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# COCKPIT WARNING SYSTEMS COMPARATIVE STUDY

ALMON J. BATE

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COMPARATIVE STUDY**

*ALMON J. BATE*

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## FOREWORD

This study was conducted in the Human Engineering Division of the Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio. The work was performed under Project 7184, "Human Performance in Advanced Systems," Task 718404, "Advanced Systems Human Engineering Design Criteria." Grateful appreciation is expressed to Mr. Charles Bates, Jr., Chief, Performance Requirements Branch, and to Dr. Herschel C. Self of the same branch, for their critical reading of the report draft and their many helpful suggestions. The author also wishes to acknowledge the efficiency and skill with which Mr. Noel Schwartz (Research Instrument Branch) assisted in the design and fabrication of the apparatus used to present the various types of malfunction warnings. Thanks are also due to Mr. Joe Yasutake, Crew and AGE Branch (C-5A), for his assistance in supplying the author with detailed information on the cockpit warning system for the C-5A, and to Mr. A. R. Vogel of the Nortronics Division of the Northrop Corporation for the B-58 voice warning tape used in the study. Gratitude is also due to Dr. M. J. Warrick, Assistant Chief of the Human Engineering Division, for his helpful comments.

This technical report has been reviewed and approved.

C.H. KRATOCHVIL, Colonel, USAF, MC  
Commander  
Aerospace Medical Research Laboratory

## ABSTRACT

This study was conducted to determine the relative merits of supplementing aircraft visual/annunciator-panel malfunction warning systems with a general alerting tone or with a voice-recording identifying specific malfunctions. When a malfunction occurred, subjects pushed the one illuminated switch of sixteen malfunction indicators located on the annunciator panel. Subjects also performed a navigation task in which they momentarily positioned, under cross hairs, a series of navigational checkpoints displayed on rear-projected aerial strip photography. The photographic imagery moved across a 10-by 10-inch viewing screen at three simulated aircraft speeds: 340, 1160, and 2260 knots. One malfunction warning occurred during the last half of each test period.

Although navigation performance (number of navigational checkpoints detected) decreased as simulated speed increased, this performance did not vary with the warning systems.

The strictly visual/annunciator-panel malfunction warning system was the poorest system tested. The addition of a general alerting tone resulted in quicker and usually less variable responses at all aircraft speeds than did any of the other systems.

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## SECTION I

### SUMMARY

In a previous experiment, Bate and Bates (1967) investigated the relative merits of supplementing a visual, annunciation paneled, malfunction warning system with a general alerting tone, or with a voice-recording identifying the specific malfunction. Each subject received 7 to 10 malfunction warnings during the one-half hour test periods. No advantage was found in supplementing the visual system with either the tone or the voice.

Due to the occurrence of several malfunctions in a relatively short time span, the subjects in the 1967 experiment were likely "sensitized" to the probability of a malfunction and thus were extremely alert to the malfunction warnings. In the present experiment, there was only one malfunction warning. This warning was presented during the last half of the test periods. The difficulty of a concurrent, simulated, navigation task was varied to determine if the relative merits of different warning systems varies with level of primary task difficulty.

### PROCEDURE

The subject's primary task was to find on the displayed imagery, and momentarily position under cross hairs, a series of navigation checkpoints (such as bridges, road intersections, and airfields). The display motion simulated an aircraft speed of 340, 1160, or 2260 knots.

The subject's secondary task was to respond to a malfunction warning by depressing an appropriate legend-light switch. Performance comparisons, under the three primary task difficulty levels, were made among the following four warning systems:

- I. Visual-Along: The master warning light came on (as it did in all systems) and one of 16 indicator lights located on the visual/annunciator-response panel also came on.
- II. Visual-Tone: This system was the same as System I, but an intermittent (1/2 second on, 1/16 second off) sweeping tone (1000 cps to 4000 cps) was added to supplement the master warning light.
- III. Visual-Voice: Same as System I, but with the addition of a female voice describing the specific malfunction.

IV. Visual-Tone Search: This system was added to investigate the situation when the specific indicator lights are not located within a single panel. This system was the same as System II; except that instead of having an annunciator panel, the subject had to scan 9 legend lights located on 3 response panels arranged in a semicircle in front of him.

## RESULTS

As simulated speed increased, the number of navigation checkpoints detected decreased in a nearly linear manner. The decrease was essentially the same for all warning systems; there were no differences between the systems at any speed. The following table summarizes the reaction times (in seconds) combined across the three speeds.

Warning System	Mean	Standard Deviation	Median	Fastest Reaction Time	Slowest Reaction Time	Range
I (Visual-Alone)	21.971	51.597	2.430	1.161	300.000	298.839
II (Visual-Tone)	2.271	1.652	1.797	1.298	8.353	7.055
III (Visual-Voice)	3.367	1.755	2.868	1.424	8.693	7.269
IV (Visual-Tone-Search)	3.951	2.220	3.278	1.710	9.936	8.226

System II, wherein a visual/annunciator panel malfunction warning system was supplemented with a general alerting tone, typically yielded shorter reaction times than any of the other three systems. System I (visual-alone) was by far the poorest system.

## SECTION II

### INTRODUCTION

Informing an aircraft pilot about a malfunction has typically been accomplished with visual displays. In recent years these displays have been an array of simple legend lights commonly called an "annunciator panel." In many instances, the visual annunciator system is supplemented by a master warning light located in a conspicuous position, usually the top center of the forward instrument panel. The annunciator panel itself is, however, usually located less conspicuously. Occasionally, an alerting tone has been used to supplement the most critical malfunction indications.

Experimental evidence, aircraft accident reports, and the growth in complexity of aircraft have fostered the development of other warning techniques that utilize the auditory channel to supplement or even replace the visual mode. A supplementary technique which has gained prominence is the voice warning system, most notably applied in the U. S. Air Force B-58 (Hustler).

In a previous experiment conducted by Bate and Bates (1967), comparisons were made of the relative merits of supplementing a common visual malfunction-warning system with a general alerting tone or with a voice recording which identified the specific malfunctions. No advantage was found with either. However, 7 to 10 malfunctions were presented in a half-hour test period. It is therefore likely that the subjects were sensitized to the probability of a malfunction and thus divided their attention between the "primary" visual navigation task and the malfunction-warning task.

To circumvent this problem, in the present experiment only one malfunction was presented during the last half of the test period and the difficulty of the primary visual navigation task was varied. If performance degraded more rapidly with a purely visual system than with an auditory system when the demands of the primary task increased, i. e., less time to find and position checkpoints, one could infer a potential superiority of the auditory system under more demanding situations.

Also investigated was a malfunction warning system without a central annunciator panel. The visual indicators were located around the navigation display to simulate the practice in some aircraft of locating individual malfunction lights or indicators at various locations on the instrument panel. A sweeping tone auditory alerting signal was used with this system.

## SECTION III

### PROCEDURE

#### PRIMARY TASK (Navigation)

The subject's primary task was to find, and momentarily position under a cross-hairing reticle, a series of specified navigational checkpoints (e.g., bridges, road intersections, and airfields) displayed on rear-projected aerial photography. In this visual navigation problem, the strip photography was displayed at three simulated aircraft speeds. The assumption was that the less time available to search the display, the more difficult the task. The simulated speeds were as follows:

##### Slow Speed:

Forty-two operators performed the navigation task while the photographic imagery moved by them at a simulated aircraft speed of 340 knots (15.1 inches/minute on the screen). They were asked to find 65 navigation checkpoints during the 1-hour trial. During the last half of the trial, the subject was presented with a randomly selected malfunction warning.

##### Medium Speed:

In the second part of this study, the simulated speed was raised to 1160 knots (51.5 inches/minute on the screen). One hundred and twenty-four navigation checkpoints were presented to 63 operators in trials lasting 1 hour. Again, a randomly selected malfunction was presented in the last half of the session.

##### Fast Speed:

Simulated speed was 2260 knots (100.4 inches/minute on the screen). Forty operators were asked to find 124 checkpoints. Because of the limited film capacity of the projector, subject trials at this speed lasted only 30 minutes.

#### SECONDARY TASK (Warnings)

The subject's secondary task was to respond to a malfunction indication by depressing the appropriate legend-light switch. There were 16 different possible malfunctions in Systems I, II, and III, and 9 different possible malfunctions in System IV. The one specific malfunction and warning system that a subject received was randomly assigned for all 145 subjects.

The four malfunction warning systems compared under the three visual navigation speed conditions in the primary task were as follows:

1. Visual-Alone (System I): When a malfunction occurred, the master warning light located directly over the screen came on and the malfunction was simultaneously indicated by one of 16 lights located on a visual-response/annunciator panel located slightly to the left of the subject. Both lights were extinguished when the subject depressed the correct malfunction indicator light.

2. Visual-Tone (System II): When a malfunction occurred, an intermittent (1/2 second on, 1/16 second off) tone sweeping from 1000 cps to 4000 cps was presented over headphones at an intensity level high enough to ensure that it could be heard over the relatively quiet ambient noise. Simultaneously, the presence of the malfunction was indicated by the master warning light and one of the 16 lights on the response/annunciator panel. Both lights and the tone were extinguished when the subject responded by depressing the correct malfunction indicator light.

3. Visual-Voice (System III): When a malfunction occurred, the master warning light went on and, simultaneously, a female voice warning was presented over headphones. This auditory warning was indicated by a light on the visual-response/annunciator panel. This panel was the same one used in Systems I and II. Both lights and the voice were extinguished when the subject depressed the correct indicator light.

4. Visual-Tone-Search (System IV): This system was added to investigate the results one can expect, in a visual-tone system, System II, when the specific malfunctions are not located within a single panel. When a malfunction occurred, the same master warning light and intermittent tone came on as in System II, but the subject's response task was to scan through a series of 9 lights located on 3 response panels arranged in a semicircle in front of the operator. This condition was designed to add an element of search to the response task, thereby simulating the situation in some aircraft where not all of the warnings are visually displayed on a single annunciator panel. Both the tone and the master warning light were extinguished when the subject depressed the lighted legend light switches arranged around the operator.

The following outline will clarify the experimental condition used in the study:

Warning Systems Tested	Part I (Slow Speed)	Part II (Medium Speed)	Part III (Fast Speed)
I. Visual-Alone	1 hour at	1 hour at	1/2 hour at
II. Visual-Tone	340 knots*,	1160 knots*,	2260 knots*,
III. Visual-Voice	65 checkpoints,	124 checkpoints,	124 checkpoints,
IV. Visual-Tone-Search	42 subjects	63 subjects	40 subjects

\* Simulated ground speed.

## APPARATUS

### Navigation Performance:

The strip photography for the visual navigation task was displayed on a modified rear-projection viewer, Model 1062A, built for the Air Force by the Fairchild Camera and Instrument Corporation (figs. 1 and 2).

The five-inch strip of aerial photography, covering terrain from New Orleans, La. to Mobile, Ala., was magnified four times and rear projected onto a 10-by 10-inch screen at a scale of 1:27,360. Thus, only one-half of the width of the image on the film could be displayed at one time. A fixed cross-in-ring reticle was centered on the screen. The displayed image moved from the subject's left to his right and the film transport could be moved, independently of the projection optics, 2.5 inches in the vertical dimension (10 inches on the screen) by use of a tracking handle operated by the subject. By moving the film transport in this fashion, the subject could search the entire 20-inch-wide, projected image on his 10-by 10-inch viewing surface for checkpoints.

The subject was to find and position checkpoints under the reticle as directed by a set of briefing cards on the right armrest of the viewer. On each numbered card was printed the name; where necessary, the description; and the distance coordinates in nautical miles of one checkpoint (see figure 3). After finding a checkpoint, the subject turned to the following card for a description of the next checkpoint he was to find. To provide the subjects with a means of catching up and centering the film transport when they missed a checkpoint, a heavy vertical line was placed across the film after each checkpoint with the letter "T" on its center and the number of the next checkpoint he was to find. The line and the "T" did not appear on the display until the missed checkpoint had moved off of the display.

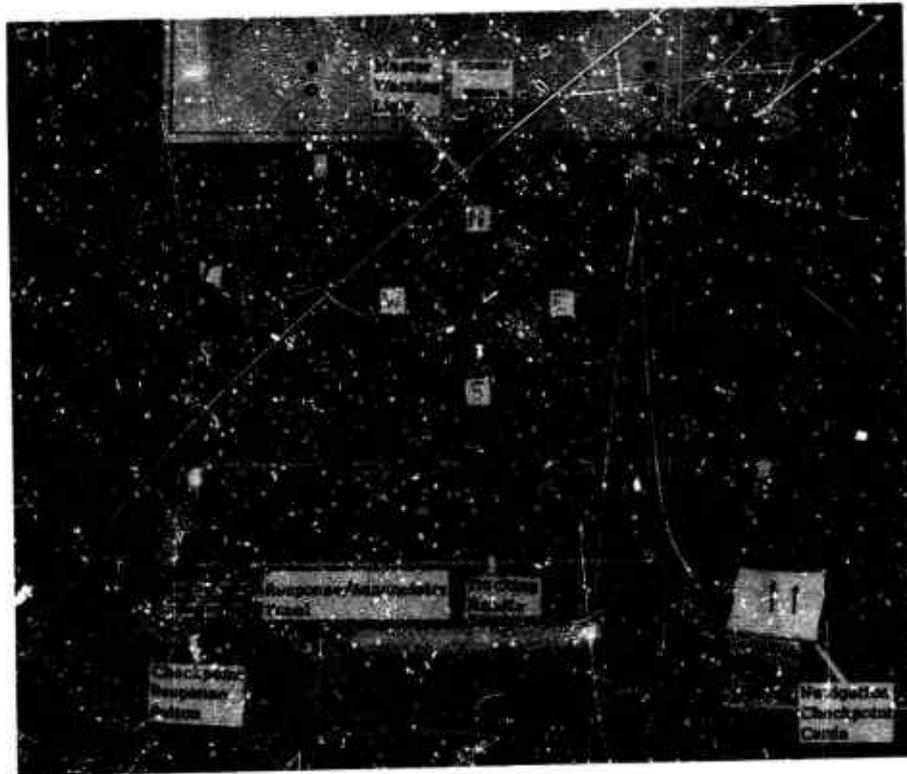


Figure 1. Fairchild Viewer ready for presentations of warnings via Systems I, II, or III.

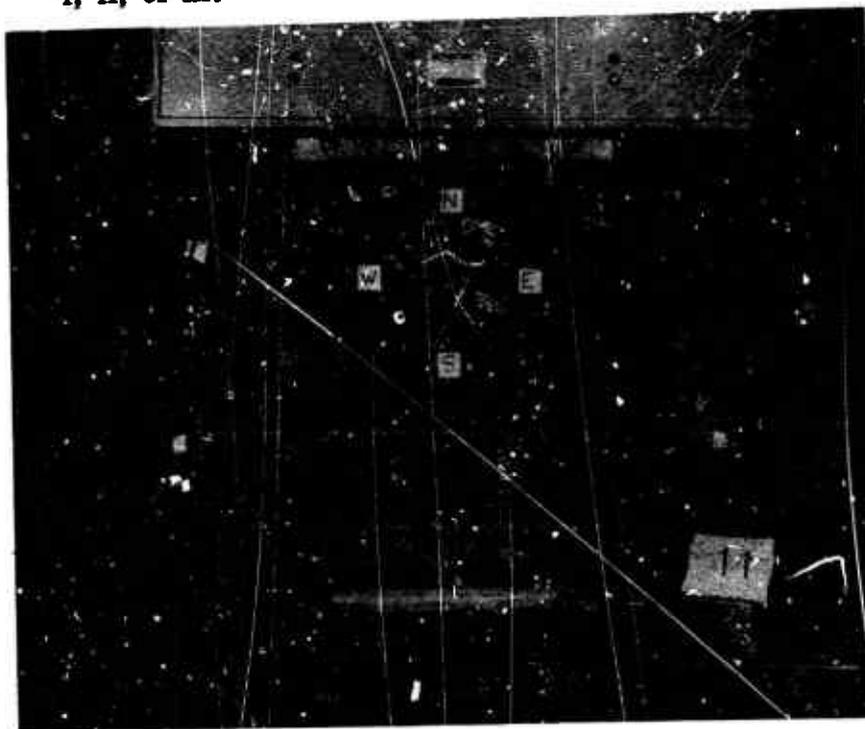


Figure 2. Fairchild Viewer ready for presentation of warnings via System IV. Note nine specific malfunction buttons spaced around the viewer.

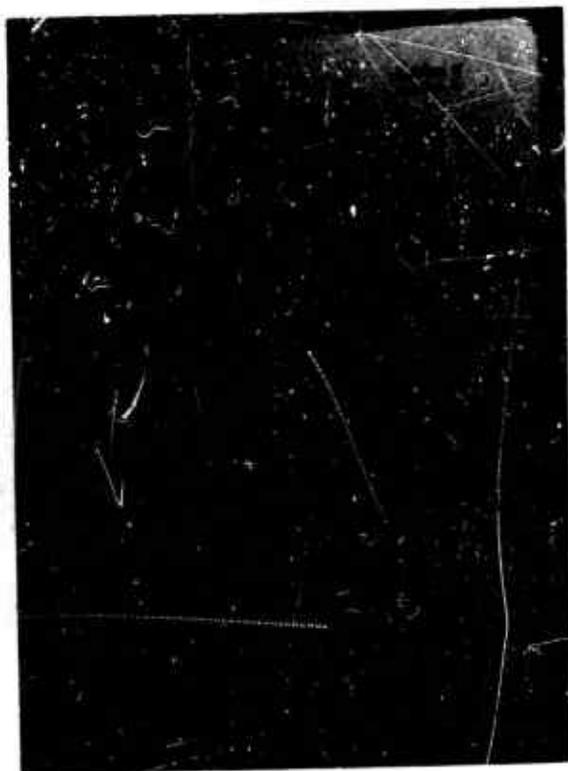


Figure 3. Navigation Description Cards.

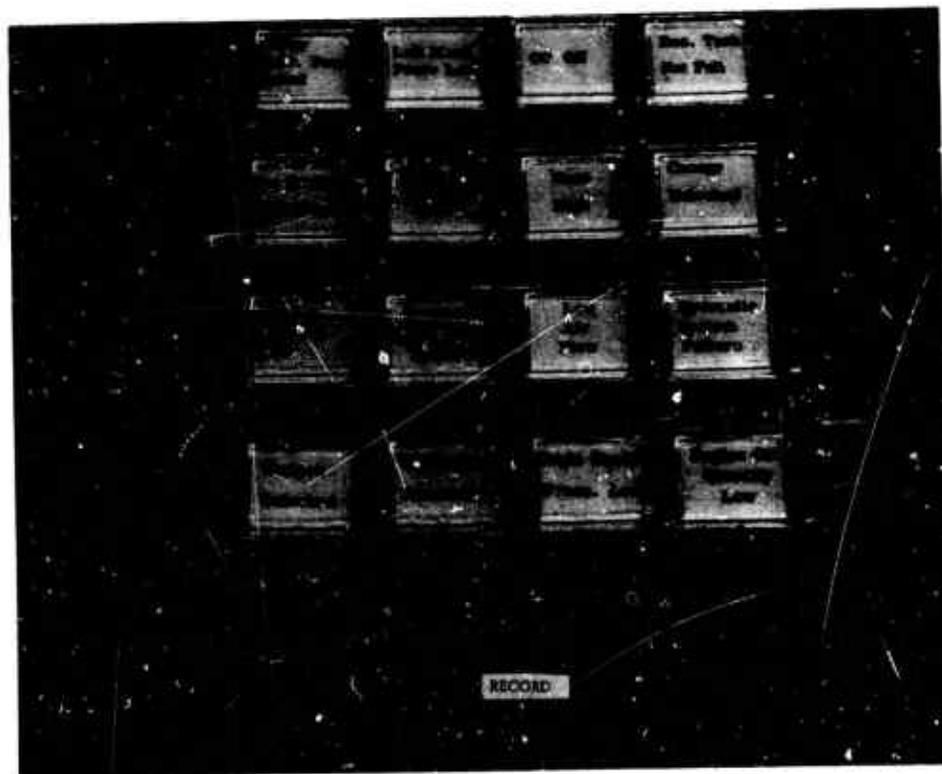


Figure 4. Visual Annunciator Panel.

### Malfunction Warnings:

The following apparatus was used to present the malfunction-warnings:

1. A master warning legend light at a brightness of 20 footlamberts was located at the top of the 10-inch-square screen. This legend light was used in all warning systems (fig. 1).
2. Subjects in warning Systems I, II, and III used the annunciator/response panel, located on the left armrest of the Fairchild viewer. The legend lights in this 4-by 4-inch matrix was of uniform brightness at a level of approximately 10 footlamberts and depicted sixteen different malfunctions (fig. 4). These malfunction messages were from the B-58 warning system. The particular malfunction presented was randomized across subjects.
3. Subjects in warning System IV used a series of three response panels instead of the single, annunciator/response panel used in all of the other systems. One panel was located to the left of the subject; one was located to the right of the subject; and the third was located above the master warning light in front of the subject. Each panel included three lights of uniform brightness at a level of approximately 10 footlamberts. These panels were covered except when used with the fourth system, at which time the single annunciator/response panel of sixteen lights was covered (fig. 2). The nine messages displayed on the panels were randomly drawn (with the constraint that all appeared an equal number of times) from the same sixteen located on the annunciator panel in the other warning systems. Once again, the particular malfunction presented was randomly chosen for each subject. All malfunctions were used an approximately equal number of times.
4. Malfunctions for all systems were programmed and presented to each subject with an eight-channel punched paper tape reader (Friden Model SB-2) which was pulsed at equal intervals by a pair of decade interval timers (Hunter Model 111C). Four channels of the tape reader were used to trigger a malfunction control relay board. Two more channels of the reader were used to trigger either the tone or voice message when an aural signal was used with the visual system. Another channel of the reader was used to allow the message tape to reach operating speed.
5. A message repeater (Cousino Model SR-7341) was used to present the auditory stimuli. In the visual-tone system (II) and the visual-tone-search system (IV), the tone was repeated until the subject responded. In the visual-voice system (III), a female voice repeated the message until a response was made. The pause between repetition of the tone or voice was 1/16 of a second. The voice tape was a portion of the latest B-58 Hustler Voice Warning System.

6. A Hunter Klockcounter indicated the subject's response time in thousandths of a second.

#### CONTROLS AND PERFORMANCE MEASURES

Under each of the three simulated speeds used in this study, slow (340 knots), medium (1160 knots), and fast (2260 knots), subjects were randomly assigned to one of the four warning systems. Just prior to being tested, each subject was given a set of written instructions describing the procedures involved in the navigation task (appendixes IV through VII). To further familiarize the operator with the equipment and task, he was aided in identifying five navigation checkpoints at the simulated speed he was to experience in his trial. Written instructions also informed the subject that he might receive a malfunction warning during his test. The general type of warning was described, his response procedure was outlined, and he was presented with two warnings to ensure that he understood the instructions. Although he was told to be on the alert for a malfunction warning, the navigation task was emphasized in order to lessen the subjects' expectation of a warning. To further reduce such expectancies, only one warning was presented to a subject, and that in the last half of each testing period.

During the test runs the following performance measures were obtained:

1. The number of navigation checkpoints correctly aligned and identified.
2. The number of navigation responses made to incorrect objects.
3. Reaction time to the correct malfunction indicator light.

#### SUBJECTS (Operators)

The subjects used in this study were university students, male and female. All had normal vision and hearing, natural or corrected. None had any previous training or experience with the visual navigation task or at locating targets on aerial photography. Subjects were randomly assigned to one of the four warning systems and tested at one of the three simulated speeds. Data were collected on 42 subjects tested at the slow speed of 340 knots, 63 subjects tested at the medium speed of 1160 knots, and 40 subjects tested at the fast speed of 2260 knots.

## SECTION IV

### RESULTS

#### NAVIGATION SCORES

Note that the number of navigation checkpoints correctly aligned and identified, and the number of navigation responses made to incorrect (i.e., non-checkpoints) objects, were collected in each of the four warning systems. Based on these two navigation measures, two additional scores were computed for each subject:

1. Percentage of responses correct (number of correct responses/total number of responses), and
2. Completion scores (number of correct responses/total number of checkpoints available).

These data were collected under three simulated aircraft speeds of 340 knots, 1160 knots, and 2260 knots (tables I, II, and III).

The mathematical analysis to follow is valid if the scores are from a population of scores that are normally distributed and if the variances are homogeneous. Due to the small sample sizes, it was not possible to estimate the degree of skewness and kurtosis of the parent populations. Also, a chi square test of goodness of fit, to a normal curve was not conducted, because such tests are very insensitive for small sample sizes. However, homogeneity of variance was checked with Bartlett's test which has a high degree of sensitivity even with small samples.

The variances of the four types of navigation scores were found to be essentially the same at the .05 level of probability, regardless of the warning system. This homogeneity of variance held for all three simulated aircraft speeds.

To determine whether the differences between the mean navigation scores achieved in each of the four warning systems were significantly greater than would be expected on the basis of chance, an F test and Duncan's New Multiple Range Test were conducted for each simulated speed. In all cases, the differences between the means were not larger than would be expected on the basis of chance at the .05 level of probability. Thus, different warning systems did not have different effects on any of the four types of navigation scores.

TABLE I

NAVIGATION SCORES\* (SLOW SPEED = 340 KNOTS)

Navigation Scores*	I Visual Alone	II Visual Tone	III Visual Voice	IV Visual-Tone- Search
Correct Responses	50.900	40.200	43.200	44.400
Incorrect Responses	13.000	12.700	12.600	12.300
Proportion of Responses Correct = (Number of Correct Responses) (Total Number of Responses)	0.791	0.757	0.775	0.789
Completion = (Number of Correct Responses) (Total Number of Checkpoints)	0.783	0.619	0.668	0.683

\* Scores are arithmetic means of the test groups.

\*\* Because of the one hour time limitation for each trial, subjects in Part I could view only approximately half the total film length. In the one hour test session there were 65 navigation checkpoints. This fact must be noted before comparisons are made between the navigation scores at the slow speed and the navigation scores made at the faster speeds.

TABLE II

NAVIGATION SCORES\* (MEDIUM SPEED = 1160 KNOTS)

Navigation Scores*	I Visual Aloae	II Visual Tone	III Visual Voice	IV Visual-Tone- Search
Correct Responses	69.500	62.900	62.400	75.400
Incorrect Responses	23.800	33.700	39.700	23.800
Proportion of Responses Correct = (Number of Correct Responses) (Total Number of Responses)	0.743	0.654	0.631	0.758
Completion = $\frac{\text{Number of Correct Responses}}{\text{Total Number of Checkpoints}}$	0.560	0.507	0.503	0.608

\* Scores are arithmetic means of the test groups.

\*\* 124 checkpoints were presented to each subject.

TABLE III

NAVIGATION SCORES\* (FAST SPEED = 2260 KNOTS)

Navigation Scores*	I Visual Alone	II Visual Tone	III Visual Voice	IV Visual-Tone- Search
Correct Responses	36.200	38.600	28.000	29.700
Incorrect Responses	40.500	34.000	29.000	31.600
Proportion of Responses Correct = (Number of Correct Responses) (Total Number of Responses)	0.484	0.512	0.500	0.542
Completion = (Number of Correct Responses) (Total Number of Checkpoints)	0.292	0.311	0.226	0.240

\* Scores indicate group means.

\*\* 124 checkpoints were presented to each subject.

Even though the average navigation scores were essentially the same for each of the warning systems, if there was any effect due to the warning, it is likely that the duration of this effect would be short. This temporary change in performance would likely occur after the introduction of a warning signal and, at the most, only two or three of the 65 to 124 checkpoints would be influenced.

Since some checkpoints are much easier to find than others and warnings occurred at random intervals, the previous analysis of average scores was certainly not sensitive enough to detect slight or temporary performance changes. A test comparing performance before and after with that of the average subject for the same checkpoint would remove the large variance in checkpoint difficulty, thus giving a sensitive test to before-after performance.

Each subject's responses to the three checkpoints presented just prior to the presentation of a warning signal were statistically compared with his responses to the three checkpoints presented just after the presentation of a warning signal. Analysis by means of Walsh's Test (1949, a, h) revealed that, regardless of the type of warning given, there was no significant (at .05 level) difference in pre- and post-warning navigation scores. This lack of effect was again found for all simulated speeds.

As navigation performance was not differentially affected by type of warning system, the relative desirability of the various warning systems rests largely on their ability to consistently elicit fast and accurate responses.

Since no responses to malfunction were ever inaccurate, reaction time is the only remaining variable of concern.

#### REACTION TIME

A plot of reaction times for each warning system revealed that, at all three speeds, the variability of scores in the strictly visual system (Condition I) was much larger than that in any other system (figs. 5, 6, and 7, and appendixes I, II, and III).

At the slow speed, this large variance is attributable to four subjects who did not respond to a warning for exceptionally long periods of time; at the medium speed, it is due to the same behavior of two subjects; and at the fast speed, it is due to slow reactions by four subjects.

The standard deviations of the reaction time scores of the four systems were far from equal. Thus, to make statistical comparisons of the group averages it was necessary to use nonparametric tests which do not assume homogeneity of variance. The Extension of the Median Test was used to determine whether the warning systems resulted in significantly different median reaction times, and a series of Mann-Whitney U Tests was conducted, and checked for significance at the .05 level, to determine the relationship between the reaction times in each system.

#### Slow Speed (340 knots):

The Extension of the Median Test resulted in a chi-square value (14.55) that was significant at  $P < .01$ . Therefore, the hypothesis that different warning systems will result in equal reaction times is rejected. The Mann-Whitney U Tests showed that the visual-tone warning system (System II) resulted in significantly ( $P < .02$ ) shorter reaction times than did any of the other warning systems (table IV). Inspection of the reaction time means, medians, and standard deviations in each of the systems (table V) shows that visual-tone warnings consistently resulted in superior performance.

#### Medium Speed (1160 knots):

At medium speed the overall difficulty of the navigation task would be expected to be greater than at the slow speed. The data showed a 21-percent decrease in navigation completion score (number of correct responses/number of available checkpoints), thus confirming this expectation.

The Extension of the Median Test once again resulted in a significant ( $P < .01$ ) chi-square value (10.98). Results of the series of Mann-Whitney U Tests (table VI) showed that median reaction time was faster in the visual-alone and the visual-tone systems, than in the visual-voice system. Reaction time in the visual-tone-search system did not significantly differ from that in any other system. The extreme variability in the visual-alone system is sufficient cause to reject this system as undesirable. In comparing the visual-tone with the visual-tone-search system (see table VI), the visual-tone system consistently comes out ahead, i. e., mean reaction time is faster, and the variability of the reaction time scores is less. From an overall point of view, the visual-tone system proved superior to the other systems.

#### Fast Speeds (2260 knots):

At the fast speed the difficulty of the navigation task once again increased. As compared to the medium speed, the percent of targets detected at the fast speed showed a 51-percent decrease.

The Extension of the Median Test again resulted in a significant ( $P < .05$ ) chi-square value (7.82), and the series of Mann-Whitney U Tests (table VIII) demonstrated the superiority of the visual-tone system. See table IX for reaction time scores in each system.

#### All Speeds Combined:

After combining the reaction time scores across all three speeds, statistical comparisons of the four warning systems were repeated.

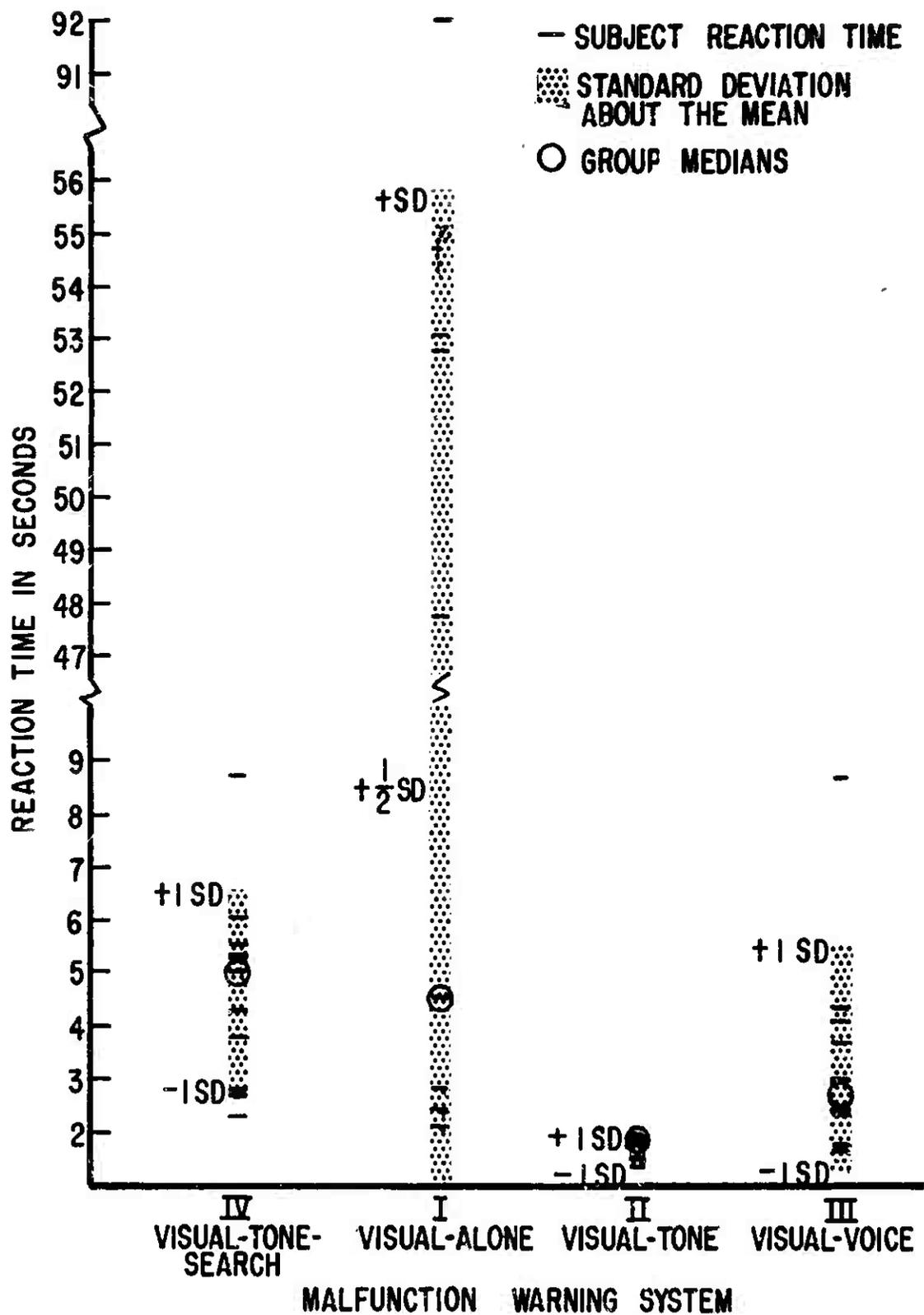


Figure 5. Subject reaction time and standard deviation about the mean  
(Simulated aircraft speed of 340 knots)

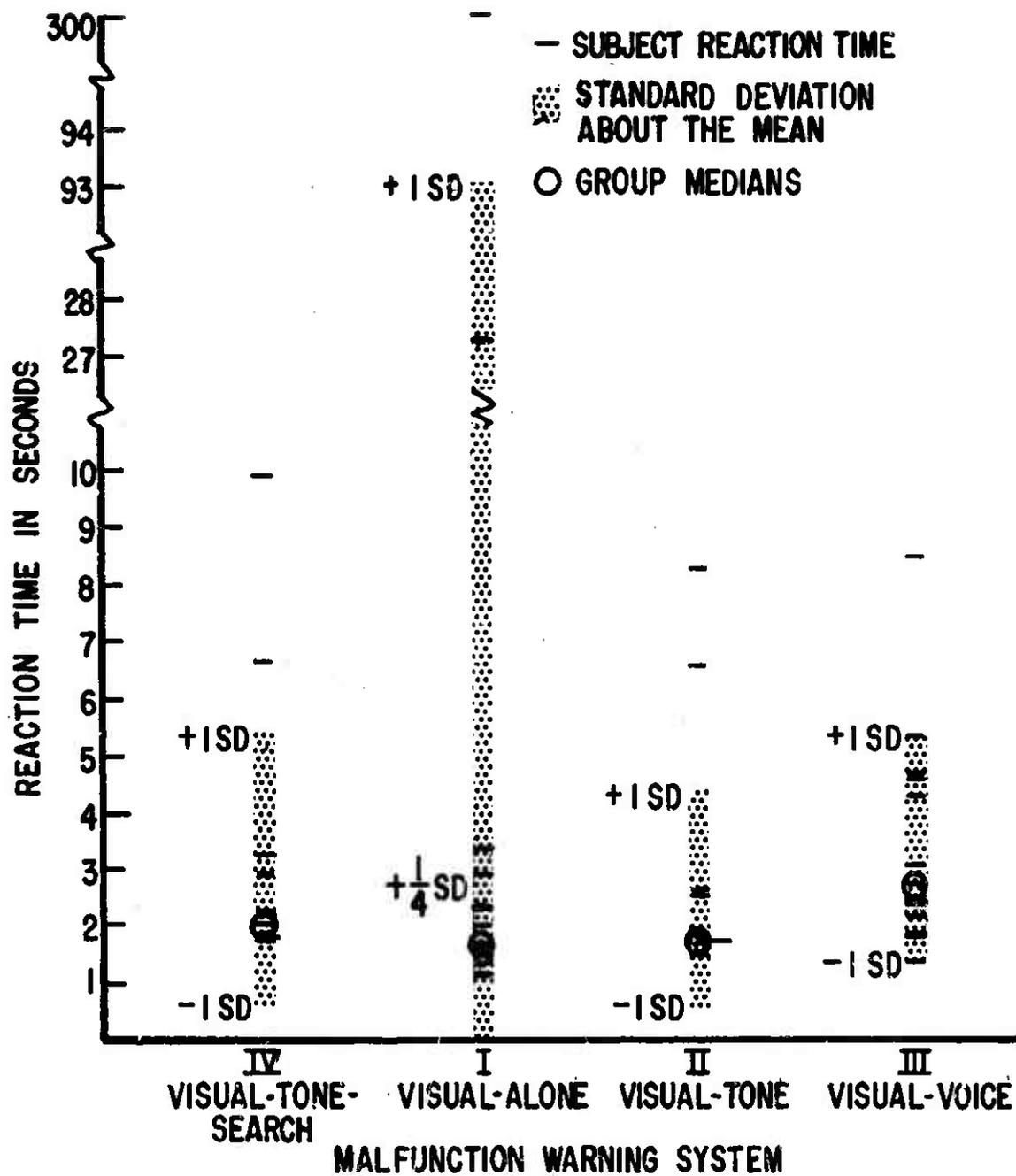


Figure 6. Subject reaction time and standard deviation about the mean (Simulated aircraft speed of 1160 knots).

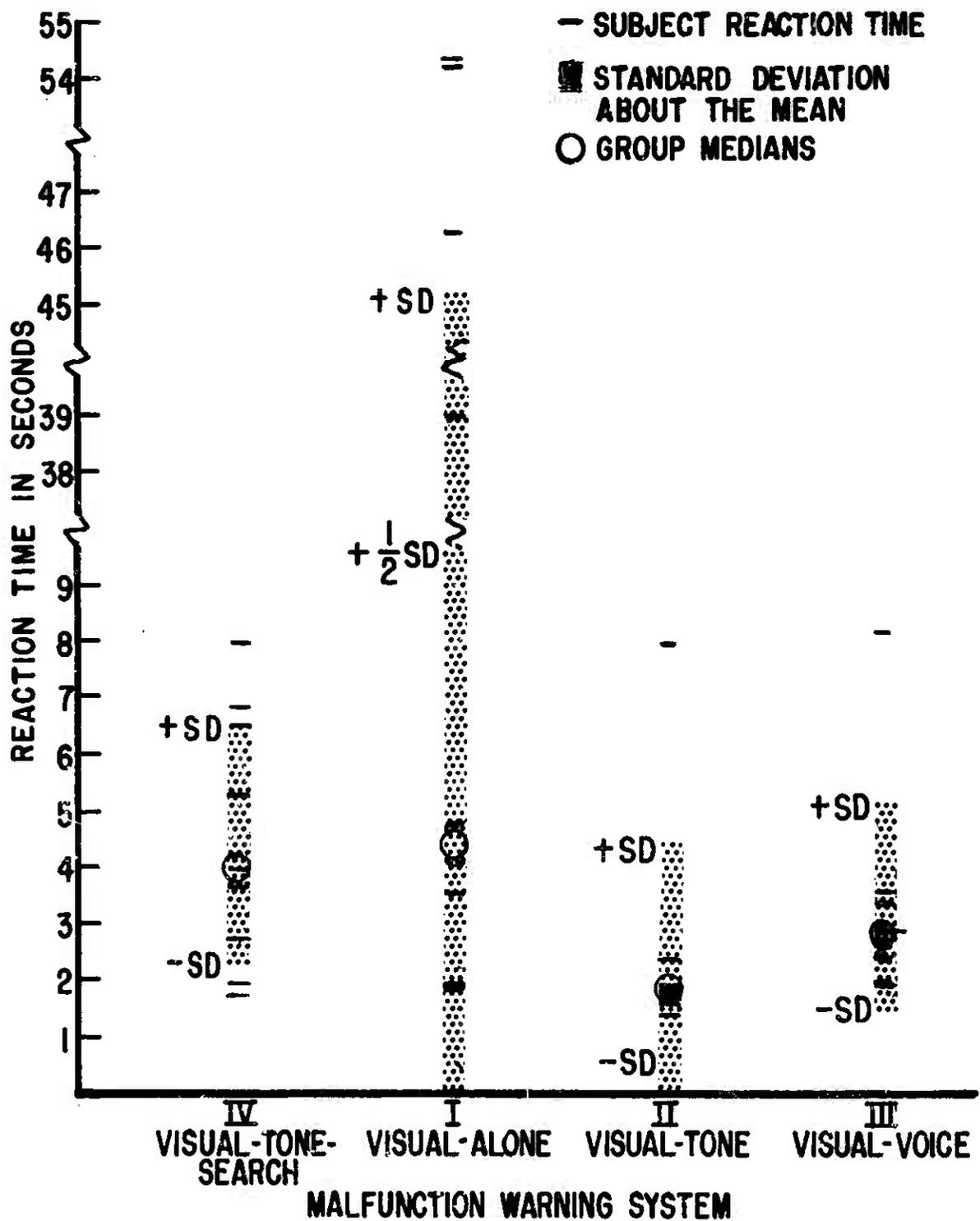


Figure 7. Subject reaction time and standard deviation about the mean (Simulated aircraft speed of 2260 knots).

TABLE IV

RESULTS OF A SERIES OF MANN-WHITNEY U TESTS ON  
REACTION TIMES AT SLOW SPEED = 340 KNOTS

II Visual-Tone	III Visual-Voice	I Visual-Alone	IV Visual-Tone-Search
1.726	2.681	4.540	5.003

Groups are ranked according to median reaction time in seconds. Any two groups not underscored by the same line are significantly different from each other ( $P < .02$ ).

TABLE V

REACTION TIMES\* (SLOW SPEED = 340 KNOTS)

Condition	Mean	Deviation	Median	Fastest Reaction Time	Slowest Reaction Time	Range
I (Visual-Alone)	24.264	31.511	4.540	2.080	51.952	89.872
II (Visual-Tone)	1.657	0.263	1.726	1.298	2.018	0.720
III (Visual-Voice)	3.393	2.089	2.681	1.559	8.693	7.134
IV (Visual-Tone-Search)	4.699	1.848	5.003	2.285	8.731	6.446

\*Group Reaction Times in Seconds.

TABLE VI

RESULTS OF A SERIES OF MANN-WHITNEY U TESTS ON  
REACTION TIMES AT MEDIUM SPEED = 1160 KNOTS

I Visual-Along	II Visual-Tone	IV Visual-Tone-Search	III Visual-Voice
1.698	1.795	2.017	2.759

Groups are ranked according to median reaction time in seconds. Any two groups not underscored by the same line are significantly different from each other ( $P < .05$ ).

TABLE VII

REACTION TIMES\* (MEDIUM SPEED = 1160 KNOTS)

Condition	Mean	Deviation	Median	Fastest Reaction Time	Slowest Reaction Time	Range
I (Visual-Along)	20.899	72.189	1.698	1.161	300.000	298.839
II (Visual-Tone)	2.547	1.903	1.795	1.510	8.353	6.843
III (Visual-Voice)	3.375	1.875	2.759	1.424	8.539	7.115
IV (Visual-Tone-Search)	3.015	2.375	2.017	1.710	9.932	8.222

\* Group Reaction Times in Seconds.

TABLE VIII

RESULTS OF A SERIES OF MANN-WHITNEY U TESTS ON  
REACTION TIMES AT FAST SPEED = 2260 KNOTS

II Visual-Tone	III Visual-Voice	IV Visual-Tone-Search	I Visual-Alone
1.850	2.873	3.962	4.391

Groups are ranked according to median reaction time in seconds. Any two groups not underscored by the same line are significantly different from each other ( $P < .02$ ).

TABLE IX

REACTION TIMES\* (FAST SPEED = 2260 KNOTS)

Condition	Mean	Deviation	Median	Fastest Reaction Time	Slowest Reaction Time	Range
I (Visual-Alone)	21.156	23.856	4.391	1.833	54.259	52.426
II (Visual-Tone)	2.415	1.956	1.850	1.376	7.936	6.560
III (Visual-Voice)	3.328	1.736	2.873	1.947	8.106	6.159
IV (Visual-Tone-Search)	4.439	2.130	3.962	1.724	7.956	6.232

\* Group Reaction Times in Seconds.

Again, the Mann-Whitney U Tests revealed that the visual-tone warnings, System II, resulted in faster reaction times than the other systems (table X). Inspection of the mean, range, and variability of the overall reaction times (see table XI) further substantiates the conclusion that of the four systems tested, System II is superior.

#### SUMMARY

As simulated aircraft speed increased, operator efficiency in the navigation task decreased in a nearly linear manner. There was no similar task effect upon reaction times in any of the warning systems. Reaction time to the occurrence of a malfunction warning did not vary with the difficulty of the primary task used in this study. Conversely, none of the warning systems differentially affected the navigation scores.

At both the slow and fast speeds, statistical tests showed that the visual-tone system was significantly superior to any of the other warning systems tested. At the medium speed, except for statistical superiority over the visual-voice system, median reaction time in the visual-tone system did not differ significantly from the other conditions. However, the visual-alone system is unacceptable because of the few extremely long reaction times which sometimes occurred in this system. The visual-tone-search system is also unacceptable because of slower mean reaction time scores and larger group variances. Thus, it was again shown that of the systems tested, the visual-tone is the best.

An analysis of the reaction times combined across all three speeds again demonstrated the superiority of the visual-tone system in achieving fast reaction times (see figure 8.) A summary of the results across the three speeds is plotted in figure 9.

TABLE X

RESULTS OF A SERIES OF MANN-WHITNEY U TESTS ON  
 MEDIAN REACTION TIMES COMBINED ACROSS ALL THREE SPEEDS

II Visual-Tone	I Visual-Alone	III Visual-Voice	IV Visual-Tone-Search
1.797	2.430	2.868	3.278

Groups are ranked according to median reaction time in seconds. Any two groups not underscored by the same line are significantly different from each other ( $P < .02$ ).

TABLE XI

REACTION TIMES\* COMBINED ACROSS ALL THREE SPEEDS

Condition	Mean	Deviation	Median	Fastest Reaction Time	Slowest Reaction Time	Range
I (Visual-Alone)	21.971	51.597	2.430	1.161	300.000	298.839
II (Visual-Tone)	2.271	1.652	1.797	1.298	8.353	7.055
III (Visual-Voice)	3.367	1.755	2.868	1.424	8.693	7.269
IV (Visual-Tone-Search)	3.951	2.220	3.278	1.710	9.936	8.226

\* Group Reaction Times in Seconds.

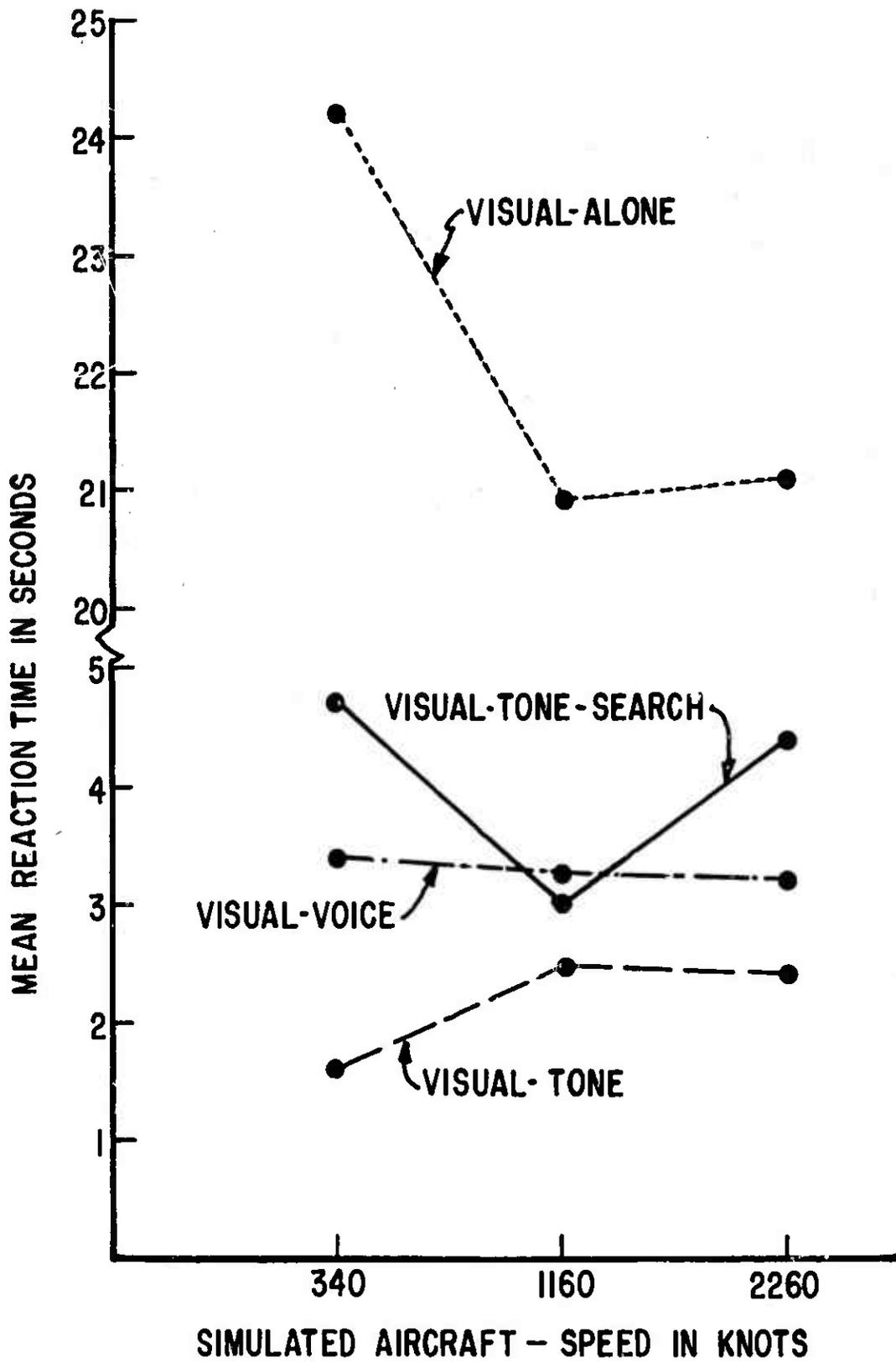


Figure 8. Mean subject reaction time to malfunction warnings at each simulated aircraft speed.

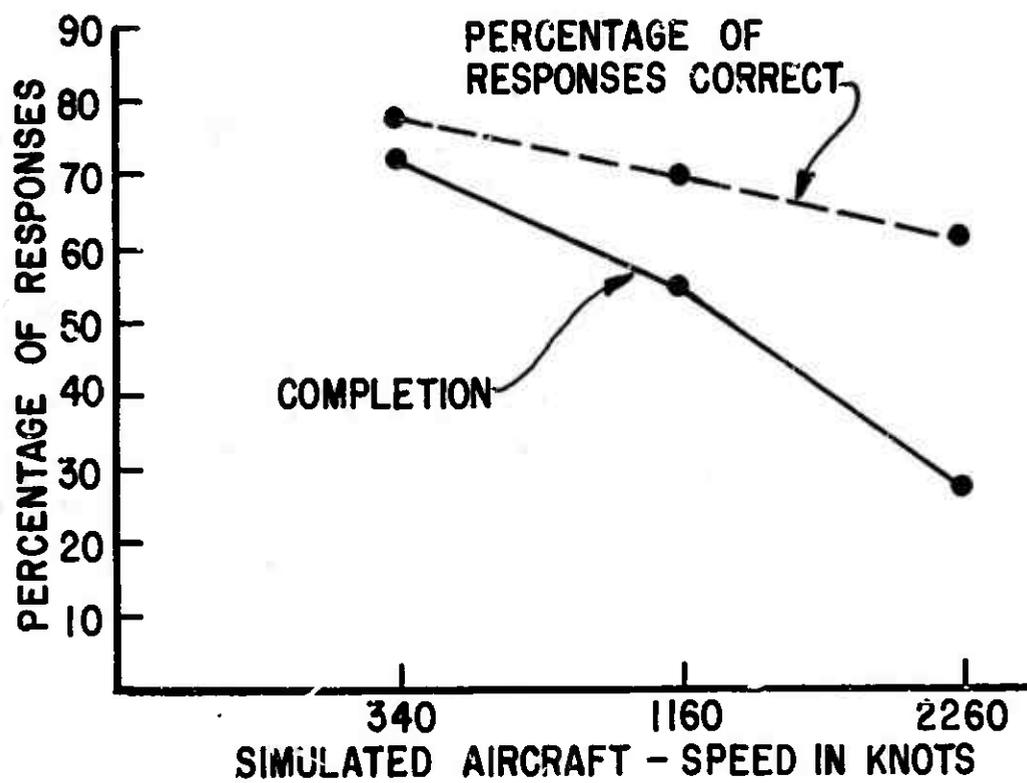


Figure 9. Mean percentage of navigation responses correct and completion scores at each simulated aircraft speed.

## SECTION V

### DISCUSSION

This study demonstrates the fact that even though a stimulus is visible, operators will not necessarily be aware of its presence. Reaction times to the occurrence of malfunction warnings demonstrated that, even if operators engaged in a navigation task are cautioned that malfunction warnings can occur at any moment, they will occasionally be very slow in responding to a visual warning not supported by an auditory warning. This occurred at all three different levels of difficulty (simulated aircraft speed) in the operator's navigational task. In an actual flight situation, a pilot would likely be even less aware of a strictly visual malfunction warning than in the present controlled laboratory situation. This type of a human error could be extremely dangerous and result in the loss of an aircrew and an aircraft.

In the experimental context, the visual-tone system was unquestionably quite superior to the visual-alone and somewhat superior to a visual-voice. It might be argued, however, that without a flashing master-indicator light we may not have had a good comparison visual system. On the other hand, it is not certain that a blinking light would be more attention-gaining in an actual cockpit -- if a pilot had his head turned to observe something outside the aircraft (or even within it) it will make little difference whether a light, unsupported by an alerting auditory cue, is blinking or remains glowing.

Gallup, et al (1956) established that in order for a steady light to be as reliable an attention-getter as a flashing or an alternating light, its brightness must be increased many times. As the master warning light used in our study was relatively very bright (20 footlamberts) in comparison to its background (dull black), this was likely not an important variable, but in an aircraft it might be.

This experiment gives evidence that a voice warning is not necessarily as effective as a tone in alerting operators to the existence of malfunctions. Voice warnings may prolong an operator's response by encouraging him to listen for the completion of the voice message of the specific malfunction. In some phases of flight, such as landing, a voice message might not be distinguishable over landing instructions or other voice communications taking place at the same time. On the other hand, a tone merely alerts a pilot that a malfunction is present, and requires no other auditory attention. Although tones can also be masked by other sounds, suitably selected tones can be much more resistant to masking than can voices.

In comparing the relative merits of the visual-voice versus the visual-tone systems, even though voice warnings prolong responses to an extent that is statistically significant, this prolongation amounts, from a practical standpoint, to an average increase of only about 1 second more than response to an alerting tone. Also, with voice warnings, variability in reaction time is as low as with a tone. Whether 1 additional second is critical and whether there are some possible advantages not examined in this study which will offset the increased cost of a voice warning system, are questions which should be answered in regard to a particular aircraft situation.

The visual-voice system does offer a feature not tested in this study, the ability to tell the pilot what to do in an emergency, in addition to alerting him to the fact that an emergency exists. When time permits, such aural check lists can be effective, especially for a pilot who is relatively new to a particular aircraft. This feature has been one of the major reasons for the popularity of the voice system among some Air Force pilots. The degree to which such dependence on an automatic check list affects pilot motivation to learn printed check lists and emergency procedures is not known. The difficulties in designing voice systems, i. e., the specific sequencing and wording used to present a given malfunction, have not been determined for many aircraft. Experience in this area may prove that the addition of voice to a warning system may raise more problems than it solves. Because of the sometimes complex interactions between subsystems, when a malfunction occurs, a number of almost simultaneous corrective actions may be required.

Manageable generalized research on "which is the best warning system?" is virtually certain to be inconclusive in respect to a specific application. It is therefore recommended that future research in this area take one, or both, of two directions:

- a. Given a specific type of warning system -- what characteristics should it have? (For example, if an alerting tone is used should it sweep, warble, ring, wail, or what?)
- b. Given a specific problem, or usage, and all of the constraints typically surrounding such, what is the most cost-effective type of system to develop? (For example, an auditory or voice warning system may be mandatory in some situations, helpful in others, and a waste of money in others. What are the criteria and guidelines in making trade off decisions?)

## SECTION VI

### A SUGGESTED DESIGN APPROACH TO WARNING SYSTEMS

As was stated earlier, for any warning system to be effective, it must be tailored for the particular requirements and restraints of the aircraft in which it is to be used. However, the system can be made up of standardized building blocks by standard design practices. The concept of a primarily visual system, made up of a master caution and/or warning light, together with other specific malfunctions spelled out on one central annunciator panel is sound if both displays are visible to the pilot.

As a redundant signal for this basic visual system, where simplicity and economy are paramount, an aural signal should be added. The designer should not overlook the use of position and color-coding in designing the visual system; nor should providing a means for changing the importance of a given malfunction as a function of the mission segment be ignored. In addition, selected malfunction indicators could be made to pulse or flash to indicate their importance and to draw attention to them when the pilot is occupied with a malfunction of lesser importance.

The third block of this cockpit warning system could be a voice-warning package that could be economically integrated with the visual-tone components of the system. The voice warning could then be used where the specific application required its unique features.

Although little has been said in this report about the type of tone which should be used to supplement a visual annunciator panel, the auditory signal should be selected with great care. If it is too loud, it may distract the pilot from control of his aircraft; and if it is too quiet, he may not notice it. Also, the wide range of the noise spectrum in an aircraft makes it difficult to select any one tone that will serve under all conditions.

Providing that the response task remains constant and that the operator can immediately silence an alerting auditory signal, it is hypothesized that in relatively quiet backgrounds little practical difference can be expected in the ability of different kinds of auditory signals to alert pilots. However, where voice communications or aircraft noises might mask auditory warnings, the warnings selected should be highly resistant to masking. An intermittent tone which sweeps through a series of frequencies seems to be an excellent choice.

The tone used in the present study was selected to utilize the results of research conducted by Houston and Walker (1949) at the University of Maryland. They found that a pure tone of 2500 cycles per second, presented intermittently through earphones, was heard more clearly in the presence of background noises of different complexities than was any other signal tested.

The tone used in the present study was an intermittent sweeping tone which started at approximately 1000 cps and went up to 4000 cps within a one-half second time period. Delay time between each cycle was 1/16 of a second.

In selecting a warning tone for any one particular aircraft, it would be advisable to analyze the different frequency components of the particular aircraft in various flight modes. The particular tone and method of presentation used in this study can serve as a base from which to design a warning system for any particular series of aircraft.

APPENDIX I

SUBJECT REACTION TIME\*  
(SIMULATED AIRCRAFT SPEED 340 KNOTS)

Condition I Visual-Alone	Condition II Visual-Tone	Condition III Visual-Voice	Condition IV Visual-Tone-Search
2.080	1.298	1.559	2.285
2.095	1.309	1.700	2.686
2.430	1.408	2.287	2.764
2.790	1.487	2.289	3.793
2.810	1.655	2.397	4.269
4.540	1.797	2.965	5.003
4.648	1.847	3.682	5.275
47.740	1.852	4.053	5.343
52.728	1.898	4.307	5.530
53.041	2.018	8.693	6.014
91.952			8.731

\* Reaction Times in Seconds

APPENDIX II

SUBJECT REACTION TIME\*  
(SIMULATED AIRCRAFT SPEED 1160 KNOTS)

Condition I Visual-Alone	Condition II Visual-Tone	Condition III Visual-Voice	Condition IV Visual-Tone-Search
1.161	1.510	1.424	1.710
1.349	1.748	1.805	1.791
1.390	1.785	1.829	1.792
1.401	1.788	1.941	1.793
1.404	1.789	2.208	1.839
1.531	1.792	2.454	1.881
1.645	1.793	2.463	2.011
1.695	1.795	2.759	2.022
1.698	1.796	3.052	2.233
1.713	1.798	3.116	2.336
2.032	1.818	4.336	2.900
2.309	1.829	4.612	3.278
2.361	1.891	4.722	6.687
2.907	2.554	5.371	9.932
3.365	2.655	8.539	
27.322	6.606		
300.000	8.353		

\*Reaction Times in Seconds

APPENDIX III

SUBJECT REACTION TIME\*  
(SIMULATED AIRCRAFT SPEED 2260 KNOTS)

Condition I Visual-Alone	Condition II Visual-Tone	Condition III Visual-Voice	Condition IV Visual-Tone-Search
1.833	1.376	1.947	1.724
1.878	1.551	2.353	1.902
1.907	1.683	2.675	2.711
3.507	1.781	2.706	3.600
4.028	1.838	2.868	3.955
4.754	1.862	2.878	3.968
38.988	1.865	2.907	5.273
46.246	1.928	3.328	6.489
54.161	2.331	3.509	6.810
54.259	7.936	8.106	7.956

\*Reaction Times in Seconds

## APPENDIX IV

### INSTRUCTIONS FOR SUBJECTS IN COCKPIT SIMULATION TASK

#### (SYSTEM I -- VISUAL-ALONE)

This study will measure your ability to locate navigational checkpoints. You are to correctly locate as many checkpoints as you can, while also attempting to make as few false responses (responses to non-checkpoints) as possible.

When the study begins, the photographic imagery on the 10 inch screen in front of you will begin to move across the screen from the left to the right of the screen. By reference to the deck of briefing cards located on your right you are to place your right hand on the tracking handle located directly in front of you, and move the film up or down the screen to achieve the proper coordinates indicated on the card. As the target moves across the screen you are to position it under the cross hair ring, by use of the tracking handle, and push the red response button located on the left console shelf. At random intervals after each target has passed the cross hairs, a heavy line across the film will come into view. This line is marked with a "T" at its center, the "T" will serve as a navigational guide. You are to note the number indicated along with the cue line and flip your briefing cards to correspond to the same number. This number indicates which checkpoint you are to locate next.

All navigational checkpoints are given in nautical miles. Therefore you must remember that the distance from the top edge of the film to the bottom is exactly 7.5 nautical miles.

As in any aircraft flight there is always the possibility of a malfunction, you must not only concentrate upon the navigational task, but you must also remain alert for the possibility of a malfunction occurring in your aircraft. If a malfunction occurs the master warning light located directly over the screen will light up and simultaneously one of the 16 push buttons on the visual annunciator panel will begin to glow. Push the glowing button on the annunciator panel as rapidly as possible and continue with your navigation.

Questions?

## APPENDIX V

### INSTRUCTIONS FOR SUBJECTS IN COCKPIT SIMULATION TASK

#### (SYSTEM II -- VISUAL-TONE)

This study will measure your ability to locate navigational checkpoints. You are to correctly locate as many checkpoints as you can, while also attempting to make as few false responses (responses to non-checkpoints) as possible.

When the study begins, the photographic imagery on the 10 inch screen in front of you will begin to move across the screen from the left to the right of the screen. By reference to the deck of briefing cards located on your right you are to place your right hand on the tracking handle located directly in front of you, and move the film up or down the screen to achieve the proper coordinates indicated on the card. As the target moves across the screen you are to position it under the cross hair ring, by use of the tracking handle, and push the red response button located on the left console shelf. At random intervals after each target has passed the cross hairs, a heavy line across the film will come into view. This line is marked with a "T" as its center, the "T" will serve as a navigational guide. You are to note the number indicated along with the cue line and flip your briefing cards to correspond to the same number to locate next.

All navigational checkpoints are given in nautical miles. Therefore you must remember that the distance from the top edge of the film to the bottom is exactly 7.5 nautical miles.

As in any aircraft flight there is always the possibility of a malfunction, you must not only concentrate upon the navigational task, but you must also remain alert for the possibility of a malfunction occurring in your aircraft. If a malfunction occurs the master warning light located directly over the screen will light up and simultaneously one of the 16 push buttons on the visual annunciator panel will begin to glow, and you will hear an alerting tone through your earphones. Push the glowing button on the panel as rapidly as possible and continue with your navigation.

Questions?

## APPENDIX VI

### INSTRUCTIONS FOR SUBJECTS IN COCKPIT SIMULATION TASK

#### (SYSTEM III -- VISUAL-VOICE)

This study will measure your ability to locate navigational checkpoints during a one hour simulated flight. You are to correctly locate as many checkpoints as you can, while also attempting to make as few false responses (responses to non-checkpoints) as possible.

When the study begins, the photographic imagery on the 10 inch screen in front of you will begin to move across the screen from the left to the right of the screen. By reference to the deck of briefing cards located on your right you are to place your right hand on the tracking handle located directly in front of you, and move the film up or down the screen to achieve the proper coordinates indicated on the card. As the target moves across the screen you are to position it under the cross hair ring, by use of the tracking handle, and push the red response button located on the left console shelf. At random intervals after each target has passed the cross hairs, a heavy line across the film will come into view. This line is marked with a "T" at its center, the "T" will serve as a navigational guide. You are to note the number indicated along with the cue line and flip your briefing cards to correspond to the same number. This number indicates which checkpoint you are to locate next.

All navigational checkpoints are given in nautical miles. Therefore you must remember that the distance from the top edge of the film to the bottom is exactly 7.5 nautical miles.

As in any aircraft flight there is always the possibility of a malfunction, you must not only concentrate upon the navigational task, but you must also remain alert for the possibility of a malfunction occurring in your aircraft. If a malfunction occurs the master warning light located directly over the screen will light up and simultaneously you will hear a female voice through your earphones describing the specific malfunction and one of the series of 16 push buttons on the visual annunciator panel will begin to glow. Push the glowing button as rapidly as possible and continue with your navigation.

Questions?

## APPENDIX VII

### INSTRUCTIONS FOR SUBJECTS IN COCKPIT SIMULATION TASK

#### (SYSTEM IV -- VISUAL-TONE-SEARCH)

This study will measure your ability to locate navigational checkpoints. You are to correctly locate as many checkpoints as you can, while also attempting to make as few false responses (responses to non-checkpoints) as possible.

When the study begins, the photographic imagery on the 10 inch screen in front of you will begin to move across the screen from the left to the right of the screen. By reference to the deck of briefing cards located on your right you are to place your right hand on the tracking handle located directly in front of you, and move the film up or down the screen to achieve the proper coordinates indicated on the card. As the target moves across the screen you are to position it under the cross hair ring, by use of the tracking handle, and push the red response button located on the left console shelf. At random intervals after each target has passed the cross hairs, a heavy line across the film will come into view. This line is marked with a "T" at its center, the "T" will serve as a navigational guide. You are to note the number indicated along with the cue line and flip your briefing cards to correspond to the same number to locate next.

All navigational checkpoints are given in nautical miles. Therefore you must remember that the distance from the top edge of the film to the bottom is exactly 7.5 nautical miles.

As in any aircraft flight there is always the possibility of a malfunction, you must not only concentrate upon the navigational task, but you must also remain alert for the possibility of a malfunction occurring in your aircraft. If a malfunction occurs the master warning light located directly over the screen will light up and simultaneously begin to glow and you will hear an alerting tone through your earphones, and one of the series of nine push buttons located in the semicircle about you will begin glowing brightly. Push the glowing button as rapidly as possible and continue with your navigation.

Questions?

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