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FINAL REPORT

Project No. 560-101-02X (PHASE 1)

EXPERIMENTATION AND EVALUATION OF IMPROVED STALL WARNING EQUIPMENT

FEDERAL AVIATION ADMINISTRATION

DECEMBER 1969

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
National Aviation Facilities Experimental Center
Atlantic City, New Jersey 08405

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PROJECT NO. 560-101-02X (PHASE I)

REPORT NO. NA-69-35
(DS-69-15)

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for

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DEPARTMENT OF TRANSPORTATION
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ABSTRACT

A flight simulation project was conducted at the FAA's National Aviation Facilities Experimental Center at Atlantic City, New Jersey, to determine the relative alerting efficacy of artificial aural and tactile warning signals for alerting pilots to an impending stall condition.

Five pilots with current private flying experience participated as subjects in the evaluation of a continuous warning horn signal, an interrupted warning horn signal, and tactile stickshakers with and without an aural (clacker-type) signal.

While performing an intricate in-flight pattern task in a flight simulator, pilots were required to respond to aural and tactile warning signals if and when they were detected.

The results show that a stickshaker warning signal is the most effective means of alerting a pilot (99 percent effective) followed by an interrupted horn (84 percent effective). The continuous or steady horn, currently used in most aircraft, was only 64 percent effective in alerting a pilot. The results also show that aural signals are least detected when the in-cockpit task or workload requires a high degree of pilot attention.

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INTRODUCTION

Federal Aviation Regulation (FAR) 23.207 for general aviation aircraft requires a stall warning that must be clear and distinct with the flaps and landing gear in any position. The stall warning must begin at a speed exceeding the stalling speed by not less than 5 miles and not more than 10 miles per hour, and must continue until the stall occurs.

The National Transportation Safety Board reported[1] the occurrence of 494 stall-type accidents in 1966. Of these accidents, 142 were fatal, 74 involved serious injury and 231 aircraft were destroyed. These figures, respectively, represent 23 percent of all fatal accidents, 22 percent of all serious injury accidents and over 23 percent of all aircraft destroyed. Thus, despite a stall warning requirement, the stall-type accident continues to account for a high percentage of general aviation accidents.

Purpose

The purpose of this flight simulation project was to evaluate the relative effectiveness of various stall warning signals for alerting a pilot to an impending stall condition.

Background

A project was initiated by the Aircraft Development Service, Federal Aviation Administration (FAA), Washington, D. C., and carried out by the National Aviation Facilities Experimental Center (NAFEC), Atlantic City, New Jersey. The overall objective of this project was to provide a comparative evaluation of available stall warning systems to determine the relative degree with which they alert a pilot to an impending stall.

An initial study[2] under this project, completed in February 1968, examined the stall/spin accidents occurring in 1964-65-66. The data indicated that despite the use of stall warners, the stall/spin category of accidents continued to cause more fatalities and serious injury than any other type of general aviation accident except inadvertent VFR flight

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[1] General Aviation Accident Statistical Review for 1966, National Transportation Safety Board, Department of Transportation.

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[2] J. Grambart, "Reduction of Stall/Spin Accidents Related to Take-Off, Departure and Landing," Interim Report No. NA-68-4, FAA, Department of Transportation, February 1968.

into IFR weather. The study hypothesized that any one of the following conditions may prevent effective reaction to a stall warning signal:

1. The signal is not detected.

2. The signal is belatedly observed and corrective action begun too late.

3. It is observed, but deliberately ignored, as in an attempted stretched glide to an emergency landing or during a maximum effort initial climb.

4. Under certain conditions, such as a power loss during initial climb or excessive entry rates into high speed turns, the signal may not lead the stall sufficiently in time to permit corrective action.

That a stall warning signal can go undetected, as mentioned in the first condition above, may possibly be attributed to pilot concentration on cockpit workload, high ambient cockpit noise, inability of a weak signal to penetrate pilot fixation on outside visual cues during critical phases of flight or malfunctioning stall warning equipment.

With these factors in mind, a preliminary sampling of stall warning system information was obtained through a series of planned stall maneuvers in several representative single-engine general aviation aircraft.

Airspeeds at stall signal onset and full stall as well as time histories from stall signal onset to stall were recorded manually.

The results of these informal data substantiated the hypothesis that under certain conditions, signal detection is difficult, fails to warn and, during certain maneuvers, does not lead the stall sufficiently in time to prevent a stall.

The information obtained was the basis for dividing the project into two separate phases. Phase I, which this report describes, was a flight simulation evaluation of stall warning signals of an aural and tactile nature. Phase II was established to evaluate complete stall warning systems in an aircraft through a series of comprehensive flight maneuvers. A stall warning system includes the stall sensor, associated circuitry and the signal output which may be of a visual, aural or tactile nature or a combination of these signals.

Objective performance measurements of the various stall systems evaluated should determine the relative effectiveness of the systems for alerting a pilot to an imminent stall. The results of the Phase II evaluation will be detailed in a future report.

DISCUSSION

Flight Simulation Facility

The flight simulation test environment consisted of a fixed-base flight simulator representative of a single-engine general aviation aircraft, with appropriate flight instrumentation, which responded according to movement of the flight and engine controls.

The pilot was provided with a yoke-mounted pushbutton which in turn was interconnected to an analog recorder. Activation of the pushbutton by the pilot indicated his detection of a warning signal. The recorder registered warning signal onset, pilot detection of the warning signal, undetected signals and time from signal onset to pilot response.

The warning signal generator consisted of a control box with a two-position switch for activating either one of two installed signals. A rheostat on the control box enabled the experimenter to establish and control threshold levels of signal intensity and amplitude for each subject.

Ambient cockpit noise was provided by a tape player and tape which contained a recording of a realistic general aviation single-engine cockpit noise level under cruise conditions. Simulator engine noise levels in the cockpit were matched to live engine noise levels by means of an octave band noise analyzer.

Warning Signals Evaluated

Two aural and two tactile signals were evaluated. The aural signals consisted of (1) an aircraft stall warning horn with a continuous signal frequency of 2,000 hertz (Hz), and (2) a low pitch (1,000 Hz) warning horn which provided an interrupted signal at the rate of 1.67 Hz.[3] Both devices were mounted on the exterior front end of the flight simulator cab approximately 6 feet from the pilot's position.

The tactile signals evaluated included two stickshakers mounted directly on the pilot's control column forward of the instrument panel.

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[3]Sensitivity of the average ear is reported to be greatest at frequencies between 1,000 and 2,000 Hz.

They differed in that one stickshaker contained an aural (clacker-type) signal while the other did not. Maximum amplitude of the stickshaker's motion was measured as .5 inch, with a frequency of 20 Hz.

Subjects

Five male private pilots were selected as subjects from FAA personnel at NAFEC. All had current flight experience, but none of the subjects held an instrument rating. Their ages ranged from 30 to 42 years and total flight time varied from 200 to 950 hours. Hearing tests confirmed each subject's normalcy of hearing between the frequencies of 250 and 2,000 Hz.

Experimental Design

The experimental design for warning signal generation is depicted in Table I.

Each subject flew a total of 10 flights in evaluating the continuous aural warning horn (X) and the interrupted warning horn (Y). In the course of one flight, each signal was generated seven times in the order shown in Table I for a total of 14 signals per flight. In 10 flights, each subject had an opportunity to respond to 70 X and 70 Y signals. Thus, for five subjects, a total of 350 X and 350 Y signals was generated.

A flight consisted of subjects flying an instrument flight pattern commonly referred to as the "C" pattern indicated in Figure 1. The pattern is a complex series of climbing, descending and turning maneuvers of 16 minutes' duration. Flying the pattern demands a high degree of pilot concentration and skill in order to remain within specific limits of altitude, heading and time.

For example, if one considers the first ascending turn of the pattern in Figure 1, the pilot must start the turn on time, turning at a rate of 3° per second while climbing at a rate of 660 feet per minute (ft/min). Thus, at the exact end of 1.5 minutes, the pilot should have completed a 270° turn to a heading of east and simultaneously gained 1,000 feet. The method of scoring pilot performance was to manually record the position of the flight in the pattern in terms of altitude and heading every 30 seconds. Referring again to the first ascending turn, a perfect score for this turn requires the pilot to start the turn on time, turn exactly 90° (to a westerly heading) and gain 330 feet in 30 seconds. Since the pattern takes 16 minutes to complete, 30-second recordings of aircraft position allowed for 32 checkpoints for heading and 32 checkpoints for altitude, or 64 scoring checkpoints.

TABLE I

EXPERIMENTAL DESIGN FOR WARNING SIGNAL EVALUATION

Signal Number	Flight Number 1	2	3	4	5	6	7	8	9	10
1	X	Y	X	Y	Y	X	Y	X	Y	X
2	X	Y	X	Y	X	Y	Y	X	Y	X
3	X	Y	Y	X	Y	X	X	Y	Y	X
4	Y	X	Y	X	X	Y	X	Y	X	Y
5	Y	X	X	Y	Y	X	Y	X	X	Y
6	Y	X	Y	X	X	Y	X	Y	X	Y
7	Y	X	X	Y	Y	X	Y	X	X	Y
8	X	Y	Y	X	X	Y	X	Y	Y	X
9	X	Y	X	Y	Y	X	Y	X	Y	X
10	X	Y	Y	X	X	Y	X	Y	Y	X
11	X	Y	X	Y	Y	X	Y	X	Y	X
12	Y	X	X	Y	X	Y	Y	X	X	Y
13	Y	X	Y	X	Y	X	X	Y	X	Y
14	Y	X	Y	X	X	Y	X	Y	X	Y

70X + 70Y = 140

X = Continuous signal

Y = Interrupted signal

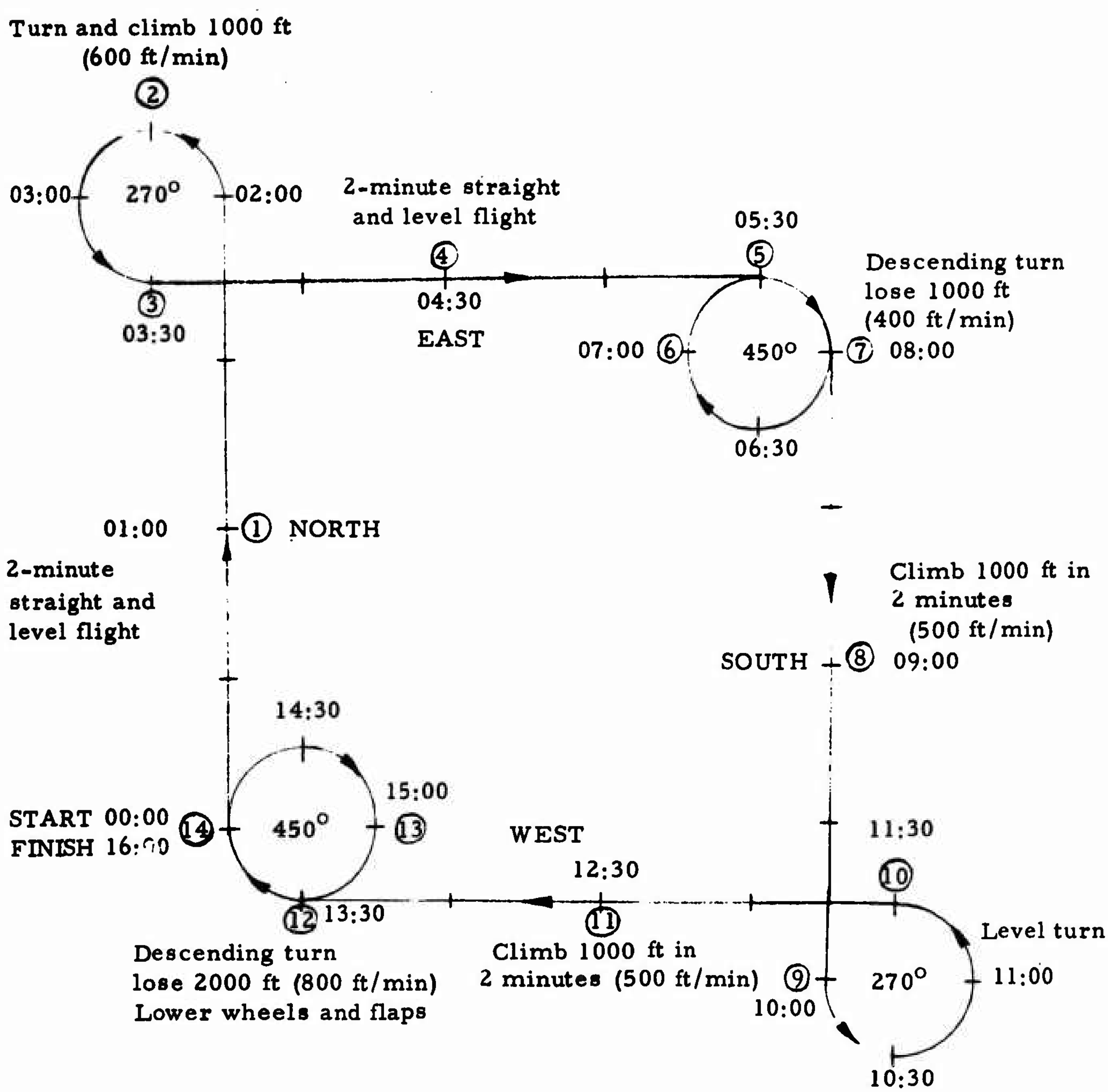

FIG. 1 "C" PATTERN

As it was unreasonable to expect pilots to fly perfect patterns initially, tolerances of ±50 feet of altitude, ±5 degrees of heading and ±5 seconds of time were permitted. Pilots received plus scores for each checkpoint achieved and minus scores when exceeding the aforementioned limitations. The tick marks shown in the pattern designate 30-second checkpoints.

The circled numerals inscribed about the "C" pattern in Figure 1 depict the general areas of warning signal generation. The numerals from 1 to 14 relate to the order and type signal generated as specified in the experimental design of Table I.

An identical design was employed in the evaluation of the aural stickshaker (A) and the nonaural stickshaker (B).

Warning signal evaluation was carried out in two simulator flight phases. The first 10 flights were assigned to the paired aural warning horn signals; i.e., continuous vs. interrupted signals. The second 10 flights were assigned to the paired tactile signals; i.e., aural stickshaker vs. nonaural stickshaker.

Signal Measurements

Prior to a data run, measurements of each subject's threshold level of aural horn signal detection were observed and recorded with a noise analyzer. The measurements were taken over a reproduced ambient cockpit engine noise level of 96 decibels (dB). These readings provided for a constant volume control of signal emission for each subject throughout the aural signal evaluations. The aural signals of 1,000 and 2,000 Hz bracketed the ambient cockpit engine noise level, and were detectable even though the measured dB level of signal emission was measured at 73 to 76 dB.

Threshold levels of each subject's tactile detection in terms of amplitude (i.e., yoke vibration or displacement) averaged between .1 and .2 inch.

The reader is reminded that the intent of these evaluations was not to analyze and establish specifications for desirable signals with respect to type, signal intensity, frequency and/or amplitude, but rather to evaluate the alerting effectiveness of various existent signals and the frequency with which pilots do or do not respond to these warnings.

Data Run Description

Subjects were briefed before each data run. They were not informed of the true nature of the project. Instead, they were told that cockpit workload was being investigated to determine what effect, if any, engine noise, communications or warning signals had on their instrument performance. They were briefed on the elements of the "C" pattern with emphasis on achieving as many checkpoints as possible. They were advised that during the flight the experimenter would attempt to distract them either by conversation or with warning signals. If a signal was observed, they were to respond by pushing the yoke button.

The emphasis on pattern performance precluded subjects from neglecting the flight pattern task to concentrate solely on the signals generated.

The experimenter occupied the rear seat of the flight simulator and controlled the tape recorder of taped engine noise and the control box for generating either of two installed signals. The pilot occupied the normal front and left seat of the flight simulator. The experimenter's rear seat position prevented the subject pilot from observing when or what signal was activated by the experimenter.

After attaining a pattern altitude of 2,000 feet and a heading of north, the pilot would advise the experimenter he was prepared for the data run. At this moment, both pilot and experimenter would start individual, elapsed time, sweep-second-hand clocks, and the flight would begin. As the pilot concentrated on flying the pattern, the experimenter manually recorded achieved or missed checkpoints in altitude and heading every 30 seconds. In accordance with the experimental design, the warning signals were generated by the experimenter throughout the pattern. The signal continued to sound until the pilot's yoke button was depressed, which broke the signal circuitry and indicated to the experimenter that the pilot heard the signal. It became common practice for the experimenter to observe the pilot depressing the yoke button in addition to noting signal cutoff.

With the yoke button and signal generator connected to the analog recorder, items recorded were signal onset, pilot detection of signals, undetected signals and time from signal onset to pilot response. A failure to respond to a signal within a 5-second period was regarded as a failure to detect a signal. When the first of two flights was completed, the pilot took a 15-minute "break" before starting his second and final flight of the day.

These procedures were employed for all subjects and remained the same until all the required flights were completed. However, to minimize the pattern learning effects acquired by subjects in the first 10 flights for aural warning signal evaluation, "C" pattern direction was changed 180° for the next 10 flights required for tactile warning signal evaluation. Thus, instead of starting the pattern on a northerly heading with a first turn to a heading of east, subjects started the pattern on a southerly heading with a first turn to the west. This was the only change in procedure for the paired evaluation of installed tactile warning signals, and the change proved effective by reducing previous learning effects.

Results

The results of aural and tactile warning signal evaluation are shown, respectively, in Tables II and III.

Column 1 of Table II shows that the detection frequency of the continuous warning horn signal (X), for five subjects, ranges from a minimum of 33 to a maximum of 62 responses. The sum total of pilot responses is 225 out of a possible 350 responses. This means that the continuous warning signal was heard on an average of 64 percent of the time by subjects while they were actively engaged in an in-flight pattern task. The frequency of undetected signals is shown in Column 2 of Table II.

Column 3 of Table II shows that the detection frequency of the interrupted warning horn signal (Y), for five subjects, ranges from a minimum of 53 to a maximum of 66 responses. The sum total of detections is 293 out of a possible 350 responses. Therefore, the interrupted warning horn signal was heard on an average of 84 percent of the time. Column 4 depicts the number of undetected signals.

Columns 5 and 6 of Table II show that the average times for subjects to respond to the two different signals are, respectively, 1.7 and 1.5 seconds for the continuous and interrupted warning horns.

In a similar manner, Column 1 of Table III, for tactile warning signal results, shows that the aural stickshaker signal (A) was detected 349 out of 350 times, while Column 2 of Table III depicts the number of undetected signals. Column 3 of Table III shows the frequency of detection for the nonaural stickshaker signal (B) was 345 out of 350 possible responses. Therefore, the alerting effectiveness of the tactile warning (stickshaker) signals is approximately 99.1 percent.

Columns 5 and 6 of the same table show that the average times for subjects to respond to the aural and nonaural tactile warning signals were equal at 1.1 seconds.

The data of Tables IV, V and VI are pertinent to pilot task achievement scores during aural warning signal evaluation. The tables list the total number of pattern checkpoints achieved (Table IV), "C" pattern areas of

TABLE II

DATA SUMMATION OF AURAL SIGNAL EVALUATION

Subject	Detected Number of X Signals	Undetected Number of X Signals	Detected Number of Y Signals	Undetected Number of Y Signals	Average Response Time to X Signal	Average Response Time to Y Signal
A	62	8	66	4	.9	1.1
B	49	21	57	13	1.7	1.3
C	33	37	53	17	2.7	1.6
D	37	33	61	9	1.7	1.6
E	44	26	56	14	1.7	1.8
TOTAL	225	125	293	57	8.7	7.4
PERCENTAGE	64	36	84	16	1.7 s	1.5 s

X = Continuous horn signal

Y = Interrupted horn signal

TABLE III

DATA SUMMATION OF TACTILE SIGNAL EVALUATION

Subject	Detected Number of A Signals	Undetected Number of A Signals	Detected Number of B Signals	Undetected Number of B Signals	Average Response Time to A Signals	Average Response Time to B Signals
A	69	1	70	0	.8	.9
B	70	0	66	4	1.1	1.3
C	70	0	70	0	.9	1.0
D	70	0	70	0	1.3	1.0
E	70	0	69	1	1.2	1.3
TOTAL	349	1	345	5	5.3	5.5
PERCENTAGE	99.7	.3	98.6	.4	1.1 s	1.1 s

A = Aural Stickshaker

B = Nonaural Stickshaker

missed signals (Table V) and heading/altitude errors within specific pattern areas (Table VI).

TABLE IV

"C" PATTERN PERFORMANCE SCORES ACHIEVED
DURING AURAL SIGNAL EVALUATION

Subject	Pattern Checkpoints Achieved	Pattern Checkpoints Missed	Task Achievement Percentage Level
A	572	68	89.3
B	555	85	86.7
C	546	94	85.3
D	547	93	85.4
E	552	88	86.2
TOTAL	2772	428	432.9
AVERAGE	554.4	85.6	86.5

Table IV shows that the five subjects made an average performance achievement score of 86.5 percent by achieving approximately 554 checkpoints out of a possible 640 points.

Table V shows the frequency of missed signals at specific areas of the "C" pattern. It can be seen that fewer signals are missed on the straight legs of the pattern than during the turns. Straight legs in the pattern require the pilot to control two axes of flight (pitch and yaw or heading). The turns require the control of three axes or pitch, yaw and roll. Thus, in the turns, the pilot is likely to be more mentally engaged in the pattern task and less likely to hear aural warning signals.

Table VI, showing heading and altitude errors occurring in the pattern, also shows that the greater number of errors occurs in the turns and, as expected, not during the straight legs of the pattern. Errors committed during this pattern flight are predominantly heading errors (59 percent).

Data for the tactile warning signal evaluation are listed in an identical manner in Tables VII, VIII and IX. Table VII shows that the five subjects achieved an average 82.7 percent pattern performance score.

TABLE V

FREQUENCY OF MISSED AURAL SIGNALS IN TERMS OF PATTERN AREA*
(ALL SUBJECTS)

Pattern Area	Signal (X)	Signal (Y)	Total
Leg 1	6	3	9
Turn 1	14	8	22
Leg 2	10	2	12
Turn 2	29	17	46
Leg 3	13	4	17
Turn 3	19	8	27
Leg 4	9	3	12
Turn 4	25	12	37
TOTAL	125	57	182

*Refer to "C" Pattern - Figure 1

TABLE VI

FREQUENCY OF ERRORS IN TERMS OF PATTERN AREA
DURING AURAL SIGNAL EVALUATION*
(ALL SUBJECTS)

Pattern Area	Heading Error	Altitude Error	Total
Leg 1	4	2	6
Turn 1	45	37	82
Leg 2	4	0	4
Turn 2	84	39	123
Leg 3	17	20	37
Turn 3	33	15	48
Leg 4	14	18	32
Turn 4	53	43	96
TOTAL	254	174	428

*Refer to "C" Pattern - Figure 1

TABLE VII

"C" PATTERN PERFORMANCE SCORES ACHIEVED DURING TACTILE SIGNAL EVALUATION

Subject	Pattern Checkpoints Achieved	Pattern Checkpoints Missed	Task Achievement Percentage Level
A	548	92	85.6
B	538	102	84.0
C	550	90	85.9
D	499	141	78.1
E	512	128	80.0
TOTAL	2647	553	413.6
AVERAGE	530	110	82.7

Table VIII shows the total of missed tactile signals to be six. One aural stickshaker signal (A) was missed on the fourth turn, and five nonaural signals (B) were missed; two on the second turn and four on the fourth turn.

Table IX shows heading and altitude errors occurring during pattern flight. While the fact that more errors occurred during the turns than on the straight legs still holds true, the predominant errors in this case were altitude errors (58 percent).

The apparent reason for this reversal of error; i.e., a change from heading error under the aural signal evaluation to one of altitude error, was due to the change of pattern direction employed for the tactile signal evaluation. During the first 10 pattern flights, subjects learned to associate altitude requirements of the pattern with specific headings. This learning was transferred to the reversed pattern used for the next 10 flights and, therefore, resulted in altitude errors. Thus, a process of unlearning and relearning of the pattern was required. The altitude errors were committed primarily during the first three or four flights by all subjects, and contributed to the higher percentage of altitude errors during the tactile signal evaluation.

TABLE VIII

FREQUENCY OF MISSED TACTILE SIGNALS IN TERMS OF PATTERN AREA* (ALL SUBJECTS)

Pattern Area	Signal (A)	Signal (B)	Total
Leg 1	0	0	0
Turn 1	0	0	0
Leg 2	0	0	0
Turn 2	0	2	2
Leg 3	0	0	0
Turn 3	0	0	0
Leg 4	0	0	0
Turn 4	1	3	4
TOTAL	1	5	6

*Refer to "C" Pattern - Figure 1

TABLE IX

FREQUENCY OF ERRORS IN TERMS OF PATTERN AREA
DURING TACTILE SIGNAL EVALUATION*
(ALL SUBJECTS)

Pattern Area	Heading Error	Altitude Error	Total
Leg 1	8	7	15
Turn 1	65	64	129
Leg 2	20	24	44
Turn 2	43	62	105
Leg 3	26	38	64
Turn 3	16	18	34
Leg 4	19	33	52
Turn 4	36	74	110
TOTAL	233	320	553

*Refer to "C" Pattern - Figure 1

An interesting observation was noted by the experimenter with three subjects during aural warning signal evaluation. Subjects A, B and C, having completed the first 10 required flights, continued their pattern flights for 4 additional sessions (8 flights). From the sixth through the eighth flight, these subjects were attaining 100 percent pattern scores. At the same time, appreciable differences between the continuous aural and the interrupted aural signals were reduced to a minimum. It appears that continued training to the overlearning stage enables pilots to concentrate more on generated signals to the degree that both warning signals are detected equally by the subject pilots a greater number of times.

With a change of pattern, this ability was no longer apparent. Error scores in pattern performance confirm the subjects return to a relearning phase.

SUMMARY OF RESULTS

Aural Signal Results

The data indicated that at the threshold level of hearing, pilots heard and responded to a continuous horn signal 64 percent of the time while occupied with an in-flight pattern task. Under identical conditions, pilot response to the interrupted horn signal was on the order of 84 percent, a 20 percent differential favoring the interrupted horn signal.

When aural signals were detected, no significant difference was observed in average response time. Response times for the continuous and interrupted horn signals were, respectively, 1.7 and 1.5 seconds.

During aural signal evaluation, the average task achievement score in pattern flight was 86.5 percent with a scoring range from 85.3 percent to 89.3 percent. Frequency of errors in terms of pattern area was highest in the second and fourth descending turns. Frequency of missed aural signals in terms of pattern area was also greatest within these two descending turns.

A thorough familiarity with the "C" pattern (task overlearning) produced high achievement scores in pattern flight, a high detection rate of aural warning signals and, consequently, negligible differences between responses to both signals.

Tactile Signal Results

Pilots responded to stickshaker signals (at the threshold level of tactility) 99.1 percent of the time while engaged in an in-flight pattern task. These signals showed an improved alerting effectiveness 15 percent greater than that of the interrupted warning horn signal, and a 35 percent improvement over the continuous warning horn signal. No significant difference was observed between the aural- and nonaural-type stickshaker signals. Response times for both signals were equal at 1.1 seconds.

During tactile signal evaluation, the average task achievement level was 83 percent with a range of 78.1 to 85.9 percent. A high frequency of error in terms of pattern area occurred in three of the four possible turns. The frequency of missed tactile signals in terms of pattern area was almost negligible (6 missed signals out of 700 generated), but they did occur in the second and fourth turns.

Pilot opinion substantiated objective data with a preference for stickshaker signals over aural warning signals.

CONCLUSIONS

Based on the results of aural and tactile warning signal evaluations, it is concluded that:

1. The alerting effectiveness of these signals in descending order of merit is:

   a. Stickshaker (both aural and nonaural)
   b. Interrupted horn
   c. Continuous horn

2 There is no significant difference between the pilot response times to any of the signals when they are detected.

3. Aural signals are least detected when the in-cockpit task or workload requires a high degree of pilot attention.

4. A very high degree of pattern learning by pilots results in high performance achievement scores, higher aural signal detection rates and reduced detection differences between continuous and interrupted warning horn signals.

RECOMMENDATIONS

Based on the results of the aural and tactile warning signal evaluation, it is recommended that:

1. A prototype stickshaker be procured and installed in the agency's Cessna 210.

2. A flight evaluation of this tactile warning signal be conducted under Phase II of the subject project which is currently evaluating the effectiveness of stall warning systems with respect to angle of attack and rate of change of angle of attack.

3. The effectiveness of the stickshaker as demonstrated in a fixed-base simulator be evaluated in turbulent air conditions.

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