions in the test plane.

TABLE 1

DISTRIBUTION OF AGES OF THE FORTY-FOUR INSTRUCTORS INITIALLY EXAMINED

Age	No.	Cumulative No.
46	1	44
39	3	43
38	1	40
37	1	39
36	2	38
35	0	36
34	0	36
33	2	36
32	2	34
31	2	32
30	5	30
29	3	25
28	4	22
27	2	18
26	7	16
25	1	9
24	1	8
23	3	7
22	3	4
21	1	1

Average age - 28.0 years
Median age - 28.5 years

TABLE 2

TOTAL FLIGHT HOURS OF THE FORTY-FOUR INSTRUCTORS INITIALLY EXAMINED

Hours	No.	Cumulative No.
8,200	1	44
8,000	1	43
7,000	1	42
6,800	1	41
5,800	1	40
5,400	1	39
5,000	2	38
4,400	1	36
4,000	4	35
3,900	1	31
3,800	1	30
3,500	2	29
3,300	1	27
3,000	4	26
2,500	2	22
2,100	1	20
2,000	1	19
1,900	1	18
1,800	1	17
1,500	6	16
1,400	1	10
1,300	1	9
1,100	1	8
1,000	2	7
800	2	5
250	3	3
Total	44	

TABLE 3

NUMBER OF HOURS FLOWN DURING PAST NINETY DAYS BY
THE FORTY-FOUR INSTRUCTORS INITIALLY EXAMINED

Hours	In All Plane Types "N"	In All Plane Types Cum. "N"	In Same or Similar Model Planes "N"	In Same or Similar Model Planes Cum. "N"
350	1	44	1	44
300	2	43	0	43
250	2	41	0	43
200	5	39	0	43
180	1	34	2	43
175	1	33	0	41
160	1	32	0	41
150	11	31	1	41
140	1	20	0	40
135	0	19	1	40
130	0	19	1	39
120	1	19	1	38
110	1	18	1	37
100	4	17	4	36
90	1	13	0	32
80	0	12	1	32
75	3	12	1	31
70	0	9	1	30
50	1	9	2	29
40	2	8	2	27
30	3	6	2	25
20	1	3	1	23
15	0	2	1	22
12	0	2	1	21
10	1	2	1	20
1	1	1	2	19
0	0	0	17	17
Total	44		44	

A uniform procedure was utilized during each preliminary examination. The examiner[3] in each case discussed the nature of the experiment which was to be conducted, showed each subject the score sheet, and gave general directions. Each subject was told that he would be scored on his nearest approach to the stall, in each of the nine maneuvers listed on the score sheet. (See Exhibit III.) He was warned by the examiner that he should not stall the plane, since the purpose of the test was to indicate his ability to fly as close to the edge of the stall as possible and to recover without actually stalling the plane.[4]

During the first phase of the examination, the examiner obtained the personal information on the age and flight experience of the subject, and assembled his score sheet, clip-board, and other equipment.

The examinee was seated in the front seat of the airplane. This insured that his vision outside the aircraft was unobstructed. The examiner was seated in the rear seat and equipped with clip-board on which the indicator lamps and check lists were fastened. This method of seating also insured that the subject did not see how many lamps were lit during the maneuvers.

During the flight the examiner was entirely noncommittal. In no case did he inform the subject of his performance. He did not indicate how many vanes had been tripped, even when the subject stalled the aircraft. During the flight, the examiner recorded opposite the appropriate maneuver the number of the lamp which indicated the closest approach to the stall. A further note was made as to whether the subject made a safe recovery or whether the aircraft subsequently stalled. A further note of the turbulence which was experienced during the flight was also made.

Following the examination the subject was told that of the group being examined initially, a number would be selected for interviews. The subject was not informed of his score, and no further explanations were made at this juncture.

The preliminary examinations of the 44 instructors were carried out during the period 26 April through 24 May 1948. Examinations were conducted at each of the airfields listed on page 2.

Results

The examiner's record sheets were collected at the research center at Cambridge, Massachusetts, and here they were inspected and scored, and the results of the examinations were compiled and analyzed.

Scoring Procedures. The observation sheets were scored in the following manner: (1) a value of 1 was assigned to each vane tripped, up to a maximum

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[3]Mr. John Lindstrom served as examiner in this phase of the investigation. His job as examiner did not require expert skill in flying, but he was nevertheless selected for the work on the basis of his experience as a commercial pilot and flight instructor.

[4]The subject was not told what was meant by the expression, "actually stalling the plane." He was left to suppose that he was to get as close as possible to what he meant by the stall.

EDUCATIONAL RESEARCH CORPORATION
Cambridge 38, Massachusetts
24 April 1948

Date ________ 1948 ________ Hours ________ a.m. p.m.

Instructor ________

Age last birthday ______ Year first solo ________

Total solo _____ hrs. Solo in past 90 days _____
Solo in past 90 days in this plane make and model ______ hrs.

Climb to altitude						
Clearing turn left						
Clearing turn right						
1. Straight ahead, cruising power						
2. Straight ahead, power off						
Climb to altitude						
Clearing turn left						
Clearing turn right						
3. Left climbing turn						
4. Right gliding turn						
Climb to altitude						
Clearing turn left						
Clearing turn right						
5. Steep left turn at altitude						
6. Right climbing turn						
7. Left gliding turn						
Climb to altitude						
Clearing turn left						
Clearing turn right						
8. Straight ahead, climbing power						
9. Steep right turn at altitude						
Return to field						

of 4 in all maneuvers except for the right and left steep turns at altitude; (2) a maximum of 5 was assigned to the right and left steep turns at altitude; (3) when the pilot actually stalled the plane, he was assigned a score of 1 less than the maximum allowable for that maneuver. The maximum score value of 4 in the case of all maneuvers except the right and left steep turns at altitude corresponds to the maximum number of lamps which can be lighted in each maneuver before the airplane actually stalls. In the case of the two steep turns at altitude, 5 vanes could be tripped without actually stalling the plane. In all other maneuvers, however, the fifth light came on just as the airplane stalled.

Scoring when Subject Stalled. The procedure of scoring the performance when the subject actually stalled the airplane can be illustrated simply. In the left climbing turn, if the pilot lit 4 lamps and did not stall the airplane, he was assigned a score of 4 on that maneuver. If he lit 5 lamps, which indicated a stall, he was assigned a score of 4 minus 1, or 3; that is, 1 less than the maximum allowable. The maximum attainable score on the nine assigned maneuvers was therefore 38: 4 for each of 7 maneuvers, and 5 each for the remaining 2 maneuvers.

Scored on this basis, the performance of the 44 instructors ranged from 25 to 37, as shown in Table 4. The average score for the group was approximately 32; the median score, approximately 33. Twenty-five of the 44 instructors received scores of 33 or above out of a possible 38, whereas only 3 received a score of less than 30.

TABLE 4

Distribution of Examination Scores

Score	No. of Instructors	No. of Instructors at and Below Each Score
38	0	44
37	1	44
36	2	43
35	5	41
34	10	36
33	7	26
32	9	19
31	3	10
30	4	7
29	1	3
28	0	2
27	1	2
26	0	1
25	1	1
Total	44	

Mean - 32

Median - 32.9

These scores were then analyzed with respect to number of maneuvers performed perfectly as defined by the maximum number of points allowed in the scoring system. The distribution of total scores by maneuvers performed perfectly is shown in Table 5.

Distribution of Scores. From this table it will be noted that 25 instructors received maximum scores on 5 or more maneuvers. The average number of maneuvers performed perfectly, as here defined, was approximately 4.8, as was the median. Two subjects received the maximum score on 8 maneuvers, one of these subjects received the highest score assigned to any member of the group. This individual had logged approximately 8,000 hours of solo flying time. A total of 7 instructors received maximum scores on 3 or less maneuvers, while only 1 subject failed to receive a maximum score on any maneuver.

The score data were further analyzed with respect to age and flight experience of the subjects. These data are summarized in Tables 6 through 11, and are discussed briefly in the following paragraphs.

Distribution by Age. There was no discernible relationship between the age of instructors and the scores received on the stall recognition test. Of the 25 subjects who received a total score of 33 or above, the range in age was almost the maximum range in age for the entire group -- 22 to 39. It may be of interest to note that one of the youngest members of the group, a subject, age 22, received the second highest score, whereas the oldest subject, age 46, received the third lowest score. The data shown in Table 6, however, are so inconclusive that it would have been a highly questionable procedure to select instructors for interview on the basis of age alone.

TABLE 5

NUMBER OF MANEUVERS RECEIVING MAXIMUM SCORE VALUE IN THE FLIGHT EXAMINATION

No. of Maneuvers	No. of Instructors	Instructors at and Below Each No.
9	0	44
8	2	44
7	6	42
6	6	36
5	11	30
4	12	19
3	5	7
2	0	2
1	1	2
0	1	1
Total	44	

Mean - 4.8

Median - 4.8

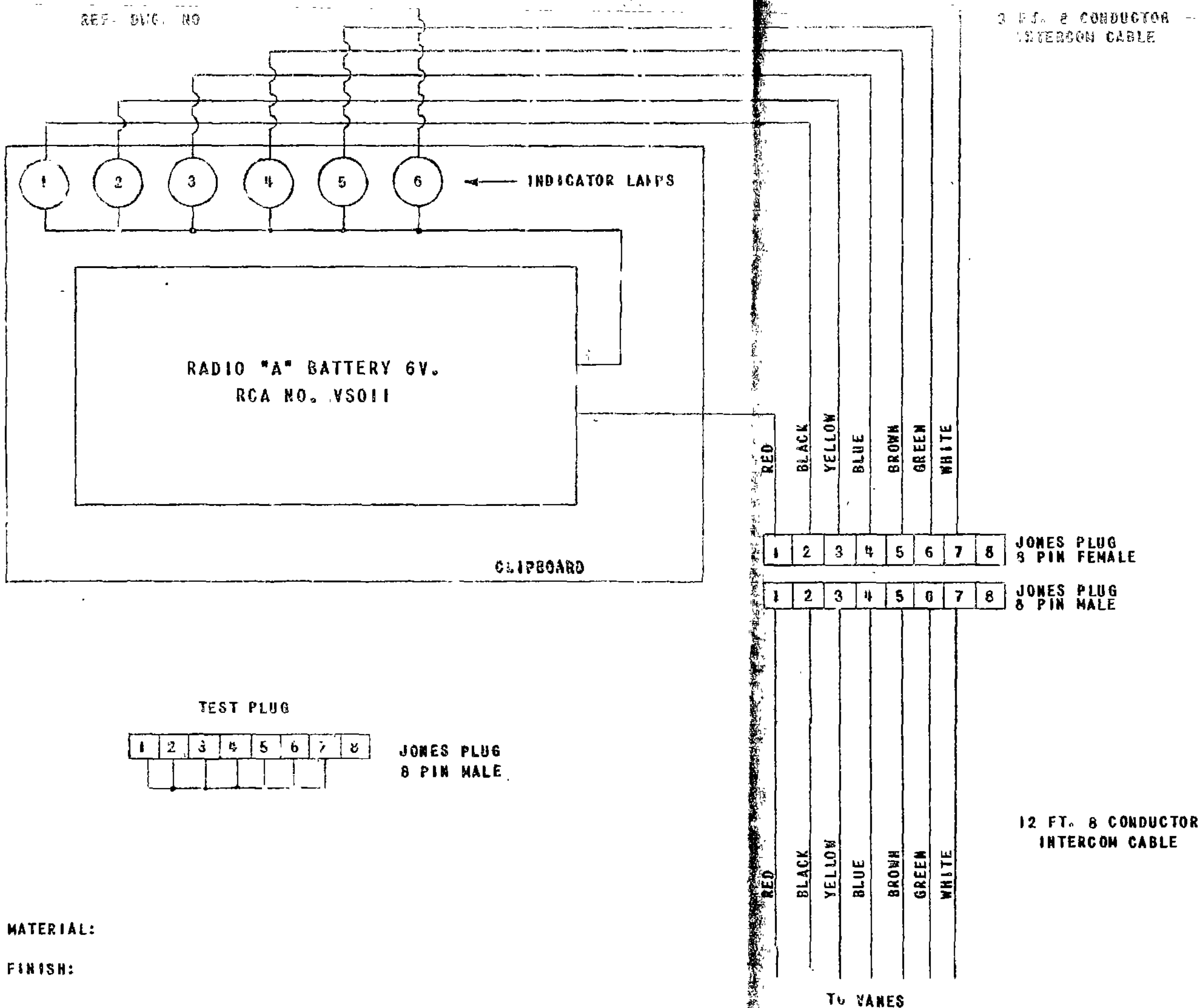
TABLE 6

DISTRIBUTION OF SCORES BY AGES OF EXAMINEES

Age in Years

Scores	21	22	23	24	25	26	27	28	29	30	31	32	33/36		37	38	39/46		Total
38																			
37																	1		1
36		1			1														2
35			1					1		1	1		1						5
34						4	1	1				1	1		1	1			10
33			1	1		1				1	1			2					7
32	1		1			1	1	1	2	1							1		9
31									1	1		1							3
30		1						1		1							1		4
29																		1	1
28																			
27		1																	1
26																			
25						1													1
Total	1	3	3	1	1	7	2	4	3	5	2	2	2	2	1	1	3	1	44

REF. DWG. NO



LIST OF PARTS

1 CLIPBOARD
1 6V. BATTERY RCA No. VS011
6 JEWELLED PILOT BRACKETS ENCLOSED TYPE
6 PILOT LAMPS 6V. GE-44
2 JONES PLUGS 8 PIN MALE
1 JONES PLUG 8 PIN FEMALE
16 FT. 8 CONDUCTOR INTERCOM CABLE

MATERIAL:

FINISH:

MACHINING TOLERANCES UNLESS OTHERWISE STATED: FRACTIONAL = 1/64", DECIMAL = .005", ANGULAR = ½°

NB. 1. Blueline prints of this drawing are for internal RRL use only.
2. Redline prints are intended for outside experimental model construction and, together with all accompanying wings, must be checked by the

deFLOREZ ENGINEERING COMPANY INCORPORATED
31 WEST 47 STREET
NEW YORK 19, NEW YORK

TITLE: TEST CLIPBOARD FOR STALL WARNING INDICATOR - CIRCUIT DIAGRAM

FOR	APPROVED BY
DRAWN BY WOLFSON	DATE 1/22/48
CHECKED BY	SCALE
DWG.	

Distribution by Flight Experience. Distributed according to total number of solo flying hours, the performance of the 44 instructors showed an equally striking variation. These data are presented in Table 7. Despite the fact that the lowest single score assigned was obtained by an instructor who had only 250-300 hours total flying time, and the highest score was obtained by a 39-year-old instructor who had more than 8,000 flight hours, the general pattern of performance on the test was definitely not highly related to the amount of solo flight hours logged.

Tables 8 and 9 present a distribution of scores by number of flying hours in all types of aircraft and similar aircraft during the 90 days just preceding the examination. Although there is some degree of relationship between the performance on the test and number of hours spent in all types of aircraft during the last 90 days, this relationship is not at all pronounced.

Tables 10 and 11 present analyses of the examination scores based on the number of maneuvers receiving maximum scores. The method of scoring dictated that the total score assigned each individual was highly related to the number of maneuvers on which the individual received the maximum number of score points. This is shown in Table 10. A further analysis of relationship between number of maneuvers of maximum score value and number of solo hours of flight experience is shown in Table 11.

Distribution by Turbulence Conditions. Since it was impossible to test all subjects under the same weather conditions, an effort was made to estimate the amount of turbulence which applied during each examination. The examiner established four categories of turbulence based on his estimate of the flying conditions. The categories established were: (1) none, (2) slight, (3) moderate, (4) heavy. As indicated in Table 12, only two examinations were conducted under heavy turbulence conditions. Twelve of the 48 examinations were conducted under ideal conditions and 21 examinations under a moderate degree of turbulence. The highest score was made under conditions of slight turbulence, while the lowest score was made under similar conditions. The other scores are distributed in such a manner as to indicate that turbulence did not markedly influence performance on the stall perception test.

General Considerations. The data presented in the preceding twelve tables indicate generally that examination methods were necessary to determine those instructors who were most capable with respect to the recognition of stall conditions. There was no reason to assume that a particular chronological age range could be defined as most indicative of capability in this respect, but there is some logical support for the assumption that extensive flight experience should result in some increase in the individual's performance in recognizing stall conditions. These data, then, indicate very clearly that a preliminary examination of performance in recognizing stall conditions was a necessary step in the investigation.

SELECTION OF SUBJECTS FOR INTERVIEW

The above analyses of performance on the stall-recognition test provided the basis for selection of the subjects to be interviewed. Following the com-

TABLE 7

DISTRIBUTION OF SCORES BY NUMBER OF TOTAL SOLO HOURS OF EXAMINEES

Number of Hours

Score	250-300	800	1000	1100	1300	1400	1500	1800	1900	2000	2100	2500	3000	3300	3500	3800	3900	4000	4400	5000	5400	5800	6800	7000	8000	8200	Total
38																											
37																									1		1
36	1												1														2
35			1				1	1				1						1									5
34							2		1	1	1				1			1			1	1				1	10
33		1											1					1	1	1			1	1			7
32		1	1		1		2					1	2			1											9
31				1											1					1							3
30	1						1										1	1									4
29														1													1
28																											
27						1																					1
26																											
25	1																										1
Total	3	2	2	1	1	1	6	1	1	1	1	2	4	1	2	1	1	4	1	2	1	1	1	1	1	1	44

TABLE 8

DISTRIBUTION OF SCORES BY NUMBER OF FLIGHT HOURS IN ALL TYPES OF AIRCRAFT DURING LAST NINETY DAYS

Number of Hours

Score	1	10	20	30	40	50	75	90	100	110	120	140	150	160	175	180	200	250	300	350	Total
38																					
37																			1		1
36					1															1	2
35				1			1						1		1		1				5
34				2		1					1	1	2			1	1	1			10
33							1		2				2				1		1		7
32	1				1				1	1			3	1			1				9
31			1										1				1				3
30							1	1	1				1								4
29													1								1
28																					
27																		1			1
26																					
25		1																			1
Total	1	1	1	3	2	1	3	1	4	1	1	1	11	1	1	1	5	2	2	1	44

TABLE 9

DISTRIBUTION OF SCORES BY NUMBER OF FLIGHT HOURS IN SIMILAR AIRCRAFT DURING THE PAST NINETY DAYS

Number of Hours

Score	0	1	10	12	15	20	30	40	50	70	75	80	100	110	120	130	135	150	180	350	Total
38																					
37													1								1
36								1												1	2
35	2			1	1																4
34	3					1	2								1		1		2		10
33	3								2		1			1		1					8
32	3	2						1				1	1					1			9
31	2		1																		3
30	3									1											4
29													1								1
28																					
27													1								1
26																					
25	1																				1
Total	17	2	1	1	1	1	2	2	2	1	1	1	4	1	1	1	1	1	2	1	44

TABLE 10

DISTRIBUTION OF SCORES BY MANEUVERS
RECEIVING MAXIMUM SCORE VALUE

Score	Number of Maneuvers									Total
	0	1	2	3	4	5	6	7	8	
38										
37									1	1
36								1	1	2
35							2	3		5
34						6	2	2		10
33					3	2	2			7
32				3	3	3				9
31					3					3
30				2	2					4
29					1					1
28										
27		1								1
26										
25	1									1
Total	1	1		5	12	11	6	6	2	44

(See text for explanation of the |__)

TABLE 11

DISTRIBUTION OF MANEUVERS RECEIVING MAXIMUM SCORE VALUE
BY NUMBER OF FLIGHT HOURS

Number of Hours

Maneuvers	250-300	800	1000	1100	1300	1400	1500	1800	1900	2000	2100	2500	3000	3300	3500	3800	3900	4000	4400	5000	5400	5800	6800	7000	8000	8200	Total
9																											
8													1												1		2
7	1							1				1						2		1							6
6		1	1				1		1														1			1	6
5		1			1		3			1	1				1			1		1	1						11
4	1		1	1			1						3	1	1				1	1				1			12
3							1					1				1	1	1									5
2																											
1						1																					1
0	1																										1
Total	3	2	2	1	1	1	6	1	1	1	1	2	4	1	2	1	1	4	1	3	1		1	1	1	1	44

TABLE 12

DISTRIBUTION OF SCORES BY ESTIMATED TURBULENCE
DURING EXAMINATION

Amount of Turbulence

Score	None	Slight	Moderate	Heavy	Total
38					
37		1			1
36		1	1		2
35	2		3		5
34	2	2	6		10
33	2	2	2	1	7
32	2	1	5	1	9
31	1	1	1		3
30	2		2		4
29	1				1
28					
27			1		1
26					
25		1			1
Total	12	9	21	2	44

pletion of the preliminary examination, it was tentatively decided to interview those subjects whose performance was above the average or typical performance of the group of 44 instructors examined. It was assumed that a group of 22 subjects would be sufficient for purposes of interview, and that those subjects who were most proficient in the recognition of stall conditions, as determined by the test employed, would provide the most adequate descriptions of physical cues employed in stall perception.

The group of 22 subjects utilized in the interview procedures was selected by a two-fold process, each related to the other, but varying by the penalties assigned to those subjects who went so far as to stall the airplane. Those subjects whose scores were above average were first tentatively selected. In order to eliminate any subject who made a high score by frequently stalling the airplane, a secondary screening was employed. The purpose of this screening was to select those who consistently came as close to the stall as possible without actually entering into the stall. These individuals were selected by identifying the subjects who performed more than the average number of maneuvers at maximum score value. The 22 subjects finally selected were those who had not only scored highest in the examination flight, but who also most consistently lighted the maximum number of lamps in performing a stall approach in each maneuver. All subjects accepted for interview received a total score on the stall-recognition test of 33 or more and also performed 5 or more of the 9 maneuvers with maximum score value. These are the 22 above and to the right of the |__ in Table 10.

THE INTERVIEWS

The interviews employed in this investigation involved two stages: (1) a flight interview, during which the subject performed a series of ten maneuvers and described while in flight the physical stimuli he utilized in recognizing the stall, and (2) confirming interviews held on the ground after the flight performance. The general methodology employed in these interviews is described in succeeding paragraphs. A team of Educational Research Corporation interviewers[5] flew with the selected "experts" and, on occasion, served as a team in interviewing subjects on the ground.

Selection of Maneuvers

The ten maneuvers employed were selected because of their application in flight instruction and learning. All of these maneuvers are discussed specifically in CAA bulletins and are taught in training programs. The maneuvers were: (1) straight ahead with climbing power, (2) straight ahead with cruising power, (3) straight ahead with power off, (4) straight ahead slow flight, (5) left climbing turn at constant bank, (6) right climbing turn at constant bank, (7) left gliding turn at constant bank, (8) right gliding turn at constant bank, (9) steep left turn at altitude, and (10) steep right turn at altitude.

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[5]Mr. Francis G. H. Sherman, Mr. Donald H. Hunt, and Mr. Philip H. Wye. Each of these workers had had many hundreds of hours of flight experience and in addition had specialized in personnel work in his university studies.

This study did not consider "high-speed stalls." This maneuver is not required by the CAA for private pilots, and furthermore, there seems to be no reason why any pilot should get into a high-speed stall unless he is doing maneuvers not included in the CAA manual for private pilots. The crossed control stall was also excluded from this study. This study was therefore concerned with standard, practical maneuvers which all private pilots are required to perform and in which stall conditions may be approached inadvertently in departures from normal flight conditions.

Interviews in the Air

Before the flight, each "expert" was informed of the general purpose of the flight, and what was expected of him. He was told to report to the interviewer what he saw, heard, or felt in the approach to the stall in each maneuver, and to answer any question which might be put to him by the interviewer. He was requested to describe both his impressions and reactions as accurately as possible.

During the flight interviews the expert was seated in the front seat, in full view of all of the instruments with which the plane was equipped. These instruments were: a sensitive altimeter, tachometer, airspeed indicator, ball-bank indicator, compass, oil pressure and temperature gauges, and an accelerometer. The subject was given no advanced instructions concerning the possible use of instruments. He was told merely to proceed in each maneuver with a constant throttle setting from normal flight to the very edge of the stall, as directed by the interviewer.[6] No restriction or suggestion was made concerning the possible use of instruments.

During the departure from normal flight, the interviewer observed the subject's performance and checked it against the lamp indicators and the other instruments installed in the plane. The subject described the sensory stimuli employed in recognizing the approach of stall conditions, and these were checked by the interviewer, both with and without the lamp indicators. All stimuli which could be communicated by demonstration to the interviewer were accepted as valid. That is, when the subject could describe a characteristic of the plane in the approach to the stall and when this could be confirmed by the interviewer, then the explanation was accepted and recorded.[7]

The interview conditions were specifically designed to prevent the subject from having access to the information provided by the stall-warning indicator. It was deemed especially important that the subject could describe and demonstrate the warning signals he experienced without the use of this device, for one purpose of the investigation was to determine what information **is** available to a pilot when such a special instrument is not.

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[6]An advance of throttle setting was required immediately before all climbing maneuvers. This was standard practice at the airports where the interviews were conducted.

[7]Cues not transmissible to our interviewers would not be readily transmissible to a student pilot and therefore would not have much value in the curriculum for the private pilot.

"Flight Testing" of Cues

Following the completion of the first eight interviews, charts or check lists of cues which the eight experts used were prepared on the basis of the flight demonstrations and discussions of the aerial interviews. These preliminary charts were then flight tested by the staff of interviewers. Several corrections were made in the case of cues which were not quite definite, and the observations of the airspeed indicator and tachometer were confirmed and added. (The data given by these two instruments were not obtained from the expert pilots. They were determined by the interviewing staff, and were observed and checked during succeeding interviews.)

Revision of the preliminary lists of cues proceeded through the first 14 interviews. The preliminary lists were revised, corrected, and additions were made until, at the end of 14 interviews, a point was reached where no significant corrections or additions were made to the list. All of the cues provided by the remaining 8 subjects were classified in the revised list. Thus the test of whether more interviews were needed was whether additional interviews added any information or types of cues. That the last 8 interviews fitted into the pattern derived from the first 14 showed that the point of diminishing returns was reached and safely exceeded.

Interviews on the Ground

The aerial interviews were supplemented by interviews on the ground, with all available personnel taking part. The individual flight was discussed thoroughly, and confirmation of questionable points was secured or, failing confirmation, was deleted from the tables of acceptable clues. In this way, aerial observations were substantiated under unhurried circumstances. Usually, the subjects were quite willing to enlarge upon their feelings and to describe them more adequately. These interviews were not all recorded, but sufficient notes were made in all cases to enable the interviewers to make adequate corrections and additions to the list of cues.

On six occasions, discussion of observations was invited from other instructors who had taken the preliminary examination but had not been selected for interview purposes. These instructors happened to be present when subjects were being interviewed and showed considerable interest in being asked to give corroboration from their own experience.[8]

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[8] The interviews in the air and on the ground took place at the following airports:

	Air	Ground
Beverly	2	
Shawsheen Pines (Billerica)	2	
Bolton	1	2
Brockton	1	1
Richardson (Dracut)	1	
Fitchburg	2	1
Norwood Municipal	1	
Plum Island (Newburyport)	1	2
Revere	2	
Worcester	1	

II. RESULTS

The information obtained in the interviews is presented in this report in the form of summary charts. The ten charts, one for each of the ten maneuvers employed in the investigation, are designed to permit a pilot to familiarize himself fully with the sensory cues that may be encountered when he departs from normal flight in the direction of the stall. Instrument readings are included for each successive stage of departure from normal flight, as the stage is indicated by the number of lamps lighted on the stall-warning indicator. The instrument data pertain only to the Piper J-3 airplane used in the investigation, but the indications are clear enough to enable pilots to recognize dangers in similar light aircraft.

In these charts, the physical cues are grouped according to the headings Vision, Audition, Kinesthesia, and Composite. The Composite category represents performance which involves more than one of the primary senses and pertains particularly to conditions which are descriptive of the airplane rather than of experiences of the pilot.

These charts may be read as follows: the first column labeled Lights ranging from 0 through 5 indicates successive stages of departure from normal flight toward stall conditions in terms of the vane installation. The corresponding values for the airspeed and tachometer readings are presented opposite. In the columns devoted to the physical cues, certain cues are followed by a number in parentheses. This number corresponds to an explanatory note following the chart.

General Considerations

It will be seen from these charts that in all maneuvers there is the expected decrease in r.p.m. and airspeed readings, as the airplane departs from normal flight and approaches the stall.

In power-on maneuvers, the r.p.m. decreases in an approach to the stall with a given throttle setting. Consequently, there is an increased laboring of the engine which, in turn, partly causes an increased vibration of the aircraft. Amount of vibration varies with each aircraft, and it appears that the amount that is characteristic of an individual aircraft at the point of stalling can be determined only from experience with it.

For the testing aircraft, it was found that for all maneuvers the indicated stalling speed varied between 28 miles per hour for straight-ahead maneuvers and 37 miles per hour in the steep left turn. The rated stalling speed (at standard temperature of 59° F.) is 38 miles per hour.[9] The discrepancy between these indicated stalling speeds and the speeds called for by the manufacturer is partly due to differences among maneuvers, and partly due to faulty calibration of the airspeed indicator employed in this study. The indicator used repeated its readings very well, always giving the same reading under the

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[9]Piper Aircraft Corporation, Piper J-3 Owner's Manual, p. 47. Our airspeed meter was reliable, but was not accurately calibrated.

CHART I

STRAIGHT AHEAD, CLIMBING POWER

Lights	Indicated Air-speed mph	Tachometer	Vision	Audition	Kinesthesia	Composite
0	55	2300				
1	50	2200	Nose and inclination of wings above normal climbing position (3); nose tends to turn left (4).	Engine labors (9).	Resistance to back pressure on stick (11); vibration felt in stick and body.	Back pressure required to keep the nose and inclination of wings above normal climb; need for right rudder to maintain direction (4).
2	45	2150	Climb slows down (5).	Noticeable laboring of the engine.	Considerable vibration felt in stick and body (12).	
3	40	2150	Aircraft slows down relative to the ground (6); noticeable tendency for nose to move to the left.		Rudders offer little resistance.	Need for appreciable amount of right rudder to maintain heading.
4(1)	30	2150	Climb stops; altimeter remains constant (1); nose may drop slightly (7).		Slight sinking feeling (13).	
5	28 (2)	2140 (2)	Loss of altitude (8); nose drops and aircraft picks up speed after the stall.	Engine seems to quiet down immediately before the stall (10).	Sinking feeling more pronounced; resistance to back pressure of stick decreases rapidly at edge of stall (14); vibration seems to lessen right at edge of stall (10)	Controls mushy (11); ailerons slightly effective (15).

Straight Ahead, Climbing Power - Notes

(1) We could fly continuously at light number 4.
We could fly continuously at light number 4.

(1) We could fly continuously at light number 4.
(2) Plane and instrument vibrating so violently that it was difficult to get a reliable reading.
(3) The nose and inclination of wings remain above normal and increase toward the stall.
(4) This is due to the effect of torque. With power on, the nose tends to move to the left. This might
not be noticed by a good pilot, as he might "automatically" correct this tendency, through uncon-
scious habit.

(5) This may not be noticed without a rate-of-climb indicator, but the tendency can be noticed on a
sensitive altimeter.

(6) This state continues through light 4, until one appears to be "almost stopped" at light 5. But there
is doubt that this would be noticed at altitude unless pilot expecting it.

(7) Here there is a tendency, if using uncoordinated controls, for the plane to oscillate erratically.

(8) Altitude cannot be maintained with the 5th lamp lit.

(9) With every decrease in engine r.p.m.'s a corresponding increase of the engine laboring will occur,
which may be so small that it will not be noticed by all pilots.

(10) A few seconds before the stall the engine seems to quiet down. It has been suggested that this
may be due to the effect of the climb upon the pilot's hearing.

(11) With every decrease in the airspeed, a corresponding decrease will occur in the effectiveness of
the controls. This has been described by most pilots as "mushy," "sloppy," "sluggish," etc., but
what is meant is a decrease in the pressure required to move the controls or a greater movement of
the controls to change the attitude of the airplane: a decrease in the responsiveness of the plane
to pressures applied to the controls.

(12) With the engine laboring (note 9), there is a corresponding vibration felt in the stick and body
which increases as the laboring of the engine increases.

(13) This is a feeling that the aircraft "may drop away" from the pilot.

(14) Just before this point very little resistance is offered by the elevators. In fact, it is possible
to stall the aircraft (our Piper J-3) with just a slight finger pressure.

(15) Any uncoordinated movement will precipitate the stall in direct ratio to the degree of the unco-
ordination of the controls. The use of ailerons at this point will precipitate the stall.

CHART II

STRAIGHT AHEAD, CRUISING POWER

Lights	Indicated Airspeed mph	Tachometer	Vision	Audition	Kinesthesia	Composite
0	70	2150				
1	45	2075	Nose and inclination of wings above normal cruising position (2); slight rise in altimeter reading (3); nose tends to turn left (4)	Engine laboring (7).	Resistance to back pressure on stick (10); vibration of aircraft felt in stick and body (11).	Back pressure is required to keep the nose and inclination of wings above normal cruising position; need for right rudder to maintain direction (4).
2	40	2050	Aircraft slows down relative to the ground (5).	Increased laboring of the engine (8). .	Slight feeling of deceleration.	
3	35	2000	No further gain in altimeter; wings wobble; noticeable tendency for nose to move to the left.		Resistance to back pressure on stick decreases; rudder offers little resistance; increased vibration.	More back pressure required to keep nose and inclination of wings up; need for greater amount of right rudder to maintain direction.
4	30	1950	Slight loss of altitude (6).		Sinking feeling (12).	Controls mushy (10); ailerons slightly effective (14).
5	28(1)	1945 (1)	Increased loss of altitude; at edge of stall nose starts to drop.	Engine seems to quiet down immediately before the stall (9).	Resistance to back pressure on stick rapidly decreases at edge of stall (13); vibration seems to lessen right at edge of stall (9).	

Straight Ahead, Cruising Power - Notes

(1) Plane instruments vibrated so violently that it was difficult to get a reliable reading.

(2) This departure continues and increases toward the stall.

(3) Not noticed readily unless the plane has a sensitive altimeter.

(4) This is due to the effect of torque. With power on, the nose tends to move to the left. This might not be noticed by a good pilot, as he might "automatically" correct this tendency, through unconscious habit.

(5) This continues through lights 3 and 4 and the plane seems to be almost "hovering" at light 5. Doubtful whether this would be noticed at altitude unless pilot expecting it.

(6) Since this could be the result of a down draft, it is not a reliable stall cue.

(7) With every decrease in engine r.p.m.'s a corresponding increase of the engine laboring will occur which may be so small that it will not be noticed by all pilots.

(8) This is a continuum.

(9) It has been suggested that this may be an indication that the propeller is stalled.

(10) With every decrease in the airspeed, a corresponding decrease will occur in the effectiveness of the controls. This has been described by most pilots as "mushy," "sloppy," "sluggish," etc., but what is meant is a decrease in the pressure required to move the controls or a greater movement of the controls to change the attitude of the aircraft.

(11) With the engine laboring (note 7), there is a corresponding vibration felt in the stick and body, which increases as the laboring of the engine increases.

(12) This is the feeling that the aircraft "may drop away" from the pilot.

(13) Just before this point very little resistance is offered by the elevators; in fact, it is possible to stall the aircraft (our Piper J-3) with just a slight finger pressure.

(14) Any uncoordinated movement will precipitate the stall in direct ratio to the degree of the uncoordination of the controls. The use of ailerons at this point will precipitate the stall.

CHART III

STRAIGHT AHEAD, POWER OFF

Lights	Indicated Airspeed mph	Tachometer	Vision	Audition	Kinesthesia	Composite
0	55(1)	750				
1	50	700	Nose and inclination of wings above normal gliding position (2); nose tends to swing to right (3).	Noise of slipstream decreases (7); whistling sound made by wind.	Strong resistance to back pressure on stick (8).	Strong back pressure required to keep nose and inclination of wings above normal; need for left rudder to maintain direction (3).
2	45	700	Loss of altitude decreases temporarily.			
3	38	700	Nose tends to drop but rises again when aircraft picks up a slight amount of extra speed (4); constant decrease of altitude 600 feet per minute.	Slipstream noise at a minimum.	Slight decrease in stick resistance. Sinking and dropping feeling (9); longitudinal rocking felt as nose rises and falls.	Greater movement of rudder required to maintain direction (8).
4	35	700	Wings may wobble (5); no definite dropping of nose (6).		Elevator and rudder resistance less than in cruise position. Controls sloppy.	Ailerons slightly effective but use will precipitate the stall (10).
5	(Not observed under conditions of the slow approach to the stall). No clean break in stall as long as ailerons not used.					

Straight Ahead, Power Off - Notes

(1) Owner's Manual, Piper Cub Special J3C-65 (Piper Aircraft Corp., Lock Haven, Pennsylvania, May 15, 1946, p. 41) recommends, "Glide between 50-60 mph depending upon loading of airplane and gust conditions." We have used 55 mph indicated for gliding, but our air-speed meter seemed to read low.

(2) The nose and inclination of the wings remain above normal gliding position and this departure increases toward the stall.

(3) This is due to absence of torque; i.e., without power the nose will move to right. This might not be noticed by a good pilot as he might "automatically" correct this tendency, through unconscious habit. Furthermore, the tendency is much weaker than is the left-nose tendency in the climb.

(4) This state continues with constant back pressure.

(5) Not in all aircraft.

(6) Some pilots look for a definite dropping of the nose for all stalls; did not occur in our J3 in the slow approach to stall. It has been suggested that our airplane didn't stall. Absence of fifth lamp's lighting suggests this.

(7) Noise of slipstream decreases through lights 1 and 2 and reaches a minimum at lights 3 and 4, except there may be a slight variation in the sound as the airplane oscillates slightly.

(8) With every decrease in airspeed, a corresponding decrease will occur in the effectiveness of the controls. This has been described by most pilots as "mushy," "sloppy," "sluggish," etc., but what is meant is a decrease in the pressure required to move the controls or a greater movement of the controls to change the attitude of the airplane.

(9) This is the feeling that the aircraft is "dropping from beneath" the pilot.

(10) We found the ailerons could be used, but the use caused the stall to occur at 3 lights instead of 4, which is a difference of 3 mph. See also note on uncoordinated controls.

CHART IV

STRAIGHT AHEAD, SLOW FLIGHT

Lights	Indicated Air-speed mph	Tachometer	Vision	Audition	Kinesthesis	Composite
1	45	1700	Wings wobble (1); nose tends to turn left (2); nose and inclination of wings above normal (3); slight increase in altitude (4).	Engine begins to labor (5).	Resistance to back pressure on stick (6); vibration of whole airplane (7).	Back pressure is required to keep the nose and inclination of wings above normal (10); need for right rudder to maintain direction (2).
2	40	1700	Inclination of nose and wings seem high in relation to ground, horizon, etc.			
3	38	1675	Aircraft begins to lose altitude.	Engine labors more.	Feeling of sinking and settling (8).	Considerable amount of rudder needed to maintain attitude and heading (6).
4	35	1650	Nose tends to swing to left appreciably and may drop (2); wings continue to wobble; continued loss of altitude at increasing rate.		Rudders offer little resistance; considerable vibration; definite sinking feeling.	
5	30 (airplane stalls)	1625			Resistance to back pressure decreases at point of stall (9).	

Straight Ahead, Slow Flight - Notes

(1) Pilots report this not true for all types of aircraft.

(2) This is due to the effect of torque. With power on, the nose tends to move to the left. This might not be noticed by a good pilot because he might "automatically" correct this tendency through unconscious habit.

(3) The nose and inclination of wings remain above normal and increase toward the stall.

(4) The sensitive altimeter shows a slight increase through lights 1 and 2, and at light 3 begins to decrease and continues to decrease at an increasing rate at light 4. These observations valid only in still air, free from thermals and down drafts.

(5) With every decrease in engine r.p.m.'s a corresponding increase of the engine laboring will occur which may be so small that it may not be noticed by all pilots.

(6) With every decrease in airspeed, a corresponding decrease will occur in the effectiveness of the controls. This has been described by most pilots as "mushy," "sloppy," "sluggish," etc., but what is meant is a decrease in the pressure required to move the controls, or a greater movement of the controls to change the attitude of the airplane.

(7) With the engine laboring (note 5), there is a corresponding vibration in the stick which increases as the laboring of the engine increases.

(8) This is the feeling that the airplane is "dropping away" from the pilot.

(9) Here the elevators lose practically all effectiveness, and the stick comes back rapidly under little pressure.

(10) At a normal attitude for this airspeed and tachometer setting the airplane will not stall, but back pressure must be used to maintain "slow flight," when trim tab set for cruise.

CHART V

LEFT CLIMBING TURN AT CONSTANT BANK

Lights	Indicated Air-speed mph	Tachometer	Vision	Audition	Kinesthesia	Composite
0	55	2250				
1	48	2200	Nose and inclination of wings above normal (1).	Engine laboring (5).	Resistance to back pressure on stick (6); vibration felt in stick and body (7).	More back pressure required to maintain bank and climb; right rudder correction needed (3).
2	45	2150	Rate of increase in altitude decreases (2); rate of turn tends to increase.	Increased laboring.		
3	38	2150	Turn slows down (4); no increase in altitude.		Resistance to rudder decreases; increased vibration felt in stick and body (7).	More right rudder needed (3).
4	35	2150	Turn stops; left wing starts to come up or go down (10); slight loss of altitude.		Feeling of aircraft settling (8); resistance to controls decreases noticeably (9).	Controls mushy. (6).
5	30 (airplane is stalled)	2150	Nose drops away from pilot.			

Left Climbing Turn at Constant Bank - Notes

(1) The nose and inclination of wings remain above normal and this departure increases toward the stall.

(2) This will not be noticed unless the airplane is equipped with a rate-of-climb indicator or a sensitive altimeter.

(3) This is due to the effect of torque. With climbing power, the nose tends to move to the left. See Note 10.

(4) With constant bank and a decrease in airspeed, using coordinated controls, the rate of turn should <u>increase</u> in normal flight.

(5) With every decrease in engine r.p.m.'s a corresponding increase of the engine laboring will occur, which may be so small that it will not be noticed by all pilots. This is a continuum.

(6) With every decrease in airspeed, a corresponding decrease will occur in the effectiveness of the controls. This has been described by most pilots as "mushy," "sloppy," "sluggish," etc., but what is meant is a decrease in the pressure required to move the controls or a greater movement of the controls to change the attitude of the airplane.

(7) With the engine laboring (note 5), there is a corresponding vibration of the aircraft felt in the stick and body which increases as the laboring of the engine increases. This is a continuum. In advanced stages, vibration may be due to buffeting.

(8) This is a feeling that the aircraft may "drop away" from the pilot.

(9) Just before the stall the resistance of the stick decreases noticeably so that very little pressure is required to stall the aircraft.

(10) More often up. For explanation see Wolfgange Langewiesche, "The Spin over the Top and the Overbanking Tendency," <u>Air Facts</u>, Vol. 7, No. 4; pp. 64-82, April, 1944.

CHART VI

RIGHT CLIMBING TURN AT CONSTANT BANK

Lights	Indicated Airspeed mph	Tachometer	Vision	Audition	Kinesthesia	Composite
0	55	2250				
1	50	2200	Nose and inclination of wings above normal (1).	Engine laboring.	Resistance to back pressure on stick (6); vibration felt in stick and body (7).	More back pressure to maintain bank and climb; rudder pressure required (3).
2	45	2150	Rate of increase in altitude decreases (2); rate of turn tends to decrease (11).	Increased laboring (5).		
3	40	2150	Turn slows down (4); no increase in altitude.		Resistance to rudder decreases; increased vibration felt in stick and body.	More rudder pressure required (3).
4	35	2150	Turn stops; right wing starts to come up or go down (3); slight loss of altitude.		Feeling of aircraft settling (8); aircraft shudders (9); resistance to controls decreases noticeably (10).	Controls mushy (6).
5	33 (airplane is stalled)	2150	Nose drops away from pilot.			

Right Climbing Turn at Constant Bank - Notes

(1) The nose and inclination of wings remain above normal and this departure increases toward the stall.

(2) This will not be noticed unless the airplane is equipped with a rate-of-climb indicator or a sensitive altimeter.

(3) The effect of torque in the right climbing turn is less noticeable than in the left climbing turn. For a discussion of this, and of the tendency for the down wing to come up at the stall, see reference in Note 10, preceding maneuver.

(4) With constant bank and a decrease in airspeed, using coordinated controls, the rate of turn should <u>increase</u> in normal flight.

(5) With every decrease in engine r.p.m.'s a corresponding increase of the engine laboring will occur, which may be so small that it will not be noticed by all pilots. This is a continuum.

(6) With every decrease in airspeed, a corresponding decrease will occur in the effectiveness of the controls. This has been described by most pilots as "mushy," "sloppy," "sluggish," etc., but what is meant is a decrease in the pressure required to move the controls or a greater movement of the controls to change the attitude of the airplane.

(7) With the engine laboring (note 5), there is a corresponding vibration of the aircraft felt in the stick and body which increases as the laboring of the engine increases. This is a continuum.

(8) This is the feeling that the aircraft "may drop away" from the pilot.

(9) Refers to vibration of entire aircraft.

(10) Just before the stall the resistance of the stick decreases noticeably so that very little pressure is required to stall the aircraft.

(11) See note (4). At 2 lamps the airplane should be flying almost normally. Perhaps this decrease in turn rate is due to improper torque correction. Note that in the <u>left</u> climbing turn (preceding maneuver) the turning rate <u>increases</u> at 2 lights.

CHART VII

LEFT GLIDING TURN AT CONSTANT BANK

Lights	Indicated Airspeed mph	Tachometer	Vision	Audition	Kinesthesis	Composite
0	55(1)	750				
1	48	700	Nose and inclination of wings above normal gliding position (2).	Noise of slipstream decreasing (6); whistling sound made by wind.	Resistance to back pressure on stick.	Back pressure required to keep the nose and inclination of wings above normal gliding position.
2	46	700	Rate of descent decreases.		Increased resistance to back pressure on stick.	Aileron and rudder pressure needed to maintain constant bank; greater movement of ailerons and rudders needed for desired response (9).
3	39	700	Loss of altitude increases to approximately 600 ft/min; turn slows down (3); nose rocks up and down; propeller seems to slow down.	Noise of slipstream at a minimum.	Sometimes feeling that aircraft settles and sinks (8); longitudinal rocking felt through the seat and stick; definite resistance to back pressure.	
4	34	700	Turn stops; left wing may tend to rise (4); no definite drop of the nose (5); constant loss of altitude 600 ft/min.	Rolling sound of buffeting (7).	Steady resistance to back pressure (9).	
5	(Not frequently observed because aircraft sank without definite stall.)					

Left Gliding Turn at Constant Bank - Notes

(1) <u>Owner's Manual Piper Cub Special J3C-65</u> (Piper Aircraft Corp., Lock Haven, Pennsylvania, May 15, 1946, p. 41) recommends, "Glide between 50-60 mph depending upon loading of airplane and gust conditions." We have used 55 mph for normal gliding.

(2) The nose and inclination of the wings remain above normal gliding position and this departure increases toward the stall.

(3) Possibly due to un-banking tendency not properly corrected by pilot. See reference in Chart V, note 10.

(4) Or fall. This is not as noticeable as the right wing in a right gliding turn at the same light.

(5) Most students look for a definite drop of the nose for all stalls. Let this absence be a warning.

(6) Noise of slipstream decreases through lights 1 and 2 and reaches a minimum at lights 3 and 4.

(7) At this point the aircraft is oscillating, and the sound has been described as "like that of breakers on the seashore a long way off."

(8) This settling and sinking is a feeling that the aircraft is "dropping away from" the pilot.

(9) With every decrease in airspeed, a corresponding decrease will occur in the effectiveness of the ailerons and rudders. This has been described by most pilots as "mushy," "sloppy," "sluggish," etc., but what is meant is a decrease in the pressure required to move the controls or a greater movement of the controls to change the attitude of the airplane.

CHART VIII

RIGHT GLIDING TURN AT CONSTANT BANK

Lights	Indicated Air-speed mph	Tachometer	Vision	Audition	Kinesthesia	Composite
0	55(1)	750				
1	48	700	Nose and inclination of wings above normal gliding position (2).	Noise of slipstream decreasing (5); whistling sound made by wind.	Resistance to back pressure on stick.	Back pressure required to keep the nose and inclination of wings above normal gliding position (8).
2	46	700	Rate of descent decreases.		Increasing resistance to back pressure on stick.	Aileron and rudder pressure needed to maintain constant bank. Greater movement of ailerons and rudders needed for desired response (8).
3	39	700	Loss of altitude increases to approximately 600 ft/min; turn slows down (3); nose rocks up and down; propeller seems to slow down.	Noise of slipstream at a minimum.	Sometimes feeling that aircraft settles and sinks (7); longitudinal rocking felt through seat and stick; resistance to elevators still "hard" and elevators effective.	
4	36	700	Turn stops; right wing tends to rise; no definite drop of nose (4); constant loss of altitude 600 ft/min.	Rolling sound of buffeting (6).	Steady resistance on elevators, even near the stall.	
5	(Not frequently observed because aircraft sank without definite stall.)					

Right Gliding Turn at Constant Bank - Notes

(1) Owner's Manual, Piper Cub Special J3C-65 (Piper Aircraft Corp., Lock Haven, Pennsylvania, May 15, 1946, p. 41) recommends, "Glide between 50-60 mph depending upon loading of airplane and gust conditions." We have used 55 mph for normal gliding.

(2) The nose and inclination of the wings remain above normal gliding position and this departure increases toward the stall.

(3) Possibly due to un-banking tendency not properly corrected by pilot. See reference in Chart V, note 10.

(4) Most students look for a definite drop of the nose for all stalls. Let this absence be a warning.

(5) Noise of slipstream decreases through lights 1 and 2 and reaches a minimum at lights 3 and 4.

(6) At this point the aircraft is oscillating, and the sound has been described as "like that of breakers on the seashore a long way off."

(7) This settling and sinking feeling is a feeling that the aircraft is "dropping away from" the pilot.

(8) With every decrease in airspeed, a corresponding decrease will occur in the effectiveness of the ailerons and rudders. This has been described by most pilots as "mushy," "sluggish," "sloppy," etc., but what is meant is a decrease in the pressure required to move the controls, or a greater movement of the controls to change the attitude of the airplane.

CHART IX

STEEP LEFT TURN AT ALTITUDE

Lights	Indicated Airspeed mph	Tachometer	Vision	Audition	Kinesthesia	Composite
1	60	2200	Noise just above horizon and moves smoothly.	Engine labors (5).	Strong resistance to back pressure on stick; vibration (6).	More back pressure required on controls to maintain steep turn.
2	55	2160	Turn is established. (1).		Strong resistance to back pressure on stick; great force keeping pilot in seat.	Pressure on stick required to maintain bank (2).
3	50	2000	Turn slows down (9).	Engine labors considerably (5).	Strong resistance to back pressure on stick; increased vibration.	
4	46	2000	Turn continues to slow down.		Strong resistance to back pressure on stick.	More back pressure required.
5	42	2000	Nose high; turn stops (3); left wing starts to come up or go down (4).		Strong resistance to back pressure on stick; aircraft shudders (3); resistance to back pressure decreases (7).	
6	37	2000	Aircraft stalls. Nose falls away from pilot.		Resistance to back pressure relaxes; sudden relaxation of "G" forces (8).	

Steep Left Turn at Altitude - Notes

(1) The pilots may mean the turn has sped up to the rate expected from their experience. With decreased airspeed the turn rate should increase.

(2) With increased power the torque effect causes the nose to turn to the left and pressures are required to correct this.

(3) Here the turn seems to hesitate, but with a slight release of back pressure will continue at a slower rate.

(4) Possible start of an "over the top" or "out the bottom" spin.

(5) With every decrease in engine r.p.m.'s a corresponding increase of the engine laboring will occur, which may be so small that it will not be noticed by all pilots. This is a continuum.

(6) With the engine laboring (note 5), there is a corresponding vibration felt in the stick and body which increases as the laboring of the engine increases. This is a continuum.

(7) At the point where the aircraft shudders, the resistance to back pressure immediately decreases and a slight amount of pressure will cause the stall.

(8) Possible disorientation may occur, either affecting recovery or pilot behavior after recovery.

(9) Possibly to be interpreted as "the turn doesn't speed up any more."

CHART X

STEEP RIGHT TURN AT ALTITUDE

Lights	Indicated Airspeed mph	Tachometer	Vision	Audition	Kinesthesis	Composite
1	58	2200	Nose just about horizon and moves smoothly.	Engine labors (5).	Strong resistance to back pressure on stick; vibration (6).	More back pressure required on controls to maintain turn.
2	55	2150	Turn is constant (9).		Strong resistance to back pressure on stick; great force keeping pilot in seat.	Pressure on stick required to maintain bank and prevent underbanking tendency.
3	50	2000	Turn slows down (1).	Engine labors considerably.	Strong resistance to back pressure on stick; increased vibration.	
4	45	2000	Turn continues to slow down.		Strong resistance to back pressure on stick.	More back pressure required.
5	40	2000	Nose high (2); turn stops (3); right wing starts to come up or go down (4).		Strong resistance to back pressure on stick; aircraft shudders (3); resistance to back pressure decreases (7).	
6	36	2000	Aircraft stalls.		Resistance to back pressure relaxes; relaxation of "G" forces (8).	

Steep Right Turn at Altitude - Notes

(1) Possibly to be interpreted as "the turn doesn't speed up further."

(2) This is higher than in a steep left turn at altitude for the same point.

(3) Here the turn seems to hesitate, but with a slight release of back pressure will continue at a slower rate.

(4) Possible start of an "over the top" or "out the bottom" spin.

(5) With every decrease in engine r.p.m.'s a corresponding increase of the engine laboring will occur, which may be so small that it will not be noticed by all pilots. This is a continuum.

(6) With the engine laboring (note 5), there is a corresponding vibration felt in the stick and body which increases as the laboring of the engine increases. This is a continuum.

(7) At the point where the aircraft shudders, the resistance to back pressure immediately decreases and a slight amount of pressure will cause the stall.

(8) Possible disorientation may occur, either affecting recovery or pilot behavior after recovery.

(9) Possibly to be interpreted as "turn speeds up to where experience dictates."

same conditions, so that it could be depended upon, once the pilot learned what a given indicated air speed meant in terms of the plane's behavior.

All of the cues reported in Charts I through X refer to steady stall approaches with coordinated controls and with the trim tab in cruise position. It was found by experiment that uncoordination of controls caused the lamps to be brought on earlier that in coordinated maneuvers at the same airspeed readings. Therefore, on all occasions, pilots were requested to fly with coordinated controls in an attempt to obtain results under comparable conditions.

The results of these interviews demonstrate clearly that recognition of stall conditions is an exceedingly complex behavior. Not only are visual, auditory, and kinesthetic clues utilized at various stages of departure from normal flight, but also certain complex behaviors -- here described as composite because they cannot be readily described as being predominately dependent on one of these senses -- are also important. There was in this study no attempt to determine the relative importance of these clues in any maneuver or at any stage of departure from normal flight conditions. A clue is important when a pilot detects it and uses it, and different pilots may detect different clues, even though all are available. The present study provides a comprehensive list of the physical clues which do occur for use in detecting and avoiding stall conditions. No one pilot will use more than a few of these clues -- it seems logical to assume that a pilot begins to depend upon those cues which he has been taught or which through experience he learns will aid in avoiding stall conditions. The present summary, therefore, does not deal with the frequency with which each clue was utilized by the 22 subjects; it does deal with the over-all set of clues from which expert pilots choose the ones they use.

While the preceding charts are essentially summaries in themselves, it may be useful here to consider the several maneuvers again, and in the present summary to discuss briefly the physical clues which might be used by pilots in detecting the approach of stall conditions.

The Straight Ahead Maneuvers

Straight Ahead -- Climbing Power. Deviations from the straight ahead normal climb first manifest themselves in inclination of the nose and wings of the plane above normal climbing position, in a laboring engine, and in resistance to back pressure on the stick. This is accompanied by vibration in the stick and body of the plane and in the need for application of right rudder to maintain direction. As the plane increases its deviation from normal flying attitude, there is a more pronounced laboring of the engine and considerable vibration in the stick and body of the plane. The rate of climb decreases, but this may be imperceptible unless the plane is equipped with a rate-of-climb indicator, or unless the pilot glances repeatedly at the altimeter. In the advanced stages of the stall, the climb stops, the altimeter remains constant, and the nose may drop slightly. At this stage, the pilot feels a slight "sinking feeling."

The uniformity with which the expert pilots reported this "sinking feeling" points up one of the difficulties in investigating the use of clues. The man on the street may never have experienced anything which he describes as a "sinking feeling" unless he has ridden on a high-speed elevator in a tall building. His idea of a "sinking feeling" may be his sensation when discharged from a job or served a summons. To the reader who hasn't ridden through a stall and hasn't ridden a high-speed elevator, it can only be said that when he does, he will soon or late come to agree with others that he feels something at the time of downward acceleration which others have called a "sinking feeling." The interviewers learned to report the feeling whenever the expert reported it, and this seemed an adequate test of the feeling as a clue.

At stage 4, where the climb stops, the altimeter remains constant, and the under-surface of the wing is presented to the air in an exaggerated angle of attack. Apparently, flight will continue indefinitely in this position, as long as the airplane can maintain an air speed at least as great as the meter indicated as 30 miles per hour. However, when the airplane slows down to about 2 miles per hour less, there is loss of altitude, the nose drops, and the engine begins to quiet down immediately. This is accompanied by a pronounced "sinking feeling" by the pilot, and a decreased resistance to back pressure on the stick.

Straight Ahead -- Cruising Power. The sensory cues which appeared when flying straight ahead climbing power (see above) begin to manifest themselves in much the same manner in this maneuver. The airplane gradually assumes the same flying attitude as that which pertains in the straight ahead climbing power maneuver. At the point of stall, the position of the airplane in both maneuvers is almost identical, and the sensory clues in the later stages of departure from the normal flight attitude are quite similar. At the stall, the airspeed indicator reads "28" as in the preceding maneuver.

Straight Ahead -- Power Off. When the stall was approached slowly in the experimental airplane, a "clean break" into the stall was not evident. The nose began to sag at 3 lights, 38 m.p.h. indicated airspeed, but when speed increased with nose down, the nose came back up. Possibly the limits of elevator travel were such as to prevent the stall in this situation. At 4 lights, use of ailerons would sometimes precipitate the stall. And all controls were "sloppy" at this point. Note that a red mark on the "30" of the airspeed indicator would have kept the pilot out of the stall in the first two -- (i.e., power-on) maneuvers, but with power off the nose would drop before the airspeed hand got down to 30. This difference may signal a defect in the airspeed indicator, but in any case it signals the old warning not to expect the nose to drop at a predetermined airspeed reading.

Straight Ahead -- Slow Flight. The sensory indications that something is wrong in this maneuver are almost identical with those described above under straight ahead cruising power, except that the maneuver started right out at an abnormal attitude, which wasn't part of the stall approach proper. The nose of the plane tends to turn left, the engine labors, and there is resistance to back pressure on the stick,[10] which is accompanied also by vibration of the whole airplane and wobbling of the wings. The plane itself begins

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[10]The airplane was trimmed for cruise.

to settle and assumes a position similar to that indicative of the stall in straight ahead climbing power and cruising power maneuvers. The airspeed meter repeats its readings at successive approaches, and could be used as a stall warning indicator.[11]

Straight Ahead -- Summary. In the straight ahead stall approaches, the cues which were used throughout were the "sinking feeling," and the sloppiness of the controls when the edge of the stall was reached. A slight dropping of the nose or a wobble of the wings or a loss of altitude were noted by some experts, but these were not regarded as dependable. The one instrument on the airplane which would have labeled the edge of the stall dependably was not used by the expert pilots; i.e., the airspeed indicator. Possibly these experienced pilots were aware of the many serious limitations of the airspeed indicator as a stall-warning device. But one would think they should have learned its limitations and how to interpret it in these maneuvers. Instead, they had become expert at getting along without the airspeed indicator.

The Turning Maneuvers

Left Climbing Turn at Constant Bank. In this maneuver and in its twin -- the right climbing turn, the experts use the faltering or stopping of the turn as the indication of stall imminence. At the edge of the stall the turn stops, the down wing starts to come up, and the pilot reports a "sinking feeling" and a "sloppiness" of the controls. Before the edge of the stall, however, the experts have difficulty in divorcing their expert management from the airplane behavior they are watching. At 2 lights (45 m.p.h.) they call attention to the tendency of the airplane to increase its rate of turn and in the interview they say this is due to torque effect. With climbing power, they correctly point out, the nose of the airplane tends to turn left. They fail to remark that allowing it to do so would result in an uncoordinated turn, albeit a faster one, and these experts are supposed to make mostly well-coordinated turns. It is known that in a coordinated turn (torque effect nil) the turn speeds up when the airspeed decreases, other things being equal. Apparently our experts are more conscious of torque effect in a climb than they are of the turn-rate at varying airspeeds, even though they correctly employ the faltering of the turn as the indication of stall imminence.

Right Climbing Turn at Constant Bank. The behavior of the airplane in the right climbing turn at constant bank is quite similar to that in the left climbing turn at constant bank. There is, however, a difference with respect to the airspeed reading at successive stages in approaching the stall. This may be accounted for by the effect of torque, which may not have been properly corrected, as well as by the asymmetry in pitot mounting, in the vane installation, and in the natural tendencies of the airplane itself. In the left climbing turn, the rate of turn tended to increase before it decreased, whereas in the right climbing turn there was a steady decrease of turn rate until the turn stopped at the edge of the stall. Apparently the climbing turn is a complicated business, aerodynamically. But in either direction, the faltering of the turn is a signal that the stall comes next.

Left Gliding Turn at Constant Bank. Here again the stall is signalled by a stopping of the turn. Two of the clues which the unskilled pilot may rely on are missing: the drop of the nose at the stall, and the sloppiness

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[11]That is, under the conditions of this experiment.

of the elevator control. The stick continues to resist back pressure right up to the stall, and the nose did not drop, in the usual sense of the word. Of course, by comparison with what the nose is supposed to do in a turn -- namely continue to sweep around the horizon -- the stopping of the turn is a "dropping" of the nose. But the pilot reports this as a stopping of the turn. And perhaps the student pilot should be taught in these terms -- the stopping of the turn, rather than the relative dropping of the nose, unless the "dropping" is taught to include the "drop" which is the faltering of the turn.

Right Gliding Turn at Constant Bank. Flight characteristics and sensory cues in this maneuver are quite similar to those in the left gliding turn at constant bank. Here, however, as in previous turns, the airspeed indications at the advanced stages are somewhat lower for the left turn than for the right turn. In the left gliding turn, 4 lamps are lit at 34 miles per hour (indicated), whereas in the right gliding turn, the 4 lamps are lit at 36 miles per hour. Since the airspeed indicator was read from a single pitot tube on one wing, and since perfect symmetry in the two-wing vane system could not be assured, these differences may be due to the instrumentation, rather than to actual differences in the behavior of the airplane. As in the case of the left gliding turn, the turn stops at the stall in the right gliding turn. The turn may be continued by the use of uncoordinated controls, but of course this is the method of choice for precipitating the stall. Again the stick still resists back pressure and the nose does not drop (in the usual sense) at the edge of the stall, and a pilot waiting for these cues will stall while waiting. When something goes wrong with the gliding turn -- the turn falters or a wing starts up -- the expert pilot doesn't wait for back pressure to decrease on the stick or for the nose to "drop."

Steep Left Turn at Altitude. Here again the signal for the stall is the stopping of the turn. The nose does not "drop" in the usual sense, and resistance to back pressure on the stick does not decrease until right at the edge of the stall.

Steep Right Turn at Altitude. Similar behavior characteristics are exhibited during the stall approach in the steep right turn at altitude. There is some question about the rate of turn in the early stages of the stall approach, but no question of the stopping of the turn at the stall. What is a drop of the nose in a straight ahead stall with power on is here a stopping of the turn; relative to what the nose does in continued normal flight, it drops away from the pilot.

Turning Maneuvers -- Summary. In all turning maneuvers the stall is signalled by "something going wrong with the turn." The turn falters or stops completely or a wing comes up and the expected relation between angle of bank and rate of turn is destroyed. Other cues depend upon the maneuver.

Summary of Results by Sensory Clues

Tables 13, 14, and 15 following give some idea of what the student pilot faces if he essays to learn the many clues used by expert pilots in detecting departure from normal flight in the direction of a stall approach. These tables summarize the sensory cues for each successive level of departure from normal flight conditions in each of the ten maneuvers. Each table is discussed briefly in the following paragraphs.

Visual Cues. The scatter of X's in Table 13 shows how the visual cues indicative of departure from normal flight attitudes differ with different maneuvers. Lighting one or two lamps does not indicate a serious departure from normal flight, but referring only to the part of the table which deals with 3, 4, and 5 lamps lit, it will be noted that a given visual clue is used in one maneuver and not in another, and the amount of learning which would be required to master the connections between visual cues and maneuvers must be tremendous. The experts must be expert indeed. And it must appear questionable whether the airplane will ever be an every-day vehicle if a mastery of the linkages in Table 13 is a prerequisite to its safe operation. And yet these are the visual clues to assign for the student pilot to learn and for the private pilot to use. The one uniform clue in all straight ahead maneuvers -- namely airspeed -- is withheld from the student by most instructors[12] and the use of the airspeed meter in teaching stalls is not emphasized in the standard instructional literature. The one uniform clue for turning maneuvers -- namely the stopping of the turn -- is not emphasized in the standard instructional literature, and most instructors do not emphasize with their students that the turn rate is supposed to be uniform, even though these instructors fully realize this and employ it in their own flying.

Auditory Cues. Table 14, for auditory cues, shows the same scatter of X's as was seen in the preceding table. The table is smaller, showing that auditory cues are not much used by our expert pilots. And the student pilot might learn Table 14 easier than the preceding table, but its contents would not be much protection to him in stall recognition, because of the paucity of clues at the 3-, 4-, or 5-lamp stages.

Apparently the student or private pilot listening for sounds of stall warning will do well to watch while listening: watch the airspeed indicator in straight maneuvers, and watch the turn in turns. Or still better, have an instrument without the limitations of the air speed indicator.

Kinesthetic Cues. Table 15, for kinesthetic cues, shows the same widely scattering X's as in Table 13 for visual cues. The expert pilots report many visual and kinesthetic cues compared to the number of auditory cues employed. But in Table 15 the part concerning 3, 4, and 5 lamps shows very wide scatter of numerous X's, and there appears not one kinesthetic cue which is a dependable indicator of stall imminence at the 4- or 5-lamp stage. Indeed, the cues seem highly specialized: each useful in some situations and not in others. Surely learning to recognize the stall approach "by the seat of the pants" is an onerous undertaking.

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[12] It is of considerable significance that the 22 subjects interviewed in this investigation did not rely on airspeed indicator and tachometer readings. These instruments provide information which can be obtained by seeing and interpreting the readings that would prove to be most helpful in detecting the approach of the stall. None of the subjects indicated at any time that they relied upon either the airspeed indicator or the tachometer for additional information as to what was happening to the airplane.

TABLE 13

SUMMARY OF VISUAL CUES

Lamps Lit	Cue	1. Str. Abd. Cl. Pwr.	2. Str. Abd. Cr. Pwr.	3. Str. Abd. Pwr. Off	4. Str. Abd. Slow Flt.	5. Lft. Clim. Turn	6. Rht. Clim. Turn	7. Lft. Glid. Turn	8. Rht. Glid. Turn	9. Steep Lft. Turn	10. Steep Rht. Turn
		Applicable to these Maneuvers									
1 Lamp											
	1. Nose and inclination of wings above normal	X	X	X	X	X	X	X	X	O	O
	2. Nose tends to turn left	X	X	O	X	O	O	O	O	O	O
	3. Slight rise in altimeter reading	O	X	O	X	O	O	O	O	O	O
	4. Nose tends to turn right	O	O	X	O	O	O	O	O	O	O
	5. Wings wobble	O	O	O	X	O	O	O	O	O	O
	6. Nose above horizon	O	O	O	O	O	O	O	O	X	X
2 Lamps											
	1. Rate of climb slows down	X	O	O	O	O	O	O	O	O	O
	2. Aircraft slows down relative to the ground	O	X	O	O	O	O	O	O	O	O
	3. Loss of altitude decreases	O	O	X	O	O	O	O	O	O	O
	4. Inclination of nose and wings seem high in relation to ground, horizon, etc.	O	O	O	X	O	O	O	O	O	O
	5. Rate of increase in altitude decreases	O	O	O	O	X	X	O	O	O	O
	6. Rate of descent decreases	O	O	O	O	O	O	X	X	O	O
	7. Turn is established	O	O	O	O	O	O	O	O	X	O
	8. Turn is constant	O	O	O	O	O	O	O	O	O	X
3 Lamps											
	1. Aircraft slows down relative to the ground	X	O	O	O	O	O	O	O	O	O
	2. Noticeable tendency for nose to move to the left	X	X	O	O	O	O	O	O	O	O
	3. No further gain in altimeter	O	X	O	O	X	X	O	O	O	O
	4. Wings wobble	O	X	O	O	O	O	O	O	O	O
	5. Nose tends to drop but rises again when aircraft picks up a slight amount of extra speed	O	O	X	O	O	O	O	O	O	O

TABLE 13 (Continued)

SUMMARY OF VISUAL CUES

Lamps Lit	Cue	1. Str. Ahd. Cl. Pwr.	2. Str. Ahd. Cr. Pwr.	3. Str. Ahd. Pwr. Off	4. Str. Ahd. Slow Flt.	5. Lft. Clim. Turn	6. Rht. Clim. Turn	7. Lft. Glid. Turn	8. Rht. Glid. Turn	9. Steep Lft. Turn	10. Steep Rht. Turn
		Applicable to these Maneuvers									
3 Lamps (Continued)											
6.	Constant decrease of altitude 600 feet per minute	O	O	X	O	O	O	X	X	O	O
7.	Aircraft begins to lose altitude	O	O	O	X	O	O	O	O	O	O
8.	Turn slows down	O	O	O	O	X	X	O	X	X	X
9.	Nose rocks up and down	O	O	O	O	O	O	X	X	O	O
10.	Propeller seems to slow down	O	O	O	O	O	O	X	X	O	O
4 Lamps											
1.	Rate of climb stops; altimeter remains constant	X	O	O	O	O	O	O	O	O	O
2.	Nose may drop slightly	X	O	O	O	O	O	O	O	O	O
3.	Slight loss of altitude	O	X	O	O	X	X	O	O	O	O
4.	Wings may wobble	O	O	X	O	O	O	O	O	O	O
5.	No definite dropping of nose	O	O	X	O	O	O	X	X	O	O
6.	Nose may swing to left appreciably and drop	O	O	O	X	O	O	O	O	O	O
7.	Wings continue to wobble	O	O	O	X	O	O	O	O	O	O
8.	Continued loss of altitude at increasing rate	O	O	O	X	O	O	O	O	O	O
9.	Turn stops	O	O	O	O	X	X	X	X	O	O
10.	One wing starts to come up	O	O	O	O	X	X	X	X	O	O
11.	Constant loss of altitude 600 feet per minute	O	O	O	O	O	O	X	X	O	O
12.	Turn continues to slow down	O	O	O	O	O	O	O	O	X	X
5 Lamps											
1.	Loss of altitude	X	O	O	O	O	O	O	O	O	O
2.	Increased loss of altitude	O	X	O	O	O	O	O	O	O	O
3.	Nose drops	X	O	O	O	O	O	O	O	O	O
4.	Aircraft picks up speed	X	O	O	O	O	O	O	O	O	O

TABLE 13 (Continued)

SUMMARY OF VISUAL CUES

Lamps Lit Cue	Applicable to these Maneuvers: 1. Str. Abd. Cl. Pwr.	2. Str. Abd. Gr. Pwr.	3. Str. Abd. Pwr. Off	4. Str. Abd. Slow Flt.	5. Lft. Clim. Turn	6. Rht. Clim. Turn	7. Lft. Glid. Turn	8. Rht. Glid. Turn	9. Steep Lft. Turn	10. Steep Rht. Turn
5 Lamps (Continued)										
5. Right at edge of stall, nose starts to drop	O	X	O	O	O	O	O	O	O	O
6. Nose high	O	O	O	O	O	O	O	O	X	X
7. Turn stops	O	O	O	O	O	O	O	O	X	X
8. One wing starts to come up	O	O	O	O	O	O	O	O	X	X
6 Lamps										
1. Aircraft stalls	O	O	O	O	O	O	O	O	X	X

TABLE 14

SUMMARY OF AUDITORY CUES

Lamps Lit / Cue	1. Str. Ahd. Cl. Pwr.	2. Str. Ahd. Cr. Pwr.	3. Str. Ahd. Pwr. Off	4. Str. Ahd. Slow Flt.	5. Lft. Clim. Turn	6. Rht. Clim. Turn	7. Lft. Glid. Turn	8. Rht. Glid. Turn	9. Steep Lft. Turn	10. Steep Rht. Turn
	Applicable to these Maneuvers									
1 Lamp										
1. Engine labors	X	X	O	X	X	X	O	O	X	X
2. Noise of slipstream decreases	O	O	X	O	O	O	X	X	O	O
3. Whistling sound made by wind on struts	O	O	X	O	O	O	X	X	O	O
2 Lamps										
1. Increased laboring of engine	X	X	O	O	X	X	O	O	O	O
3 Lamps										
1. Slipstream noise at a minimum	O	O	X	O	O	O	X	X	O	O
2. Increased laboring of engine	O	O	O	X	O	O	O	O	X	X
4 Lamps										
1. Rolling sound of buffeting	O	O	O	O	O	O	X	X	O	O
5 Lamps										
1. Engine seems to quiet down immediately before the stall	X	X	O	O	O	O	O	O	O	O

TABLE 15

SUMMARY OF KINESTHETIC CUES

Lamps Lit	Cue	1. Str. Abd. Cl. Pwr.	2. Str. Abd. Gr. Pwr.	3. Str. Abd. Pwr. Off	4. Str. Abd. Slow Flt.	5. Lft. Clim. Turn	6. Rht. Clim. Turn	7. Lft. Glid. Turn	8. Rht. Glid. Turn	9. Steep Lft. Turn	10. Steep Rht. Turn
		Applicable to these Maneuvers									
1 Lamp											
	1. Resistance to back pressure on stick	X	X	X	X	X	X	X	X	X	X
	2. Vibration felt in stick and body	X	X	0	0	X	X	0	0	X	X
	3. Vibration of whole airplane	0	0	0	X	0	0	0	0	0	0
2 Lamps											
	1. Considerable vibration felt in stick and body	X	0	0	0	0	0	0	0	0	0
	2. Slight feeling of deceleration	0	X	0	0	0	0	0	0	0	0
	3. Slight decrease in stick resistance	0	0	X	0	0	0	0	0	0	0
	4. Increased resistance to back pressure on stick	0	0	0	0	0	0	X	X	X	X
	5. Great force keeping pilot in his seat	0	0	0	0	0	0	0	0	X	X
3 Lamps											
	1. Rudders offer little resistance	X	X	0	0	0	0	0	0	0	0
	2. Resistance to back pressure on stick decreases	0	X	0	0	0	0	0	0	0	0
	3. Increased vibration	0	X	0	0	X	X	0	0	X	X
	4. Sinking and dropping feeling	0	0	X	X	0	0	0	0	0	0
	5. Longitudinal rocking felt as nose rises and falls	0	0	X	0	0	0	X	X	0	0
	6. Resistance to rudder decreases	0	0	0	0	X	X	0	0	0	0

TABLE 15 (Continued)

SUMMARY OF KINESTHETIC CUES

Lamps Lit	Cue	1. Str. Ahd. Cl. Pwr.	2. Str. Ahd. Cr. Pwr.	3. Str. Ahd. Pwr. Off	4. Str. Ahd. Slow Flt.	5. Lft. Clim. Turn	6. Rht. Clim. Turn	7. Lft. Glid. Turn	8. Rht. Glid. Turn	9. Steep Lft. Turn	10. Steep Rht. Turn
		Applicable to these Maneuvers									
3 Lamps (Continued)											
7.	Sometimes feeling that aircraft settles and sinks	0	0	0	0	0	0	X	X	0	0
8.	Definite resistance to back pressure on stick	0	0	0	0	0	0	X	X	X	X
4 Lamps											
1.	Slight sinking feeling	X	0	0	0	0	0	0	0	0	0
2.	Sinking feeling	0	X	0	X	X	X	0	0	0	0
3.	Elevator and rudder resistance less than in cruise position	0	0	X	0	0	0	0	0	0	0
4.	Controls sloppy	0	0	X	0	0	0	0	0	0	0
5.	Rudders offer little resistance	0	0	0	X	0	0	0	0	0	0
6.	Considerable vibration	0	0	0	X	0	0	0	0	0	0
7.	Resistance to controls decreases noticeably	0	0	0	0	X	X	0	0	0	0
8.	Aircraft shudders	0	0	0	0	0	X	0	0	0	0
9.	Steady resistance to back pressure on stick	0	0	0	0	0	0	X	X	X	X
5 Lamps											
1.	Sinking feeling more pronounced	X	0	0	0	0	0	0	0	0	0
2.	Resistance to back pressure on stick decreases rapidly at edge of the stall	X	X	0	0	0	0	0	0	X	X
3.	Vibration seems to lessen right at edge of stall	X	X	0	0	0	0	0	0	0	0
4.	Strong resistance to back pressure on stick	0	0	0	0	0	0	0	0	X	X
5.	Aircraft shudders	0	0	0	0	0	0	0	0	X	X

TABLE 15 (Continued)

SUMMARY OF KINESTHETIC CUES

Lamps Lit	Cue	1. Str. Abd. Gl. Pwr.	2. Str. Abd. Gr. Pwr.	3. Str. Abd. Pwr. Off	4. Str. Abd. Slow Flt.	5. Lft. Clim. Turn	6. Rht. Clim. Turn	7. Lft. Glid. Turn	8. Rht. Glid. Turn	9. Steep Lft. Turn	10. Steep Rht. Turn
		Applicable to these Maneuvers									
6 Lamps											
1.	Resistance to back pressure relaxes	O	O	O	O	O	O	O	O	X	X
2.	Sudden relaxation of "G" forces	O	O	O	O	O	O	O	O	X	X

Composite Cues. Some of the experts used the experimental approach to determine the imminence of the stall. That is, they applied elevator (or some other) control and watched to see whether the airplane responded. Or they pressed on the rudder to see how easily it yielded. Or they gave particular attention to what corrections were necessary to keep the airplane flying as desirable; e.g., the amount of torque correction necessary. All these complex actions have been grouped together under "Composite Cues." Table 16 shows how they scatter among the maneuvers. At the 4- and 5-lamp stages the two cues which apply throughout are (a) one or more controls (aileron, elevator, or rudder) become "mushy" or "sloppy," yielding with considerable motion to relatively light pressure exerted by the pilot; (b) the airplane fails to respond in the usual manner to control application. Which control is to be watched varies with the maneuver. Furthermore, it cannot be regarded as safe to propose that unskilled pilots experiment with the controls in a situation where the stall is thought imminent, for any one of the three controls may precipitate the stall in one or another situation. The only single recommendation for the Sunday pilot from the set of cues as a whole is: when any control fails to offer resistance to movement (gets "mushy"), or the airplane fails to respond normally to any control, don't experiment; start a recovery immediately.

III. IMPLICATIONS AND RECOMMENDATIONS

Cues from Instruments. It was noted in Charts I through IV that the conditions which give rise to most of the visual, auditory, and kinesthetic cues reported by the expert pilots can be predicted fairly accurately, in the cases of straight ahead maneuvers, from the airspeed indicator and, in the case of power on, the tachometer readings.[13] None of the subjects reported that they used airspeed readings and tachometer readings as clues as to what was happening to the airplane. Instead, certain of the subjects glanced at only the altimeter and relied primarily on auditory and kinesthetic cues. It is natural to suppose that private pilots trained by these experts will fail to utilize the instruments in front of them, and will rely instead upon sensory cues derived from other stimuli.

The expert pilot can perhaps dispense with instruments and successfully employ the welter of relationships portrayed in Tables 13 to 16, using one cue here and another there. Whether or not the typical private pilot can be expected to is another question. Surely a tremendous amount of learning will be a prerequisite. Any sober consideration of Tables 13 through 16 must raise the question whether it wouldn't be safer to teach the private pilot to use the instruments in his airplane.

Disturbance of the Turn. In Charts V through X, it appeared that the turn was disturbed before or at the stall in all turning maneuvers. Yet the standard instructional literature places little or no emphasis upon rate of turn. Uniform angle of bank is stressed, and uniform rate of climb, and uniform gliding speed; but several man-days of search failed to find any quotable treatment of uniform rate of turn. The books in aerodynamic theory contain adequate treatments of rate of turn, but the implications of the theory have not been provided for in the curriculum for the private pilot.

[13] A fixed-pitch propeller was used.

TABLE 16

SUMMARY OF COMPOSITE CUES

Lamps Lit	Cue	1. Str. Abd. Cl. Pwr.	2. Str. Abd. Cr. Pwr.	3. Str. Abd. Pwr. Off	4. Str. Abd. Slow Flt.	5. Lft. Clim. Turn	6. Rht. Clim. Turn	7. Lft. Glid. Turn	8. Rht. Glid. Turn	9. Steep Lft. Turn	10. Steep Rht. Turn
		Applicable to these Maneuvers									
1 Lamp											
	1. Back pressure is required to keep nose and inclination of wings above normal	X	X	X	X	O	O	X	X	O	O
	2. Need for rudder to maintain direction	X	X	X	X	X	X	O	O	X	X
	3. More back pressure required to maintain bank and climb	O	O	O	O	X	X	O	O	O	O
	4. More back pressure required on controls to maintain steep turn	O	O	O	O	O	O	O	O	X	X
2 Lamps											
	1. Aileron and rudder pressure needed to maintain constant bank	O	O	O	O	O	O	X	X	X	X
	2. Greater movement of ailerons and rudders needed for desired response	O	O	O	O	O	O	X	X	O	O
3 Lamps											
	1. Need for appreciable amount of right rudder to maintain heading	X	X	O	O	O	O	O	O	O	O
	2. More back pressure required to keep nose and inclination of wings up	O	X	O	O	O	O	O	O	O	O
	3. Greater movement of rudder required	O	O	X	X	X	X	O	O	O	O

TABLE 16 (Continued)

SUMMARY OF COMPOSITE CUES

Lamps Lit	Cue	1. Str. Ahd. Cl. Pwr.	2. Str. Ahd. Cr. Pwr.	3. Str. Ahd. Pwr. Off	4. Str. Ahd. Slow Flt.	5. Lft. Clim. Turn	6. Rht. Clim. Turn	7. Lft. Glid. Turn	8. Rht. Glid. Turn	9. Steep Lft. Turn	10. Steep Rht. Turn
		Applicable to these Maneuvers									
4 Lamps											
	1. Controls mushy	O	X	O	O	X	X	O	O	O	O
	2. Ailerons slightly effective	O	X	X	O	O	O	O	O	O	O
	3. More back pressure required	O	O	O	O	O	O	O	O	X	X
5 Lamps											
	1. Controls mushy	X	O	O	O	O	O	O	O	O	O
	2. Ailerons slightly effective	X	O	O	O	O	O	O	O	O	O

In a turn with a constant bank and constant throttle setting, the turn slows down and finally stops at the stall or close to it. In a turn with constant throttle setting and a constant rate of turn, a bank becomes steeper as the stall is approached and eventually goes into either a diving spiral or a spin under. Therefore, the first indication of an incipient stall in an airplane turning at a constant degree of bank and with a constant throttle setting is a slowing down or apparent stopping of the turn. If the pilot attempts to maintain a fairly constant rate of turn by banking more steeply or using down rudder, the plane goes into either a diving spiral or a "spin under."

It is worthy of note that as the air speed decreases <u>in normal flight</u>, the rate of turn (and, accordingly, the rate at which the nose appears to sweep around the horizon) increases. In a turn with constant bank, the nose of the airplane should sweep <u>faster</u> around the horizon as the air speed decreases.

The formula relating rate of turn, angle of bank, and air speed is

$$w = \frac{\tan \phi}{0.000795v}$$

where w is number of degrees of turn per second,

ϕ is the angle of bank, and

v is speed in miles per hour.[14]

If a constant 30-degree bank is maintained, then $\tan \phi = \tan 30^\circ = .577$ and the rate of turn becomes

$$w = \frac{.577}{p.000795v}$$

from which it can be seen that as speed v decreases, the rate of turn w increases. In fact, if v is halved, w is doubled.

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[14]This formula was first supplied to the author by Messrs. Leonard Gillman and Harry Goode of Tufts College in 1944 in the form

$$\tan \phi = .000795wv$$

where the symbols are as defined above. It is more commonly encountered in the form

$$\tan \phi = \frac{WV}{g}$$

where W is rate of turn in radians per second,
V is speed in feet per second, and
g is the gravitational constant.

See, for example, Bairstow, Leonard, <u>Applied Aerodynamics</u>, Longmans, Green and Co., New York, etc., Second Edition, 1939 p. 236, formula V.2.38. The two forms are interchangeable with appropriate adjustments of the constants.

Substituting successive speeds from 40 to 80 miles per hour for v in this expression gives turning rates in radians per second as indicated in the following tabulation:

Turning Rates, 30° Bank, for Various Speeds

Speed	Turning Rate
80	9.1
75	9.7
70	10.4
65	11.2
60	12.1
55	13.2
50	14.5
45	16.1
40	18.2

It will be seen from this tabulation that when a pilot makes a coordinated turn in level flight at 80 miles per hour, holding an angle of bank of 30°, the nose of the airplane will start around the horizon at 9.1 degrees per second. If the bank is held constant, as is recommended in the standard instructional literature, and the air speed decreases, then the rate of turn must increase if normal flight is maintained. Our expert pilots were correct in theory as well as experience when they interpreted a slowing down of the turn with decrease in speed as the sign of an abnormal condition. If, during the advanced stages of the turn, the sweep of the nose of the plane around the horizon decreases and the turn falters and stops, a stall is imminent.

Use of Instruments. The majority of all light planes are equipped with an airspeed indicator, altimeter, tachometer, and compass; but their use in instruction is commonly frowned upon. The examiners and interviewers participating in this study inquired at each airport concerning the use of the airspeed indicator and the tachometer in the instructional process. The comments received were of the character of the following:

"No two of these airspeed indicators will read the same."
"The airspeed indicator readings in these airplanes (all of the same type) will vary as much as ten miles per hour."
"Not reliable."
"Poor equipment."
"A bug may get in the pitot tube."
"You can't trust them."
"Somebody is always using the pitot tube to push the airplane."
"Ice forms in the pitot tube," etc.

A reliable airspeed indicator (not necessarily calibrated correctly) appears to be as good an indicator of stall conditions in straight ahead flight as the elaborate, twelve-vane stall-warning device used in this investigation. Nevertheless, the present investigators did not find a single airport or one instructor of the 22 serving as subjects in this investigation who taught the proper use of the airspeed indicator or the tachometer. In fact, the tendency on the part of instructors is to forbid students to use the airspeed indicator in most maneuvers. It was reported also that inspectors covered up the airspeed indicator during check flights, and prohibited applicants from having and using this important information.

Instructors readily admitted that, if instruments such as the oil-pressure gauge or oil-temperature gauge were registering improperly, they would order the airplane to return to the ground. This same type of logic was not applied in the case of the airspeed indicator, which was not only permitted to remain inactive in many airplanes but was covered up or otherwise denied to the student pilots when it did operate.

The various air speeds and their correlates of physical cues as presented in this report apply only to the Piper J-3 airplane NC14302. This, however, does not exclude the applicability of the principle to all light airplanes. There is no particular reason why any student cannot simulate a landing at about 2,000 feet altitude and record the airspeed readings of the particular airplane he is flying. In other words, each student and instructor could determine for himself by experiment at a safe altitude the same general type of readings as presented in the preceding section of this report.[15]

Our expert pilots performed well as to coordination, and for them the fact that uncoordination precipitates the stall may not be serious. But what of the private cross-country pilot -- or the student pilot who wants to know whether his coordination is correct at some point? A ball-bank indicator is an inexpensive and very reliable device; more reliable even than the artificial horizon. It reports more accurately, and at a far smaller hourly fee, than the most expert instructor. Surely the complexity of Tables 13 through 16 argues for providing this easy guide to learning about coordination.

An important observation during the flight interviews was that instructors themselves, even though they could competently recognize the approach of the stall, were at a loss to describe what was happening to the plane and what they were experiencing. Frequently, the subjects would remark that they had never analyzed their feelings, and, in fact, found it difficult to express what they felt and to attribute what they felt to a specific physical sense. This undoubtedly indicates that current instruction of student pilots with respect to recognition of stall conditions leaves much to be desired. It even hints that if instruction is to be depended upon to reduce stall accidents, then instructors must be put through some regime comparable to their experiences in this investigation, so that they can tell students what they do see, hear, feel, and try in stall approach situations. For how can the instructor communicate to the student what he is supposed to see and feel if the instructor himself cannot identify it?

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[15]This principle was used by all Naval carrier pilots before attempting field carrier landing practice, and it was also mandatory for all Naval pilots to return to base if the airspeed indicators were proved unreliable.

Discussion. It must be remembered that this study was conducted in order to find out what cues the experts use which can be demonstrated to the student, so they could be used in instruction. These cues may or may not be dependable and the private pilot may or may not be well advised to depend upon them. The fact that the cues are many and various, and specific to certain conditions of flight, makes it appear that the cues may not be very useful to the private pilot unless he does a lot of learning to prepare himself to use them, and does a great deal of frequent and systematic reviewing to keep himself in practice. Typically, private pilots do not spend their flying time in such study or review, and the suggestion that they do so does not seem very practical or promising.

Furthermore, the private pilot must learn that the cues are not dependable. The experts use these undependable cues, but that does not mean that they are dependable. Loss of altitude may be due to a down draft instead of to a semi-stall condition: gain in altitude may be due to a thermal. Rate of climb is similarly a function of air conditions. Back pressures on the stick are affected by the trim. Wobbling of the wings and dropping of the nose may be caused by turbulence. Rudder correction needed in a climb is uneven in turbulent air. Even in straight-ahead maneuvers the airspeed indicator is unreliable as a stall-warning device in turbulent air or in pull-outs or pull-ups of even mild extent. And in turns, the nose may falter in its uniform sweep because of turbulence, and because of turbulence at a particular moment, the nose may continue around the horizon after the stall is dangerously near. The down wing doesn't always come up when expected in the turning stall -- it depends on many things, including the pilot's coordination. Furthermore, the down wing's going farther down may be a far more hazardous development in the turn at low altitude, since the "spin under" may look to the private pilot as though he has merely got to turning too fast. An attempted turn recovery here where a stall recovery is called for could be fatal.

What is needed is (a) for the private pilot to know what flight situations involve the hazard of a stall; (b) a way of telling him whether the hazard is developing in his case when he is in that flight situation; and (c) for him to know what to do if it is. The second of the above clearly refers to a stall-warning indicator -- not the manifold and complicated cue system the experts have taken so many flight hours to master -- and which are not dependable without expert interpretation anyway!

Recommendations: The results of this investigation, combined with those of previous studies and with the considerations discussed above, appear to warrant two sets of recommendations:

1. The first set of recommendations applies to the existing situations in private flying. The fact is that under existing conditions many private pilots are flying planes which are not adequately equipped in so far as basic flying instruments are concerned. Even when present, such instruments are frequently inoperative. When operating, they are usually undependable because of faulty calibration and generally inadequate maintenance. So long as such conditions are allowed to exist in the operation of licensed private planes, the following recommendations are indicated by the results of the study:

a. To the student or private pilot, the results seem to say: "If in straight ahead flight the air speed gets low, don't wait for the controls to get mushy or the nose to drop; if in a turn something goes wrong -- the turn falters or the down wing comes up or goes down -- don't wait for the turn to stop or the controls to get mushy or the air speed to recover; if in any maneuver close to the ground any control fails to resist pressure or the airplane fails to respond to the control, don't wait for the nose to drop or a wing to go down or up; commence a recovery from the situation at once."

b. The findings of the study also lead directly to two other recommendations designed to help the private pilot avoid stalls without the aid of adequate instruments. These are:

(1) that instructional literature be revised to place a more definite emphasis upon the uniform rate of turn, as emphasis is already placed upon uniform rate of climb, uniform angle of bank, uniform gliding speed, etc.

(2) that in the training period stress be placed upon the information that can be provided by properly maintained instruments as a basis for understanding and appreciating the approach of stall conditions.

2. One of the major findings of the current series of stall studies is that the human organism is a very inadequate detector of the incipient stall. Moreover, skill in the detection of the incipient stall in one maneuver or in one airplane does not transfer to the recognition of the stall in another maneuver or in another airplane. This general finding necessarily leads to a second set of recommendations, calling for regulations requiring the installation and maintenance of instruments necessary for the accurate recognition of the incipient stall regardless of the maneuver performed by the pilot or the airplane in which he performs this maneuver.

a. In the Letter of Transmittal to the report, A Study of the Accuracy of Recognition of the Incipient Stall in Familiar and Unfamiliar Planes,[16] the Committee on Aviation Psychology made the following recommendation:

"The study reveals consistent failure on the part of student pilots, private pilots and flight instructors to detect the pre-stall

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[16] Rulon, P. J. Op. cit.

conditions in light aircraft. On the basis of these findings the Committee on Aviation Psychology recommends that regulations be formulated requiring the installation of approved stall-warning devices in all private airplanes, providing that field tests demonstrate that available instruments can be adequately maintained and function properly over an extended period."

The results of the present study lend further support to this recommendation since an adequate stall warning instrument provides warning under nearly all flight conditions.

b. The results of the present study suggest an alternative to the above recommendation which may merit special consideration if data are not yet at hand to demonstrate that available stall warning instruments can be adequately maintained and function properly over an extended period. This is that regulations be formulated requiring the installation and proper maintenance of four basic instruments on all licensed training and "private" airplanes, viz.: (1) airspeed indicator, (2) tachometer, (3) altimeter and (4) ball-bank indicator, and that instructional material be revised to include training in the use of pertinent instruments in the detection of the incipient stall under varying flight conditions.[17] One advantage of this alternative recommendation is that it will require that airplanes be equipped with properly maintained instruments which can be used for purposes other than the detection of the incipient stall. There are three major disadvantages in so far as the primary purpose of detecting the incipient stall is concerned, viz.:

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[17]These recommendations are not out of line with results of earlier work conducted under the auspices of the Committee on Aviation Psychology on the effectiveness of instruments as a training aid. (Walker, R. Y., et al. The effectiveness of directed attention to instruments as a training aid. Washington, D.C.: CAA Division of Research, Report No. 69, October 1946.) This research indicated that, under the conditions of the experiment, subjects given special training in which reference to the ball bank, airspeed indicator and altimeter was emphasized performed no better in terms of various criterion measures than did subjects trained without special reference to these instruments. In fact such differences as were evident, although not statistically significant, favored the control group.

However, in this experimental course, emphasis was not given to these instruments during stall instruction. Thus there is no direct evidence on the effectiveness of reference to these instruments during stall instruction. Furthermore, this study had no bearing on the use of instruments in detecting the incipient stall.

(1) The regulations would require the proper maintenance of four instruments. But, of course, they ought to be properly maintained anyway.

(2) The use of these instruments, instead of the single stall-warning device would still call for the interpretation by the pilot of rather complex interrelationships between the airspeed indicator and the tachometer readings for the detection of the incipient stall in different maneuvers, and for readjustment of instrument readings in transfer from one type of airplane to another.

(3) Research by Dr. Dean R. Brimhall and Dr. Raymond Franzen[18] and examination of accident reports suggest that many accidents resulting from an inadvertent stall may occur while the pilot's attention is directed outside the plane, or while he is otherwise preoccupied. It is doubtful whether, under such conditions, he would be giving sufficiently close attention to the flight instruments to render them of value or a source of cues to the incipient stall. Under these conditions, however, he would more likely be aware of a specific stall-warning signal, such as a horn.

Disadvantages characterizing the alternative recommendations suggest that regulations should call for the installation of stall-warning devices providing available stall-warning devices can be adequately maintained and function properly.

IV. IMPLICATIONS FOR RELATED RESEARCH

This study sought to identify and describe the physical cues -- visual, auditory, kinesthetic, and experimental -- which experienced pilots utilize in stall perception. The findings reported supplement the findings of Melton and Bakan[19] in their study of the effect of sensory deprivation on stall perception.

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[18] Franzen, Raymond, & Brimhall, Dean R. A study of serious and fatal accident records during 1939 and 1940. Washington, D.C.: CAA Division of Research, Report No. 77, May 1948.

[19] Melton, A. W., & Bakan, D. An investigation of the effect of sensory deprivation on stall perception. Progress report to the National Research Council Committee on Aviation Psychology, June 21, 1948. (Copy in Committee files. Final report in preparation.)

The present study and that by Melton and Bakan parallel each other in important respects. Melton and Bakan studied the deprivation of vision and audition, but did not consider the effect of deprivation of kinesthetic cues. The different maneuvers considered were:

Rulon and Vaughn	Melton and Bakan
1. Straight ahead -- climbing power	1. Straight and level
2. Straight ahead -- cruising power	
3. Straight ahead -- power off	2. Straight glide
4. Straight ahead -- slow flight	
5. Left climbing turn	3. 180° left climbing turn
6. Right climbing turn	4. 180° right climbing turn
7. Left gliding turn	5. 360° left gliding turn
8. Right gliding turn	6. 360° right gliding turn
9. Steep left turn	7. 360° left turn
10. Steep right turn	8. 360° right turn

The data of the Melton and Bakan report permitted the drawing of inferences concerning the relative importance of vision and audition, but necessarily did not permit the drawing of inferences concerning the relative importance of kinesthetic cues in relation to vision and audition. The present report discusses the cues which experienced pilots utilize in stall perception. No attempt was made to determine their relative effectiveness. Furthermore, the results present cues which impinge upon the pilot who is in full possession of his faculties. Nevertheless, there are certain contrasts and confirmations in the findings of the two studies, and inferences and assumptions may be drawn upon the basis of the findings of the two studies. These may be best considered maneuver by maneuver, examining in the Melton-Bakan report only the results for stall recognition and omitting the results for normal flight.

1. Straight ahead -- power on.

Stall Flight Conditions (Melton and Bakan, page 52):

> "There is no evidence of any harmful effect of removal of vision or audition singly. However, removal of both produce a marked decrement in performance. This evidence supplies a basis for believing that pilots can shift from one to another modality with no deleterious effects."

The experts utilized visual, auditory, kinesthetic, and experimental cues in this maneuver, and several visual cues were reported. However, many non-visual cues were also reported. The pilots reported enough non-visual cues to make the Melton-Bakan finding look plausible. The experts might have switched easily to utilization of other cues, had vision been denied them. The pilots didn't consult the airspeed indicator. Presumably, the Melton-Bakan pilots, when seeing, similarly ignored the airspeed meter. It would be interesting to see whether a user of the airspeed indicator was handicapped by deprivation of vision. Surely the result would depend upon the expertness of the pilot.

2. Straight ahead -- power off.

Stall Flight Condition (Melton and Bakan, page 52):

> "No evidence that either vision or audition or both play a role. The importance of other cues is indicated. There is a suggestion that the presence of audition may be a handicap to the use of other cues."

Again our pilots reported enough non-visual cues to make the above finding plausible. Also enough non-auditory cues. The column for audition in Chart III is missing any cue for distinction between Lamps 3, 4, and 5. Perhaps noises are actually misleading to the non-seeing pilot. As regards vision, it is to be remembered that the "blind" pilots in the Ohio State research were being deprived of an indication (airspeed meter) which they probably didn't use when seeing anyway.

3. Left climbing turn.

Stall Flight Condition (Melton and Bakan, page 52):

> "There is evidence that both vision and audition, when both are available, play a role. There is some evidence that when vision is not available, audition by itself is fairly efficient. There is also some evidence that when audition is not available, vision is fairly efficient."

Chart IV for this maneuver bears out the first sentence but not the rest. Kinesthetic and composite cues appear numerous in this chart. Indeed, unless Melton and Bakan masked out kinesthetic cues and prevented the employment of such cues as composite cues, their statements above that "audition by itself is fairly efficient" and "vision is fairly efficient" may be stronger than their data warrant.

4. Right climbing turn.

Stall Flight Condition (Melton and Bakan, page 52):

> "Vision plays a role. Audition seems to be a hindrance."

The ERC pilots reported visual cues which would seem to bear out the first statement. They also reported a continual increase in the laboring of the engine, this being an auditory cue. Taking it away seemed to improve the approaches of some of the Melton-Bakan pilots. It would be interesting to see whether the improved performances were those of pilots who when hearing fell short in the approach. Perhaps removing a warning allowed the timid performers to earn a higher approach score.

5. Left gliding turn.

Stall Flight Condition (Melton and Bakan, page 52):

> "The evidence seems to indicate that, if anything, vision and audition are hindrances. The importance of non-auditory and non-visual cues is indicated."

This is the finding most at odds with the results of the Educational Research Corporation research. There are definite and seemingly very useful cues in the vision column (Chart VII) and several in the hearing column. In the advanced stages of the near-stall conditions, the rate of turn decreases and the nose rocks up and down. Finally, a wing starts to rise, the nose stops turning, and the loss of altitude reaches a maximum (600 ft./min.). When the plane is gliding at normal speed (55 miles per hour) there is a noticeable noise of the slipstream and the whistling of the wind. As the airplane approaches the stall, these sounds are reduced in intensity, and just before the stall the airplane becomes "dangerously" quiet.

Despite the fact that there are definite visual and auditory cues available in this maneuver, the finding of Melton and Bakan may be genuine, of course. Even experienced pilots apparently do not use the airspeed indicator and tachometer[20] in the glide. They rely, it may be assumed, upon the feel of the controls more than they do on either visual or auditory cues. But suppose pilots were <u>taught</u> to use the turn-falter, and <u>then</u> deprived of vision? Perhaps Melton and Bakan have found what ERC did: that standard instruction places little emphasis on uniform rate of turn!

6. <u>Right gliding turn</u>.

<u>Stall Flight Condition</u> (Melton and Bakan, page 52):

> "The evidence does not indicate any assignable role to vision and audition. The importance of non-auditory and non-visual cues is indicated."

The physical cues available in this maneuver are similar to those in the left gliding turn. At the advanced stages the turn slows down and a wing tends to rise. Did the Melton-Bakan pilots, when seeing, ignore the slowing turn? Or did they not get close enough to the stall for a wing to rise or fall?

7. <u>Left turn</u>.

<u>Stall Flight Condition</u> (Melton and Bakan, page 52):

> "Vision plays an important role. There is no demonstrable role of audition."

Chart IX bears out this finding. The auditory cue is engine laboring. It is a continuously increasing thing and hard to interpret. Furthermore, the same laboring might be <u>felt</u> by a deaf pilot.

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[20] The tachometer is much less valuable in this maneuver than in certain of the others.

8. Right Turn.

Stall Flight Condition (Melton and Bakan, page 53):

> "Both audition and vision alone play a role in each other's absence. Performance when both are absent is significantly worse than when both are present."

The physical cues available for stall perception in this maneuver are quite similar to those pertaining to the left turn, including the tendency of a wing to rise just at the point of stall. It would be judged from Chart X for the steep right turn at altitude that deprivation of vision and audition both would leave only the last-minute cues available. A pilot who feared to push to where he felt them might score low by reason of failure to approach the stall, and the pilot bold enough to go to where he did sense them might fail through actually stalling the airplane.

From the foregoing observations, it appears that the results of the present study are in general not inconsistent with the results of the study reported by Melton and Bakan. Since the two studies had different origins and purposes, employed different procedures, and did not record the same kind of observations, they cannot be expected to corroborate one another except in a general way. This they do. For example, the Ohio State study shows vision to be very important in normal flight, even though stall recognition was not fully impaired by deprivation of vision. Recommendations from observations made in the course of the ERC study concern the preservation of normal flight -- or its restoration -- and they involve vision quite intimately. They also involve the cues found important by Melton and Bakan when vision is absent.

None of the recommendations is rendered in any way suspect by any of the Ohio State results. This is not surprising, since both studies report what happens when people fly airplanes under various conditions.