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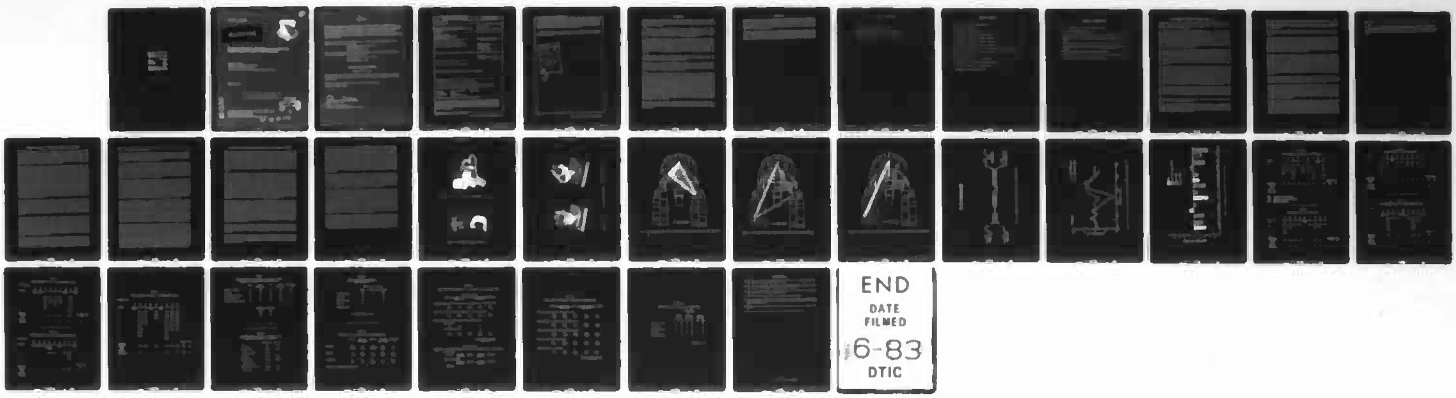

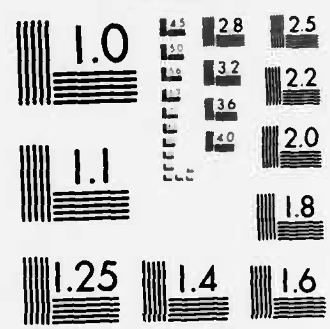

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NEUROPHYSIOLOGICAL MEASURES OF A-10 WORKLOAD DURING SIMULATED LOW ALTITUDE MISSIONS

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DECEMBER 1982

AIR FORCE AEROSPACE MEDICAL RESEARCH LABORATORY
AEROSPACE MEDICAL DIVISION
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NOTICES

TECHNICAL REVIEW AND APPROVAL

AFAMRL-TR-83-0003

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

CHARLES BATES, JR.
Chief
Human Engineering Division
Air Force Aerospace Medical Research Laboratory

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFAMRL TR-83-0003	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) NEUROPHYSIOLOGICAL MEASURES OF A-10 WORKLOAD DURING SIMULATED LOW ALTITUDE MISSIONS		5. TYPE OF REPORT & PERIOD COVERED Technical Report 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) GLENN F. WILSON* ROBERT D. O'DONNELL, Colonel LAWRENCE WILSON, Major		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS AFAMRL, Human Engineering Division, AMD, AFSC, Wright-Patterson AFB OH 45433		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62202F/7184-14-07
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE December 1982 13. NUMBER OF PAGES 34
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

workload, single trial analysis, odd ball task, oculometer, EEG, evoked response, reaction time, simulator, emergency procedures

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

Eye movements and evoked responses were used to test pilots' reactions to emergency conditions while flying simulated A-10 missions. Two types of stick jam or other minor emergencies occurred during a pull up maneuver. Oculometer and behavioral data were collected to measure the pilots' responses to these situations. Evoked responses to single tones that were presented one second after the onset of each emergency were used to assess whether or not the pilots were yet aware of the presence of the emergency.

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The oculometer data showed that the pilots very efficiently responded to the emergencies with a few appropriately directed eye movements. The correct indicators and response areas were looked at and the proper responses to correct the emergency were rapidly made. The evoked response data supported the oculometer data. Movement artifacts during the evoked response analysis epochs indicated that the pilots quickly detected the emergency situations, in many cases this happened so fast that they were moving by the time the tone probe was presented.

Subjective questionnaire data showed that the pilots ranked the jam conditions as more difficult to deal with than the minor emergencies. The pilots also felt confident that they could handle the situations that occurred.

SUMMARY

Oculometer measures, evoked brain responses and subjective questionnaires were used to measure A-10 pilots responses to simulator emergencies. These measures were taken in addition to performance data collected from the simulator. It was felt that these measures would be useful in answering questions about the speed of response to several emergencies.

Oculometric measures were used because the detectability of visual indicators was not known. Also, the oculometer provides data concerning the ease of locating the appropriate secondary indicators, as well as the pattern and duration of eye movements in response to emergencies. The oculometer provides a time history of the eye movements before and after each emergency. It was felt that these records in conjunction with reaction times would be useful in the evaluation of the pilots' procedures to the emergencies.

Evoked brain responses were used to evaluate the time required to detect and process the emergency information. The strategy used was to insert an auditory test probe one second after the onset of each emergency, and to see if the brain response could reveal whether the pilot was yet aware of the emergency. This is a novel use of brain responses. Usually, brain evoked responses are used to study the brain's processing of the information contained in the evoking stimulus. In this case, they were used to tell whether or not a pilot has detected another situation and therefore is not correctly processing the probe stimulus. This must be done on a single stimulus basis. To our knowledge, single trial procedures have not been previously attempted in the simulator environment. There is, however, a large body of laboratory studies which have used this technique in highly controlled situations.

Subjective questionnaires and post mission interviews were administered to obtain the pilot's impressions of the emergencies and their responses to them. These data provide information about the pilot's point of view which can be compared with their behavioral and physiological responses.

The simulator missions were conducted at the ASD/ENE A-10 simulator site. This is a motion based simulator with visuals from a terrain board. Twelve A-10 Tactical Air Command pilots served as subjects. The pilots were initially briefed about the missions they were to fly. They then practiced flying the simulator. During data collection, the two pilots who were currently subjects alternated flying. Each session lasted approximately one half hour. Two days were required to complete all of the testing.

The missions involved locating targets and weapons delivery. Various targets were used; most were land targets but ships in open water were also included. Three passes each at different targets were made during each mission. During one pass, one of six test conditions was presented to the subjects during the pull up following weapons delivery. The six test conditions were: hard stick jam, soft stick jam, minor emergency, hard jam and minor emergency, soft jam and minor emergency, and no emergency. The order of emergency presentation and the pass which included the emergency were randomly determined. Each emergency condition was presented twice to each pilot. In the hard stick jam condition the control stick would lock up. The pilot could not clear the jam by forcing the stick, but had to look at the emergency flight control panel to see if the left or right aileron was locked. If so, it was necessary to throw the appropriate switch to disengage the locked aileron. In the soft stick jam, the control stick would be locked but by exerting sufficient pressure on the stick the jam could be cleared. The minor emergencies were indicated by the illumination of the master caution light which is located on the upper left side of the front instrument panel. The procedure to be followed is to then look at the caution annunciator panel (CAP) which would tell him the nature of the problem, e.g., low hydraulic pressure. Then the pilot would turn off the master caution light by pushing it so that it was reset. These minor emergencies did not require further action by the pilots. To increase the pilot's workload, each jam type was also presented simultaneously with a minor emergency.

These procedures were "piggybacked" on the simulator missions. The only additional requirements were the wearing of electrodes, the post mission interviews and the wearing of the oculometer during an additional set of short missions. The procedures and results for the oculometer, evoked response and subjective data follow in separate sections.

PREFACE

This report describes the results of the project entitled: "Neurophysiological Measures of A-10 Workload During Simulated Low Altitude Missions" carried out under Project 7184. This effort was a part of the Human Factors and Life Support Working Group of the A-10 Special Review Team. The Human Factors and Life Support Working Group was directed by Lt Col Dennis Jarvis and Lt Col James Raddin. The simulator facilities of ASD/ENECC were used to conduct this project. The data in this report were collected as a part of the simulation study directed by Mr. Richard Geizelhart.

The authors gratefully acknowledge the assistance of 2nd Lt Timothy Greydanus and 1st Lt Anthony Rizzuto of the Workload and Ergonomics Branch, Air Force Aerospace Medical Research Laboratory (AFAMRL), Human Engineering Division, Wright-Patterson AFB, Ohio, for their assistance with the data collection and analysis. Operation and maintenance support was provided by Systems Research Laboratories, Inc. (SRL), 2800 Indian Ripple Road, Dayton Ohio, and special thanks are due to Mr. Timohy Heinrichs and Ms. Barbara McFawn.

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OCULOMETER PORTION OF SIMULATION EFFORT

One of the areas of concern in this study was that of pilot's gaze patterns in response to the various simulator emergency situations. It was of particular interest to know whether or not the pilots were seeing the visual indicators and whether the panels containing indicator lights and control switches are located at places in the cockpit that are readily accessible to the pilot.

A NAC model Mark IV oculometer was used to record the pilot's field of view and his point of regard within a 60° horizontal by 40° vertical area in his field of view. This instrument has been successfully used by the Army during actual helicopter flights (Simmons, 1980a and 1980b). It consists of an optical system mounted on a face mask. The mask is held in place by straps. A lens positioned in the center of the forehead is used to record the subject's field of view. A small light bulb with a "V" shaped filament is positioned beside the eye and directed so as to focus the "V" image on the subject's cornea. This image is reflected from the cornea and off of a front sufaced mirror in front of the eye. The "V" image is then optically mixed with the subject's field of view. The observer sees the "V" image move about the field of view as the subject successively changes his fixation. A video camera and video tape recorder were used to provide permanent records. The time of day, to the nearest second, was superimposed on the video record to serve as a time base.

Figure 1 is a front view of the oculometer with the fiber optic bundle and battery pack which powered the light bulb. The padding of the face mask and the straps which support the mask were modified to provide greater stability and comfort. Figure 2 shows the padding in the face mask, the modified version is on the left. Figure 3 shows the modified (left) and normal straps used to hold the oculometer on the head. These modifications are similar to those reported by Simmons, Kimball and Diaz (1976). They greatly increased the stability of the oculometer on the head. In its normal configuration, head movement caused the mask to move with an accompanying loss of eye position accuracy. The mask padding helped with the stabilization as well as increasing the comfort to the wearer. Better distribution of the weight was achieved which reduced hot spots and pressure points.

By having the pilots fixate upon a known instrument, the ADI, before and after data collection, it was possible to adjust for any errors due to oculometer movements. The front surfaced mirrors on the oculometer reduced the pilot's vision to a level where flying over hilly terrain was difficult. For this reason the oculometer trials were run separately from the other trials. The targets were all ships in an ocean setting so that they were easy to detect and did not require terrain avoidance manuevers. The six conditions used in the oculometer trials were the same as those in the other missions. They were hard jam alone, hard jam plus master caution light, soft jam alone, soft jam plus master caution light, master caution light alone and no emergency at all. The entire mission of six targets was video taped, the records from 30 seconds prior to the occurrence of the emergency to 60 seconds after the emergency were analyzed. This provided for baseline data and included the times of detection, processing and response to the emergency. Oculometer data were collected from ten of the twelve pilots. Due to difficulties in obtaining a clear image of the "V", data from one of the ten pilots were not usable.

Each pilot had a more or less unique pattern of eye movements while flying. Their responses to the emergencies were, however, fairly uniform. Table I provides a summary of their eye movements to the master caution light alone condition. The top row lists what each pilot was looking at prior to the illumination of the master caution light. Each row below that lists successive instruments that each pilot looked at until the master caution light was reset. As can be seen in the table, all pilots looked at the master caution light immediately, the row labeled 1.

The location of the master caution light and the fact that it is a visual mode indicator are no doubt responsible for the pilot's rapid eye orientation in response to its onset.

Since this indicator represents relatively minor problems, several more instruments are looked at before the master caution light is reset. The caution annunciator panel (CAP) was looked at by five of the pilots prior to resetting the master caution light. The remaining three pilots looked at the CAP immediately after resetting the light. This is the proper procedure since the CAP tells the pilot which one of several possible malfunctions caused the illumination of the master caution light.

The master caution light is reset by depressing the light itself. Resetting the light readies it for the next occurrence of an appropriate malfunction. The mean number of fixations between the light onset and its resetting was 3.6 fixations with a mean reaction time of 3.2 seconds. Figure 4 illustrates this pattern of movements for all of the pilots. As can be seen in the figure, several areas are looked at prior to resetting the master caution light.

The eye movements for the jam conditions show that a jam is reacted to differently than a master caution light. A jam is an imperative situation that must be quickly corrected. Table 2 lists the eye movements for the soft jam condition.

The onset of the jam conditions is taken as the point where the pilot excerted 20 pounds of force on the control stick. Comparison with Table 1 shows that fewer fixations occurred between emergency onset and resolution in the soft jam condition. A mean of 1.7 fewer fixations was used in the soft jam condition, and the time to respond to the emergency was 0.7 seconds faster. The jams were cleared with a mean of only 1.9 fixations and in a mean reaction time of 2.5 seconds Figure 5 graphically illustrates that fewer fixations were used by the pilots than in the master caution light only condition Note that the emergency flight control panel was frequently looked at even in this clearable jam situation. The presence of a light on the emergency panel indicates a hard jam in the controls for either the right or left aileron. The aileron disengage switches are also located on this panel. The pilots probably look at this panel in the soft jam condition to confirm that the jam was indeed a soft jam since the indicator light did not come on.

The hard jams were also quickly tended to with a mean of 2.0 fixations in 3.6 seconds (Table 3). The emergency flight panel was referred to by all of the pilots prior to disengaging the aileron. This was a necessary action since the panel is located to the pilot's left, out of his normal field of view, and contains both the jam indicator light and the aileron disengage switch. The location of the emergency flight panel did not seem to be a problem for any of the pilots since they quickly oriented to it and disengaged the ailerons with the switch. The reaction times to disengage were only 1.1 seconds longer than to clear the soft jam which involves only forcing past the jam. The same mean number of eye movements were needed in both conditions, 2.0 vs 1.9 fixations. The similarity in reaction times and eye movements for the two different jams demonstrates that the jams are treated with the highest priority and responded to quickly. The response times seem to be about as fast as a pilot could respond given the layout of the cockpit and the physical actions necessary to respond. Another factor contributing to the similar times and fixations is that they look at the emergency control panel in the soft jams to confirm the nature of the jam.

In those conditions which contained both a stick jam and a master caution light, the jam was quickly taken care of and the master caution light was later reset (Tables 4, 5, 6, and 7). There were more than twice as many fixations prior to resetting the master caution light than to correcting the jam (5.6 vs 2.1). The jams were taken care of in about half the time it took to reset the master caution light (3.4 sec vs. 6.6 sec).

Comparison of the response times, when the jams were presented alone with those trials when they were combined with the master caution light, shows that the times were essentially equal (3.3 sec vs. 3.4 sec). The number of eye fixations in these two situations were also very close (1.7 vs. 2.5). However, the response times to reset the master caution light were quite different in the two situations: master caution alone vs master caution with a control jam. The times doubled for the conditions which included the jams (6.6 sec vs. 3.2 sec). The number of eye movements also increased from 3.6 to 5.6 fixations. The occurrence of a hard or soft jam, either alone or in combination with a master caution light, causes an immediate corrective action. Master caution light situations are responded to with much less speed.

There were no differences in the oculometer data for those trials that resulted in ejection or crash. The small number of ejections and crashes (four) make any interpretation difficult. These four episodes comprise 8.8% of the oculometer missions while 22.5% of the nonoculometer missions resulted in an ejection or crash. The smaller number of ejections and crashes in the oculometer trials is due to several factors. The most important factor is that all of these missions were flown over water while the majority of the nonoculometer conditions were flown over hilly terrain which is more difficult to navigate. The oculometer trials also benefited from the previous simulator experience gained during the nonoculometer trials. The reaction times in the oculometer and nonoculometer trials are essentially identical, demonstrating that the pilots overall performance was the same in both situations. A summary of the oculometer trials, reaction times, and ejection-crash data is presented in Table 8.

The oculometer data conclusively show that jams are quickly taken care of in a very efficient manner. Few, if any, eye movements are wasted when responding to the stick jams. The location of the emergency flight control panel does not interfer with the rapid and appropriate corrective actions that were taken by the pilots. The master caution light is located in a position that is readily noticeable to pilots in the conditions of the simulator trials.

EVOKED POTENTIAL PORTION OF SIMULATION EFFORT

The time taken to recognize the occurrence of an emergency situation is an important factor in the rapid response to that situation. In order to assess the time taken to become aware of an emergency, auditory evoked potentials were used as a measure of brain activity. While this technique has not been previously used in actual simulator missions to solve a real world problem, it is supported by a body of laboratory research that suggests its utility to the current situation. (Isreal, et al, 1980a and 1980b; see Pitchard, 1980 for a recent review). In the present situation, with A-10 emergencies, evoked potentials were applied to a predefined set of parameters in a nonlaboratory setting. While the use of evoked potentials is more experimental than the oculometer procedures, they nevertheless seem to have an application to the current problem.

The actual time of recognition of external events is difficult to estimate from ongoing brain activity. This is especially true if there is no specific point in time which marks the onset of the eliciting event. This is the case with the jam conditions and, to a lesser extent, the master caution conditions. Across pilots it is difficult to determine at what point they actually become aware of the existence of the jam. If the pilot is busy looking out of the windscreen, he may not see the master caution light until some time after it comes on. The strategy used in this effort was to establish a time by which a pilot should have realized that the emergency existed so that he would have time to respond appropriately. It was decided, after consultation with a simulator personnel, that pilots should be aware of an emergency by at least one second after its onset. That is, in order to evaluate the problem and have time to respond appropriately, the pilot should be aware of the problem at least one second after its onset. To test for pilot awareness of the emergency condition, their brain response to a single tone was measured. The tone was presented over the pilot's headset one second after the onset of the master caution light or after 20 pounds of force had been exerted on the control stick in the jam conditions. Prior to engaging in the simulator flights, each pilot listened to a series of tones so that a template could be made of their normal response to these stimuli. Then his brain's response to a single tone presented one second after the beginning of an emergency could be compared to the template. If the brain's response during the emergency looked like the template, one could assume that the pilot was not yet aware of the emergency since he had heard the tone and processed it normally. On the other hand, if the response was absent or did not fit the template, then one could conclude that the pilot was aware of the emergency and ignored or did not hear the tone. See Figure 7 for a graphic representation of this strategy.

The so called "oddball" paradigm was used to elicit the brain evoked responses (ER) (Duncan-Johnson and Donchin, 1977). Tones of two different frequencies are presented to the subject, one having a probability of occurrence of 80%, the other having a probability of occurrence of 20%. Approximately 100 trials are presented, and the subject is asked to silently count the number of occurrences of the low probability tone. The ER is recorded to each of the high and low probability tones and these are separately averaged to produce two ERs, one to the high probability events and one to the low probability events. A reliable difference between these two averages appears as an enhanced amplitude to the low probability tones in a positive going component of the ER that occurs approximately 300 msec. after the stimulus onset (P3). Figure 8 presents a representative example of these ERs.

A statistical procedure, stepwise discriminant analysis, is used to determine the time points which best discriminate between the two averages. Six time points are normally sufficient for this purpose. With this information the subject's ER to a single tone can be classified as having been elicited by either a high or a low probability stimulus. During the emergency situations only low probability tones were presented to the subjects. On the basis of whether or not the ER was classified as a low probability tone, an estimate was made of whether or not the pilot heard the tone and correctly processed it during the emergency situations and the ingress periods prior to each emergency. If the ER to the single tone is classified as being elicited by a low probability tone, then one can assume that the information was processed correctly and the pilot was not yet aware of the emergency. If the single tone ER is classified as a high probability ER, then one can assume that it may have been misclassified because the pilot was aware of the emergency and was busy responding to the emergency situation and did not "hear" the tone.

In order to record the pilots' brain waves (EEG), electrodes were attached to the scalp over the parietal (Pz) area. An electrode was also attached over the right eye to monitor eye movements (EOG) which can cause artifacts in the EEG. Both of these electrodes were referenced to an electrode attached on one mastoid process, an electrode on the other mastoid served as a ground electrode. All interelectrode resistances were 5K ohms or less. Grass Model P511 amplifiers and a Vetter Model A FM tape recorder were used to amplify and record the EEG, EOG and pulses corresponding to the occurrence of each tone. A Pearl II computer digitized the EEG starting 150 msec prior to each tone, and for 850 msec following each tone, this information was stored on digital tape. The data on the digital tape were analyzed off line.

Prior to each half day's series of missions, each pilot was presented with approximately 100 tones, 80% high probability tones, 20% low probability tones. They were asked to covertly count the number of low probability tones and report the total at the end of stimulus presentation. This provided the training set of ER's which were used to classify the emergency ERs. Once this was completed, the simulator missions were conducted. ERs were recorded during the nonoculometer and the oculometer missions.

One of the first factors that became evident during data analysis was the large number of trials containing artifacts in the emergency data. The ER's during the emergency situations contained 48.6% artifact trials while only 16.1% of the ingress trials contained artifacts. The artifacts were primarily EOG, muscle and amplifier blocking. These artifacts are associated with eye, head and body movements. The very large percentage of artifact trials in the emergency situations implies that the pilots were already taking action to correct the emergency at the time that the data were sampled. A portion of these artifacts may be due to the pull up situation itself since 30.5% of the pull up only trials contained artifacts. In the pull up only trials, a tone was presented at the time an emergency would have occurred even though it was a nonemergency trial. The remaining artifacts are probably associated with the emergencies.

EEG data from eleven of the pilots were used to analyze the effects of the emergency situations. The data from one subject contained too many artifact trials to permit analysis. Further, the data from only three subjects met the rigid criteria of 80% classification of nonused regular trials. That is, all 20 of the low probability trials and 20 of the 80 high probability trials are used to derive the discriminant scores that are used to classify the single trial ERs. A test of the ability of a subject's ERs to discriminate between high and low probability trials is to classify the remaining 60 high probability ERs. A criteria of 80% classification is usually used. The data from only three pilots were correctly classified at this level. The others ranged from 52% to 70% correct classification of the extra high probability trials. This means that 8 of the 11 pilots having acceptable EEGs did not have ERs which could be readily discriminated and classified. Due to the similarity of their ERs to the low and high probability stimuli, it is difficult to classify their ERs to single trials as belonging to one or the other category. This factor is no doubt partially responsible for the low discriminate scores of the emergency condition data.

A repeated measures analysis of variance was used to test for statistically significant differences between the discriminant scores among the emergency conditions. This test showed that there were no statistically significant differences. Table 9 contains the mean disriminant scores for the emergency conditions and the ingress conditions preceding each emergency condition, see Fig. 9 also. An analysis of variance was also performed on the ingress and emergency data. No significant differences were found. The ERs to low probability tones were not significantly different when compared across emergency conditions, or when compared with the ingress portion of each mission. It is possible that flying the simulator, whether during ingress, pull up or emergency, is so demanding on the pilot that the low probability tone is processed much differently than when the pilots are sitting in the cockpit and only listening to the tones. Stated in other words, the workload associated with the ingress portions of normal low altitude simulator flights is high enough that the effect on P3 of a low probability tone is lost. This must remain only speculation at this time since only three of the eleven subjects had good enough ERs to be easily discriminated. The above statistical tests were performed on these three pilots' data with the same results. However, with so few pilots one is not surprised at the lack of statistical significance.

To summarize the evoked response results, it seems that they did not add information beyond that provided by the oculometer and reaction time data. The large proportion of artifact trials, 48.6%; indicates that by one second after the onset of the emergencies the pilots were already aware of the emergency and were in the process of collecting further information by moving their eyes and heads to look at the various indicators. Some of the artifacts in the jam conditions may have been caused by body movements associated with trying to force the stick past the jam. The overall similarity of the discriminate scores in the emergency and ingress portions of the missions indicates that the ER (P3) was not able to discriminate between situations involving low to high workload. However, it must be remembered that only three of the 11 pilots had ERs that met the discriminability criteria of 80% classification of the extra high probability trials. The reason for such a low percentage of acceptable subjects is unclear. Had it been possible to quickly analyze the data, it would have been possible to repeat the sessions in which the training ERs were collected and thereby possibly obtain better data to use in the discrimination functions. It is worth noting that technically good EEG and ERs were collected in the A-10 simulator. This is significant because of the numerous sources of electrical and mechanical artifacts that are present in the simulator environment. Further use of ERs with simulated missions is certainly indicated.

SUBJECTIVE QUESTIONNAIRE PORTION OF SIMULATION EFFORT

In addition to the oculometer and evoked response data, two brief questionnaires were given to the pilots, after each pair of nonoculometer trials. The purpose of the questionnaires was to provide data regarding the pilots' subjective estimates of the levels of difficulty of the various emergency conditions, their recall of the information that they used to respond to the emergency situations and to provide an estimate of the relative importance that three factors contributed to the outcome of each emergency. It is worth noting that, for the nonoculometer trials, each of the four conditions which included a stick jam resulted in approximately the same number of ejections and crashes. The hard jam condition yielded four (16%), the hard jam plus emergency produced six (25%), the soft jams resulted in seven (29%), the soft jam plus emergency was associated with five (20%) while there were no crashes in the emergency only condition. No one condition clearly stands out from the rest in terms of ejections and crashes. There was no significant statistical relationship between the incidence of ejection-crashes and A-10 flying hours, total flying hours, combat experience, whether or not a pilot had been a flying instructor, or age of the pilot.

After the pilots had completed all of their missions, they were asked to rank the difficulty of each of the emergency conditions that they had encountered. Tied ranks were permitted, that is, they could rank two or more situations as being the most difficult, or the easiest, etc. Table 10 summarizes the resultant rankings and shows that the hard jam plus emergency was ranked as most difficult by all of the ten pilots who performed rankings. The hard jam alone condition was ranked second receiving "hardest" rankings from one half of the pilots. The soft jam conditions were ranked below the hard jams in difficulty while the emergency only condition was ranked as having lowest difficulty. The low difficulty level accorded the emergency condition certainly corresponds to the oculometer and reaction time data which showed that jams were rapidly taken care of while master caution light emergencies were attended to when time permitted. The two types of jams, hard and soft, were ranked as much more difficult than the emergency only condition. The hard jams were seen as more difficult probably because of the more serious nature and the added procedures of looking at the emergency control panel to determine the nature of the jam, which control surface to disengage, and actuating the toggle switch to disengage the aileron. The pilots also knew that the aircraft would fly differently with one aileron disengaged, but it would respond normally after a soft jam had been cleared. There was a high degree of correspondence between the rankings of the ten subjects, coefficient of concordance of 0.84.

The pilots were also asked to complete a short questionnaire concerning the important indicators and their responses to them for each emergency condition. These were completed immediately after each pair of emergency situations while the experience was still fresh in their memories. One group of questions concerned the sensory modality which provided the first indication of the problem. Table 11 shows that the hard jam and soft jam conditions were first indicated by tactual cues from the stick (100%). The first indicators of hard jam plus emergency and soft jam plus emergency was tactual in 79% and 83% of the cases, respectively. The reason that these latter two conditions were not all first indicated by tactual cues is because the master caution light onset may have preceded the awareness of the stick jams by several seconds. This is because the master caution light came on immediately after being set by the simulator operator while the pilot had to move the stick in order to become aware of the fact that it was jammed. Several seconds could elapse between the setting of the jam and the pilots' next stick movement. This also explains the large number of first indicators attributed to visual cues in the same conditions. The emergency only condition was always remembered as being first indicated by a visual cue, the master caution light.

A second set of questions concerned whether or not the pilot had any question about what the malfunction was after having only the first indicator and how many further indicators were necessary. Table 12 shows the pilots had questions about the exact type of malfunction on approximately 25% of the emergency trials. That is, 75% of the time the pilots had no question about what the malfunction was but there were doubts on the remaining 25% of the trials.

A second question asked if further indicators were necessary for adequate malfunction recognition. These were necessary to either correctly identify or pinpoint the exact nature of the malfunction. For example, an immobile control stick is indicative of either a nonbreakable hard jam, or breakable soft jam. Further, the master caution light only indicates that a minor malfunction exists; the caution annunciator panel must be consulted to ascertain the exact problem.

The table shows that between 63% and 71% of the missions required a further indicator for adequate malfunction recognition. Soft jams, however, required slightly fewer further indicators, 54% of the trials. This difference is expanded when one looks at the number of pilots responding to the question about how many further indicators were needed to take corrective action. The soft jam alone had only 33% of the trials requiring more indicators compared to 71% for the hard jam conditions and 50% for the soft jam plus emergency condition. This corresponds to the data collected during the separate oculometer trials in which the pilots looked at the appropriate panel 100% of the trials except during the soft jam conditions. There are at least two interesting observations to be made from these data. On 25% of the emergency trials, there was doubt on the part of the pilots as to the exact nature of the problem. These were fairly evenly distributed across all of the various situations. Second, the pilots reported needing fewer cues to ascertain the nature of the soft jam condition than the others. However, on 63% of the trials they looked at the emergency control panel during the soft jam trials even though only 33% of them said that they needed at least one additional indicator. The soft jam is clearable without looking at or manipulating anything on the emergency control panel. Apparently the pilots checked the panel to be sure that it was a soft jam even though they should know by the feel of the control stick that the jam has been cleared.

Table 13 summarizes the pilots' responses to questions related to their evaluation of the emergencies and their strategies for solution. The jam conditions were seen as critical but for the most part controllable. All of the pilots had an immediate plan for corrective action; this would seem to speak well for their training. It should be noted that the number of ejections or crashes compliments the trials in which the pilots felt that the malfunction wasn't controllable. That is, 19 out of 24 trials for the hard jam condition were seen as controllable while 5 were seen as not controllable by the pilots. Four of the not controllable hard jam conditions resulted in an ejection or a crash. It must be remembered, however, that the questionnaires were taken after the missions and the pilots already knew the outcome. This may have influenced their answers to these questions.

Another questionnaire was administered which attempted to measure pilot's opinion about the amount of influence that three factors played on the time taken to interpret each emergency situation and to derive a plan of action. A six point Likert type scale was used. The three factors were: pilot's ability, design characteristics of the aircraft, and the mission situation that they were in at the immediate time of the emergency. The mission situation included airspeed, attitude, altitude and threat. Table 14 presents the number of trials in which a pilot scored a factor at least one standard deviation above the mean for the entire group of pilots for that condition. As can be seen from the table, the mean percentage of trials in this category is 10% for pilot's ability, 19% for aircraft design characteristics and 26% for mission situation (excluding the emergency only condition). These data indicate that the most important subjective characteristics that influenced the time taken to interpret the type of malfunction and arrive at a plan of action was the actual mission situation, followed by the design characteristics of the aircraft. Least important was the pilot's ability. The pilots seemed to feel that they could get themselves out of most situations. However, there was a tendency to feel that the mission situation and aircraft characteristic were capable of getting them into dangerous situations. Due to the relatively small number of data points, these results should be viewed as only suggestive.

In summary, the subjective data show that the pilots rank the jam conditions as most difficult to deal with. The hard jams were more difficult than the soft jams and the addition of the master caution light emergency slightly increased the difficulty. They felt that they knew the nature of an emergency after the first indicator 75% of the time. They used further indicators to substantiate their first impression. The soft jam alone was remembered as requiring fewer secondary indicators even though the oculometer data showed the use of the secondary indicators to actually be larger. The pilots quickly arrived at a corrective plan of action that was effective in most cases. They felt that they could handle most situations and indicated a tendency to feel that particular mission situations and aircraft characteristics would be responsible for other hard to handle situations.

Figure 1. NAC oculometer with fiber optic bundle and camera connector.

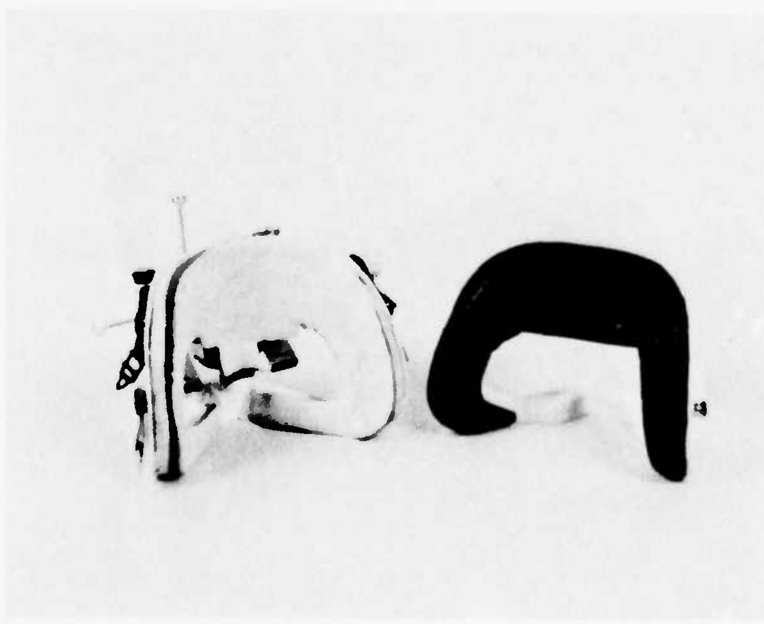

Figure 2. Face mask padding, modified version on left.

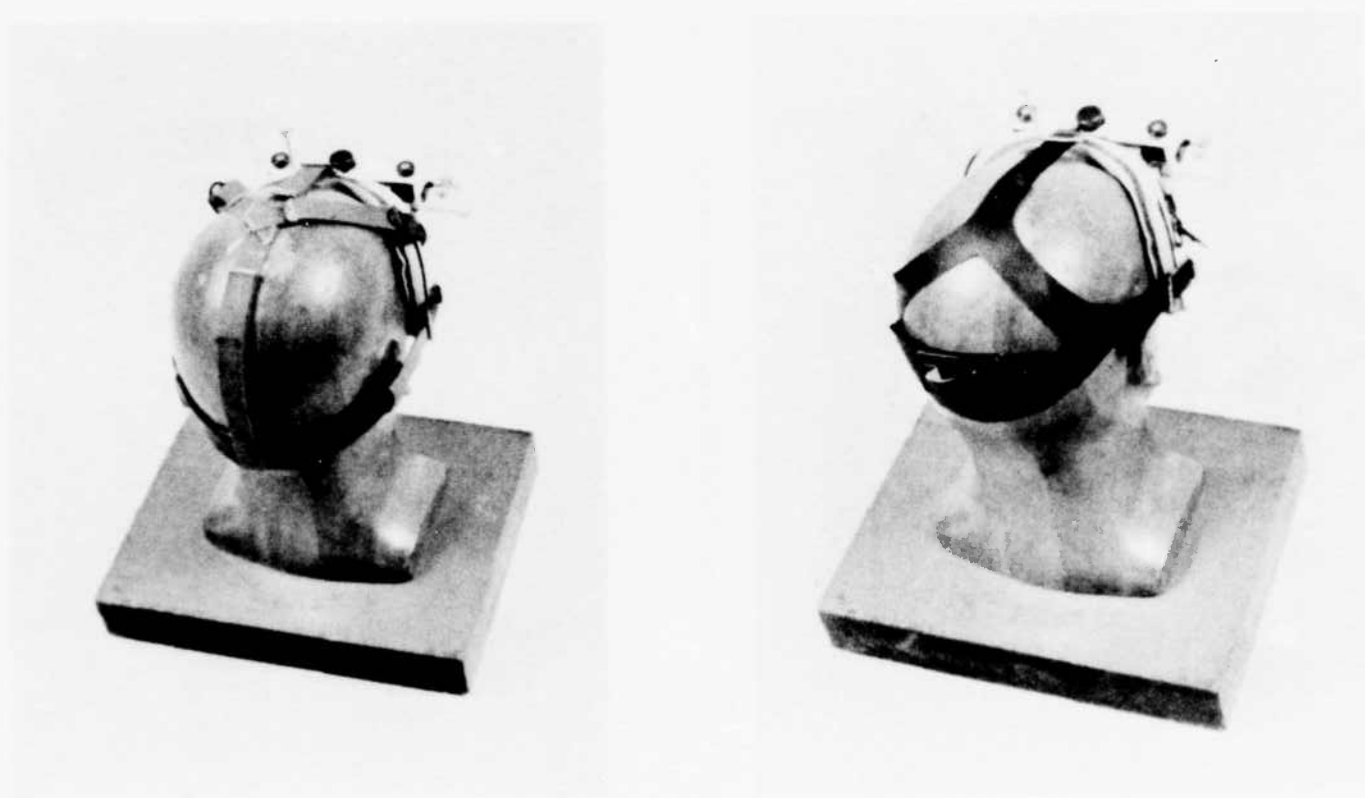

Figure 3. Securing straps used to hold the oculometer in position. The modified straps are on the left.

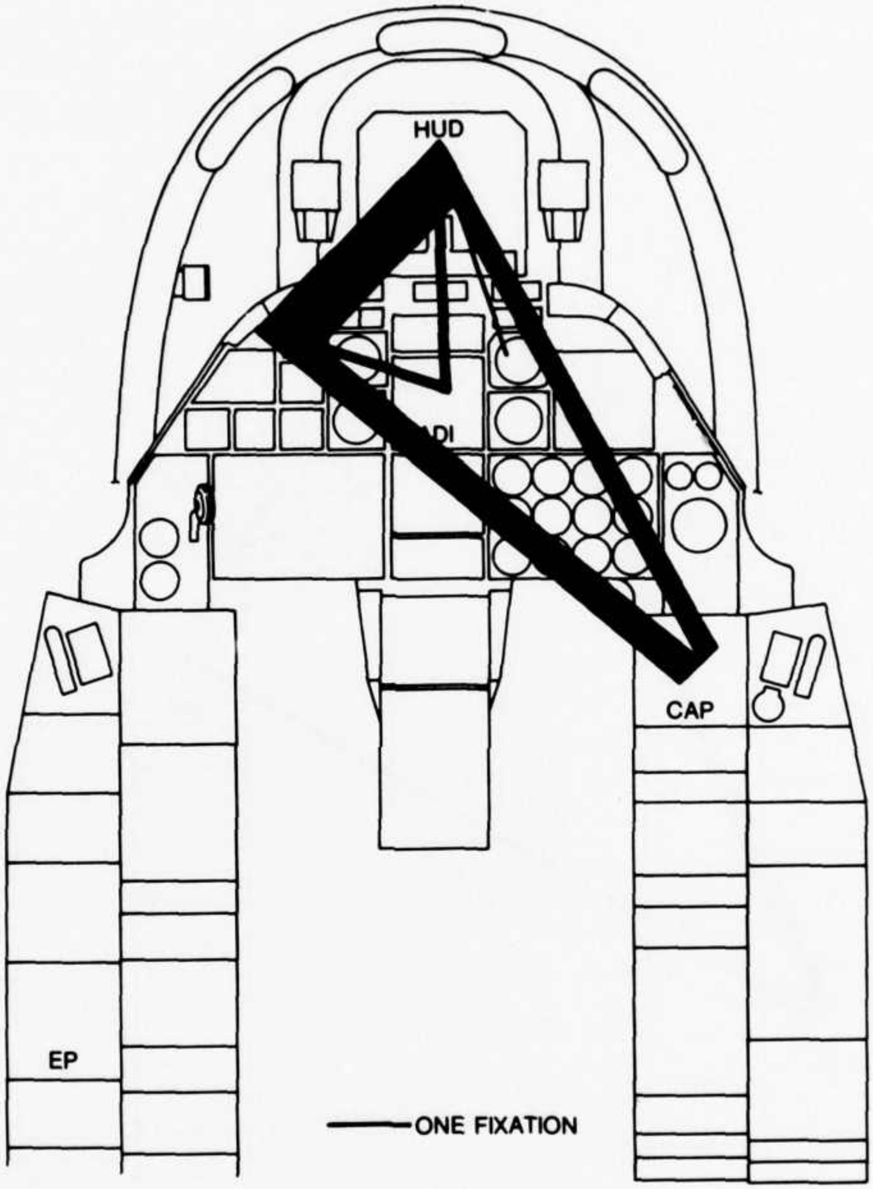

Figure 4. Eye movements made to master caution light emergencies between light onset and its being reset.

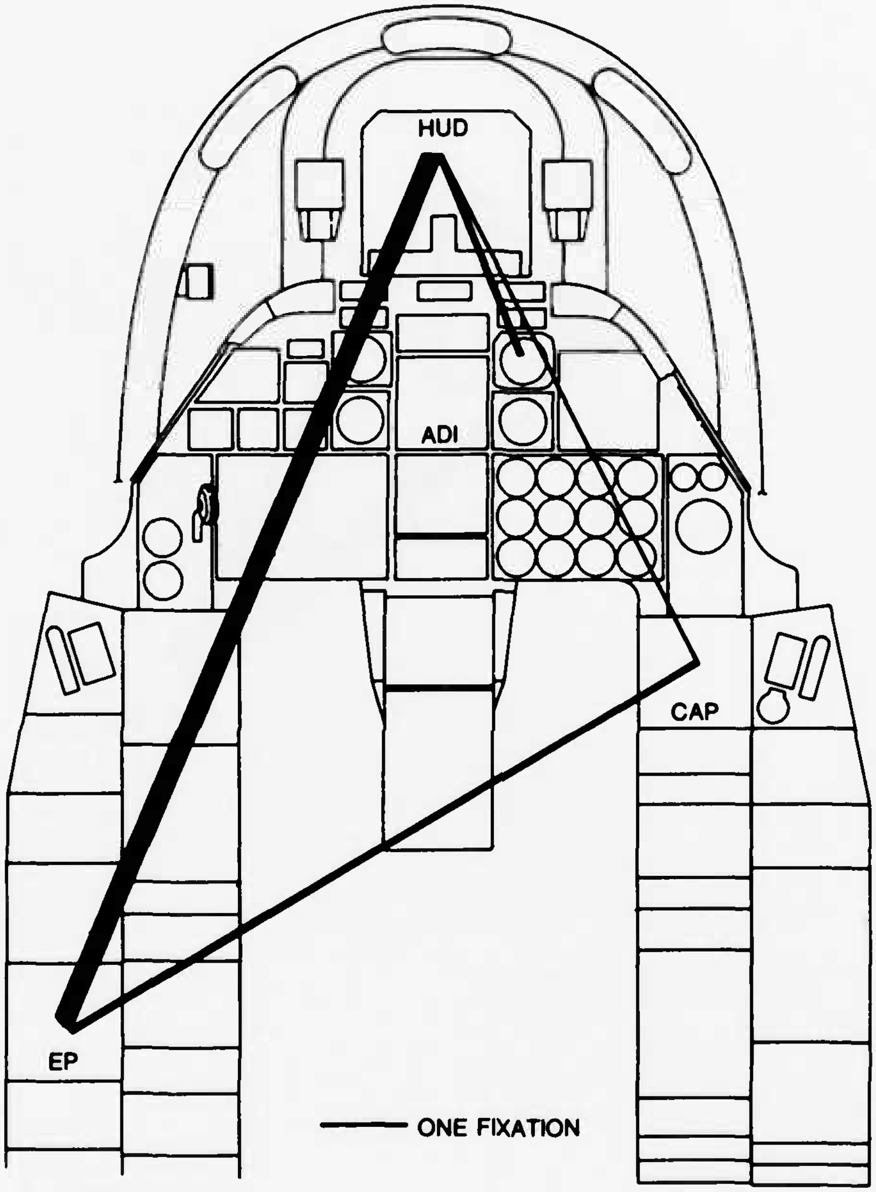

Figure 5. Eye movements made during soft jams between jam detection and its being cleared.

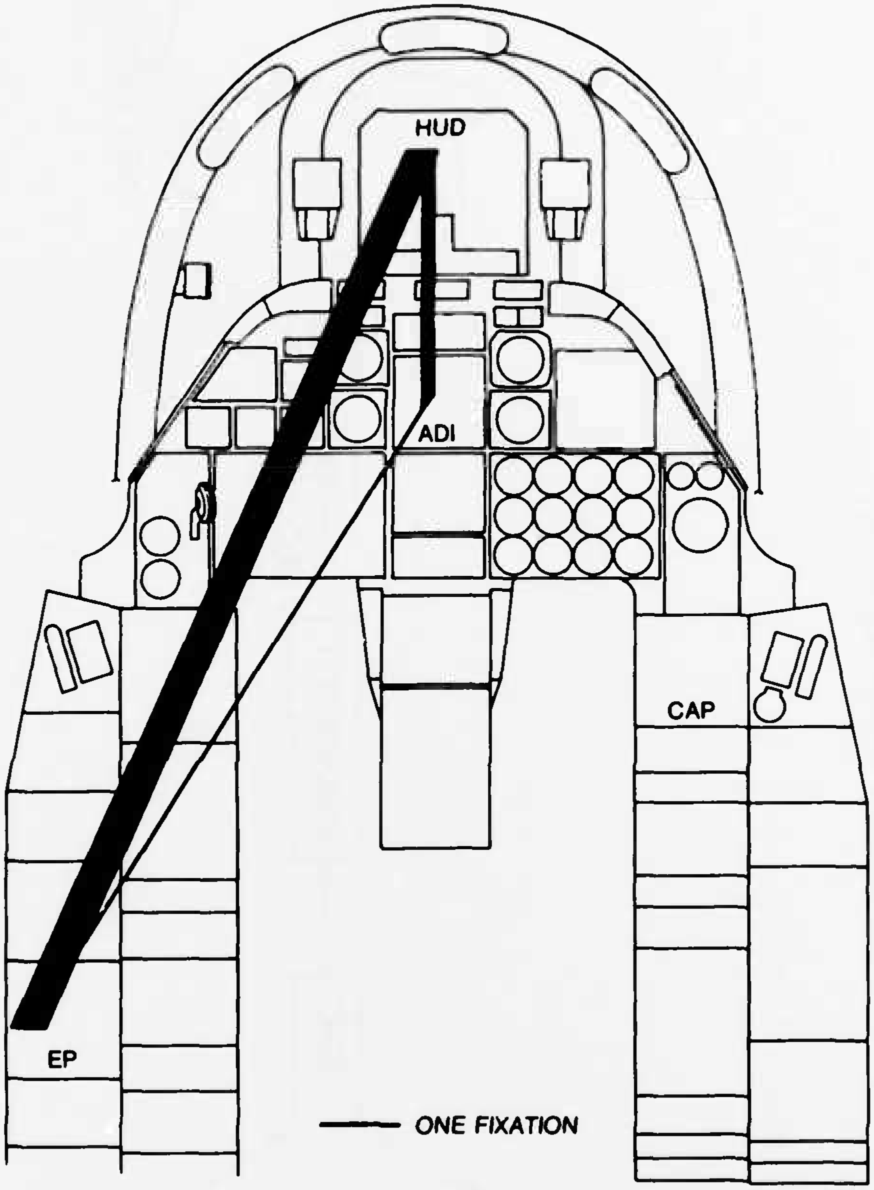

Figure 6. Eye movements made to hard jams between jam detection and disengaging of the jammed aileron.

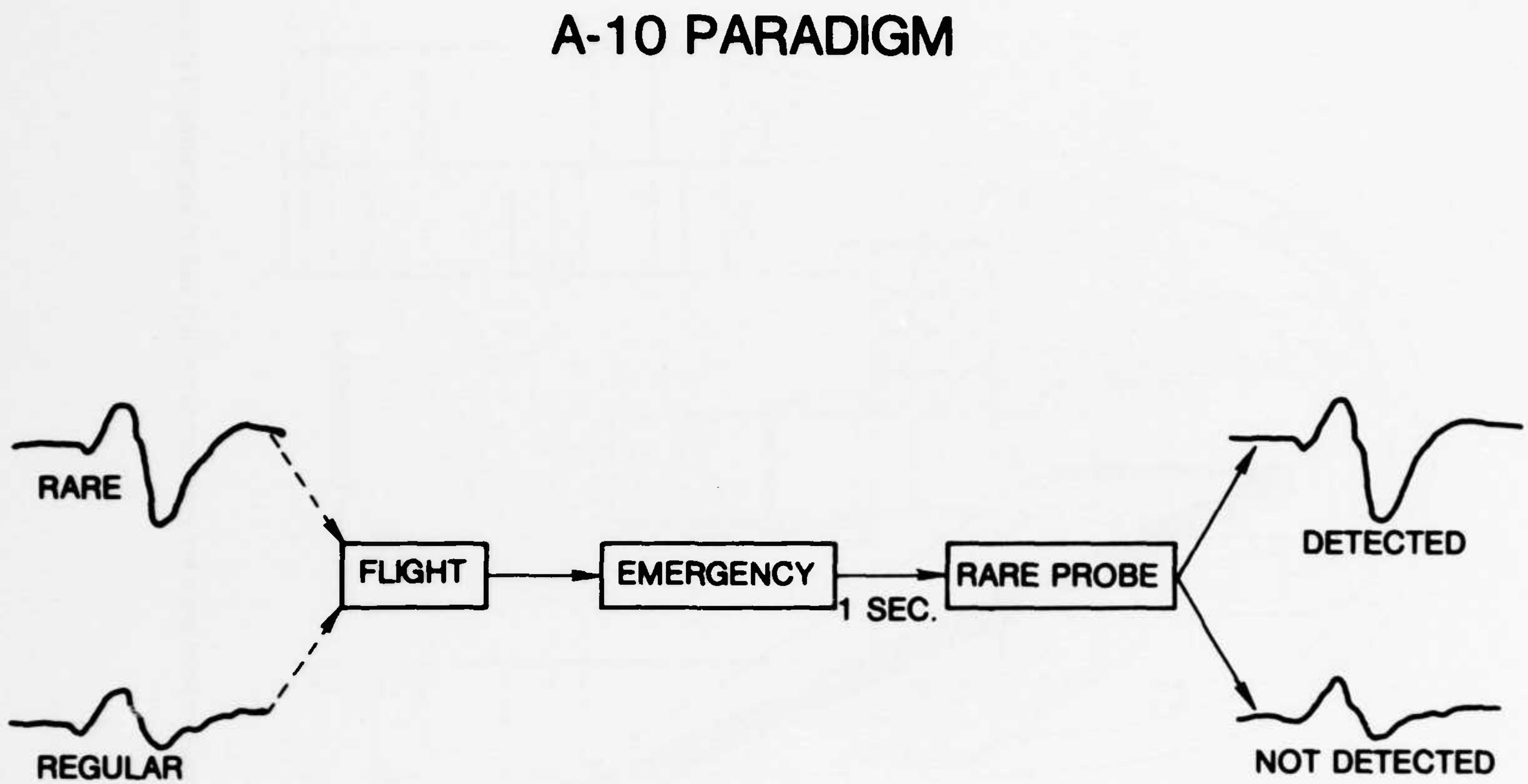

Figure 7. Paradigm used for evoked potential portion of simulation effort.

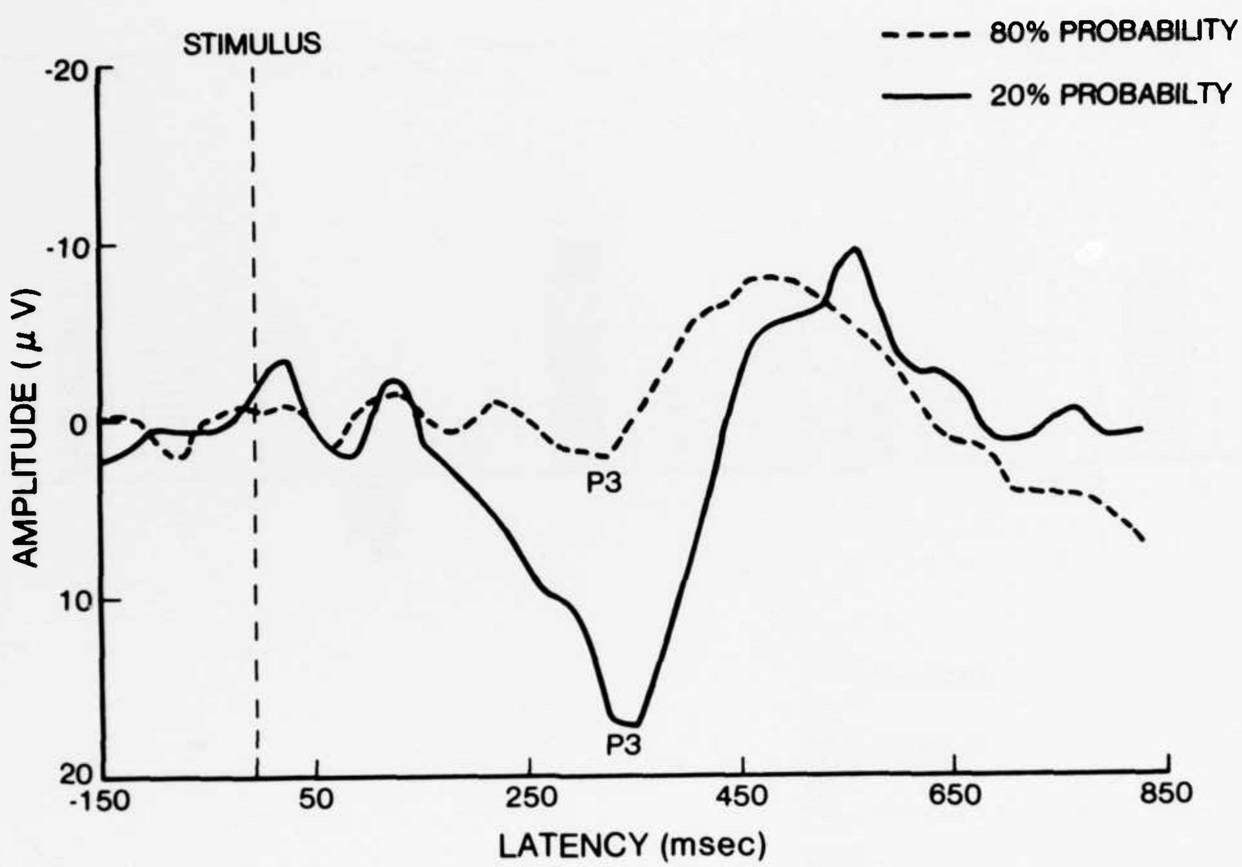

Figure 8. Evoked responses from one subject showing enhanced P3 component to low probability tones.

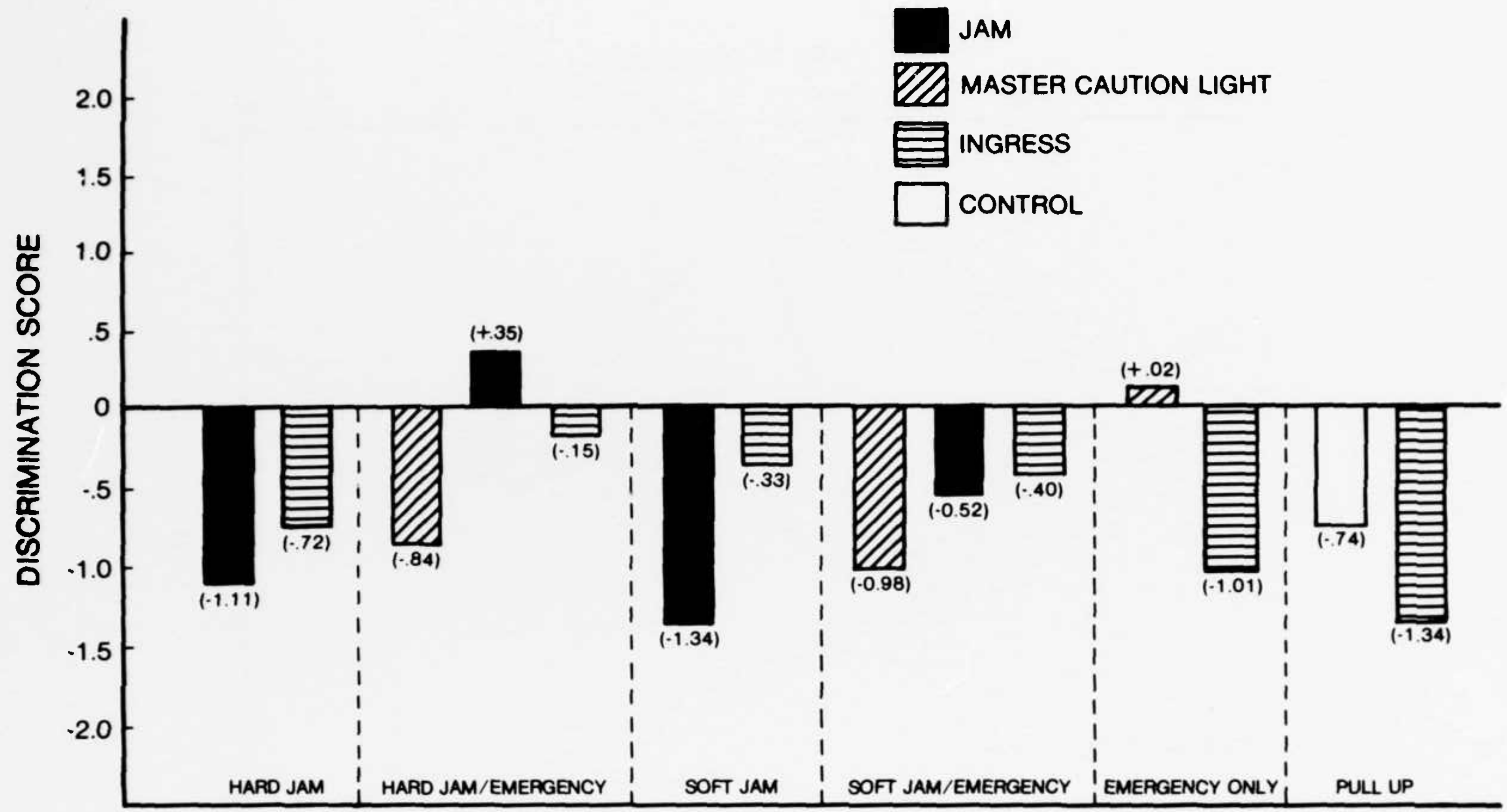

Figure 9. Discriminant scores for the emergency and pull up conditions.

TABLE 1.

EYE MOVEMENTS FOR MASTER CAUTION LIGHT ONLY

	1	3	4	5	6	7	8	11	12	MEANS	S.D.
ONSET	HUD	HUD	HUD	HUD	ADI	HUD	HUD	NO DATA	HUD		
1	MC	MC	MC	MC	MC	MC	MC		MC		
2	CAP	CAP	HUD		CAP	HUD	HUD		HUD		
3	MC	MC	CAP		MC	MC	MC		CAP		
4	HUD		HUD				HUD		HUD		
5			MC				MC		MC		
REACTION TIMES (SEC.)	2.8	2.6	5.6	1.6	1.8	3.2	3.4		4.6	3.2	1.3
NUMBER OF FIXATIONS	4	3	5	1	3	3	5		5	3.6	1.4

ADI - Attitude Director Indicator
CAP - Caution Annunciator Panel
E.P. - Emergency Flight Control Panel
HUD - Heads Up Display
MC - Master Caution Light

TABLE 2.

EYE MOVEMENTS FOR SOFT JAM ONLY

	1	3	4	5	6	7	8	11	12	MEANS	S.D
ONSET	HUD	HUD	HUD	HUD	NO DATA	HUD	HUD	HUD	HUD		
1	E.P.	E.P.	HUD	E.P.		HUD	HUD	CAP	HUD		
2	HUD	HUD					E.P.	E.P.			
3	ALT										
4	HUD										
5											
REACTION TIMES (SEC.)	2.8	2.6	2.6	1.0			4.0	2.0		2.5	1.0
NUMBER OF FIXATIONS	4	2	2	1		1	2	2	1	1.9	1.0

TABLE 3.

EYE MOVEMENTS FOR HARD JAMS ONLY

	1	3	4	5	6	7	8	11	12		
ONSET	HUD	HUD	NO DATA	HUD	ADI	HUD	HUD	ADI	HUD		
1	E.P.	E.P.		E.P.	E.P.	HUD	HUD	HUD	HUD		
2	HUD	MC				E.P.	E.P.	E.P.	E.P.		
3	ADI										
4	HUD										
5											
										MEANS	**S.D.**
REACTION TIMES (SEC.)	4.2	2.6		1.4	1.3	2.6	6.8	1.4	8.2	3.6	2.7
NUMBER OF FIXATIONS	4	2		1	1	2	2	2	2	2.0	.9

TABLE 4.

EYE MOVEMENTS FOR SOFT JAMS WITH EMERGENCIES

Soft Jams

	1	3	4	5	6	7	8	11	12		
ONSET	NO DATA	MC	HUD	HUD	NO DATA	MC	MC	CAP	NO DATA		
1		HUD	HUD	E.P.		HUD	CAP	E.P.			
2		MC					HUD	HUD			
3		HUD					MC				
4		E.P.					HUD				
5		HUD					E.P.				
										MEANS	S.D.
REACTION TIMES (SEC.)		4.4		1.0			5.4	2.6		3.4	1.7
NUMBER OF FIXATIONS		5	1	1		1	5	2		2.5	2.0

TABLE 5.

EYE MOVEMENTS FOR SOFT JAMS WITH EMERGENCIES

Emergencies	1	3	4	5	6	7	8	11	12		
ONSET	NO DATA	NO DATA	HUD	HUD	HUD	HUD	NO DATA	ALT	NO DATA		
1			ADI	E.P.	MC	MC		HUD			
2			HUD	HUD	CAP	HUD		MC			
3			MC	MC	ADI	CAP		CAP			
4			CAP		MC			E.P.			
5			MC					HUD			
6								MC			
										MEANS	S.D.
REACTION TIMES (SEC.)			7.0	2.0	2.0	6.4		8.8		5.2	3.1
NUMBER OF FIXATIONS			6	3	4	3		6		4.4	1.5

TABLE 6.

EYE MOVEMENTS FOR HARD JAMS WITH EMERGENCIES

Hard Jams	1	3	4	5	6	7	8	11	12		
ONSET	NO DATA	NO DATA	NO DATA	PILOT ANTICI-PATED	ADI	NO DATA	HUD	MC	NO DATA		
1				JAM	E.P.		E.P.	CAP			
2								HUD			
3								E.P.			
4											
5										MEANS	S.D.
REACTION TIMES (SEC.)					1.2		5.0	3.6		3.3	1.9
NUMBER OF FIXATIONS					1		1	3		1.7	1.2

TABLE 7.

EYE MOVEMENTS FOR HARD JAMS WITH EMERGENCIES

Emergencies	1	3	4	5	6	7	8	11	12	MEANS	S.D.
ONSET	NO DATA	HUD	HUD	NO DATA	ADI	NO DATA	HUD	ADI	HUD		
1		ADI	MC		MC		MC	HUD	MC		
2		HUD	CAP		CAP		CAP	MC	HUD		
3		MC	E.I.		MC		HUD	CAP	MC		
4		E.P.	HUD				E.P.	HUD	HUD		
5		HUD	MC				HUD	E.P.	CAP		
6		MC					CAP	HUD	HUD		
7		CAP					HUD	MC	MC		
8		HUD					MC				
9		MC					HUD				
10							MVC				
REACTION TIME (SEC.)		8.8	14.2		1.8		11.2	8.4	3.8	8.0	4.6
NUMBER OF FIXATIONS		9	5		3		10	7	7	6.8	2.6

TABLE 8.

REACTION TIMES AND OUTCOME DATA FOR THE VARIOUS EMERGENCY CONDITIONS-OCULOMETER TRIALS.

	Hard	Hard/ Emergency	Soft	Soft/ Emergency	Emergency	Emergency/ Hard	Emergency/ Soft
Reaction Time (Sec.)	3.6	3.3	2.5	3.4	3.2	8.0	5.2
Std. Dev	2.5	1.6	0.9	1.7	1.3	3.9	2.8
Disengaged/Break Jam	8.0	2.0	8.0	6.0	-	-	-
Ejected/Crashed	1.0	2.0	1.0	0.0	-	-	-
No Data/No Response/etc.	0.0	5.0	0.0	3.0	1.0	3.0	4.0

TABLE 9.

MEAN DISCRIMINATE SCORES IN THE EMERGENCY AND INGRESS PHASES OF A-10 MISSIONS.

	Emergency	Ingress
Hard Jam	−1.11	−0.72
Hard Jam Plus	+0.35	−0.15
Master Caution	+0.84	
Soft Jam	−1.34	−0.33
Soft Jam Plus	−0.52	−0.40
Master Caution	−0.98	
Master Caution Only	+0.02	−1.01
Pull Up Only	−0.74	−1.34

TABLE 10.

RANKS FOR THE FIVE CONDITIONS
(TIES PERMITTED)

	Ranked as Most Difficult		
	MEAN	FREQUENCY	PERCENT
Hard/Emergency	5.0	10	100
Hard Jam	4.5	5	50
Soft/Emergency	3.6	1	10
Soft Jam	3.0	1	10
Emergency Only	1.1	0	0

Coef. of Concordance = 0.84

TABLE 11.

WHAT WAS THE FIRST INDICATION OF THE EMERGENCY?

	Hard Jam	Hard Jam & Emergency	Soft Jam	Soft Jam & Emergency	Emergency
TACTUAL	24 100%	19 79%	24 100%	20 83%	1 4%
VISUAL	3 13%	16 67%	4 17%	14 58%	24 100%
AUDITORY	1 4%	1 4%	0 0%	1 4%	2 8%

Number of yes responses, maximum = 24.

TABLE 12.

USE OF COCKPIT INDICATORS — QUESTIONNAIRE AND OCULOMETER DATA

Questionnaire Data

	HARD JAM	HARD JAM/ EMERGENCY	SOFT JAM	SOFT JAM/ EMERGENCY	EMERGENCY
Given the indicator, was there any question or doubt about what the malfunction was?					
	6 25%	4 17%	6 25%	6 25%	8 33%
Was a further indicator necessary for adequate malfunction recognition?					
	17 71%	15 63%	13 54%	17 71%	27 71%
Number of additional indicators needed to take corrective action?					
Open Ended	20	24	8	19	4
# of Pilots responding					
	17 71%	17 71%	8 33%	12 50%	2 8%

Number of Yes Responses
MAX = 24

Oculometer Data

Frequencies of looking at appropriate instrument during oculometer trials (% of trails with data)

	HARD JAM	HARD JAM/ EMERGENCY	SOFT JAM	SOFT JAM/ EMERGENCY	EMERGENCY
Prior to Action	100% E.P.	100% E.P. 100% CAP	63% E.P.	67% E.P. 80% CAP	63% CAP
Prior Plus After Action	100% E.P.	100% E.P. 100% CAP	63% E.P.	67% E.P. 100% CAP	100% CAP

TABLE 13.

EVALUATION AND RESPONSE STRATEGIES TO EMERGENCIES

	HARD JAM	HARD JAM/ EMERGENCY	SOFT JAM	SOFT JAM/ EMERGENCY	EMERGENCY
Did the Malfunction appear to be a critical one?					
	24 100%	23 90%	23 90%	23 90%	3 13%
Did the malfunction appear to be controllable by you?					
	19 79%	18 75%	17 17%	20 83%	24 100%
Did you have an immediate plan for corrective action?					
	24 100%	24 100%	24 100%	24 100%	24 100%
Was the corrective action effective?					
	23 96%	24 100%	22 92%	20 83%	24 100%
Number of ejections or crashes.					
	4 17%	6 25%	7 29%	5 21%	0 0%

Number of Yes Responses
MAX = 24

TABLE 14.

IMPORTANCE OF FACTORS ON EVALUATION TIME

	FACTORS					
	Pilot's Ability		Design Character		Mission Situation	
	Freq.	PCT.	Freq.	PCT.	Freq.	PCT.
Hard/Emergency	2	8	5	20	6	25
Hard Jam	3	12	5	20	4	17
Soft/Emergency	2	8	3	12	7	29
Soft Jam	3	12	6	25	8	33
Emergency Only	1	4	1	4	1	4

(Maximum = 24)

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☆U.S.Government Printing Office: 1983 — 659-005/2041

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