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ASD-TR-88-5031

A COMPARISON OF SMALL SETS OF VOICE VERSUS TONE WARNINGS AS A FUNCTION OF TASK LOADING AND BACKGROUND COMMUNICATION

AD-A200 594

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September 1988

Final copy for the period July 1987 to October 1987

DEPUTY FOR ENGINEERING
AERONAUTICAL SYSTEMS DIVISION
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SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release, distribution unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) ASD-TR-88-5031	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Crew Station Design Facility 6b. OFFICE SYMBOL (If applicable) ASD/ENECH	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) Wright Patterson AFB Ohio, 45433-6503	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION F/FB/EF-111 SPO 8b. OFFICE SYMBOL (If applicable) ASD/SDFE	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code) Wright Patterson AFB Ohio, 45433-6503	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)
A Comparison of Small Sets of Voice versus Tone Warnings as a Function of Task Loading

12. PERSONAL AUTHOR(S)
J.A. Hassoun; J. R. Kinzig; J. M. Barnaba

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM ______ TO ______	July, 1988	22

16. SUPPLEMENTARY NOTATION

17. COSATI CODES

FIELD	GROUP	SUB-GROUP
17	07	03

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
Response Time; Cockpit Warning Systems; Voice Warning Systems; Tone Warning Systems

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

In support of the F/FB/EF-111 Digital Flight Control System Program Office, the present human engineering study evaluated the merits of voice versus tone warning systems in terms of pilot response time and response accuracy performance. Task loading and background communication were two other varibles that were evaluated. Non-significant study results for the warning systems found in this study, suggest that for this small number of messages (four), neither a voice nor a tone warning system has an advantage over the other. However, based on the present and previous research in the area of warning systems, and considering the total number of tone messages in the F-111, the long term benefits of implementing a voice warning system may be great in terms of reducing pilot workload. These study results demonstrated statistically significant main effects for task loading and background communication. Therefore, these results suggest that specifying pilots' response times for a time critical system, such as a

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL John A. Hassoun	22b. TELEPHONE (Include Area Code) (513) 255-4109 22c. OFFICE SYMBOL ASD/ENECH

DD Form 1473, JUN 86 Previous editions are obsolete. SECURITY CLASSIFICATION OF THIS PAGE

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Continued from Block 19.

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ground collision advisory system, may require further consideration of relevant factors that have a significant influence on human reaction and response times.

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INTRODUCTION

An effort is currently underway which will upgrade the F/FB/EF-111 aircraft through the introduction of a digital flight control system (DFCS). An added safety of flight capability planned for inclusion into this modification is a voice message generation system. This system will be used as a primary means of alerting the operators to flight critical, terrain following radar, and ground proximity warnings. It is intended that the results of this study will aid the aircraft designer in the development of a user interface for the F/FB/EF-111 aircraft.

A major issue, associated with the implementation of voice warnings, is whether or not the warning messages offer an advantage over the present tone warning messages. While some prior research results have indicated that response to voice warnings can be more advantageous with respect to speed (Kemmerling et al., 1969), others have suggested that no difference in response time can be derived (Bates & Bates, 1966). Since the introduction of voice warnings may not result in any significant increase in speed or accuracy of operator performance, an evaluation is necessary to determine the relative merits of voice and whether a costly mechanization process, both in terms of money and computer memory, is warranted. A secondary objective of this report will focus on past research in the area of voice versus tone message warning comparisons, and address its relevance to the F/FB/EF-111 interface.

The objective of the present study, which took place at Aeronautical Systems Division's (ASD) Crew Station Design Facility (CSDF), was to perform an evaluation of pilot accuracy and response time performance as a function of two small sets of aircraft cockpit aural warning signals: Tone messages versus voice messages. The performance characteristics were evaluated independent of other relevant factors associated with the messages. The evaluation does not address such factors as the number of tones versus the number of voice warnings, the criticality of the messages, the prioritization of the responses, pitch, amplitude, frequency, etc... The study does, however, examine the effects of task loading and background communication (on the subject's response). Task loading is manipulated by increasing the difficulty of the flying task, while background communication introduces representative conversation, into the auditory channel, which is not critical to the pilot. Considering the scope of this effort, a possible follow-on study could examine the same relevant factors, as in this study, using larger sets of tone and voice signals.

From a theoretical perspective, an operator's response to a tone warning should involve behavioral and cognitive activities comprised of several stages of human information processing. These stages can be simplistically described as the operator's ability to detect, acknowledge, and identify a warning. This is followed by a decision and the initiation of the proper response activities. The same should be true when the operator responds to a voice warning. In support of this logic, certain assumptions were made in the study which would allow for equal chance of identification between tone and voice warnings while allowing for variability in the operator's decision and response activities. Some of these assumptions are as follows: (1) the number of warnings to be memorized by the operator should be kept low; (2) the semantic and physical featural distinctions between the warning messages (tone and voice) should be significant; (3) the subjects should receive a sufficient amount of training in responding to the warnings; and (4) the warnings should occur frequently enough to keep the subjects in a motivated state and supplement the learning behavior. This list should not, by any means, be considered complete.

METHOD

SUBJECTS

Twelve subjects, who volunteered for the experiment, were Wright-Patterson AFB employees with no previous flying experience. The subjects verbally reported corrected-to-normal vision, and no auditory skill deficiencies. Prior to the data collection segments, all 12 subjects were allowed sufficient practice flying a Terrain Following Radar (TFR) mission in the F-16 simulator.

WARNING MESSAGES

Voice Warning Messages. Four distinct voice warning messages (from a physical and semantic featural perspective) were selected to represent specific aircraft malfunctions, which may be corrected by pressing the appropriate switch on the left Multi Function Display (MFD) of the F-16 cockpit simulator. A female employee of the Crew Station Design Facility recorded the voice messages on an AMIGA micro computer.

The following is a list of the four voice warning messages and their appropriate responses:

WARNING	RESPONSE
1. COMPUTER	RECYCLE
2. ELECTRICAL	BATTERY
3. HYDRAULICS	PRESSURIZE
4. OIL	VENTILATE

The AMIGA used a high speed voice digitizer, called Future Sounds, with a sampling rate of 10,000 samples per second, to convert the messages from analog to digital format. The AMIGA was thereafter connected to the main frame computers using an RS-232 interface.

Tone Warning Messages. Four distinct tone warning messages were selected to represent specific aircraft malfunctions. Just as for responding to the voice warning messages, responding to the tone warnings also required pressing the appropriate switch on the left MFD of the F-16 cockpit simulator. The tones were generated by a Simulation Engineering Laboratories (SEL) Gould series 32/7780 and 32/8780 mainframe computers and transmitted to the pilots' headset through the same channel as the voice messages.

The following is a list of the four tone warnings:

WARNING	RESPONSE
1. Continuous 700 Hz	RECYCLE
2. Intermittent 1400 Hz (200 ms "on"/100 ms "off"/ 600 ms "on")	BATTERY
3. Intermittent 2100 Hz (600 ms "on"/100 ms "off")	PRESSURIZE
4. Intermittent 2800 Hz (200 ms "on"/100 ms "off")	VENTILATE

APPARATUS

Facility. The study was conducted at the Crew Station Design Facility (CSDF), a U.S. Air Force simulation facility located at Aeronautical Systems Division (ASD), Wright Patterson AFB (shown in Figure 1). The CSDF government personnel are assigned by the Human Factors Branch of the Directorate of Support Systems Engineering (ENE). The facility is used to conduct human engineering and system design mechanization studies in support of a variety of System Program Offices (SPO).

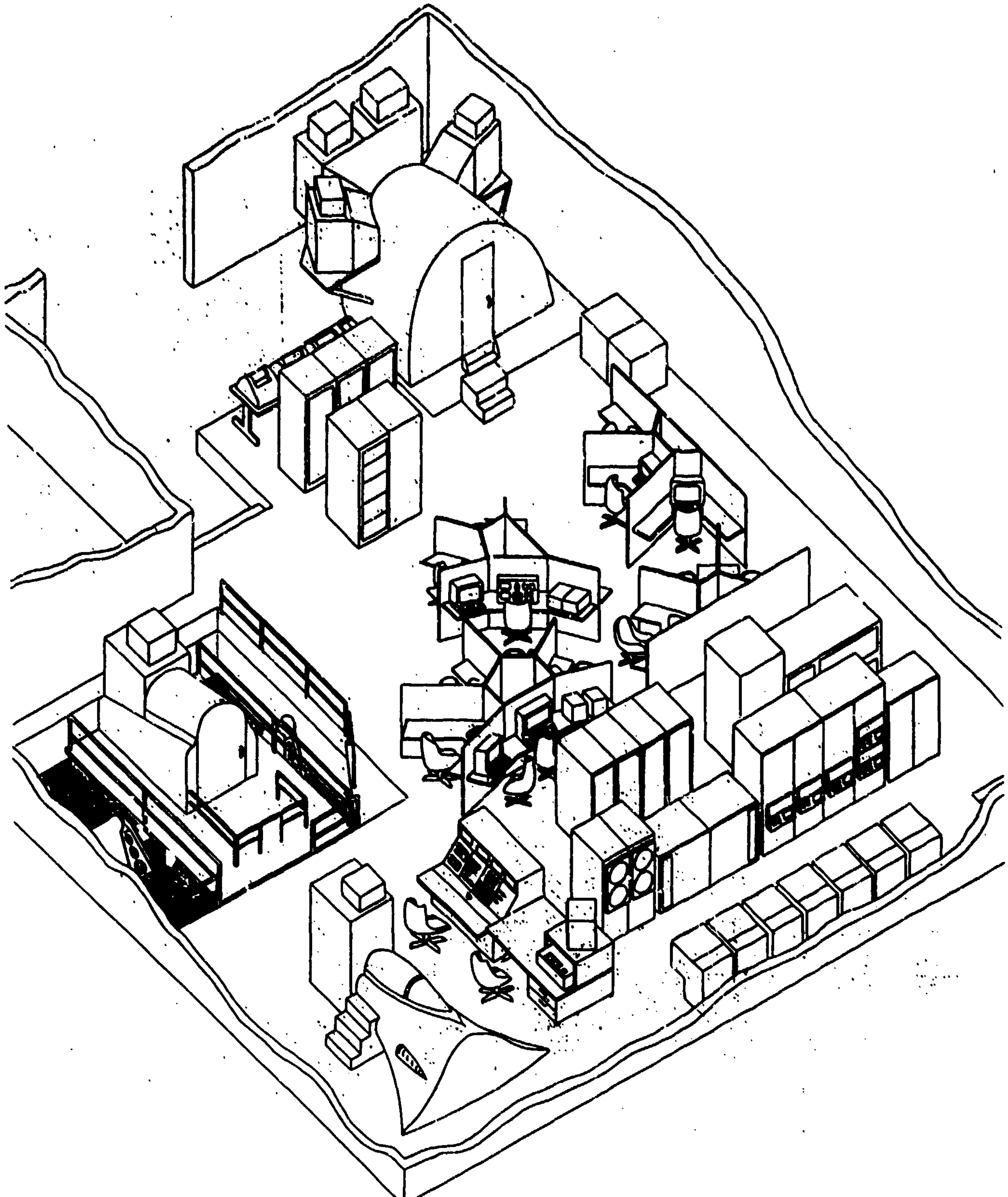

Figure 1. Crew Station Design Facility simulator area.

Simulator. Since the construction of the F-111 simulator was not yet completed at the time of this study, the available F-16 simulator was used instead. This simulator was developed using a salvaged single seat F-16 cockpit, truncated in front of the forward portion of the windscreen, and approximately 57 inches behind the canopy lines. The F-16 cockpit simulator is comprised of an all digital design which includes two 4X4 inch Multi Function Displays (MFD), a Wide Field of View raster video Head-Up Display (HUD), Hands on Stick and Throttle (HOSAT) controls, the LANTIRN avionics suite, and other actual systems found on the F-16 C/D aircraft.

Computer Complex. The simulator, shown in Figure 2, is connected to a series of large and small computer systems. This computer complex includes five Gould series 32/7780, one Gould concept 32/8780, two PDP 11/34, three PDP 11/35, and two Silicon Graphics Iris 2400 Computer Aided Design (CAD) stations.

Visual Systems. The out-the-window visual scene was provided by using a computer generated Night Visual System along with a SMK 23 terrain model, and was shown to the pilots on the Wide Angle Collimating window. The simulated LANTIRN symbology was presented on the HUD, using a Vector General symbol generator to display the caligraphic symbology, and a PDP 11/34 computer to map and control the HUD's position. The Gould mainframe computers transmitted the flight parameters to the PDP in order to position the stroke symbology within the raster video scene, so the pilots could use the Integrated Control Panel and the HUD embedded symbology to fly the simulator.

Experimenter's Console. The experimenter's console is located approximately ten feet away from the simulator. It includes a complete intercom system, together with communication to and from the pilot inside the simulator. The console's displays duplicate the pilot's visual, HUD, Data Entry Display, and MFDs, and are used by the experimenter to observe and monitor the pilot's

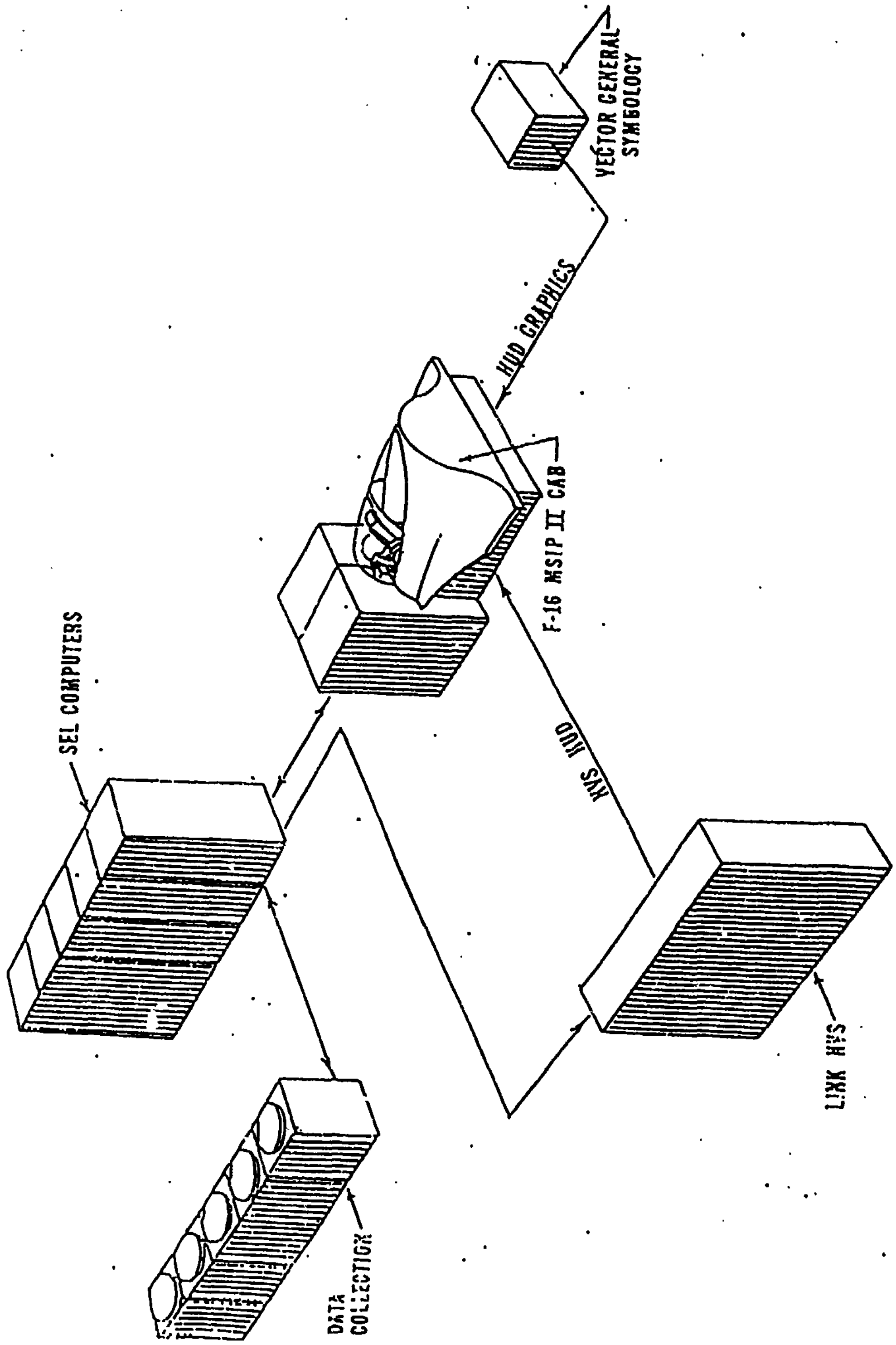

Figure 2. Schematic of the F-16 simulator

performance. Furthermore, the console's controls permit the experimenter to start, stop, and reset the simulation at any time.

Audio Systems. The voice messages were subjectively judged by the authors to be equally loud to each other, and to the four tones. Background communication was simulated by an audio tape which was replayed throughout selected missions of the experiment, on a Panasonic Technics Panasonic tape player (model number RS-263AUS), and transmitted, through the intercom channel, to the pilot's headset (an ASTROCOM model number 20680 with MX-2508/A/C pads.

PROCEDURE

Subjects were trained to perform a dual task type of experiment. One task involved steering the aircraft and ensuring it did not deviate from a set altitude. A second task required the pilots to manually respond to a series of tone and voice warning messages.

The primary task required each pilot to fly the F-16 simulator in a Terrain Following (TF) mission, using the flight path marker (the aircraft symbol) on the HUD to follow two critical LANTIRN cues: The TFR box, and the steer point bearing marker. An example of the HUD configuration is shown in Figure 3. While the TFR box commanded pitch corrections on the part of the pilot, the steer point marker was more concerned with bank improvements. Pilot scores on the flying task were computed by measuring the vertical offset deviation from the center of the TFR box. A score of ten milliradians in absolute deviation was used as a cutoff point for accepting or rejecting a pilot's data. None of the 12 pilots had to be rejected from the study.

The flying task was comprised of two different missions:

Easy and difficult. In flying the easy mission, the pilots had to follow the TFR cues in a straight direction; from point A to point B. The difficult mission was more complex, in that the pilots had nine different steer points located at different intervals. Each time the steer point changed location, the pilots had to command a significant bank in order to stay on track, while keeping the flight path marker inside the TFR box. The length of each mission was approximately 80 miles, and lasted about 10 minutes.

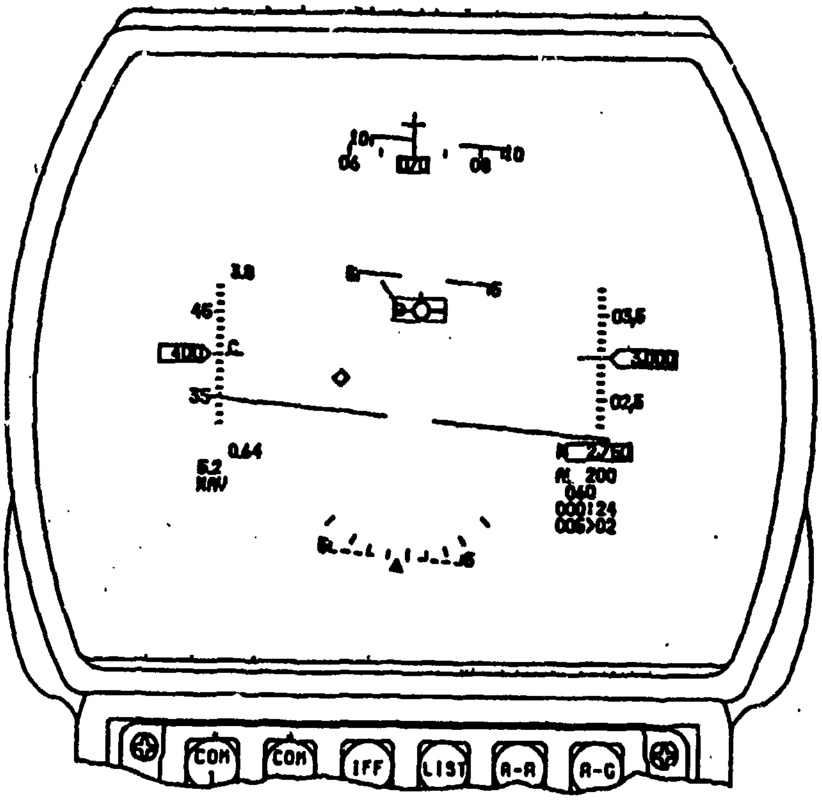

Figure 3. <u>An example of the HUD format in TFR mode</u>.

The secondary task involved presenting the pilot with an aural warning that required an immediate response. Either a tone or a voice message was transmitted to the pilot's headset at an average of 15 seconds (with a standard deviation of three seconds). Throughout half the missions, background communication was presented by playing an audio tape of a combat mission recorded during the Vietnam war, and transmitted to the pilot through the headset.

To make the study more motivating, the subjects were told that they had been recruited as part of a test team to evaluate a recently developed major self-diagnostic and self-corrective on-board computer. Furthermore, the subjects were told that they would be helping in the decision making process for the selection of the most efficient type of warning system (voice versus tone).

The subjects were instructed to primarily concentrate on the flying task, while still responding to the warnings as quickly as possible, but without making many errors. At an average of 15 seconds, a warning was repeatedly heard on the pilot's headset for seven seconds, or until some type of response was initiated. At that time, the pilot was expected to perform two responses. The first response required the pilot to verbally respond to the warning by stating the corrective action, while simultaneously moving the left hand off the throttle and pressing one of the four buttons, located on the left MFD, that corresponded with the correct malfunction. Figure 4 shows what the MFD appeared like throughout the experiment. Following each response, whether correct or incorrect, the correct option was highlighted for one second. This highlighting was used as a feedback procedure to aid the pilots in learning the appropriate responses to the warning messages.

It should be noted that the verbal response was expected to trigger a timer that measured vocal reaction time. Unfortunately, the system did not work properly, which caused the measure to be dropped from data reduction and analysis.

Each subject received one pre-practice session, which included ten minutes of system familiarization, one session of practice, and one session of data collection. The subjects were allowed to take a 5-10 minute break between each session. Both the practice and data collection sessions were comprised of four missions, each of ten minutes duration, for a total of 45-50 minutes per session.

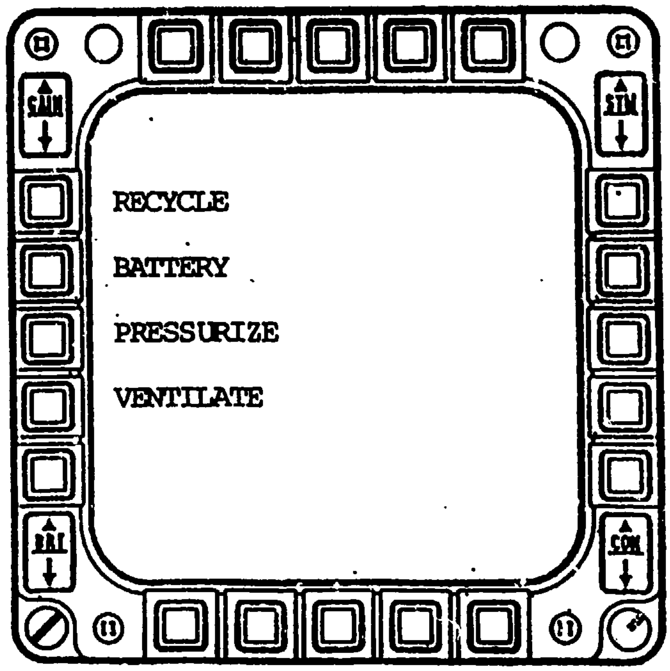

Figure 4. An example of the four responses on the MFD.

DESIGN

The experiment was designed to compare pilots' response time and response accuracy to either a tone or a voice warning. Response time was defined as the time interval from onset of the warning message until the pilot pressed the correct button on the MFD. Also of interest to this evaluation, were the effects of task loading and background communication on response time performance. There were two levels of task loading (easy versus difficult flying mission), and two levels of background communication (on versus off).

The missions that were flown during the study were counterbalanced in such a way that the order of presentation was never replicated across pilots. However, the missions flown during the practice session were in the same order as the missions flown during the training session. Within each mission, four tone and four voice warnings were presented, five times each, for a total of 40 warnings. The warnings were randomly selected from the set of eight stimuli with the following restrictions:

(1) The exact same warning could not appear consecutively.

(2) Warnings requiring the same response could not be presented consecutively.

(3) and no more than three warnings of the same type (voice or tone) may come on consecutively.

RESULTS

MEAN CORRECT RESPONSE TIME

Subjects' mean correct response time data were analyzed using a 2X2X2 three way repeated measures analysis of variance. The three independent variables were comprised of two types of warning messages (voice versus tone), two levels of flying difficulty (easy versus difficult), and two levels of background communication (on versus off).

The analysis of variance resulted in statistically significant differences in the main effects for flying difficulty, $\underline{F}(1,11)=7.53$, $\underline{p}=0.01$, and background communication, $\underline{F}(1,11)=13.34$, $\underline{p}=0.003$; but not for type of warning message, $\underline{F}(1,11)=0.09$, $\underline{p}=0.7$. The means from the three main effects of flying difficulty, background communication, and type of warning are respectively shown in Tables 1, 2 and 3.

An inspection of Table 1 indicates that, on the average, the subjects responded faster to the warning messages (both for tones and voices combined) when they were flying the easy mission versus the difficult mission. These results in turn translate into a sensitive task loading effect that led to higher levels of workload when the subjects were flying the more difficult mission.

The means shown in Table 2 suggest that background communication interfered with the pilots' abilities to process failure warning messages. Subjects' response times were slower when the background communication tape was turned ON as opposed to when it was turned OFF.

The two means, presented in Table 3, indicate that the type

TABLE 1. Reaction time performance for flying difficulty.

	LEVEL OF FLYING DIFFICULTY	
	DIFFICULT	EASY
RESPONSE TIME (in seconds)		
MEAN	2.451	2.221
STANDARD DEV.	0.608	0.445

TABLE 2. Reaction time performance for background communication.

	BACKGROUND COMMUNICATION	
	OFF	ON
RESPONSE TIME (in seconds)		
MEAN	2.254	2.417
STANDARD DEV.	0.543	0.511

TABLE 3. Reaction time performance for type of warning.

	TYPE OF WARNING	
	TONE	VOICE
RESPONSE TIME (in seconds)		
MEAN	2.346	2.326
STANDARD DEV.	0.576	0.477

of warning did not have a significant effect on pilots' reaction time performance. The time it took to perceive the warning until an appropriate response was initiated, did not differ whether the message was presented in a tone or a voice format. These results imply that similar human information processing stages were encountered when responding to a tone or a voice warning.

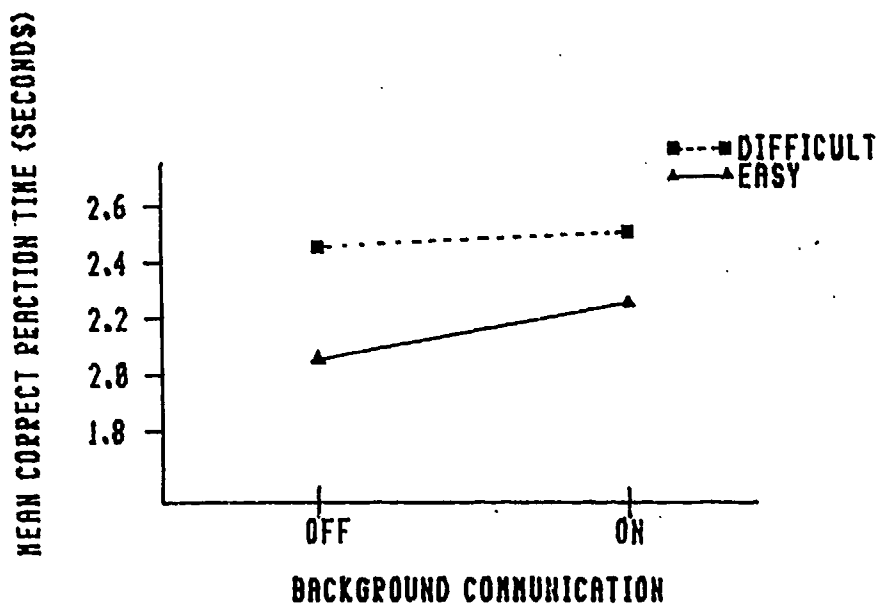

Figure 5. Mean correct response time as a function of difficulty and background communication.

Of all the interactions, only one two-way, involving mean correct response time as a function of the two levels of difficulty and the two levels of background communication, was statistically significant, $F(1,11)=10.96$, $p=0.007$. An inspection of the means, presented in Figure 5, suggests that while there was a difference in pilots' response time performance between the easy and difficult missions, background communication had more of an interference effect during the easy mission than it did during the difficult mission. The analysis of the simple main effects for the independent variable, background communication, resulted in statistically significant differences in response time

TABLE 4. ANOVA table for response time performance.

	DF	SS	F	p	
AXBXC	1	0.127	3.32	0.10	
AXB	1	0.035	3.86	0.08	
AXC	1	0.068	1.08	0.30	
BXC	1	0.168	10.96	0.007	*
A	1	0.010	0.09	0.70	
B	1	0.637	13.34	0.004	*
C	1	1.265	7.53	0.01	*
AXBXCXS	11	0.421			
AXBXS	11	0.100			
AXCXS	11	0.693			
BXCXS	11	0.168			
AXS	11	1.169			
BXS	11	0.525			
CXS	11	1.849			
S	11	41.365			

* Results were significant

A=TYPE OF WARNING
(VOICE VERSUS TONE)
B=BACKGROUND COMMUNICATION
C=FLYING DIFFICULTY
S=SUBJECTS

performance during the easy mission, $F(1,1)=25.7$, $p=0.0004$, but not during the difficult mission, $F(1,1)=2.18$, $p>0.1$. The results of this two-way interaction might suggest that, in a high workload environment, pilots' performance is deteriorated to the extent that additional task loading (in the means of background communication) does not further affect performance.

None of the other two or three way interactions were found to be statistically significant. A complete ANOVA table is shown in Table 4.

MEAN PERCENTAGE OF CORRECT RESPONSES

The subjects' mean percent correct responses were also analyzed, as a function of two types of warning (voice versus tone), two levels of flying difficulty (easy versus difficult), and two levels of background communication (on versus off), in a 2X2X2 repeated measures analysis of variance.

TABLE 5. Subjects' mean percent accuracy for each of the three main effects.

INDEPENDENT VARIABLE	LEVEL		MEAN PERCENT ACCURACY
TYPE OF WARNING	TONE	:	96
	VOICE	:	98
FLYING DIFFICULTY	DIFFICULT	:	97
	EASY	:	96
BACKGROUND COMMUNICATION	ON	:	96
	OFF	:	97

Neither the interactions (two and three ways), nor the main effect analyses resulted in any statistically significant differences. It can be seen by examining the main effect means, shown in Table 5, that the subjects were fairly accurate in responding to the warning messages in all the tested dimensions; at no time did the subjects miss more than four percent of the warnings. The accuracy results indicate that the subjects did conform with the experimenter's instructions requesting them to respond as quickly as possible, but without forcing many errors. The complete ANOVA table is shown in Table 6.

TABLE 6. <u>ANOVA table for percent correct performance</u>.

	DF	SS	F	P
AXBXC	1	1.78	0.13	0.73
AXB	1	18.86	0.76	0.40
AXC	1	2.80	0.31	0.59
BXC	1	4.28	0.14	0.71
A	1	76.82	1.48	0.25
B	1	10.21	0.48	0.50
C	1	50.66	3.90	0.07
AXBXCXS	11	156.21		
AXBXS	11	272.28		
AXCXS	11	101.01		
BXCXS	11	327.99		
AXS	11	570.24		
BXS	11	233.33		
CXS	11	142.78		
S	11	391.11		

A=TYPE OF WARNING
(VOICE VERSUS TONE)
B=BACKGROUND COMMUNICATION
C=FLYING DIFFICULTY
S=SUBJECTS

CONCLUSION

The results of the present study have significant implications on the future design and development of an aircraft warning system. The following paragraphs discuss the major key issues that should be considered by designers.

If the aircraft warning system is limited to no more than four warning messages, then the speed and accuracy of responding to a warning message do not favor one mode of presentation over another (voice or tone). In this case, it is more advantageous (both in terms of monetary and computer resources expenditures) to install a less costly Tone Warning System (TWS), as opposed to installing a more expensive Voice Warning System (VWS).

Based on a compilation of information discussed in this and other basic (Deatherage, 1972) and applied (MIL-STD-1472) reports and documents, it is be concluded that if a warning system may ever contain a large number of messages (five or more), as does the F/FB/EF-111 aircraft, then the implementation of a VWS would make it easier and faster for the crewmembers to interpret the warnings, process the necessary information, decide upon the appropriate response, and initiate the correct response activities.

Despite the present conclusions on the tone versus VWS, it should be noted that, when using large sets of warning messages, the most significant advantage of a VWS is not necessarily related to the speed or accuracy of responding, but rather that it provides the crewmember with the capability of being able to evaluate the reported failure, without scanning back into the cockpit. A 1969 study, performed at the CSDF by Kemmerling et al., examined the effects of F-111 pilots' visual scanning patterns as a function of tone versus voice warning messages. The results of video analyses on visual scan patterns indicated that pilots who received tone warnings were forced to cross-check the annunciaton panel even when they encountered a non-critical failure. However, these same pilots were able to process the voice warnings, decide on their level of criticality and, if necessary, elect to ignore them until they reached a less demanding portion of the mission.

One of the major criticisms of VWS, made by individuals with operational experience, deals with the interference effect it can have on other audio transmissions inside the cockpit. Thornburn (1971) discussed the development of an override option and combat mode blocking mechanism as two methods for dealing with this interference effect. The override option allows the crewmember to silence the voice message unless there is another message that needs to be acknowledge. The combat mode restricts all messages from being presented to the pilot, unless they are classified as critical (such as a ground collision advisory system), specifically during high workload demanding portions of the mission.

Other specific elements that should be considered throughout speech display design are compiled from a paper by Werkowitz (1979) and listed below:

1. What specific voice messages best represent the user population's definitions ?

2. Should VWS be required to use a preliminary alerting tone as required in MIL-STD-1472, or can the voice message be reliably detected without it ?

3. Should the voice message be repeated to the pilot until a corrective response is completed or a shut-off switch is depressed, or should the VWS repeat the message a specified number of times (such as two or three times) ?

4. Should the intensity of the messages be 20 dB on top of a baseline background noise level, or should it be related to the change in background noise level ?

5. Are the voice messages contained in the VWS distinctive and intelligible ?

6. Should the voices be recorded by a male, a female, or a machine ?

7. Should the message inform the crewmember of what is wrong, or should it command for a specific response ?

In conclusion, the end result of the present report was to set the stage for follow-on studies that could possibly influence the development of a VWS. A follow-on study, to be performed at the CSDF, will examine three of the above mentioned variables. Most importantly, it will evaluate the proposed voice messages in terms of comprehension and distinction. Furthermore, the study will examine pilots' performance as a function of preliminary alerting bell (with and without the bell), and also the number of times a warning message is presented (two versus until a response is made).

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