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A COMPARISON OF VOICE AND TONE WARNING SYSTEMS AS A FUNCTION OF TASK LOADING

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Aeronautical Systems Division
Wright-Patterson Air Force Base, Ohio

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TECHNICAL REPORT ASD-TR-69-104

SEPTEMBER 1969

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FOREWORD

The work reported was performed at the Crew Station Simulation Facility, Personnel Subsystems Branch of the Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio. The effort covered in this report was accomplished during the period 10 October 1968 through 10 January 1969.

Special acknowledgement is given the Controls and Displays Branch of the 6570th Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio who sponsored the research and provided for the operation and maintenance of the Crew Station Simulation Facility under Contract F33-615-18C-1097 during the period covered in the report. General Precision, Link Group, Binghampton, New York was the operation and maintenance contractor.

This report was submitted by the authors 8 August 1969.

This technical report has been reviewed and is approved.

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ABSTRACT

Twelve Air Force pilots current in high performance aircraft flew a 100-nautical-mile simulated combat bomb sortie under varying task load and auditory saturation levels in order to compare voice and tone warning systems. An F-111 flight simulator, with three-degrees-of-motion and Link SMK-23 visual system, was employed as the test bed for the experiment. Task loading was induced by giving the subjects no practice on the actual mission terrain prior to the first data run, introducing combat tapes to increase auditory saturation, and displaying pressure altitude commands instead of radar altitude commands on the HUD (head up display). A noncritical emergency and an associated warning were given at three specific geographical points in the mission. Each of these geographical points represented a different task loading condition based on mission requirements. The pilot was warned by either a voice message or a tone, in conjunction with an annunciator light. The voice and tone warning systems were evaluated by comparing the pilots' visual scan patterns and response times under various task load and saturation conditions. From the visual scan pattern, it was found that pilots who received tone warning were forced to cross check the Annunciator Panel when receiving the noncritical failure. The voice warning afforded the pilot the option of responding to or completely ignoring a failure based on mission requirements. In addition, in those cases where voice warned pilots chose to respond to the failure, they did so with faster response times than pilots receiving tone warning.

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INTRODUCTION

The use of recorded voice transmissions as a means of signaling aircraft status has been an operational possibility since 1958 (Reference 1). Since then, interest in voice warning systems (VWS) by military and industrial research planners has generally increased, while at the same time there has been a marked reluctance on the part of operational elements to accept this new approach. Voice warning systems were criticized as being too costly, too heavy and bulky, too unreliable, and too vulnerable to saturation (References 1 and 2). In 1961, the Air Force equipped its fleet of B-58 aircraft with a Voice Interruption Priority System (VIPS) on an experimental basis, and the response was extremely favorable. Out of 97 experienced B-58 pilots responding to a questionnaire recently prepared by the Office of the Directorate of Aerospace Safety, all but six felt that the Voice Warning System had contributed to flight safety in the B-58, and all but two wanted VWS in the FB-111 if they were assigned to that program (Reference 2). In 1963, the Tactical Air Command, using an F-100F, performed an extensive flight test at Langley AFB, Virginia, of a voice warning system similar to that used on the B-58 (Reference 3). During the same time period, the Navy performed a flight test of a different voice warning system to determine its suitability as a supplement to existing warning systems in Naval aircraft (Reference 4). Both the Navy and Tactical Air Command studies found the voice warning systems to be superior to visual warning displays alone and acceptable for service use. In response to queries from both the F-111 and C-5 System Programs Offices (SPOs), the Air Force Inspector General for Air Safety (AFIAS) in 1965 stated that its position "...firmly supports the installation of voice warning systems in all high performance aircraft wherein there is no flight engineer position." (References 5 and 6.) In arriving at its endorsement, the AFIAS cited several documented incidents where voice warning had been valuable in preventing a serious aircraft mishap.

Although slow to begin development of voice warning systems, the Army in recent years has intensively investigated VWS, primarily for rotary wing aircraft. From the results of studies performed at the Human Engineering Laboratories (HEL), Aberdeen Proving Ground, Maryland, (Reference 7) the Army recognized the value of VWS and moved quickly to install voice warning equipment on three aircraft systems — the CH-54, the C-47, and the OV-1. Further interest in voice warning was generated through studies by contractors and private industry (References 1, 7, and 8).

Historically, most studies of voice warning systems have concentrated on flying safety rather than mission performance. However, in certain types or portions of missions, a voice warning which identifies the failure and thus allows the pilot to evaluate it in terms of his present situation may offer a distinct advantage and added flexibility over a tone or a tone and light warning combination. Although recent hardware improvements have alleviated the high cost, size, and weight problems associated with VWS, there still remain serious objections in terms of (1) voice warning interference with other transmissions in an already audio saturated cockpit and (2) gating, sequencing, and priority of voice warning messages. With these objections in mind, the Personnel Subsystems Branch (Crew and AGE Subsystems Engineering Directorate) through its Crew Stations Simulation Facility (CSSF) at Wright-Patterson AFB, Ohio, performed a preliminary experiment to compare voice and tone warning systems under varying levels of auditory saturation.

The experiment was conducted under conditions of low and medium task loading, and little difference in performance between voice and tone warning was evident. It was decided that further investigation into voice and tone warning under very high task-loaded conditions and different mission situations should be studied. Most studies of VWS and tone warning systems (References 3 and 4) found that little advantage can be gained by either system when sufficient time is allowed for the pilot to scan his instruments and take appropriate action without jeopardizing either flying safety or mission accomplishment. However, in those cases where a pilot's attention was required to be outside the cockpit for relatively long periods of time, e.g., number three in a four-ship formation on a bombing run, there was virtually no data available. In addition, much of the voice warning data available was invariably interpreted primarily in terms of response time and its effects on safety of flight. While this is certainly an appropriate measure, it seems that flying safety also could be enhanced by a warning system which could allow a pilot to delay his response for a time — particularly when it permitted the maintenance of mission integrity as well. Failures are not simply "critical" or "noncritical" — they must be evaluated in terms of the type of mission being flown.

With this in mind, the present study was designed to create a flight condition that would be sufficiently stressful, and at the same time, require the pilot to direct his attention out of the cockpit for relatively long periods, so that an adequate comparison could be made between voice and tone warning.

SECTION II

THE EXPERIMENT

1. SUBJECTS

From a pool of pilots assigned to Wright-Patterson AFB, eleven Air Force pilots and one Navy pilot voluntarily participated as experimental subjects. The pilots' mean age was 35.2 years, and they had accumulated a mean total of 3267 hours of flying time. Ten of the twelve were combat veterans (SEA), with an average combat time of 322.1 hours. Five of the combat veterans had flown missions over North Vietnam. In addition, eleven of the pilots were current in high performance jet aircraft at the time of the study (see Table I).

2. APPARATUS

An F-111A flight simulator (Figure 1) with a three-degree-of-motion system was employed as the test vehicle for the experiment. The visual apparatus consisted of a closed-circuit TV system which used a Thompson-Houston 3-inch image orthicon high resolution camera modified to a 1029-line black and white system. The camera transferred images from a modified Link SMK-23 moving map model of rugged mountainous terrain to a standard Conrac Model CQM-13/N 1000-line monitor mounted in the pilot's windscreen. A pair of large (27-inch diameter) back-to-back single convex collimating lenses with a focal length of 80 inches collimated the light from the image so that it appeared at infinity. This collimating effect gave the pilot the impression of looking at the terrain from flight altitude.

A Librascope optical probe (Link Model 94 Articulated Lens) built to match the perspective of the pilot's eye to the terrain was used on the Thompson-Houston camera. The Librascope optical probe lens barrel moved in three planes to simulate 360° continuous heading, 360° continuous roll, and plus or minus 25° pitch by the aircraft.

A Master Caution Light located directly above the flight instruments on the pilot's instrument panel, and lights on an annunciator panel located on the

TABLE I

PERSONAL DATA ON SUBJECTS

Subject	Age	Total Hours	Major Aircraft Flown	Combat Time over NVN or SVN*	Combat Time (hours)	Current Flying Status
S-1	31	2300	F-100-1100 hrs	F-100 SVN	200	F-100, T-33 Jet
S-2	33	3500	F-100-300 hrs	FAC NVN	800	T-39 Jet
S-3	40	4400	F-105-280 hrs F-4C-150 hrs	F-105 NVN	250	F-4, T-37 Jet
S-4	37	3000	T-33-400 hrs	None	0	T-33 Jet
S-5	37	3500	F-100-1500 hrs	F-100 SVN	500	T-33 Jet
S-6	31	2700	F-4-1200 hrs	F-100 SVN	200	T-33 Jet
S-7	33	3200	F-104-400 hrs F-102-450 hrs F-101-600 hrs	None	0	F-4, F-101, T-33 Jet
S-8	33	2300	F-100-500 hrs F-105-1400 hrs	F-105 NVN	306	AFIT

TABLE I (CONT)

Subject	Age	Total Hours	Major Aircraft Flown	Combat Time over NVN or SVN*	Combat Time (hours)	Current Flying Status
S-9	35	3300	F-100-450 hrs	F-100 SVN	360	T-39 Jet
S-10	39	4400	F-100-400 hrs F-101-300 hrs F-105-500 hrs F-4-500 hrs	F-105 SVN	230	F-4, F-100 Jet
S-11	42	4000	F-102-1000 hrs RF-4-500 hrs	RF-4 NVN	419	T-33 Jet
S-12	31	2600	T-33-300 hrs	01E SVN	600	T-33 Jet

* NVN - North Vietnam
SVN - South Vietnam

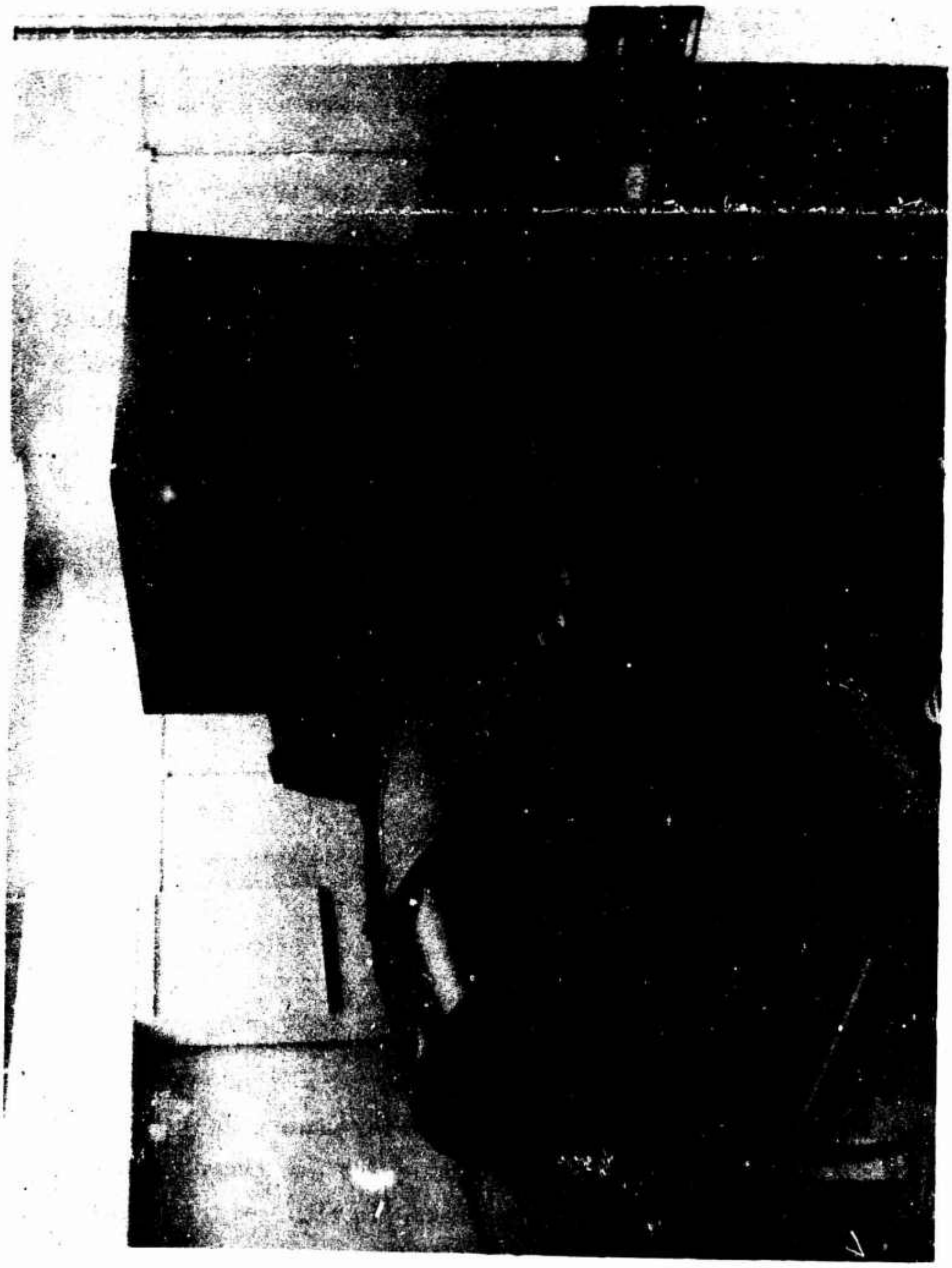

Figure 1. Outside of Simulator -- Motion Base and Cockpit

bottom center of the pilot's instrument panel provided the standard visual warning for the emergencies (Figure 2). The voice warning for the emergencies presented consisted of a recorded young adult female voice similar to that used in the B-58 VWS. The voice message was transmitted for approximately three seconds with a two-second interval between messages. The messages were repeated until the pilot depressed the Master Caution Light to extinguish the voice warning or corrected the failure in the proper sequence. The tone warning was produced by a 1250-3300 CPS continuously sweeping tone with a sweep duration of 0.5 second, which was also terminated by depressing the Master Caution light on the instrument panel or correcting the failure. The voice and tone warnings were transmitted to the pilot at a volume level approximately 10 decibels higher than any other transmissions presented and were received through his helmet earphones via the normal aircraft communications system. After depressing the Master Caution light, the audio warning terminated, however, the warning light on the annunciator panel remained illuminated until the pilot corrected the emergency in the proper sequential order. A list of the emergencies and the steps to correct each emergency can be found in Figure 3.

A digitally driven HUD, centered on the pilot's windscreen at an infinite focus, provided the pilots with command altitude and airspeed indications (see Figure 4). In order to increase task loading for the pilot and to assure a measure of standardization with respect to the route flown, the pitch command bar on the HUD was placed in the "altitude hold" mode (pressure altitude reference) for the flights. Thus, by centering the pitch steering bar, the pilot could fly at a constant indicated altitude; however, he received no command information with respect to his clearance above the terrain.

A Maryland Telecommunications (MTI Model VC-21) high-resolution low-light-level vidicon camera especially suited for the low-light levels of the cockpit was focused on the pilot's face so that eye scan and head movements could be monitored. Ten seconds before the failure occurred, an Ampex Model VR660 video tape recorder automatically started recording the pilot's head and eye scan movements. A separate audio track on the video tape recorded the voice warning so that correlation could be noted between onset of

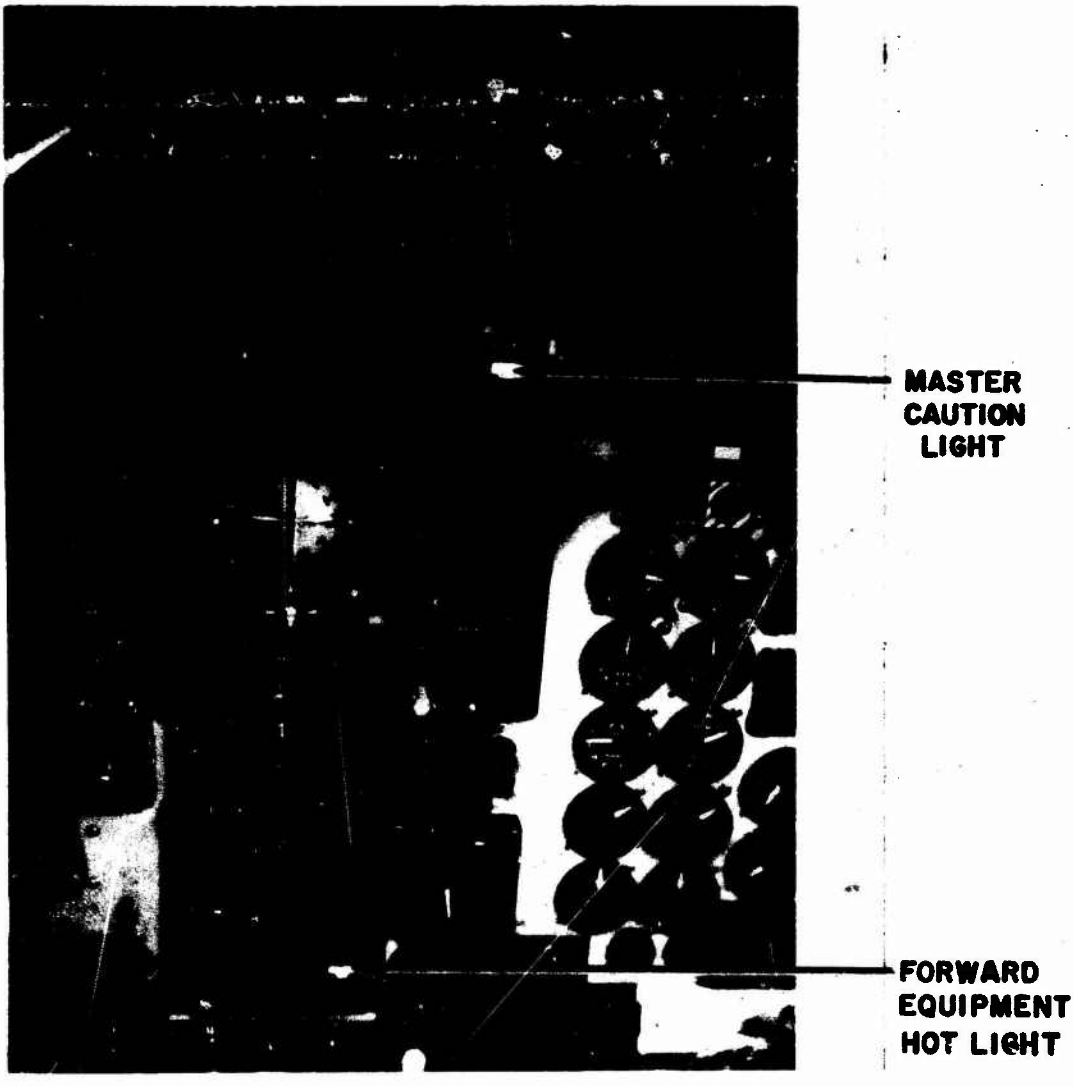

Figure 2. Cockpit Instrument Panel, Master Caution Light, and Forward Equipment Hot Light

EMERGENCY PROCEDURES

FORWARD EQUIPMENT HOT

Illumination of this lamp may occur at high angles of attack and low airspeed, or at low altitude and high airspeed, and is caused by low airflow and/or high temperature airflow being supplied for equipment cooling. The corrective action is as follows:

a. Depress Master Caution Light
b. Air Conditioner Switch - MANUAL
c. Temp Control Knob-RAM

CADC FAIL

Failure of the Central Air Data Computer (CADC) System will cause a failure in one or more of the following systems: Flight Director, LCOS, Bomb/Nav System, Angle of Attack Indexer, Translating Cowl, and ILS Approach System. The corrective action is as follows:

a. Depress Master Caution Light
b. Turn CADC Switch to Alternate
c. Monitor Aux Flight Instruments

LEFT PRIMARY HYDRAULIC
RIGHT PRIMARY HYDRAULIC

Failure of either hydraulic system will cause pitch roll and yaw damper, and the hydraulic low pressure caution lights to illuminate. The damper servo-actuators will operate as non-redundant servos. As the hydraulic pressure drops and the damper lights come on, rapidly increasing stick forces will be felt until complete stick failure occurs. The corrective action is as follows:

a. Depress Master Caution Light
b. Utility Hydraulic Switch - ISOLATE
c. Damper reset - DEPRESS

Figure 3. List of Failure Emergencies and Steps to Correct Each Failure

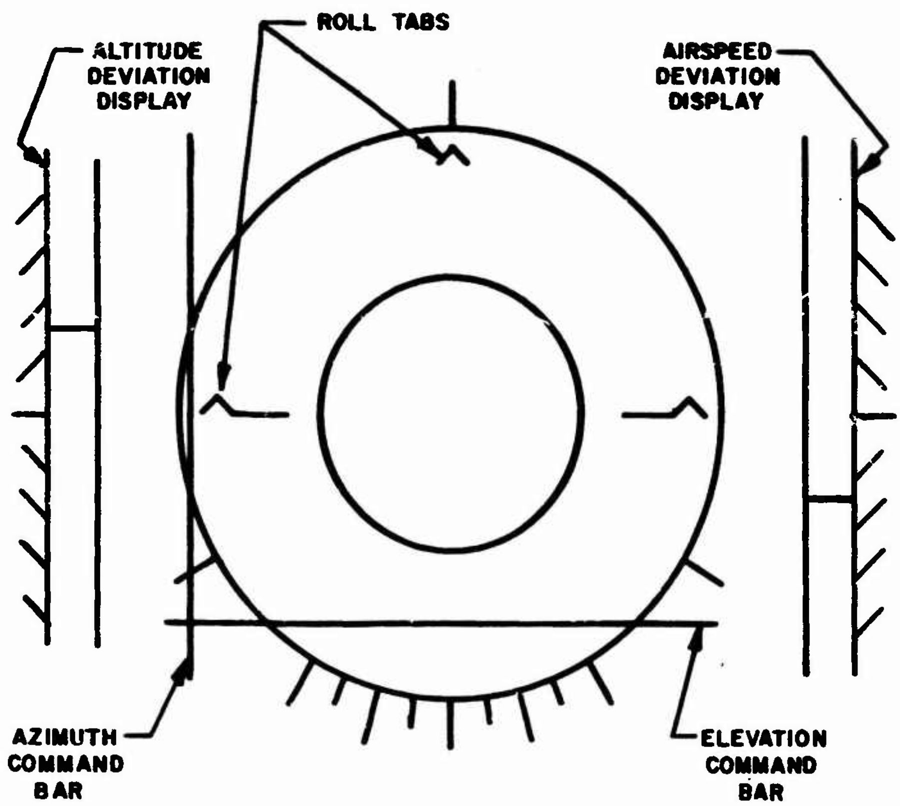

Figure 4. Diagram of Head Up Display (HUD) Projected on Pilot's Windscreen

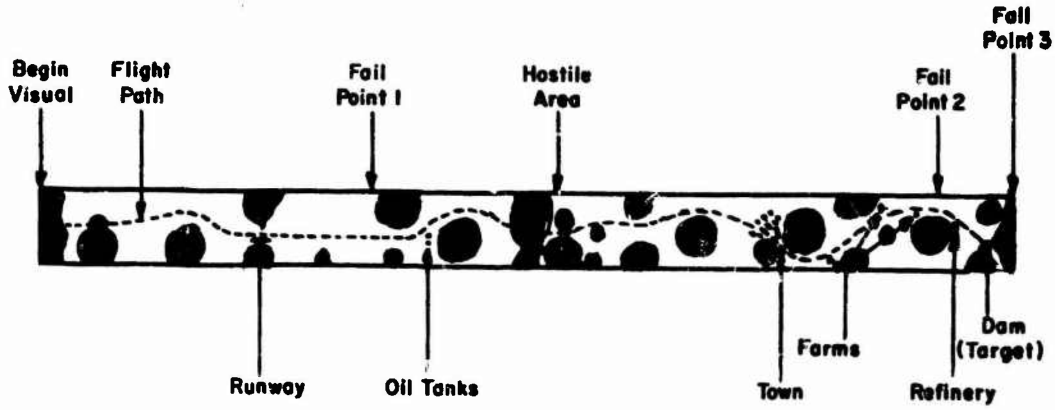

Figure 5. Mission Profile

the failure and the pilot's eye scan and head movements. It was also possible for the experimenter to record any comments simultaniously on a second audio channel on the video tape. The video tape was programmed to automatically shut off 10 seconds after the failure was corrected, or 30 seconds after failure onset if the pilot chose to ignore the emergency.

A record of pilot performance was obtained on magretic tape from the Mark I computer. Airspeed, altitude, and deviation from commanded pitch and roll were recorded from a period 10 seconds before onset of a failure until 10 seconds after the failure was corrected. In the event the pilot did not correct the failure, the magnetic tape was programmed to automatically shut off 30 seconds after failure onset. The performance measures were sampled every two-tenths of a second and all values were available on the resulting computer printout.

3. PROCEDURE

The mission profile (Figure 5) consisted of a 100-nautical mile (NM) simulated bomb sortie, with the objective being a large hydroelectric dam. The pilot would take off, climb to 3000 feet (indicated), and fly to the visual area at 450 KIAS. Upon reaching the visual area, he would immediately descend to 750 feet, using the HUD and begin his mission run. Using his target flimsey (Figure 6), he would navigate the first 50 NM in friendly surroundings; however, at this point, he was required to climb to 2500 feet to clear an escarpment, and after returning to 750 feet on the other side, he was considered to be in hostile territory. At this point the pilot would switch to his preset combat channel (CH18) on his UHF communications panel. He had been prebriefed to expect SAM and MIG information from an airborne controller working his flight. To simulate this condition, continuous tapes of actual combat sorties over North Vietnam were played to provide background saturation, and specific target information was recorded over this noise in order to insure that the pilot would attend to the warnings. The study employed artifically generated flak to enhance the realism of a hostile environment. Flak was simulated by programming a full speed-brake down condition while at high speed, coupled with an electronic flash unit affixed to the canopy of the F-111A simulator. Used sparingly, this device served quite effectively to increase the stress factor for the pilot during the target run.

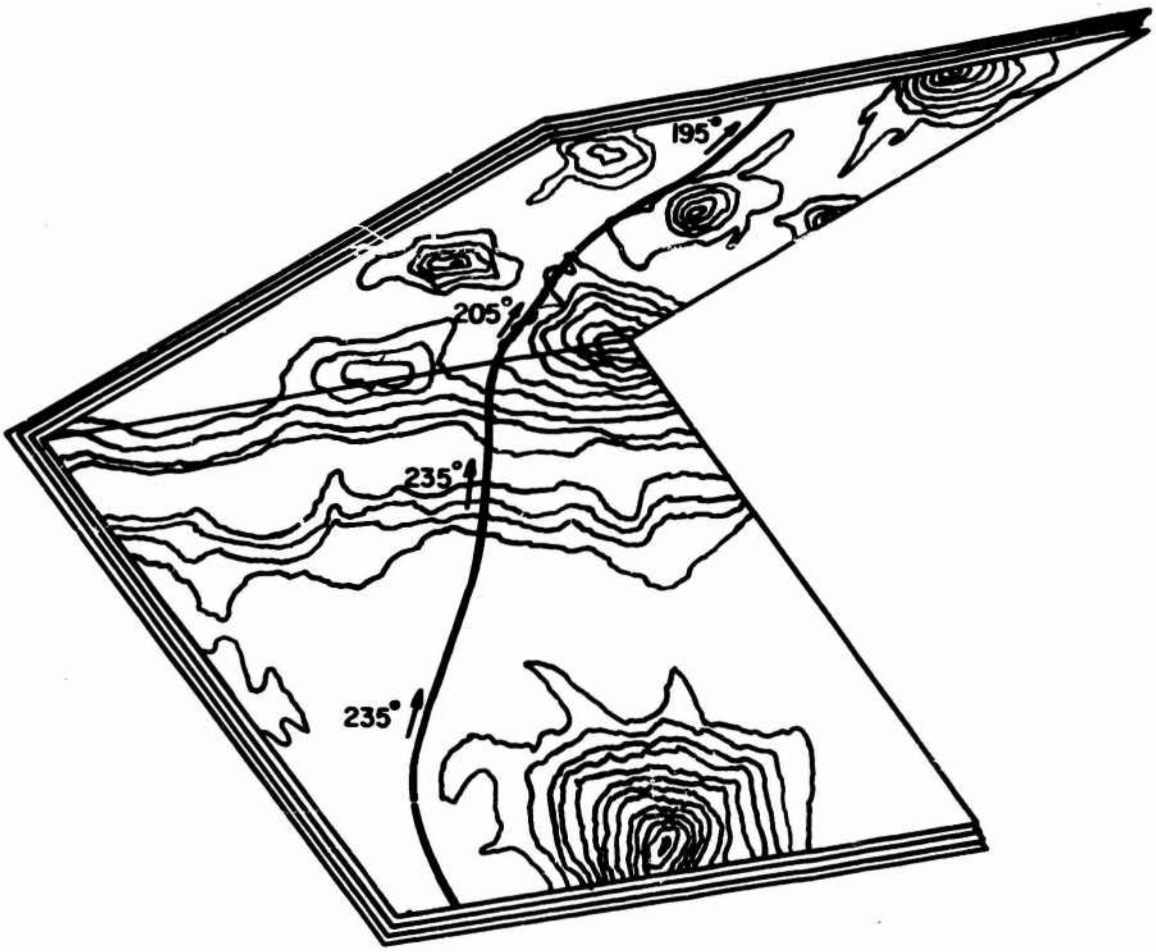

Figure 6. Drawing of Target Flimsy

Upon reaching the initial point (IP), the pilot depressed the bomb release switch on his control stick, which started the bomb timer and brought the HUD course deviation needle into view. Thus, as he made his target dash, he was receiving both azimuth and altitude commands. At a specific point approximately 2 miles from the target, the pilot received a 4 G pull-up command on the HUD. Following his prebriefed instructions, the pilot then initiated a full afterburner climb-out at a 30° climb angle to approximately 9000 feet indicated. As he passed through 1600 feet the HUD disappeared, and the pilot would then direct his attention back into the cockpit for the climb-out. At some point during this maneuver, the mission was arbitrarily terminated by the experimenter.

4. METHOD

The experimental design shown in Figure 7 called for two practice sessions and three experimental sessions conducted over a 5-day period. It was originally intended that the subjects would be equally divided between voice and tone groups. However, when the eye scan data from the first three voice subjects was analyzed, it was noted that voice warned subjects did not automatically scan the Annunciator Panel after receiving a failure. To confirm this unexpected result, six more voice subjects were chosen which produced a statistical imbalance in the voice group.

The first 1-hour practice session began with a complete briefing to each subject on the nature of the study and its requirements. This was followed by the dissemination of the emergency procedures and strip maps of the mission profile. Utilizing a master flimsy of the intended course, each pilot was then required to prepare his own strip map, using his own method of identifying the nine checkpoints scattered throughout the 100-NM course. As long as he stayed within the 10-NM width of the map, each pilot was free to draw up his own route; however, all subjects followed the same general profile. Photographs of each checkpoint were made available and the subjects were encouraged to study them thoroughly before each flight.

Practice Session II consisted of three 20-minute segments. Each subject spent the first 20 minutes familiarizing himself with the F-111A cockpit and switches, particularly the emergency switches. Dummy practice on each emergency was followed by practice using the voice-tone tapes. When the subject demonstrated facility with the emergencies, he was permitted to take off and for approximately 20 minutes practice flying at low level using the HUD over terrain similar to that encountered on a mission. Following this period, failures were introduced while the pilot continued to practice, and he was required to correct each emergency until he was proficient.

	DAY 1	DAY 2	DAY 3	DAY 4	DAY 5
VOICE N = 9 TONE N = 3	ORIENTATION AND BRIEFING	THREE-20-MIN PRACTICE SESSIONS ON EMERGENCIES	MISSION 1 (Fail During High Task Load)	MISSION 2 (Fail During Low Task Load)	MISSION 3 (Fail During Climbout)

Figure 7. Experimental Design

The experimental sessions were scheduled to last approximately 17 minutes from takeoff to mission completion. Before each session the subject would receive sufficient practice on the emergencies so as to complete each recovery in less than 7 seconds. He was then released for the run, and no radio conversation was permitted after he was airborne. If the subject got lost, he would be reset to the beginning of the mission and released again. It was arbitrarily decided that two resets would be the maximum allowable, and that individuals failing to successfully navigate the route after three tries would be dropped from the experiment.

5. FAILURE CONDITIONS

The emergency conditions established for this experiment were chosen to represent three types of failures:

a. A noncritical failure from a mission or flying safety standpoint (FWD EQUIP HOT)

b. A critical failure with respect to mission, but noncritical with respect to flying safety (CADC)

c. A critical failure from both a mission and a flying safety standpoint (complete hydraulic failure).

In addition to the description of each failure provided in the emergency list given to the pilot (Figure 3), he was permitted to experience each of the failures under simulated flight conditions during practice Session II. When the FWD EQUIP HOT failure occurred, the only indication (in addition to the voice or tone warning) was the illumination of the annunciator lights. In the case of the CADC failure, the lights would illuminate and the various fail- and OFF-flags associated with the appropriate displays would appear. In the case of the HYD FAILURE, the control stick would immediately begin to stiffen, until complete hard-up or down would occur (approximately 3 seconds). If the pilot did not correct the situation immediately, full loss of control would occur (within 6 seconds).

Only one of these failures was actually introduced in the actual mission runs - FWD EQUIP HOT.

The points at which the failure occurred were determined geographically with respect to the terrain and were programmed to occur automatically (see Figure 5). Failure Point 1 occurred early in the mission, when the pilot was under low task loading and relatively low saturation. He was, in effect, still in friendly territory, and he was not receiving any audio input. Failure Point 2 occurred late in the profile during the actual bomb run, and represented the high saturation and task loaded condition. Failure point 3 occurred at a point on climb-out when the pilot's attention was back in the cockpit and the data generated was used primarily to verify in-cockpit scan pattern and to permit some comparisons of response time.

The order of presentation of the failures was as follows: Mission 1 - Failure Point 2; Mission 2 - Failure Point 1; Mission 3 - Failure Point 3. This order was chosen primarily because it was felt that the novelty of flying the route, hence the degree of difficulty involved, would be greatest on the first run, and the major concern was to observe scan patterns during the highest task-loading condition, before possible practice effects could attenuate the stress imposed on the pilot.

SECTION III

RESULTS

The most significant findings of the study are shown in Table II, which summarizes the pilot's visual scan pattern. At Failure Point 2 (the most task loaded and saturated portion of the mission), the failure was corrected by seven of the nine pilots in the voice warning group, with the other two taking no corrective action. Eight of these nine pilots did not cross check the annunciator panel, indicating that pilots do not automatically scan the annunciator panel when using a VWS combined with a visual warning system. The finding is somewhat unexpected because one of the more frequent criticisms of the voice warning is that it serves only as an attention-getting device and that pilots will cross check failures in any case. The result cited above was further substantiated at Failure Point 1 where the scan data were identical. All of the tone group corrected both failures (1 and 2) after determining the malfunction by scanning the annunciator panel, which was the expected result.

Although the number of subjects in the tone group was too small to compare the voice and tone groups' performances statistically, it was possible to compare differences in airspeed, altitude, and pitch performance with the voice group under high and low task load conditions. The figures in Table III were used to perform an analysis of variance on deviations from commanded pitch. This analysis showed a significant interaction between task loading and pitch deviation before and after the failure (see Table IV). In similar analyses performed on airspeed and altitude (Tables V and VI), significance was not obtained, but airspeed and altitude could be considered slower acting measures and derivatives of the more sensitive pitch scores. Thus, in the short time spans involved, it is unlikely that significant differences on airspeed and altitude would be obtained unless large pitch scores were involved, which was not the case.

Another important result was noted with regard to reaction times to correct the failures. The mean response time to failures is shown in Table VII for the

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Corrected Page.

Deputy for Engineering
Aeronautical Systems Division
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio

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TABLE II

SUMMARY TABLE - PILOT VISUAL SCAN

Test Situation	Type Warning	Subject	Scanned Master Caution Light	Scanned Annunciator Panel	Scanned Fail Switches	The Failure Corrected	Remarks
High Task Loading and Saturation (Failure Point 2)	Tone	1	Yes	Yes	No	Yes	
	Tone	4	Yes	Yes	No	Yes	
	Tone	5	Yes	Yes	Yes	Yes	Incorrect sequence
	Voice	2	Yes	No	No	No	Did not correct -- ignored failure
	Voice	3	No	No	Yes	Yes	Corrected fail - incorrect sequence
	Voice	6	Yes	No	No	No	Corrected Master Caution Light only -- ignored failure
	Voice	7	No	No	Yes	Yes	
	Voice	8	Yes	No	Yes	Yes	Looked to hydraulic switches, then fail
	Voice	9	No	No	Yes	Yes	
	Voice	10	No	No	Yes	Yes	
	Voice	11	No	No	No	Yes	
	Voice	12	Yes	No	No	Yes	
Low Task Loading and Low Saturation (Failure Point 1)	Tone	1	Yes	Yes	No	Yes	
	Tone	4	Yes	Yes	No	Yes	
	Tone	5	Yes	Yes	Yes	Yes	
	Voice	2	Yes	No	No	Yes	
	Voice	3	Yes	No	Yes	Yes	
	Voice	6	No	No	Yes	Yes	Corrected Master Caution Light last
	Voice	7	No	No	No	Yes	
	Voice	8	Yes	Yes	Yes	Yes	
	Voice	9	Yes	No	Yes	Yes	
	Voice	10	No	No	No	Yes	
	Voice	11	Yes	No	No	Yes	
	Voice	12	Yes	No	Yes	Yes	Corrected Master Caution Light last

TABLE III

MEAN DEVIATION FOR TONE AND VOICE GROUPS 10 SECONDS BEFORE AND 10 SECONDS AFTER FAILURE

Tone Group (N = 3)

Test Situation	Airspeed (knots)		Altitude (ft)		Pitch (sine of pitch angle x 10^{-3})	
	Before Failure	After Failure	Before Failure	After Failure	Before Failure	After Failure
High task load condition	17	51	104	54	69	12
Low task load condition	21	14	175	361	30	20

Voice Group (N = 9)

Test Situation	Airspeed		Altitude		Pitch	
	Before Failure	After Failure	Before Failure	After Failure	Before Failure	After Failure
High task load condition	15	17	107	126	62	56
Low task load condition	8	6	101	196	15	44

TABLE IV

SUMMARY TABLE FOR ANALYSIS OF VARIANCE ON PITCH

Testing differences between scores on pitch for high and low task load conditions for 10 seconds before and after the failure.

Source of Variation	Degrees of Freedom	Mean Squared	f Ratio
Treatment A (high and low task load)	1	8,402.8	4.5*
Treatment B (before and after failure)	1	1,088.9	0.64*
Treatment C (subjects)	8	1,550.3	
Interaction of Treatment (AxB)	1	3,061.8	5.6**
Interaction of Treatment (AxC)	8	1,866.1	
Interaction of Treatment (BxC)	8	1,681.5	
Interaction of Treatment (AxBxC)	8	545.7	

*Not significant
**Significant 0.05

TABLE V

SUMMARY TABLE FOR ANALYSIS OF VARIANCE ON AIRSPEED

Testing differences between scores on airspeed for high and low task load conditions for 10 seconds before and after the failure.

Source of Variation	Degrees of Freedom	Mean Squared	f Ratio
Treatment A (high and low task load)	1	765.4	2.03*
Treatment B (before and after failure)	1	1.0	0.001*
Treatment S (subjects)	8	312.2	
Interaction of Treatment (AxB)	1	36.0	0.18*
Interaction of Treatment (AxBxS)	8	194.1	
Interaction of Treatment (AxS)	8	376.8	
Interaction of Treatment (BxS)	8	164.9	

*Not significant

TABLE VI

SUMMARY TABLE FOR ANALYSIS OF VARIANCE ON ALTITUDE

Testing differences between scores on altitude for high and low task load conditions for 10 seconds before and after the failure.

Source of Variation	Degrees of Freedom	Mean Squared	f Ratio
Treatment A (high and low task load)	1	8,961.8	0.58*
Treatment B (before and after failure)	1	29,584.0	1.56*
Treatment C (subjects)	8	43,158.0	
Interaction of Treatment (AxB)	1	12,844.5	2.56*
Interaction of Treatment (AxC)	8	15,419.8	
Interaction of Treatment (BxC)	8	18,930.0	
Interaction of Treatment (AxBxC)	8	5,014.4	

* Not significant

TABLE VII

MEAN RESPONSE TIME TO FAILURES IN SECONDS

Type Warning	Failure I	Failure II	Failure III
TONE	8.99 (N = 3)	8.93 (N = 3)	10.13 (N = 3)
VOICE	8.01 (N = 9)	6.53 (N = 7)	9.13 (N = 9)

voice and tone groups. At all three failure points, the mean response time for the voice warned group was faster than the mean response time for the tone warned group.

Further analysis of voice group's data shows that the response to the master caution light differed depending on task loading. At Failure Point 2 (high task loading), only two of the seven subjects who corrected the failure scanned the master caution light, whereas, at Fail Point 1 (low task loading), six of the nine pilots who corrected the failure also scanned the master caution light. This difference is attributed to the pilots' having more time available for nonmission oriented actions during flight at Failure Point 1.

At both Failure Points 1 and 2, all tone warned subjects corrected the failure. Under low task load conditions, Fail Point 1, all voice warned subjects also corrected the failure. However, under high task load conditions (Fail Point 2), two of the nine voice warned subjects ignored the failure.

An interesting, but unexpected result, is that under high task loading and saturation, six of the twelve pilots were able to correct the failure without looking at the fail switches.

SECTION IV

DISCUSSION

As indicated in the Introduction, initial criticism of voice warning systems can be classified into four major categories: (1) VWS are too big and too costly; (2) VWS are not reliable enough; (3) VWS do nothing more than attract a pilot's attention, which a tone could do just as well; (4) VWS are vulnerable to saturation. With the development of the third generation of VWS (Reference 1) and the resulting hardware refinements, the validity of the first two criticisms has been greatly reduced. There are now available production model VWS's with a mean time between failures (MTBF) of greater than 10,000 hours, a total weight of less than 4 pounds, and a total size of less than 45 cubic inches (Reference 8). The third category of criticisms has already been covered in the results of the eye scan data and requires no further discussion.

The results of the present study should also dispel doubts about the effectiveness of VWS in a high saturation and heavy workload environment. From the analysis of variance performed on commanded pitch deviation under high and low task loading, a significant interaction was noted (see Table V). The failure condition combined with the task load situation to produce significantly better performance under high task load conditions. This difference could be explained in terms of the Yerkes-Dodson Law (Reference 9) which suggests that the optimal level of irrelevant stimulation (i.e., task loading and audio saturation) increases as the level of task difficulty (failure correction process) decreases. With the high level of experience of the pilot subjects in this experiment, the failure correction process was assumed to be a simple task. Many of the pilots were able to correct the failure without even looking at the fail switches. It is likely that the high task loading and saturation levels utilized in this study provided an optimal level of stimulation which improved pilot performance. However, serious consideration of VWS is still necessary in terms of the effectiveness of voice warning messages in a high workload and saturation environment due to high ambient noice levels and difficulties with gating, sequencing, and message priority.

Recent studies (Reference 7) indicate that the area of message priority is one which can be handled only within the context of the specific weapon system's mission.

Current military standards require a preliminary alerting tone preceding a voice warning message (Reference 10). This type of procedure may be quite appropriate in certain aircraft systems (i.e., rotor wing aircraft) where high noise levels and crew considerations may require an initial alerting tone. In fixed wing, high performance aircraft such an alerting tone may be not only superfluous but actually detrimental. Alerting tones are already overused in the cockpit as a warning device; some of the newer operational aircraft have over 40 alerting tones. With so many possible tones, the urgency of the alerting function is reduced. Confusion about the meaning of a tone in a critical situation is also possible. Further, an initial alerting tone may actually defeat the purpose of voice warning. A pilot, receiving an initial alerting tone, may automatically check the Annunciator Panel for further failure information in an attempt to evaluate the problem as quickly as possible. The voice warning, in such a situation, becomes little more than a distracting background noise.

Data from questionnaires collected after the study (Appendix) indicate that pilots who participated in this study generally favor VWS over tone warning. However, as indicated in this questionnaire and others (Reference 2), there is an apparent reluctance to accept VWS without a backup Annunciator Panel. Visual scan records from this study indicate that the Annunciator Panel may not in some cases be required; however, this determination must be made on an individual basis for each weapon system.

SECTION V

CONCLUSIONS

1. Voice warning systems have definite advantages over tone warning systems.

2. Voice warning systems offer added flexibility by allowing a pilot to evaluate a failure in terms of mission and safety requirements before acting.

3. A voice warning does not serve merely as an alerting signal but provides direct information that enables the pilot to take corrective action immediately.

4. The benefits of a VWS are more apparent under high task load conditions.

APPENDIX

VOICE-TONE QUESTIONNAIRE

1. What is your opinion of the type and combination of cockpit warnings that alerted you to an emergency condition?

S-1 (Tone): The tone was very effective in drawing attention to the warning light. I found, however, that the sequence of action was -- alerted by tone; looked at master caution light; looked at trouble light. Perhaps with tone the master caution is a time consuming, unnecessary redundancy.

S-2 (Voice): The tone warning was very good. I have only flown with a master caution light previously and I do like a warning.

S-3 (Voice): Due to placement of the warning panel, you have to look around the stick to see what light is lighted. I love the little voice in my ear. I respond.

S-4 (Tone): The tone rather grabs me, takes my full attention until I could determine what it was.

S-5 (Tone): Tone - good
Lights - Master caution - good location
Annunciator Panel - can't see it and too many lights

S-6 (Voice): Very good. I would have also liked to have master caution type of presentation projected on the HUD.

S-7 (Voice): I liked the voice warning. I saw the master caution light each time before the voice started.

S-8 (Voice): The best I have seen. That girl gets my attention.

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S-9 (Voice): For just alerting that some emergency exists, the voice warning is unnecessary: a pilot can pick it up at the same time with the lights. It is nice not to have to read what the emergency is though.

S-10 (Voice): It is adequate for the small number of emergencies I had to remember. I don't know if I would have had to memorize a long and complicated set.

S-11 (Voice): Type - voice backed up by lights - I am in favor of this system where you can respond to the voice alone or verify by checking the lights as time permits.

S-12 (Voice): I favor a "different" type voice sound warning.

2. What tradeoffs and decisions did you make when confronted with the emergencies during the missions? (Examples: time, nature of emergency, aircraft control, segment of mission).

S-1 (Tone): Emergencies all occurred between the IP and the target (Ed. note: this is not true and where he got this impression is unknown). Emergencies were such that corrective action could be delayed momentarily until positive aircraft control to effect a good bomb run could be established. Therefore, primary attention was given to flying the aircraft with corrective action accomplished when convenient.

S-2 (Voice): When in hostile surroundings I took care of the emergency as soon as possible but with care so as not to climb or lose my nav. check points. In the I. P. to target area, I received Forward Equipment Overheat and with only a few seconds to target I did not react until after delivery.

S-3 (Voice): I did not punch "master caution" light until after I took action.

S-4 (Tone): Very little.

S-5 (Tone): Equipment overheat light: immediate action not required; could complete bomb run. Hydraulic: must act immediately regardless of conditions.

S-6 (Voice): For items which did not need immediate attention the only action taken was to hit the master caution light to turn off the voice. Action could be taken at the first available time after things were set up to do it. Actions requiring immediate attention would have to be accomplished as best as you can.

S-7 (Voice): It distracted some from the visual display because I always look at switches before I activate them (at least I take a quick glance at the general area of the switches). I also switched hands and flew with my left hand while activating the switches with my right hand.

S-8 (Voice): The only intended emergency I got was Forward Equipment Hot (Ed. note: i.e., the only one out of the three emergencies he practiced) which was not extremely time critical, so it did not interfere with aircraft control.

S-9 (Voice): All my emergencies were equipment cooling. I took care of these right away with no difficulty, but did not rush too much due to nature of the emergency.

S-10 (Voice): The voice made it easy to concentrate on aircraft control, headsup, without diverting attention. Some aircraft control was lost trying to find the right switch.

S-11 (Voice): The emergencies were in critical phases of flight, as well as in critical phases of the mission. Therefore, I completed the bold faced emergency procedure without referring to the annunciator panel or the switches for the sake of mission completion and aircraft control.

S-12 (Voice): I wanted to correct the emergency as soon as possible and continue the mission.

3. Do you have a preference for any specific type of cockpit warning system? Please discuss.

S-1 (Tone): No. As long as lights are not hidden under consoles or tones are not identical to other commonly heard transmissions.

S-2 (Voice): Preference for voice. It tells me the type of emergency and lets me evaluate without moving my eyes from flying the mission.

S-3 (Voice): I like the voice. It leaves my head out of the cockpit more. If you are told your trouble, you can verify it by the light.

S-4 (Tone): I believe the voice may be better.

S-5 (Tone): Tone; good. I would have to hear the voice to make a judgment. I would think the voice would be better since it gives the type of emergency.

S-6 (Voice): I prefer voice warning in conjunction with annunciator panel. This can give an immediate indication of a problem (not always indicated with lights due to "head out") and a very good indication of the seriousness of the problem.

S-7 (Voice): I like the voice warning very much. The lady's voice contrasted well with other radio transmission and was readily heard and easily understood.

S-8 (Voice): The voice warning is best. Flying wing in combat can take your eyes out of the cockpit for fairly long periods of time. This is not good with time critical failures.

S-9 (Voice): As in paragraph 1, the master light is sufficient to just basically let the pilot know something is wrong. The voice is good to notify the type of emergency and seems to lead to faster response and recall of proper steps.

S-10 (Voice): Being current in old airplanes, I feel almost anything is an improvement. I think I would like the voice system with some sort of visual warning for critical items.

S-11 (Voice): I would like to see selective voice warning in conjunction with the current "Caution plus annunciator" system.

S-12 (Voice): A voice warning is the fastest attention getter.

4. Did you find it necessary to confirm the voice warning by looking at the warning annunciator panel? With practice could you rely solely on the voice warning without looking at the panel to confirm?

S-2 (Voice): No. Yes, I believed it and don't know why I shouldn't. The voice should be as reliable as the lights.

S-3 (Voice): Not always. With the hydraulic failure, I felt the stick move when the voice came on; therefore, I didn't verify the hydraulic failure.

S-6 (Voice): No reference to annunciator panel. During an instrument flight (high level), I'm sure that some reference to the panel would be made. To rely solely on the voice warning could only be accomplished if the system had a very high reliability factor and even then could not give multisimultaneous failures. The panel should be retained.

S-7 (Voice): No. Yes.

S-8 (Voice): Yes. No, it would take years of reconditioning for me to accept the voice only.

S-9 (Voice): No. Yes.

S-10 (Voice): Just the opposite, I saw the master caution light and waited for the voice. The only problem I can see in leaving out the lights is a malfunction of the voice warning.

S-11 (Voice): No. I would only use this procedure if the timing and nature of flight and emergency dictated it. If voice warning was limited to only true emergency items, I would subscribe to the practice of instant response.

S-12 (Voice): No. Yes.

5. What problem areas do you recommend for further investigation when attempting to determine the adequacy of Voice-Lights or Tone-Lights emergency warnings?

S-1 (Tone): See question 6: make stress situation variable to force pilot to pay attention.

S-2 (Voice): Can the voice adequately cover battle damage problems (i.e. a hydraulic failure due to a hole in the wing)? Can it be tied into RHAW gear (SAM warning)?

S-3 (Voice): Put a time delay in the stick movement when aving the hydraulic failure. I don't think at the first pressure decay that the stick would start responding.

S-4 (Tone): Not applicable.

S-5 (Tone): You might try flashing lights on the annunciator panel. You might vary the tone for caution (amber) versus warning (red).

S-6 (Voice): 1. Multiple failure (very common in operations). 2. Problems in shirtsleeve aircraft (operation on cockpit speaker). 3. Aircraft noise level (during take off in the F-111 the noise level is sometimes so high that the tower/interphone cannot be heard. 4. Standardization of the voice. If voices are not the same then identification would be difficult.

S-7 (Voice): The reliability of the voice warning: will it always speak and will it always say the right things?

S-8 (Voice): Tone-Lights are not good, since tones require memory and are used for many other things.

S-9 (Voice): I didn't fly wit. the tone but as I see it, it would be completely useless and only serve to duplicate the master caution light. The tone could be confusing with other honest tones and very irritating.

S-10 (Voice): How about voice warning along with noncritical procedures to follow after immediate action items have been accomplished?

S-11 (Voice): I am sure that someone would tend to overwhelm the system with unnecessary warnings. Historically, this has happened to the warning lights in the cockpit. This is why we need voice warning. But it needs to be selective.

S-12 (Voice): It is strictly a problem of determining and developing a 100% reliable warning system with at least an initial voice warning.

6. How would you evaluate the realism of simulation, including motion, visual and instrumentation systems?

S-1 (Tone): Probably the most real of simulators, yet still a simulator and very difficult to forget. Problems: lack of G's in turns; fuzzy visual presentation; "pendulum" effect of visual when banking; apparent drift of visual. The best way to test a warning system is in an aircraft.

S-2 (Voice): Good Motion. The visual is a little foggy (not sharp enough). Field of view is good and focus good. Instrumentation seems good; although I am rather unfamiliar with the HUD, I still like it.

S-3 (Voice): Very good. It would help to have peripheral vision. The forward air controller (FAC) doesn't really scare me; I couldn't take any evasive action so I relied on my PEN AIDS. They didn't work and I died.

S-4 (Tone): Good.

S-5 (Tone): Very good. More peripheral visual display would enhance realism.

S-6 (Voice): Very good. Needed side vision for excellent simulation of actual terrain following.

S-7 (Voice): Good, except the visual display usually was less than desirable. The display was wiggly and shifty during turns and did not give me a good feeling for height above ground.

S-8 (Voice): The lack of side vision makes it difficult to determine height above ground, especially in turns.

S-9 (Voice): Very good. With more peripheral vision -- excellent.

S-10 (Voice): I got involved. The motion and instrumentation are outstanding. Visually I had no feeling of depth perception and there is nothing to be done about the narrow field of vision.

S-11 (Voice): Great. No adverse comment.

S-12 (Voice): It's the first simulator I've ever enjoyed flying. Its realism is tops. I was completely caught up in its realism.

7. Did you feel that the simulation of the combat environment provided effective task loading with regard to stress and saturation?

S-1 (Tone): No, because when MIG of SAM calls were made there was no action required (evasive or aggressive), and ground fire is a threat which, once recognized, is too late to avoid (like lightning: once it strikes you, the thunder is no problem). What I mean is I tended to ignore the radio chatter because there was nothing I could do about it anyway. The low level turbulence was quite realistic but the simulator response was more like a bomber than a fighter at 450 knots.

S-2 (Voice): It is as effective as can be in Area B. The task of reaching the target with a fairly difficult navigation problem was the most demanding.

I have never heard the MIG threat warnings quite like in the simulator (I've been back since December 1966). They used to be called out in areas and general calls were made, not to a specific flight with a range and bearing. The idea that we were in the run was realism enough and the theatrics aided this very much.

S-3 (Voice): Not much.

S-4 (Tone): No, I'm not sure anything short of combat really can. It did as good as it could.

S-5 (Tone): Yes.

S-6 (Voice): For low level simulation small arms (approximately 23mm, etc.), tracer fire would aid the realism and saturation. Task loading in this evaluation was fair and could have used calls from the control agency that were more applicable to the fighter, i.e., bandits at 45 miles are not considered a threat. Also the bandit calls in combat are more overriding than in this study and were not called in a direct relation to any given flight (usually).

S-7 (Voice): On the first mission yes. On subsequent missions I tended to loaf.

S-8 (Voice): It's very good, but the MIG warnings have little meaning in the simulator. Good combat simulation.

S-9 (Voice): The navigation and terrain following presented tasks, but I felt the combat tape playback had little effect. I don't know how you could correct this. It's tough to get into the feel of this part of the simulation.

S-10 (Voice): No. But my combat time involved a completely different environment. It was much noisier and busy. Even peacetime low level in B-47's seemed by contrast to be busier.

S-11 (Voice): Yes.

S-12 (Voice): I more or less tuned out the voice MIG warnings. Antiaircraft fire is a real attention getter.

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13. ABSTRACT

Twelve Air Force pilots current in high performance aircraft flew a 100-nautical-mile simulated combat bomb sortie under varying task load and auditory saturation levels in order to compare voice and tone warning systems. An F-111 flight simulator, with three-degrees-of-motion and Link SMK-23 visual system, was employed as the test bed for the experiment. Task loading was induced by giving the subjects no practice on the actual mission terrain prior to the first data run, introducing combat tapes to increase auditory saturation, and displaying pressure altitude commands instead of radar altitude commands on the HUD (head up display). A noncritical emergency and an associated warning were given at three specific geographical points in the mission. Each of these geographical points represented a different task loading condition based on mission requirements. The pilot was warned by either a voice or a tone, in conjunction with an annunciator light. The voice and tone warning systems were evaluated by comparing the pilots' visual scan patterns and response times under various task load and saturation conditions. From the visual scan pattern, it was found that pilots who received tone warning were forced to cross check the Annunciator Panel when receiving the noncritical failure. The voice warning afforded the pilot the option of responding to or completely ignoring a failure based on mission requirements. In addition, in those cases where voice warned pilots chose to respond to the failure, they did so with faster response times than pilots receiving tone warning.

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