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A COMPARISON OF TWO PITCH LADDER FORMATS AND AN ADI BALL FOR RECOVERY FROM UNUSUAL ATTITUDES

Mr. Steven A. Kinsley, Dr. Norman W. Warner, and LT David P. Gleisner
Aircraft and Crew Systems Technology Directorate
Man-Machine Integration Division
Technology Development Branch
NAVAL AIR DEVELOPMENT CENTER
Warminster, Pennsylvania 18974

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T. J. GALLAGHER
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The pitch ladder presented on the F/A-18 HUD has been reported as "marginally acceptable" by F/A-18 pilots for recovery from unusual attitudes. Loss of situational awareness is a major problem and has been cited as a contributing factor to four F/A-18 ground impact accidents.

Two experiments were conducted to assess the relative merits of the current F/A-18 pitch ladder, a revised pitch ladder, and an ADI ball as attitude indicators. Performance data were collected in the first experiment for decision times and number of errors. The results of this experiment indicated that use of the ADI ball resulted in faster decisions times than either pitch ladder format. No significant results were indicated for errors. The second experiment tested two formats, the current pitch ladder and the ADI ball in a dynamic mode, using a dynamic cockpit simulator. There were no significant differences of format for decision time. However, significant differences were found for background condition, pitch, and the interaction of format

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by pitch by roll. The results did indicate that use of the ADI ball resulted in faster recovery times. Significant differences in recovery times were also found for pitch, roll and the interaction of pitch and roll.

The results of the two experiments indicate that for the F/A-18 the ADI ball should be relocated in a more optimal location (i.e., within the central field of view) to aid in recovery from unusual attitudes. The current location of the ball within the display suite is not within the normal scanning envelope of the pilot, thus, the ADI ball is not generally used by the pilots. Other promising research efforts are proposed to improve the ability of pilots to recover loss of situational awareness.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Maintaining situational awareness is a major task in piloting an aircraft. Situational awareness is a multi-faceted phenomenon. In order to maintain situational awareness a pilot needs to know the relationship of the aircraft relative to: (1) the surface of the earth or other surface (e.g., an aircraft carrier), (2) geographical coordinates, and (3) other aircraft and threats.

Spatial orientation is a major aspect of situational awareness. To maintain spatial orientation a pilot needs information about altitude, airspeed, and attitude. This information is normally available via several sensory channels. The pilot's visual, auditory, vestibular, and kinestic senses all contribute information about his orientation in space. For example, the pilot receives aural cues from the radio altimeter, engines, and environmental control system. Force feedback from the stick and rudder and g-force vectors provide kinestic and vestibular cues. In addition, it has been estimated that over 80 percent of all information is processed visually (Senders, 1983). Thus, visual cues are the primary source of information for maintaining spatial orientation. The sources of a pilot's visual cues are the out-of-the-cockpit visual scene and his various cockpit attitude displays.

When loss of situational awareness occurs, the pilot, the aircraft, and the mission are in jeopardy. Loss of situational awareness has been identified as a contributing factor in several aircraft accidents and numerous aircraft incidents. Four F/A-18 and eleven F-16 accidents were attributed, in part, to loss of situational awareness. Maintaining situational awareness is an especially difficult task for the pilot of an F/A-18. Several of the sources of information concerning situational awareness, previously available to pilots of other aircraft, are no longer available or have been reduced in effectiveness for the F/A-18 pilot. The introduction of fly-by-wire technology has virtually eliminated the force feedback from the control stick and rudder pedals. Soundproofing of the cockpit and the use of quieter engines have reduced the effectiveness of aural cues. Thus, when flying under IFR conditions, during which there is no out-of-the cockpit visual scene, the F/A-18 pilot must rely on the primary attitude reference indicator (ARI) as the major source of information.

The primary ARI in the F/A-18 is the pitch ladder and roll scale presented on the head-up display (HUD). However, in response to a questionnaire developed at the Naval Air Development Center (September, 1984), pilots rated the HUD as "marginally acceptable" for recovery from unusual attitudes. Several aspects of the HUD format may have contributed to this less than satisfactory rating. (1) Airspeed and altitude information are presented in a digital format. Pilot comments on this method of presentation have generally been unfavorable. (2) The digital format does not provide the necessary trend information that is required in extreme environments. (3) The digital readout is updated so quickly during rapid maneuvering that it is difficult to read the display. (4) Pitch and roll scale formats were also identified as marginal to assess attitude quickly. The fourth problem was the focus of this research effort.

Taylor (1984) discusses various HUD pitch ladder formats in terms of the cognitive processes involved in assessing attitude. Pitch and roll indications on various HUD formats are complex multidimensional stimuli. He discusses the contribution of global and local cognitive processing and redundancy to the processing of this information for assessment of attitude.

Results from Taylor's research suggest several dimensions of the pitch ladder formats which might be modified to improve these formats as attitude indicators. Based on Taylor's results, several modifications to the current pitch ladder presented on the F/A-18 HUD were made by NADC. An experimental paradigm was developed to test the current and the modified pitch ladder along with a typical ADI ball.

The ADI ball was included in the experiment as a result of discussions with a group of pilots, psychologists, and engineers at the Naval Air Test Center (April, 1985). It was evident that pilots, if given a choice, prefer to have an ADI ball present as an attitude indicator. Although there is an ADI ball located in the instrument suite of the F/A-18, it was considered too small and poorly located to be useful to the pilots as a secondary instrument.

The suggestion resulting from the discussion at NATC was to optimize the location of the ADI ball and include it as a cross reference for attitude indication along with the pitch ladder on the HUD. Roscoe, Corl, and Jensen (1981) discuss several features of an ADI ball which suggest that it would be superior to a pitch ladder for attitude indication. The purpose of the current research effort was to compare the merits of two HUD pitch ladders and an ADI ball in recovering from unusual attitudes.

Situational awareness and particularly spatial orientation are compromised when conflicting information is received from the various sources of attitude information. A working group at NATC identified several situations during which loss of situational awareness was most likely to occur. In tactical situations it was most likely to occur during air combat maneuvering (ACM), all weather instrument flight (AWI), and during bombing runs when target fixation might occur. In non-tactical environments loss of situational awareness was most likely to occur during takeoff and catapult launch and on instrument landings. The non-tactical environments in which situational awareness was most likely to be lost usually involved flying against a homogeneous background (i.e., flying in clouds, clear blue sky over water, at night, or against solid-colored earth). The lack of a real, visible, horizon is one of the primary causes of loss of situational awareness.

METHODOLOGY

The current research effort was divided into two experiments. The first experiment was a static comparison of two pitch ladder formats and a pictorial representation of a typical ADI ball. The ability of these formats to aid the subject in *deciding how* to recover from unusual attitudes was assessed. The hypotheses for this experiment were that the ADI ball would result in the fastest decision times and the fewest errors, followed by the revised pitch ladder, with the use of the current pitch ladder resulting in the slowest decision times and the most errors. Decision time was defined as the amount of time required to assess the orientation and initiate an appropriate control response. Errors were defined as inappropriate control response, given a particular display orientation.

The hypotheses for this experiment were based on research conducted by Roscoe (1968) and by Taylor (1984). Roscoe's contention was that a display which more closely approximated the real world, (i.e., represented a contact analog) would be more efficient for its intended purpose. Therefore, given that the ADI represents a contact analog of real horizon more so than a pitch ladder, it is logical to assume that the ADI would be superior to the pitch ladder as an attitude indicator. The revised pitch ladder incorporated several features which resulted in faster reaction times in Taylor's experiments. Thus, it was hypothesized that the revised pitch ladder would be superior to the current pitch ladder.

The second experiment was based on results from the static experiment. The three display formats from the previous experiment were tested dynamically in a medium-fidelity, ground-based, simulator in the Crewstation Evaluation Facility (CREST) at NADC. However, due to software limitations which did not allow for an exact duplication of the revised pitch ladder format as it appeared in the static experiment, only the current F/A-18 pitch ladder and an ADI ball were experimentally compared. The modified pitch ladder in its current form was included as a matter of interest, but was not included in the formal analysis.

Two experimental hypotheses were proposed for the dynamic experiment. The first hypothesis was that decision times would be faster when using the ADI ball than when using the current pitch ladder. The second hypothesis was that recovery times defined as the amount of time between the initial control response and when the subject had the simulation stable at a straight and level attitude, would be faster when using the ADI ball than when using the current pitch ladder.

EXPERIMENT ONE: STATIC EVALUATION

SUBJECTS

Four female and eight male subjects were employed for this experiment. None of the twelve subjects were pilots. Learning effects were controlled by providing a practice session for every subject to reach a 90 percent correct response criteria. This criteria was achieved when the subject successfully corrected 17 out of 18 attitude disorientations back to straight and level.

APPARATUS

The experimental apparatus is presented in Figure 1. The apparatus consisted of: (1) an Apple II plus micro-computer, (2) a Carroll 127 X 127 dot matrix (17 in. X 17 in.) rear projection, touch panel screen, (3) two Kodak ectographic B-2, random access, slide projectors, and (4) the Workload Assessment Device (WAD).

The WAD consists of several components developed by Systems Research Laboratories (SRL) for NADC. The software development system consists of a micro-processor, a C/PM operating system, three disk drives, and a Micro-Term ERGO 301FK monitor. The air-borne unit consists of a microprocessor, a Princeton Graphics Systems SR-12 monitor, and a Measurements Systems, two-axis, joystick controller.

The complete system is called the Design By Experimentation system (DBE). A systems description is available in the users and systems documentation (Analytics, 1984). The system was interfaced to an EPSON FX-80 dot matrix printer. The printer was used to obtain hard-copy output from the system for data reduction and analysis.

STIMULI

The stimuli for this experiment were three attitude-indicator formats. The three formats are represented in Figure 2. Figure 2a presents the pitch-ladder currently available on the F/A-18 HUD. Figure 2b presents the modified pitch-ladder developed for this experiment. Figure 2c is a pictorial representation of a typical ADI ball. The features by which attitude was indicated by each of the formats were identified and explained to the subjects. The pitch-ladder formats present pitch information by the relationship of the velocity vector, -○-, to the pitch scale. The longer of the three lines represents the horizon. The shorter lines above and below the horizon line represent five degrees of pitch up and down, respectively. The pitch scale goes up to 90 degrees of pitch both up and down. However, only three lines were visible at one time. Roll is indicated by the rotation of the entire pitch ladder on the roll axis, about the velocity vector.

Both pitch-ladder displays share several features. They are both outside-in displays. The horizon line on the pitch ladder moves in relation to movement of an actual horizon. Thus, if the aircraft were rolled 25 degrees to the right, the horizon line would be displayed as angled 25 degrees to the left. Both pitch-ladder formats also have solid pitch lines when pitched up and dashed pitch lines when pitched down. The pitch lines also increase in angle with increases in the pitch angle of the aircraft in a ratio of 1:2. Therefore, if the aircraft wer pitched 40 degrees the pitch line would be angled 20 degrees. The slope of the pitch lines is always toward the horizon for both pitch-ladders. The pitch lines for both pitch-ladders have horizon markers which point to the horizon.

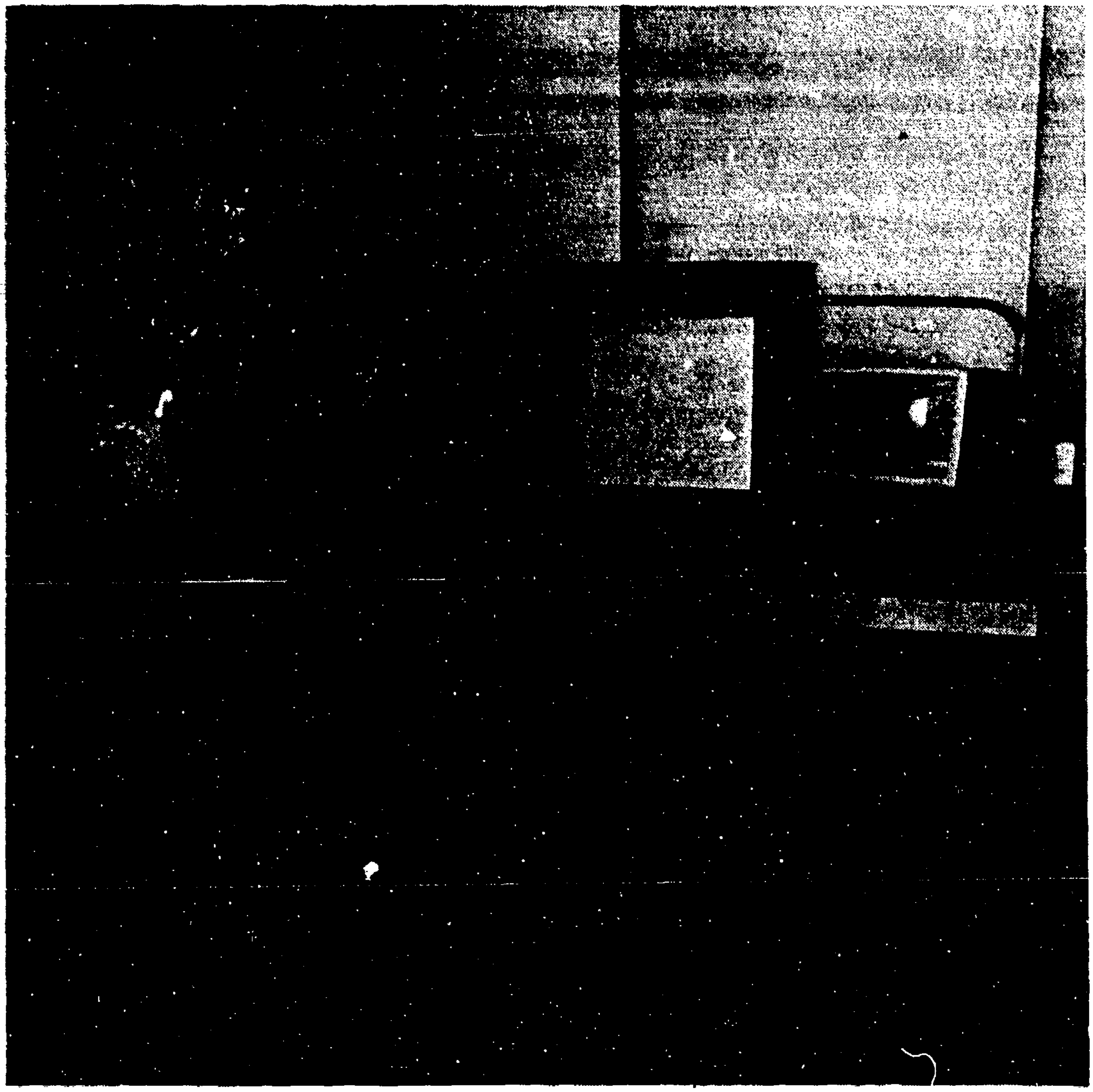

Figure 1. Experimental Apparatus for Experiment One

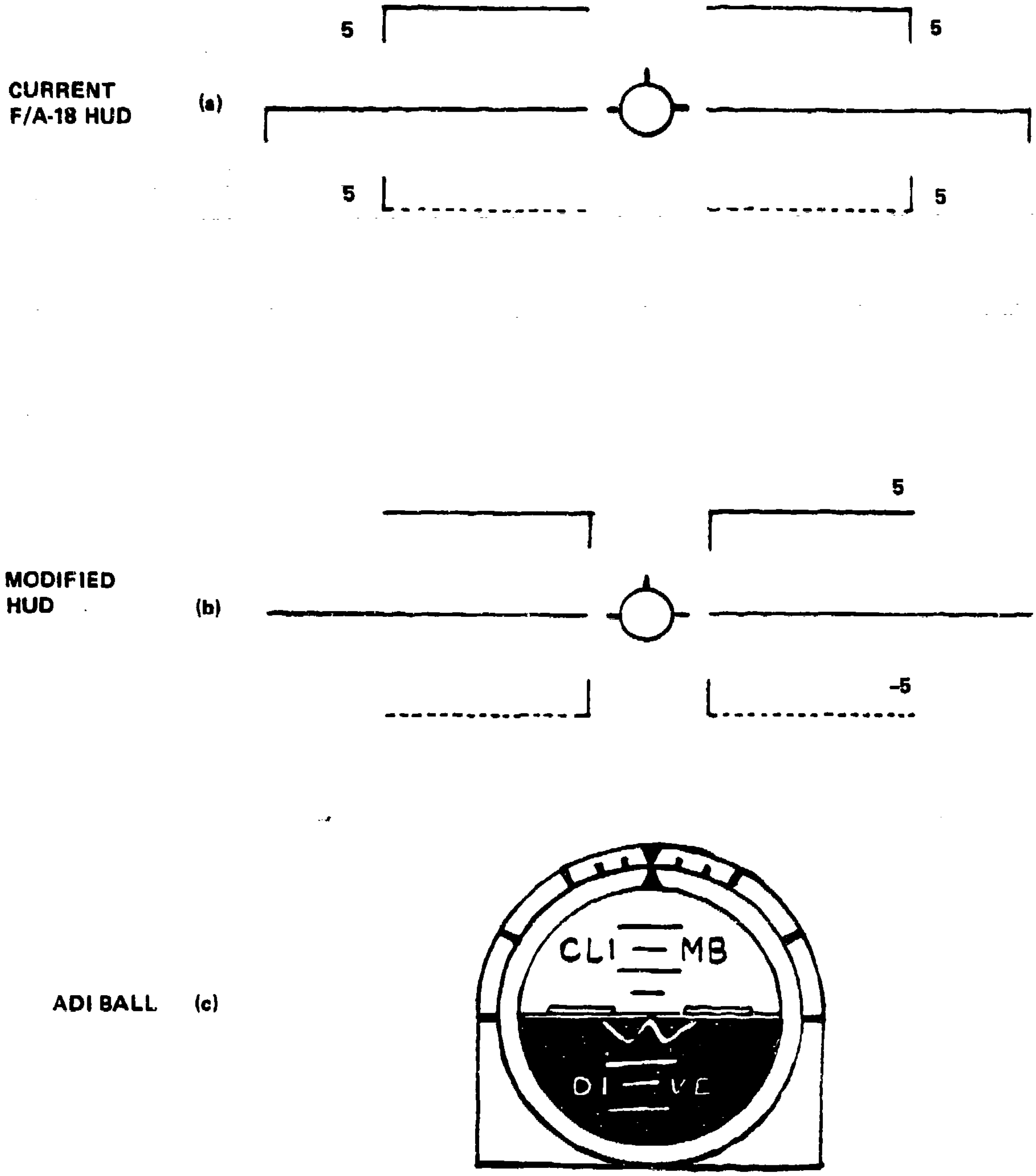

Figure 2. Attitude Indicator Formats

The two pitch-ladders had several differnt features which comprised the experimental manipulation. The labels for each pitch line are on both sides of the line for the current F/A-18 format and on one side only for the revised format. The labels are beside the pitch lines for the current format. They are on top of the pitch lines in the revised format, but only when upright. The labels remain upright even when rolled 180 degrees on the current format. The labels rotate relative to the pitch lines on the revised format. The labels have negative signs to indicate pitch down on the revised format, but do not on the current format. The horizon markers on each of the pitch lines are located on the outside of the lines on the current format and on the inside on the revised format.

The changes mentioned above were made to provide more redundant cues to attitude orientation. Taylor (1984) suggested that these changes would provide stimuli which when processed would provide globally-processed cues to attitude. Viewing the labels on the right of the pitch ladder was hypothesized to provide a global cue to being upright, whereas, if the labels were on the left they would provide global cues that the aircraft was inverted. If the labels appeared under the pitch lines they were also cues to being inverted. If the numbers were upside-down they, too, were cues for being inverted. It was, therefore, hypothesized that the available redundant cues of the revised pitch-ladder would be a better indication of attitude.

The pictorial representation of the ADI ball had several features which indicated attitude. The ball had two colors, light-blue and black. The light blue area of the ball represented the sky (i.e., pitch up) and the black area of the ball represented the earth (i.e., pitch down). The area where the two colors met was the horizon. There were scale markings on the ball which indicated five degree changes in pitch. There was also a roll scale located around the ball. It was a fixed scale with a moving indicator. There were three cues present to indicate pitch. The location of the horizon relative to the housing of the ball, the amount of one color versus the other, and the reading from the pitch scale, provided redundant cues to pitch orientation. If pitched up the majority of the ball was light blue and the horizon line appeared toward the top of the ball (unless inverted). If pitched down, the majority of the ball was black and the horizon line appeared toward the bottom of the ball. There were two cues present which indicated orientation of the horizon line and the location of the indicator on the roll scale.

The stimuli were first drawn on mylar with a Versatic Pen Plotter and were then photographed on 35mm. slide transparency film. Fifty-four slides were produced. There were three values of pitch employed for this experiment: 0°, 55°, and -55°. Six values of roll were used: 0°, 60°, 120°, 180°, -60°, and -120°. Slides were produced for each of the eighteen possible combinations of pitch and roll, for all three of the formats, for a total of 54 slides.

PROCEDURE

The experimental design was a completely within-subjects design. Each subject was presented with 18 slides for each of the three display formats. The order of display format and pitch/roll combination was counter-balanced to control for any potential carry-over effects.

The subjects were tested in the Man-Machine Interface Laboratory (MMIL), within the CREST facility. The subjects were given several practice trials in order to familiarize them with the stimuli and the experimental procedure. The practice trials were continued until the subjects reached a performance criteria of 90 percent correct responses. The experimental trials were then initiated.

Each subject received 54 trials. Each slide was a unique combination of one of three levels of pitch and six levels of roll. The subjects received all of the possible pitch/roll combinations for one format before proceeding to the next format. A trial began by prompting the subject that a slide was about to be presented. The experimenter then initiated the first slide. The subject viewed the slide, determined the orientation presented on it, and made, what they considered to be, an appropriate control input with the joystick. The subject then touched the screen and a new slide was presented.

DEPENDENT MEASURES

Two measures of performance were collected. The first measure, decision time, was defined as the amount of time that elapsed between the onset of the slide and the first movement of the joystick. The joystick position was sampled every 0.1 seconds and the first deviation from 0° pitch and 0° roll was considered a control input. The second measure, error, was defined as a joystick movement in an inappropriate direction to correct the displayed orientation back to straight and level (i.e., 0° pitch and 0° roll). Errors were converted to a percentage.

RESULTS

The means for decision time and the percentage of error for each of the display formats are presented in Table 1. The results of the Friedman test for matched groups indicated a significant difference for decision time ($X^2 = 14.86$, $p < 0.001$) (Hays, 1973). A Newman-Keuls post-hoc test (Hays, 1973) revealed that decision times for the ADI ball were significantly faster than either pitch-ladder format. The decision times for the two pitch-ladder formats were not significantly different. No differences for percentage of error were revealed.

TABLE 1

MEAN DECISION TIME AND PERCENTAGE ERRORS

DEPENDENT MEASURES	DISPLAY FORMATS					
	F/A-18 HUD		ADI BALL		PROPOSED HUD	
	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.
DECISION TIME	4.14	1.03	3.37*	0.94	4.43	0.99
PERCENTAGE ERRORS	0.06	0.06	0.09	0.11	0.10	0.09

*Significantly different ($p < 0.001$) from other two formats.

EXPERIMENT TWO: DYNAMIC EVALUATION

Experiment two dynamically assessed the same display formats used in experiment one with one exception; the revised pitch-ladder was not included in the formal analysis. The hypotheses for this experiment were: (1) decisions times would be faster for the ADI ball than the current pitch-ladder and (2) recovery times would be faster for the ADI ball than the current pitch-ladder.

The experimental design included only the current F/A-18 pitch-ladder and an ADI ball. The modified format could not be reproduced in the dynamic simulator exactly as it appeared in experiment one. Due to this limitation and the lack of significant differences between the two pitch-ladder formats in experiment one, the modified pitch-ladder was not included as part of the formal experiment.

The only difference between the modified pitch-ladder format from experiment one and the one generated by the simulator were the labels on the pitch lines. They did not rotate in conjunction with the rotation of the pitch lines. The subjects were, however, presented with the modified format after they completed the necessary trials for the current pitch ladder and ADI formats. The modified format was not subjected to formal statistical analysis.

SUBJECTS

Eight non-pilot, three female and five male, and three pilot subjects were tested for this experiment. To control for learning effects and the potential for bias due to differential exposure to attitude indicator formats by the pilots, all of the subjects were given sufficient practice on the simulator. They were also given several practice trials to determine baseline performance and to familiarize them with the experimental procedure. The subjects were required to meet a 90 percent correct performance criteria before experimental trials were initiated.

APPARATUS

The system used in this experiment was the dynamic cockpit simulator in the CREST facility at NADC. This system is presented in Figure 3. The system consisted of a Digital Equipment Corporation PDP 11/34 mini-computer with a digital to analog converter, an Evans and Sutherland PS-300 symbol generator, a Data General NOVA-820 mini-computer with an analog to digital converter, a diffractive optics head-up display (HUD), an ADI ball, a large screen virtual image television screen, a Sony V-Matic video cassette recorder, a Bowmar Programmable Control Panel, and a U.S Army Type C-1 control stick.

The PDP-11/34 contained an aerodynamic model of the F/A-18 and was the main controller of the system. It also sampled the pitch and roll coordinates every 0.1 seconds. These samples were stored in memory and used for data analysis. The Evans and Sutherland symbol generator controlled the symbology which was displayed on a HUD. The outside scene which provided the background against which the subjects flew the simulation was recorded on video tape and projected on the large screen virtual image television system. The NOVA computer controlled the dynamics of the ADI ball. More exact specifications of the system are available upon request.

STIMULI

The stimuli for this experiment were actual display formats. The current F/A-18 pitch-ladder was presented on a HUD. The HUD was developed by Hughes Aircraft Company for NADC. It

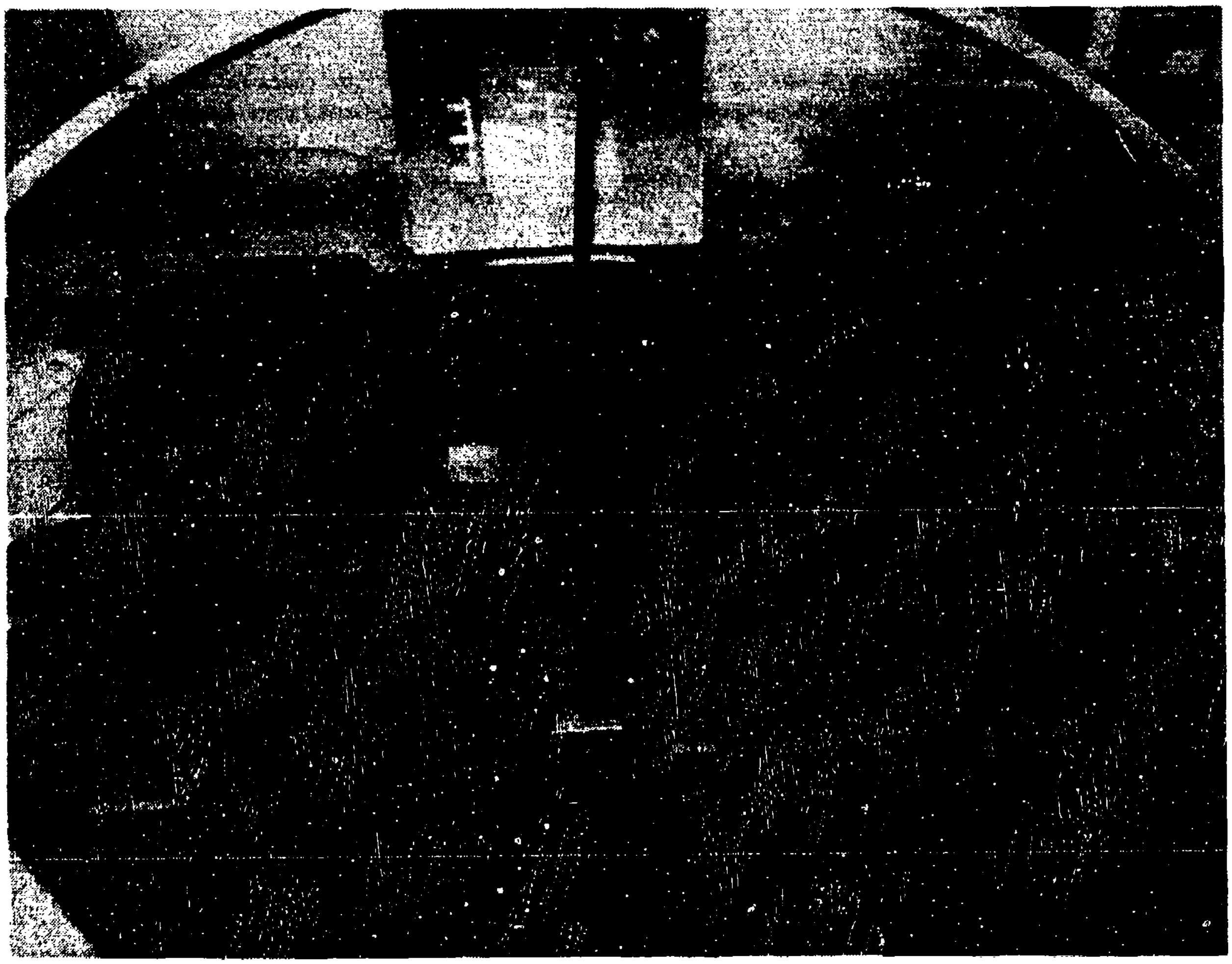

Figure 3. Side-by-Side Cockpit Simulator

has a diffractive optics combiner with a field of view of 20° X 30°. The pitch-ladder was presented along with a roll scale, a heading indicator, a digital airspeed indicator, and a digital altitude indicator. The symbology presented on the HUD was identical to that which was displayed in the most decluttered mode of the F/A-18. The pitch-ladder format was identical to the format described above for experiment one.

The ADI ball used in this experiment was the actual display from an F-14. An F/A-18 ball was not available for the experiment, but based on its similar characteristics the F-14 ball was selected. It was two inches in diameter. The pitched-up half of the ball was light gray and the pitched-down half of the ball was black.

The revised HUD format was not included as part of the formal experiment or statistical analysis, however, it was implemented on the HUD in a modified form. As mentioned above, the number labels on the pitch lines did not rotate with rotation of the pitch lines, but remained upright regardless of the orientation of the pitch lines.

Background was a factor in this experiment. It was included in this experiment as a result of discussions with the working group on situational awareness at NATC. The background against which pilots were flying was considered as an important variable in loss of situational awareness. Two backgrounds were developed. A video recording of two sky conditions were taped during flight. The first condition was a recording of clear-blue sky. The second condition was a recording of a star-lit night sky. These video tapes were displayed on the 22° by 29° field of view, large screen, virtual image, television. This television system was developed for use in the CREST facility by NADC engineers.

PROCEDURE

The subjects were tested in the side-by-side dynamic cockpit simulator in the CREST facility. The subject was seated in the right-side seat and began flying the simulator. The experimenter was located in the left-side seat. During this familiarization phase of the experiment no experimental interventions were introduced. The subject was given the opportunity to experience the control-display relationships of the simulator, the flight characteristics involved with the F/A-18 aerodynamic model, and to become familiar with the display formats used for the experiment.

The subject was given instructions and a written description of the features of each display which would be used for attitude assessment. Practice trials were begun when the subject reported being comforrable with flying the simulator and felt able to control the simulation. The practice trials were included to assess the performance of each subject to insure that the criteria of 90 percent correct responses was met. The practice trials were also included to familiarize the subject with the experimental procedure. Thirty-six practice trials were completed, six trials for each of three formats against two backgrounds.

An experimental session consisted of 144 trials. There were 18 trials for each possible combination of pitch and roll, for each of the three display formats, against each background. The subject was presented with all of the trials for each display for one background before continuing on to another background or another display. The order of presentation of the display formats was counter-balanced across the experiment. Only the ADI ball and the current F/A-18 pitch-ladder were counter-balanced. Since the revised pitch-ladder was not formally included as part of the experiment or statistical analysis, it was always presented last. The background condition was counter-balanced for each display format. The counter-balancing was included to assure against any carry-over effects which might confound the data analysis.

An experimental trial consisted of: (1) the experimenter selecting the appropriate pitch and roll parameters, (2) alerting the subject that the trial was to begin, and (3) the experimenter initiating the trial. Once the trial was initiated the subject assumed control of the simulation. The subject controlled the simulator for a brief period, maintaining the orientation at straight and level. Once the subject felt in control at straight and level, he was required to read the airspeed and enter it into the center keyboard panel. This required that the subject look away from the display. Upon pressing the "enter" key the simulation was automatically reoriented to the pre-selected pitch and roll orientation.

The subject's task at this point was to use the control stick to correct the simulation back to straight and level. Once the subject decided that he had the simulation back to straight and level and had it under control he was required to squeeze the trigger located on the control stick. This stopped the simulation. The experimenter then entered the new parameters for the next trial and prompted the subject. Rest periods were taken after each format had been tested under both background conditions.

The experimental design was a four-factor, within-subjects, repeated measures design. The four factors were: (1) display format, (2) background condition, (3) pitch, and (4) roll. Each subject received every possible combination of treatments. Data analysis was completed using an APL computer language program (Gilman and Rose, 1974).

DEPENDENT MEASURES

Two dependent measures were recorded: (1) decision time and (2) recovery time. Decision time was defined for this experiment as the amount of time that elapsed between pressing the "enter" key on the center panel and the initiation of a control stick movement. Recovery time was defined as the amount time that elapsed between initiation of the a control stick movement and when the trigger on the control stick was depressed.

Subjective preference data were also collected. During the debriefing session, after the experimental trials had been completed, the subject was asked to state which display he thought he performed the best with, which display he liked the most, and which display he thought provided the best indication of attitude. The subjective data revealed substantial individual differences. No display format was consistently named more often than the others as a response to any of the questions.

RESULTS

The mean decision times for each format, background, pitch, and roll combination are presented in Table 2. Results of the statistical analysis for decision time indicated significant main effects of background ($\underline{F} = 21.80$, $p < 0.01$) and pitch ($\underline{F} = 9.07$, $p < 0.01$). The mean decision time to determine how to recover was significantly faster with the clear-blue sky than when performing the task against a star-lit night sky.

Tukey's HSD (honestly significant difference) post-hoc multiple comparison test was employed to determine which pitch conditions were significantly different from each other (Kirk, 1968). This test revealed that the 0° pitch condition was not significantly different than either the 55° or the -55° pitch condition. However, the latter two pitch conditions were significantly different from each other. The means and the results of the HSD post-hoc test for background and pitch are presented in Table 3.

TABLE 2

MEANS FOR DECISION TIME

	F/A-18 HUD		ADI BALL	
PITCH/ ROLL	DAYLIGHT	NIGHTLIGHT	DAYLIGHT	NIGHTLIGHT
0°/0°	1.95	1.65	2.36	2.34
0°/60°	1.95	1.85	1.79	2.00
0°/120°	1.75	2.02	1.89	2.15
0°/180°	2.11	2.26	1.76	2.15
0°/-120°	1.95	2.06	1.91	1.96
0°/-60°	1.75	2.08	1.99	2.03
55°/0°	2.01	1.97	1.63	2.10
55°/60°	2.01	2.09	2.14	2.40
55°/120°	1.67	1.95	1.99	2.31
55°/180°	1.79	1.92	1.92	2.31
55°/-120°	2.02	2.05	1.99	2.30
55°/-60°	1.90	2.12	2.21	2.49
-55°/0°	1.74	1.85	1.66	1.92
-55°/60°	1.83	1.86	1.62	1.94
-55°/120°	1.75	1.92	1.79	1.93
-55°/180°	1.72	1.97	1.85	1.93
-55°/-120°	1.88	2.05	1.78	1.90
-55°/-60°	1.87	1.96	1.68	1.75

TABLE 3

RESULTS OF TUKEY'S HSD POST-HOC MEAN COMPARISON TEST FOR DECISION TIME

EXPERIMENTAL CONDITION	= BACKGROUND	
DAYLIGHT		NIGHTLIGHT
1.878		2.043

EXPERIMENTAL CONDITION	= PITCH	
-55°	0°	55°
1.840	1.976	2.054

(Those means underlined by a common line are not significantly different from each other.)

A significant interaction effect was also revealed by the overall F test. The interaction of display format by pitch by roll was significant ($F = 3.68$, $p < 0.01$). Figure 4 presents a graph of this interaction. The interaction effect was not subjected to any formal post-hoc statistical analysis. Figure 4 does, however, provide a graphical presentation of this interaction.

The mean recovery time for each format, background, pitch, and roll combination are presented in Table 4. The overall F test for the recovery time dependent measure revealed significant main effects of display format ($F = 13.38$, $p < 0.01$), pitch ($F = 30.36$, $p < 0.01$), and roll ($F = 19.49$, $p < 0.01$). Tukey's HSD post-hoc multiple comparison test was employed to determine which pitch and roll effects were significantly different from the others. The means and results of the HSD test for display format, pitch and roll are presented in Table 5.

The HSD test for recovery times revealed that the 0° pitch condition was significantly different than either the 55° or the -55° pitch conditions. The latter two pitch conditions were not significantly different. The HSD test also revealed that the 0° roll condition was significantly different than all of the other roll conditions. It also revealed that the 60° roll condition was significantly different from the 180° roll condition. No other roll conditions were found to be significantly different.

The overall F test also revealed a significant interaction of pitch and roll ($F = 7.38$, $p < 0.01$). No post-hoc statistical analysis was completed for the interaction. The interaction is graphically presented in Figure 5.

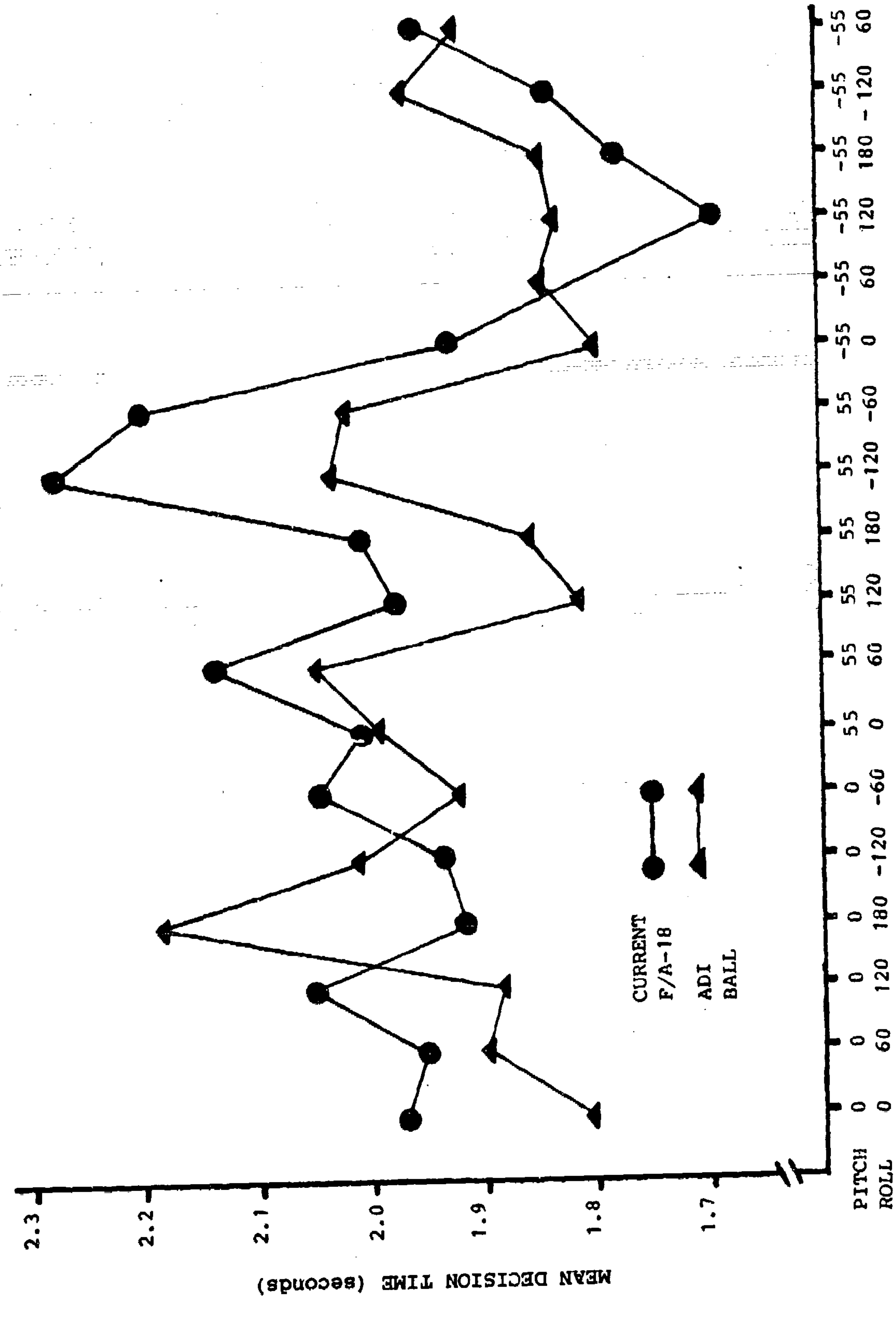

Figure 4. Display Format By Pitch By Roll Interaction

TABLE 4

MEANS FOR RECOVERY TIME

PITCH/ ROLL	F/A-18 HUD		ADI BALL	
	DAYLIGHT	NIGHTLIGHT	DAYLIGHT	NIGHTLIGHT
0°/0°	0.81	0.87	0.25	0.18
0°/60°	11.35	6.20	6.75	5.89
0°/120°	9.25	12.20	8.40	7.15
0°/180°	9.36	14.02	8.43	10.22
0°/-120°	11.74	10.88	8.91	7.63
0°/-60°	9.04	13.00	6.60	7.11
55°/0°	16.06	15.09	7.60	9.07
55°/60°	21.35	22.10	11.75	12.19
55°/120°	20.11	18.63	12.25	13.65
55°/180°	21.22	21.97	12.23	15.66
55°/-120°	19.44	21.29	13.83	14.89
55°/-60°	18.33	19.55	13.65	12.80
-55°/0°	9.82	10.61	9.97	9.05
-55°/60°	16.34	14.54	11.35	12.75
-55°/120°	15.76	15.72	13.72	11.63
-55°/180°	17.47	12.36	15.65	17.31
-55°/-120°	14.26	19.90	17.26	12.95
-55°/-60°	14.33	17.34	13.18	14.10

TABLE 5

RESULTS OF TUKEY'S HSD POST-HOC MEAN COMPARISON TEST FOR RECOVERY TIME

EXPERIMENTAL CONDITION = DISPLAY FORMAT

F/A-18 HUD	ADI BALL
14.552	12.978

EXPERIMENTAL CONDITION = PITCH

0°	-55°	55°
7.792	14.057	16.063

EXPERIMENTAL CONDITION = ROLL

0°	60°	120°	-60°	-120°	180°
7.447	12.789	13.206	13.251	14.484	14.646

(Those means underlined by a common line are not significantly different from each other.)

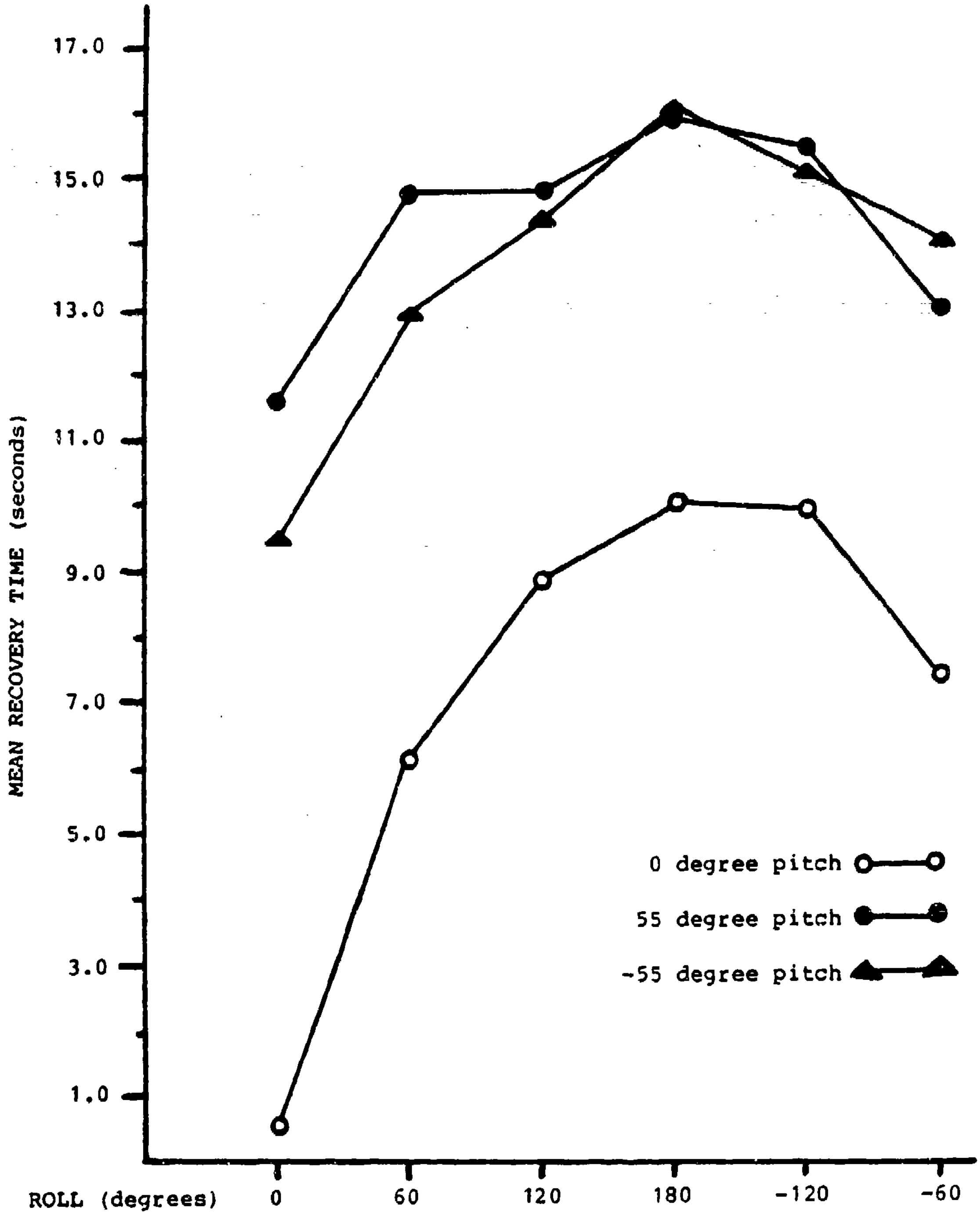

Figure 5. Pitch By Roll Interaction

DISCUSSION

The results of experiment one supported the hypothesis that the ADI ball would provide a better indication of attitude (i.e., use of the ADI ball resulted in significantly faster decision times). This hypothesis was not supported by the results of experiment two. However, the results from experiment two did indicate that the ADI ball was superior to the pitch-ladder in aiding recovery from unusual attitudes.

The second hypothesis of experiment one was not supported. The revised pitch-ladder did not surpass the current pitch-ladder in terms of faster decision times. An informal examination of the revised format in experiment two also indicated that the revised pitch-ladder format did not provide a better indication of attitude.

The significant effects from experiment two of pitch and roll were not surprising. For both pitch and roll the 0° condition was significantly different from the other conditions for recovery times. It is obvious that it would require more time to recover from a pitched or rolled condition than it would from a no-pitch or a no-roll condition.

The experimental support of the hypothesis that the ADI ball would provide a better indication of attitude than a pitch-ladder is consistent with other research in this area (Roscoe, Corl, and Jensen, 1981). The ADI ball is more consistent with the generally accepted display principle of pictorial realism. The ADI ball represents a contact analog more so than a pitch-ladder. A pitch-ladder is more symbolic in nature than a ADI ball and, therefore, requires more cognitive processing to interpret.

The lack of experimental support for the hypothesis that the revised pitch-ladder would be better than the current pitch-ladder is somewhat surprising in view of the results reported by Taylor (1984). the revisions to the current pitch-ladder were based on results obtained by Taylor which indicated that the changes he made resulted in quicker reaction times than when the changes were not included. The discussion by Taylor was presented in terms of cognitive processes involved in assessing attitude. The availability of redundant cues which could be processed globally should aid in assessing attitude.

It is possible that the changes made to the pitch-ladder, although thought to be global, may not have been cognitively processed in a global manner. Several of the modifications were apparently unnoticeable. However, the instructions to the subject included a discussion of the features of each display format which would aid him in assessing attitude. The most likely explanation of the results is that the subject tended to ignore the more subtle cues and attended, instead, to the more powerful cues, such as the orientation of the pitch-ladder about the velocity vector.

RECOMMENDATIONS

A recommendations, based on the results of these two experiments, would be to include an electromechanical ADI ball, in an optimal location, within the display suite and have it serve as the primary instrument for attitude. If a pitch-ladder presented on a HUD is the primary flight instrument, as it is in the F/A-18, an ADI ball should be present as a secondary instrument in a location such that it would require very little eye translation to cross reference between the two displays.

Research is currently proposed which would examine possibilities other than retro-fitting an ADI ball into an optimal location. Col. Grant McNaughton from the U.S. Air Force has proposed several pitch-ladder formats which merit consideration (McNaughton, 1985). They provide obvious cues which leave very little doubt as to whether they would be processed globally or not.

The Command Flight Path Display (CFPD), originally developed at NADC for use in the F-14 may provide another possible solution. The CFPD is an integration of several pieces of essential information. With specific modifications (e.g., frequency separation of the velocity vector in relation to the flight path) it may well provide an excellent indication of attitude. The CFPD has been flight tested with good results in an F-14 (Hoover, Cronauer, and Shelley, 1985). It may well prove to be an excellent solution because of the integration of several flight parameters into one readable display.

Another possible solution may result from an advancement in display technology. A new up-front controller (UFC) for the F/A-18 HUD is currently undergoing a technical review at NADC. Included in this new UFC is a three inch by three inch flat panel display. It is possible that an electronically-generated ADI "ball" could be presented on this display surface. If this electronically-generated ADI "ball" maintains the same characteristics of an electromechanical ADI ball, it may provide a good secondary attitude indicator which would be optimally located so that very little eye translation would be involved in cross-referencing.

The latter proposal is currently being developed as a potential solution addressing the problem of loss of situational awareness in the F/A-18. Continued efforts into the causes and contingencies of loss of situational awareness will lead to an eventual solution to this problem.

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