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F-15E EADI EVALUATION: A COMPARISON OF THREE FORMATS

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PREFACE

The research described in this report was funded by the F-15E System Program Office, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio. The authors thank Robert Pangburn, John Hassoun and Larry Ivey for their useful suggestions, careful review, and continuing interest in this work. The authors thank Lt Ross Dudley and John Hassoun for assistance in data collection and Chris Buell for the brilliant and timely development of the software that made this evaluation possible on such short notice. Mr Buell's support along with all the other Link Flight Simulation personnel was greatly appreciated.

The idea for the three-dimensional electronic attitude indicator developed in this evaluation came from a report published in the 30th Symposium proceedings of the Society for Experimental Test Pilots. The report is titled, "An ordinary 3-axis horizon instrument which every pilot likes - Can it be misleading and dangerous? The answer is "Yes", and was written by Ulf Frieberg and Stig Holmstrom (1986). Chris Buell, a Link employee, used the illustrations in this report to construct the three-dimensional attitude indicator for the present evaluation.

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INTRODUCTION

The ever increasing military capabilities of the Soviet and third world countries is a growing threat to the security of the United States and the free world. Our ability to deter this threat is largely based on our technological advantage. The F-15E Strike Eagle is one of, if not the most sophisticated and lethal fighter aircraft in the free world. While it is indeed a privilege to be selected to exploit the capabilities of this aircraft, it is by no means a simple job to fly low and fast at night under the weatner, while dodging missiles and trying to maintain attitude awareness. Although the principle task for pilots has not changed since the first flight of the Wright brothers, i.e., operator awareness and control of spatial orientation, it has become more critical in light of the speeds capable in today's aircraft. The purpose of this research effort is to address the issue of unusual attitude recovery in fighter/attack aircraft.

The technology that has allowed us to accomplish the night attack mission requires many controls and displays which must be integrated into an already overcrowded cockpit. There simply is not enough space available to present all the necessary system information to the flight crew. Electronic multifunction displays are now being used to present to the pilot flight information that is timeshared with other systems information. There are many advantages to be gained with electronic displays; one of the primary advantages is the flexibility available to the system engineer to design displays from a human factors perspective. However, when there are time and schedule constraints (as is often the case during development of highly sophisticated aircraft), decisions are often made based on past experience.

Electronic displays are often simple repeaters of their electromechanical counterparts or they are slightly modified displays where the modification was aimed at solving a minor problem reported with previous displays. Unfortunately, what sometimes appears to be a trivial solution ends up having a negative impact, e.g., color electronic attitude director indicators (EADIs). While a blue/brown color coded EADI appears to be in synergy with the real world, thus more intuitive to the operator, it could become hazardous in low-light levels where the blue/brown color contrast is lost with scotopic vision and the resultant luminance contrast diminishes to below that which is found with a standard gray/black attitude indicator.

Another example is the 1:1 pitch attitude scale in the head-up display. While a high resolution pitch attitude scale permits precise control in the pitch axis (which is great for formation flying and instrument landings); the reduction in field-of-view, sacrificed for the high resolution scaling, and the increased rate of motion during high energy pitch excursions can significantly degrade one's ability to acquire and maintain spatial awareness when using such a display. Such problems should not necessarily preclude the use of these coding techniques, rather it should point out that additional research is necessary in order to arrive at electronic displays that are satisfactory for all flight regimes and light levels.

The specific purpose of this evaluation was to determine if the use of sky pointer arrows presented below the horizon on an EADI will improve the pilot's ability to recover from unusual attitudes. Although maintaining attitude awareness (especially during nighttime low light viewing levels) was not an issue under investigation in this evaluation, it is expected that the formats investigated have a lot of potential as attitude awareness displays for nighttime fighter aircraft such as the F-15E Strike Eagle.

Frieberg and Holmstrom (1986) developed and evaluated a pictorially coded attitude indicator in both a simulator and flight test aircraft. Two modified indicators, a large 3-axis attitude indicator with sky pointer arrows presented below the horizon and a smaller 2-axis indicator with sky pointer arrows presented below the horizon were compared with a baseline 3-axis indicator. Twelve military pilots were presented with a variety of attitude situations and were instructed to recover to wings level with as little altitude loss as possible. The number of hesitations and incorrect actions were recorded. Slow, but deliberate correct actions were not considered as hesitations. Response times and altitude loss data were recorded but not presented. Overall, the simulation results show that the 3-axis attitude indicator with arrows performed equally or better than the baseline display for both the number of hesitations and incorrect actions (the number of incorrect actions for the upright dive was the only exception). While these results appear to be significant, statistical analyses were not presented. Frieberg and Holmstrom reported that flight test results, which were also not presented, were similar to the simulation results.

At the request of the F-15E System Program Office, the Aeronautical Systems Division Crew Station Design Facility (CSDF) has conducted a similar evaluation of 3 electronic attitude indicator display formats. The baseline F-15E attitude display with a 60 degree field-of-view (FOV), the same F-15E display modified with sky pointer arrows presented below the horizon, and a 180 degree FOV three-dimensional attitude display with sky pointer arrows presented below the horizon, were used to recover from several imposed unusual attitudes.

OBJECTIVES

The specific objectives in this study were:

1) To determine if the use of sky pointer arrows on an electronic attitude indicator display would improve pilot performance during recovery from unusual attitudes, and

2) To determine if a 180 degree FOV attitude display would aid in recovery from unusual attitudes.

METHOD

APPARATUS

Experimental Facility. The study was conducted at the Crew Station Design Facility (CSDF), which is a U.S. Air Force simulation facility that belongs to the Aeronautical Systems Division (ASD) of Air Force Systems Command, at Wright-Patterson AFB, Ohio. The CSDF government personnel are assigned by the human factors branch of ASD (ENECH). The facility is used to conduct human engineering and system design/mechanization studies in support of a variety of System Program Offices (SPOs). Figure 1 is a diagram of the CSDF simulator area; Figure 2 is a schematic of the F-16C simulator system.

F-16C Simulator. The F-16C simulator was developed from a salvaged single seat F-16 cockpit, truncated in front of the forward portion of the windscreen, and approximately 57 inches behind the canopy hinge. The F-16C cockpit simulator is comprised of an all digital design which includes two 4X4 inch monochromatic Multi-Function Displays (MFDs), a Wide Field of View raster video Head-Up Display (HUD), an upfront Integrated Control Panel, a Data Entry Display, Hands on Throttle and Stick (HOTAS) controls, and the LANTIRN avionics suite. The center console was modified for the present study to include a 5-inch color raster CRT for presentation of the electronic attitude indicators. The side control stick, throttle and flight controls are actual F-16 components. All of the other instruments, controls, and displays are simulated using locally available equipment. The use of the F-16 simulator as a testbed to evaluate F-15E displays was not a concern since the displays

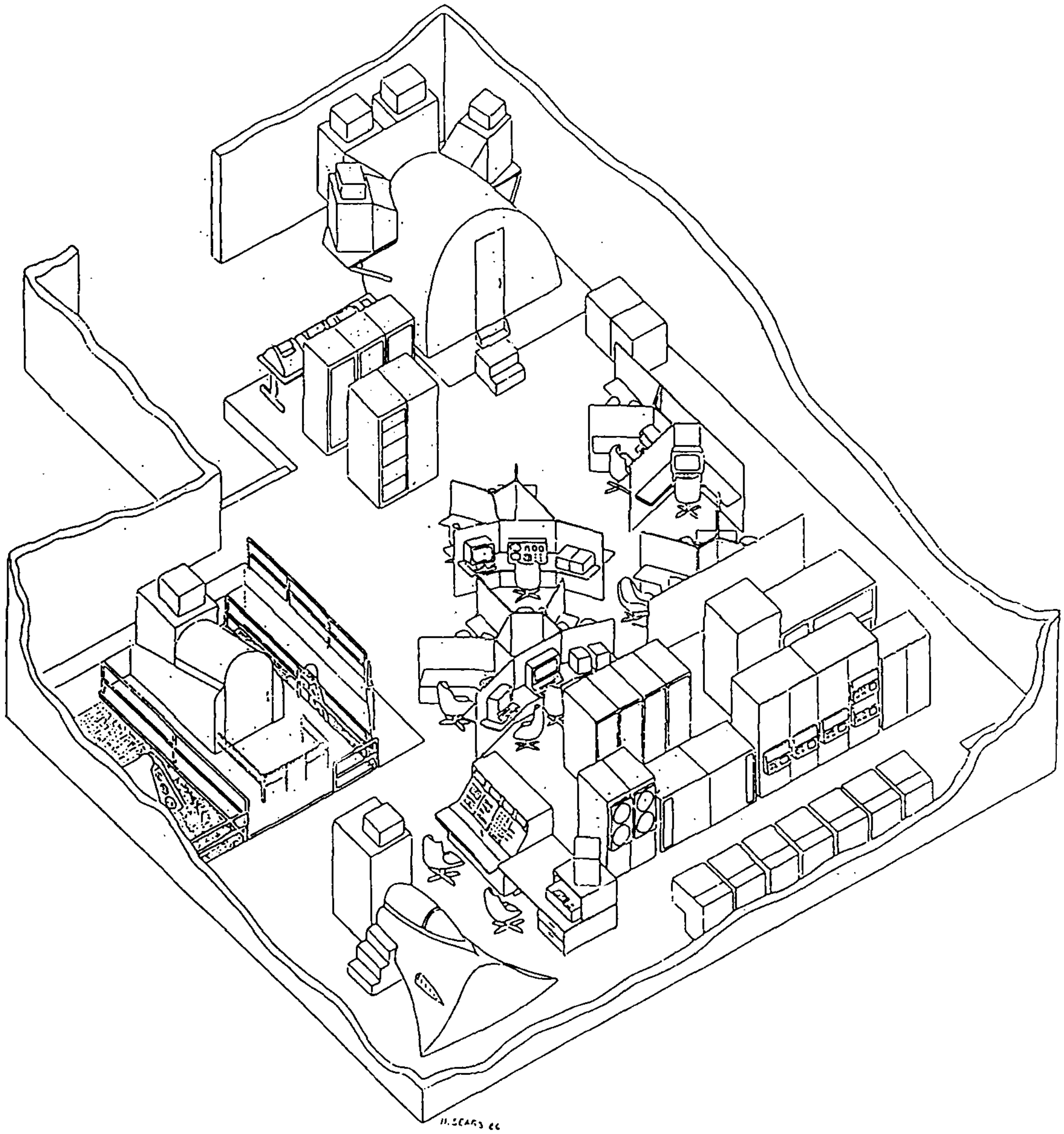

Figure 1. Crew Station Design Facility simulator area

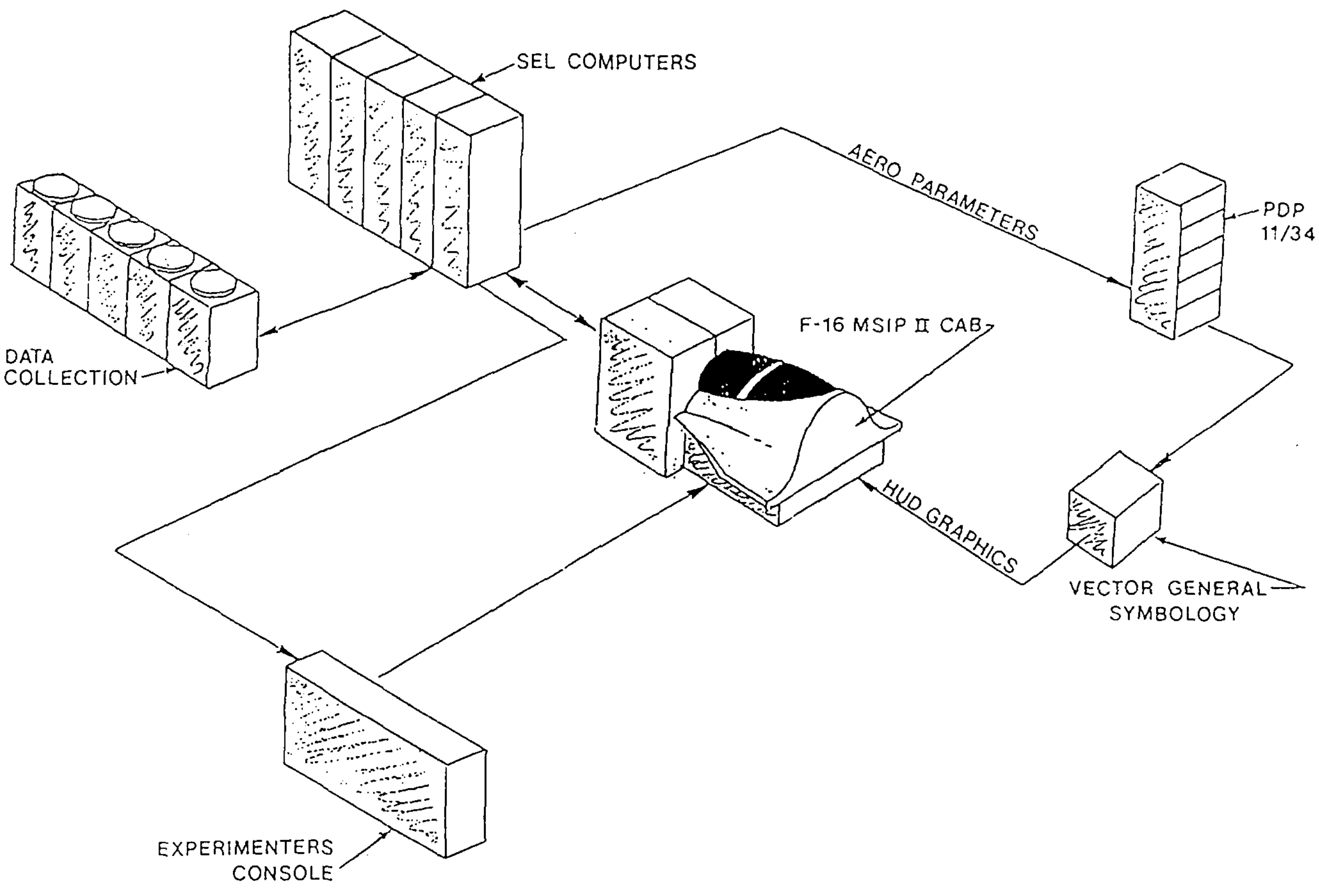

Figure 2. Schematic of the F-16 simulator

being evaluated in this study are independent of any particular cockpit design.

Computer Complex. The simulator is connected to a series of large and small computer systems. This computer complex includes five Gould series 32/7780s, one Gould concept 32/8780, two PDP 11/34s, three PDP 11/35s, and two Silicon Graphics Iris 2400 Computer Aided Design (CAD) stations. The aft section of the simulator, the area formerly occupied by the fuel cells, now contains the microprocessor racks which encompass the Advanced Simulator Technology (AST) interface. The microprocessors operate the controls and displays, while two fifty pin ribbon cables connect the simulator to the mainframe computers which perform the aerodynamic calculations. The combination of F-16 real and simulated instrumentation, the fully operational controls and displays, the realistic visual system and HUD, and the actual cockpit, work together to create a high fidelity replica of the F-16 cockpit. THe aerodynamic model is the same one that is used for aircrew training, and its validity has been demonstrated in a number of prior experiments.

Experimenter's Console. The experimenter's console is located approximately ten feet away from the simulator. It includes a complete intercom system, together with communication to and from the pilot inside the simulator. The console's displays duplicate the pilot's visual scene, HUD, Data Entry Display, MFDs, and the center console color CRT. These displays are used by the experimenter to observe and monitor the pilot's performance. Furthermore, the console's controls permit the experimenter to start, stop, and reset the simulation at any time.

DISPLAY DESCRIPTION

Following is a detailed description of the three display formats used in this evaluation. The three formats consist of the one currently proposed for use in the F-15E, a modification to this format that includes 'up arrows' in the lower (ground) hemisphere, and a three-dimensional perspective format. All three displays were driven by the same simulator attitude and heading reference sources. Similarly, performance parameters (airspeed, altitude, vertical velocity and angle-of-attack (AOA)) were the same on all formats. Navigation displays, such as the flight director steering bars and raw localizer and glideslope deviation indicators were not required, or shown in this evaluation.

The unusual attitudes flown in this evaluation were established using the autopilot system in the simulator. The autopilot would fly the simulator to the predetermined unusual attitude and freeze in that position until the EADI was selected for display by the subject. As such, the aircraft was trimmed for 1 g flight by the autopilot when the recovery was initiated by the subject.

Proposed F-15E EADI. This display, shown in Figure 3, consists of a blue sky/brown ground presentation displaying approximately 60 degrees of aircraft attitude at a time (+/- 30 degrees from the miniature aircraft). Pitch scaling is numbered in 10 degree increments from +/- 10 degrees to +/- 80 degrees of pitch. The bank scale, scaled to 60 degrees of left and right bank angle, is at the bottom circumference of the display with a ground pointer

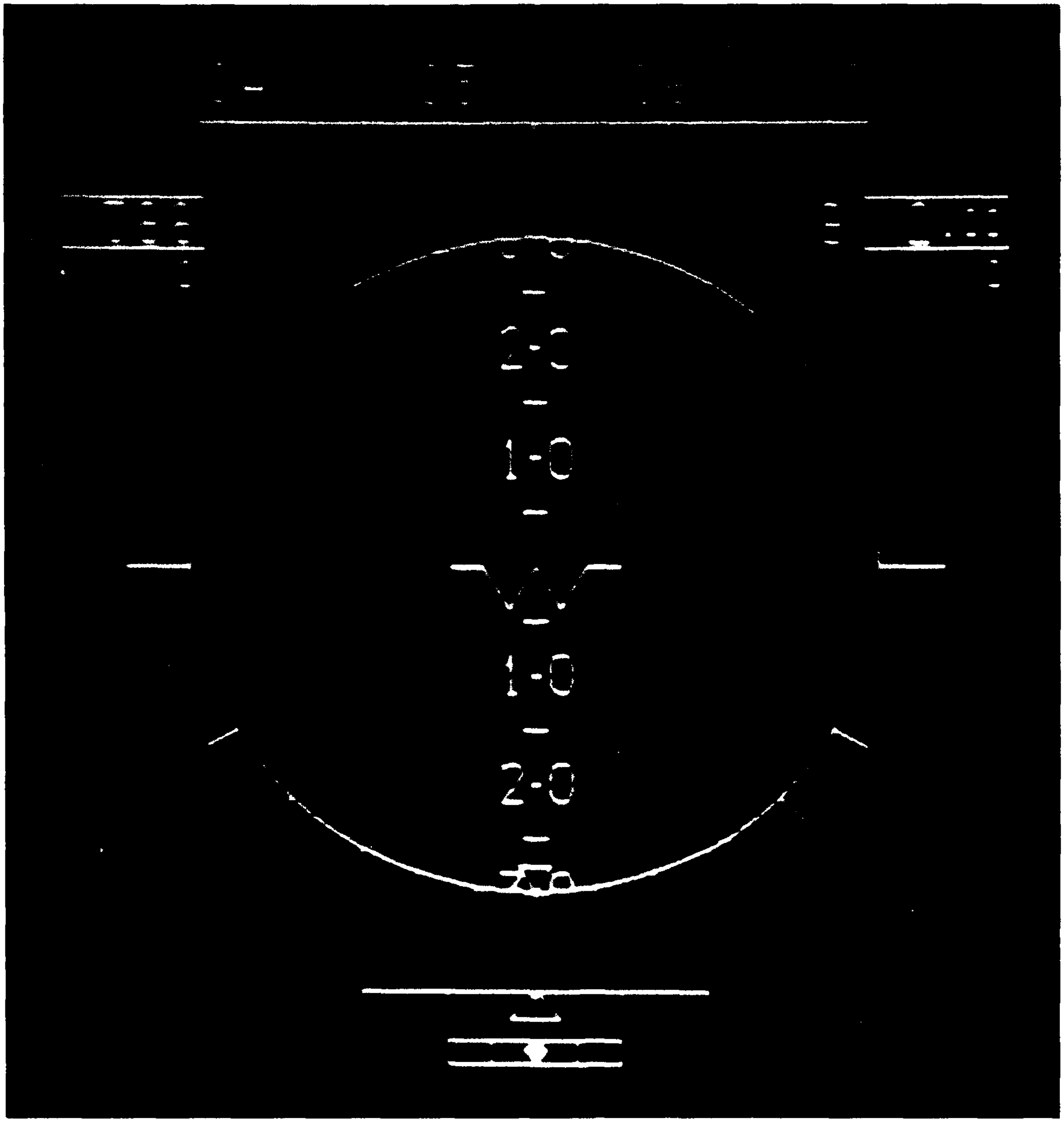

Figure 3. Baseline F-15E display

index.

Modified F-15E EADI with arrows. The modified display, shown in Figure 4, is the same as that described above, except that 'up' arrows have been added in the ground (brown) section of the display. The number of arrows shown at any given time varies with nose low pitch attitudes from ten in level flight to twenty at 30 degrees or more nose low. For nose high conditions, the number decreases from ten in level flight to zero at 25 degrees nose high.

Three-dimensional perspective. The three-dimensional display shown in Figure 5 displayed the same scales and blue sky/brown ground format as the other two displays but it presented a 180 degree perspective view of the attitude sphere. Arrows were shown in the ground (brown) portion of the sphere and were drawn in perspective as well. Pitch scale lines were displayed at 10 degree intervals around the sphere with numbers presented at +/- 30 and +/- 60 degrees. Unlike other classical electromechanical and graphic attitude displays, the 180 degrees of coverage left some portion of the sky and ground display visible at extreme pitch attitudes approaching the vertical. Only at +/- 90 degrees of pitch did the sky (blue) or ground (brown) cover the entire display surface. The number of arrows shown at any given time varies with nose low pitch attitudes from fifteen in level flight to thirty-six at 90 degrees nadir. For nose high conditions, the number decreases from fifteen in level flight to zero at 65 degrees nose high.

SUBJECTS

Twelve rated pilots and two weapon system operators took part in the

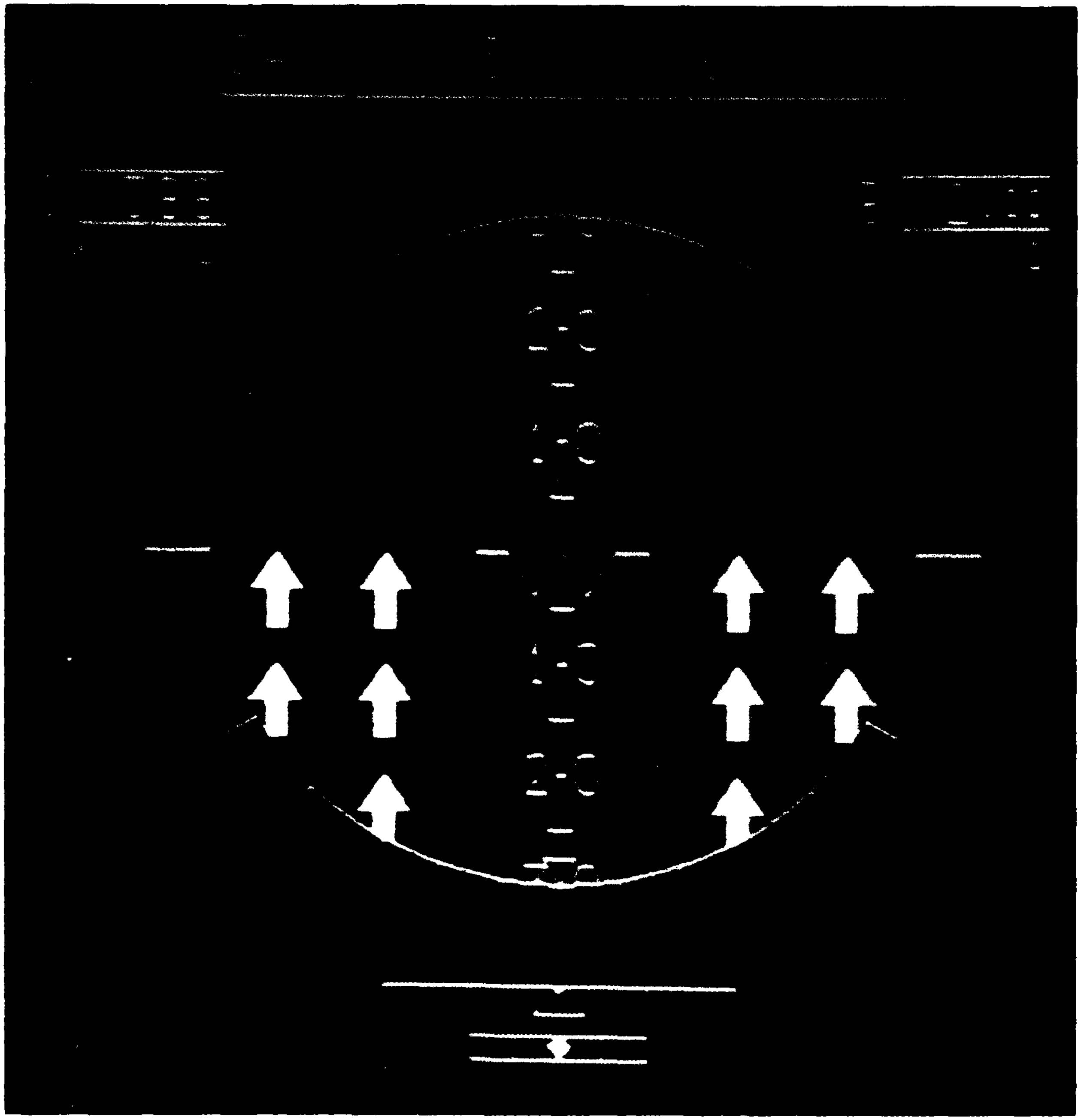

Figure 4. F-15E display with arrows

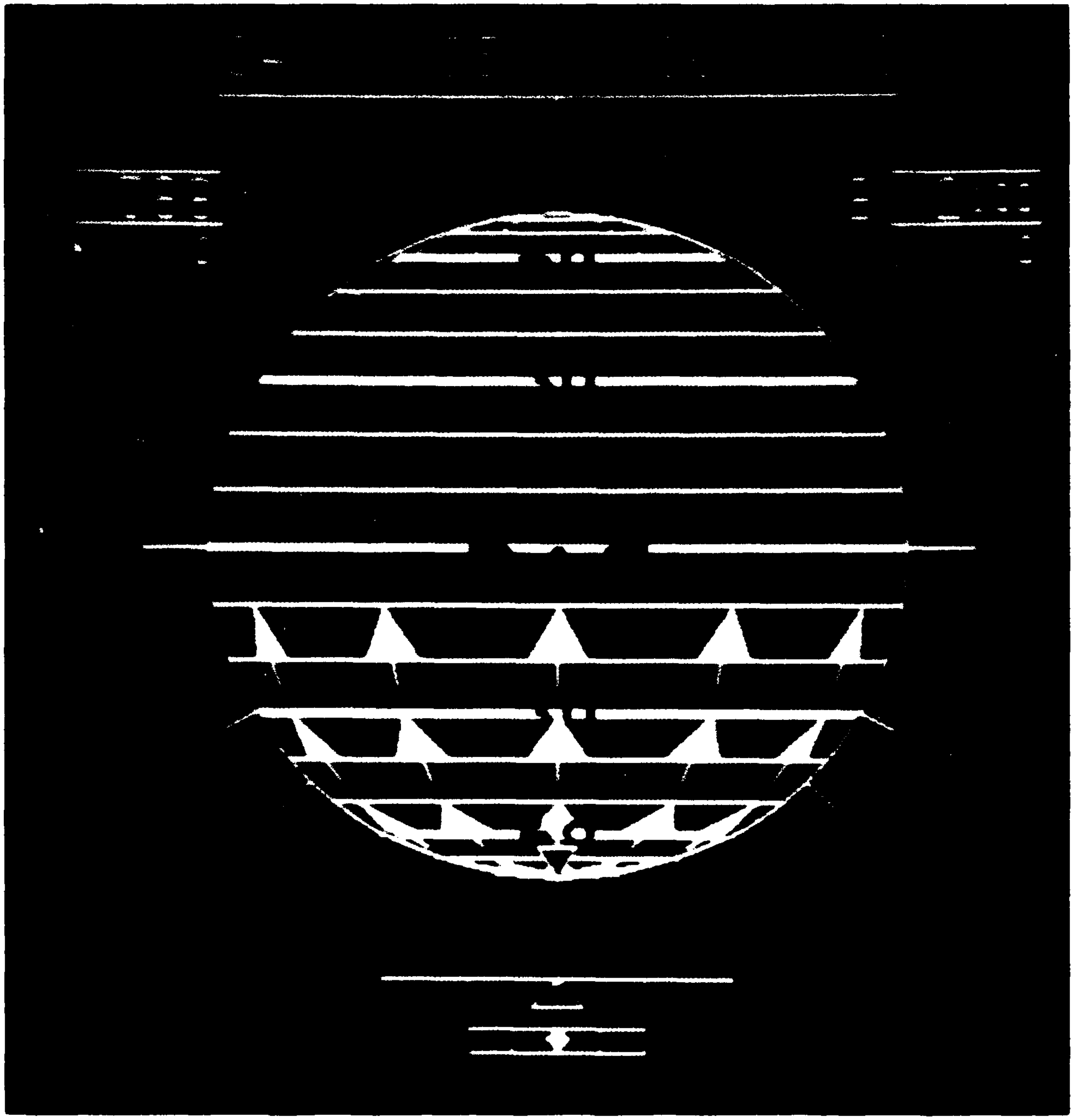

Figure 5. 180-degree FOV three-dimensional display

TABLE 1. Subject pilot flying experience.

Aircraft	Pilots	Hours
F-4	8(4)*	8650
F-15	2	1435
F-16	2	1650
F-111	1	660
A-7	2(1)*	1000
C-5	1	1700
C-141	1	750
Trainers	-	7894
Other	-	14408
Total	12	38317

Aircraft	WSOs	Hours
F-4	2(1)	2790
F-15	1	250
Total	2	3040

* Numbers in parentheses indicate the number of pilots who have flown more than one of the aircraft listed above (excluding trainers and other aircraft).

study. TABLE 1 shows their qualifications and flying experience. Pilot flying experience ranged from 960 to 7180 flight hours. WSO flying experience was not recorded.

EVALUATION PROCEDURES

Procedures were the same on all data flights. To avoid unnecessary distractions prior to and during recovery, the HUD was turned off in the simulator and the standby attitude indicator and horizontal situation indicator (HSI) were blanked. Additionally, during the time that the autopilot flew the simulator into the unusual attitude, the CRT displayed a stationary digital map such as might be in use in the F-15E.

Selection of the attitude display was accomplished by moving the F-16C display management switch (located on the flight control stick) to the down position. This switch is essentially the same in appearance and function as the display sequencing switch on the flight control stick in the F-15E. EADI selection by the pilot brought up the attitude display on the color CRT, started the simulation, and initiated objective data collection. The subject then flew the recovery to a straight and level atttiude. When the recovery was complete (+10/-5 degrees of pitch and +/- 10 degrees of bank), squeezing the trigger on the flight control stick stopped simulation, data collection, and called up the map display to allow positioning for the next recovery. In this way, 2-3 recoveries could be completed in approximately one minute. TABLE 2 is a listing of the pitch and roll attitudes used in the evaluation.

Preflight briefing. All personnel participating in the evaluation were given

TABLE 2. Attitudes evaluated

Pitch	Roll
0	0
0	60
0	-60
0	90
0	-90
0	120
0	-120
0	180
60	0
60	60
60	-60
60	90
60	-90
60	120
60	-120
60	180
-60	0
-60	60
-60	-60
-60	90
-60	-90
-60	120
-60	-120
-60	180

Each subject received each condition twice for each display for a total of 144 data runs per subject. Practice trials were flown for each display until the subjects demonstrated satisfactory performance and felt comfortable with each display and trial procedure.

the same briefing prior to data collection. This briefing covered a description of each display format and details on procedures to be followed during data collection.

Subjects were instructed to accomplish each recovery as they would in a fighter type aircraft. They were advised that the test was not a race against the clock but that they should consider energy management, realistic positive and negative 'g', and to attempt to minimize altitude gain or loss as they would in any air traffic management scenario.

To evaluate both the unusual attitude recovery potential for each display and the use of digital performance information, participants were briefed to complete the recovery to within +/- 5 degrees of pitch and roll attitude, then to make one attempt at maintaining level flight. This gave each evaluator the opportunity to use the attitude display, digital altitude and vertical velocity as they would be required to use them in a routine instrument flight context. During data reduction, it was discovered that all subjects did not recover to within the +/- 5 degree pitch and roll window that was requested before they terminated the simulation via the trigger switch on the flight control stick. With a +/- 5 degree pitch and roll window, a substantial portion of the data would have been lost. Consequently, the window was opened to +10/-5 degrees of pitch and +/- 10 degrees of roll (all subjects did recover to within this window).

Familiarization flights. Each display was flown briefly prior to data collection, first to allow each subject to become familiar with data collection procedures, and second, to allow them to become familiar with the display in all attitude flight conditions. This familiarization included from

2 - 10 recoveries and approximately 5 minutes of free flight time to become comfortable with the display. Performance data were collected and the display was monitored during familiarization to ensure that subjects received sufficient practice prior to their request to start data collection. After the subject advised that he was ready to start data runs, the simulation was set up for the scheduled sequence and the recoveries were started. The orders of presentation for the recoveries and display formats were counterbalanced and randomized with restrictions to preclude order, practice, and fatigue effects.

OBJECTIVE DATA

Dependent measures collected in this evaluation were decision time, recovery time, correct response, altitude gain and altitude loss. Objective performance data were gathered during each recovery.

SUBJECTIVE DATA

Subjective data collected in this evaluation were obtained from debriefings conducted subsequent to each simulator session, from pilot questionnaires completed after each session and at the end of the evaluation.

Debriefings. Subsequent to each series of evaluation runs, subjects discussed any problems they had or any features they liked as they applied to the display they had just flown. Included in this debriefing was a review of any observations made by the outside experimenter.

Subjective questionnaire data. During the debriefing sessions described above, a Modified-Cooper-Harper (MCH) rating scale questionnaire was completed for each display (Appendix A). Comments were also solicited for future reference when completing the end of evaluation (more comprehensive) questionnaire.

The end of evaluation questionnaire (Appendix B) was completed after all the runs and debriefings. This questionnaire addressed broader ADI issues and allowed the pilots to make comparisons of features on all three displays.

The MCH scale (Wierwille Casali, 1983) has been shown to be sensitive and useful across a wide variety of task types (Warr, 1986). The MCH scale was chosen in this study because of its ease of use, its non-intrusiveness on operator performance and its high degree of operator acceptance. Additionally, most of the subjects in this study were quite familiar with the MCH scale. The MCH data obtained in this study were analyzed using the analysis of variance procedure (ANOVA).

RESULTS

OBJECTIVE DATA

A 3 x 3 x 8 repeated measures ANOVA was performed on the data with EADI (3), pitch (3) and roll (8) as the three independent variables in the experiment. Dependent measures were decision time, recovery time, correct response, altitude gain and altitude loss. Decision time began with the onset of the EADI on the display (initiated by the subject via the display management switch on the flight control stick) and ended with the first stick input by the subject. Recovery time began with the first stick input and continued until the aircraft was recovered to within a +10/-5 degree pitch and +/- 10 degree roll window. Once the subjects had recovered to the window, (flagged by the computer), they were asked to take one shot at levelling the aircraft using the digital vertical velocity and altitude readouts located on the display. Correct responses (direction of the first control movement) recorded for the zero pitch and nose low attitude recoveries provided an accuracy measure for each display. The subjects' mean altitude (ft) differences relative to the initial release altitude were examined for the eight roll conditions with each of the three pitch attitudes, nose high, zero pitch, and nose low. The mean altitude change was positive for the nose high attitudes and negative for the zero pitch and nose low attitudes.

Pilot data were analyzed separately and then with the WSO data to determine if the WSOs' limited flying experience would influence the results. WSO performance was essentially identical to pilot performance, thus, the data presented herein reflect all 14 subjects used in the study. Figure 6 shows

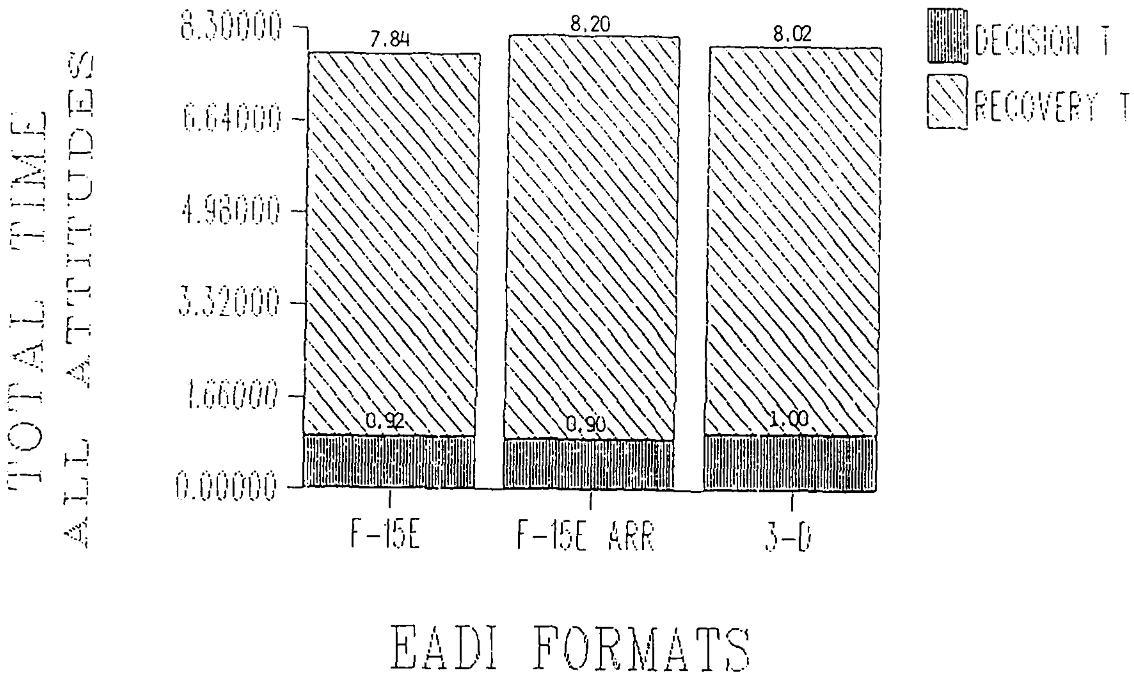

Figure 6. Total time for all attitudes evaluated

the total time taken (decision time and recovery time) for each of the display formats across all 24 attitude configurations. For decision time, the baseline F-15E (0.921 second) and the F-15E with arrows (0.902 second) were both significantly faster than the three-dimensional display (0.996 second), $F(2,26) = 5.6$, $p < 0.01$. The differences in recovery time (F-15E/6.922 versus F-15E with arrows/7.300 versus Three-dimensional/7.025 seconds) were not significant, $F < 1.0$. These data were then separated by pitch attitude (0, 55, and -55 degrees) and analyzed for significance. Figure 7 shows the decision and recovery times for the nose low conditions. For decision time, the F-15E with arrows required 0.889 second, followed by the baseline F-15E with 0.915 second, then the three-dimensional display (0.936 second). These results, however, were not significant at the $p = 0.05$ level, $F(2,26) = 2.3$, $p > 0.05$. Neither were the differences for recovery time (6.618 versus 6.665 versus 6.100 seconds, respectively), $F(2,26) = 2.8$, $p > 0.05$ for the nose low attitudes. The decision and recovery times for the nose high attitudes are shown in Figure 8. For decision time, the baseline F-15E (1.028 seconds) and the F-15E with arrows (1.000 second) were significantly faster than the three-dimensional display (1.182 seconds), $F(2,26) = 4.0$, $p < 0.05$. Again, recovery time was not significantly different (F-15E/11.387 versus F-15E with arrows/12.408 versus Three-dimensional/11.953 seconds, respectively), $F(2,26) = 1.4$, $p > 0.05$. Figure 9 shows decision and recovery time for the zero pitch attitudes. For decision time, the F-15E (0.820 second) and the F-15E with arrows (0.817 second) were both significantly faster than the three-dimensional display (0.871 second), $F(2,26) = 5.7$, $p < .01$. The differences in recovery time (2.761 versus 2.826 versus 3.021 seconds, respectively) were not significant, $F(2,26) = 1.7$, $p > 0.05$.

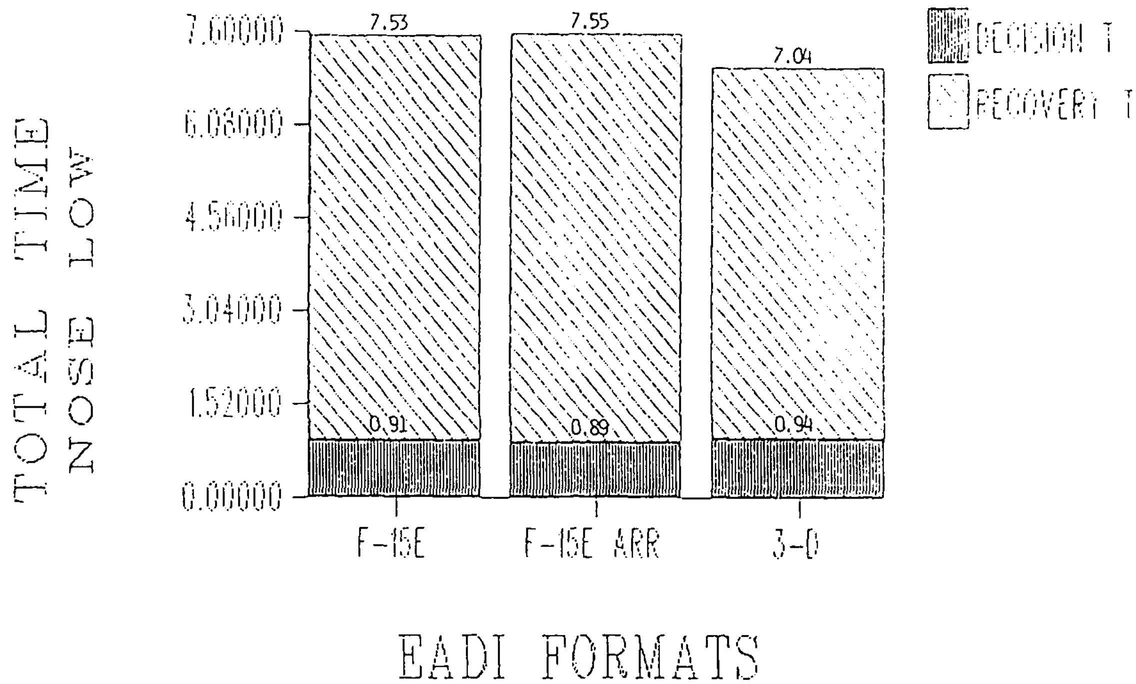

Figure 7. Total time for nose low attitude conditions

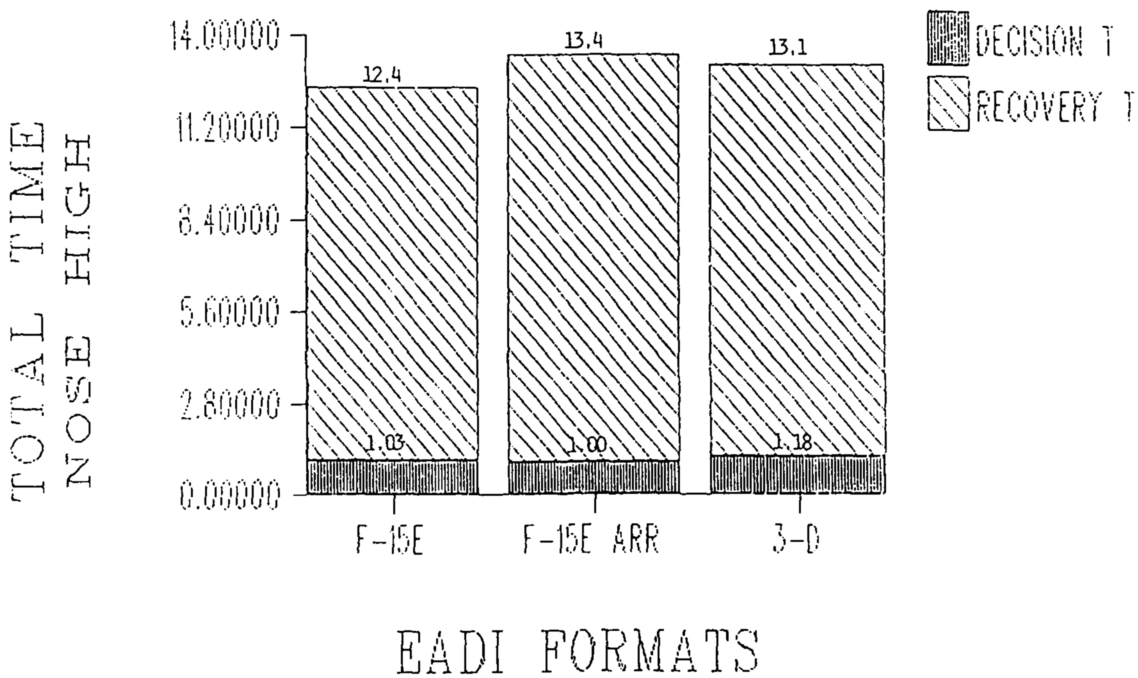

Figure 8. Total time for nose high attitude conditions

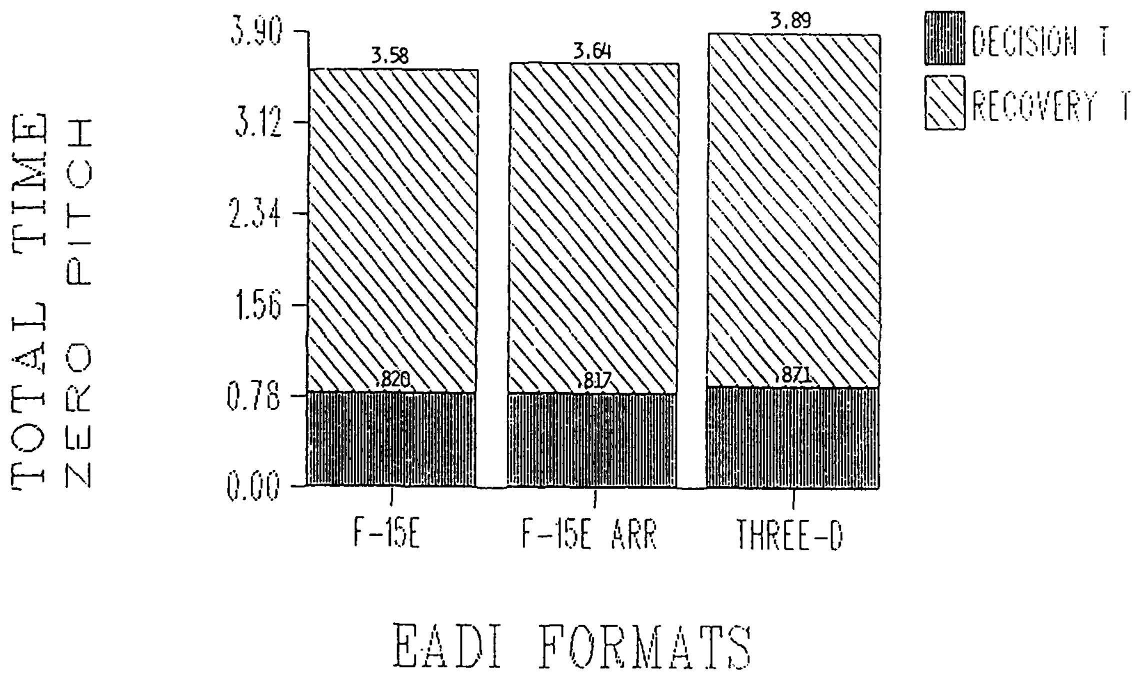

Figure 9. Total time for zero pitch attitude conditions

The accuracy data are depicted in Figures 10 and 11 for the zero pitch and nose low attitudes. The F-15E display with arrows provided the highest percentage of correct responses with 97% for the zero pitch condition (this display was not significantly different from the other two displays, see Figure 10) and 90% for the nose low condition (see Figure 11). Note that the F-15E display with arrows also resulted in the fastest decision times as seen in Figures 6 through 9. For the zero pitch condition, the baseline F-15E (94.9%) and the three-dimensional (95.5%) yield almost identical performance. Whereas, for the nose low condition, accuracy decreased to 84% for the three-dimensional display and 76% for the baseline display. For the nose low condition, only the F-15E display with arrows (90%) was significantly different from the baseline F-15E display (76%), $\underline{F}(2,26) = 5.2$, $\underline{p} < 0.01$. The three-dimensional display (84%) was not significantly different than either of the other two displays.

Altitude gain (nose high) data are presented in Figure 12 and altitude loss data are presented in Figures 13 (nose low) and 14 (zero pitch). For the nose high condition, altitude gain with the three-dimensional display was 2374 ft versus 2438 ft for the other two displays. For the nose low condition, altitude loss with the three-dimensional display was 4223 ft versus 4399 ft for the F-15E display with arrows and 4435 ft for the baseline display. In the zero pitch condition, altitude loss was -364 ft for the three-dimensional display versus -325 ft for the baseline display and -331 ft for the F-15E display with arrows. None of the findings for the altitude data were significant at the $\underline{p} = 0.05$ level of confidence.

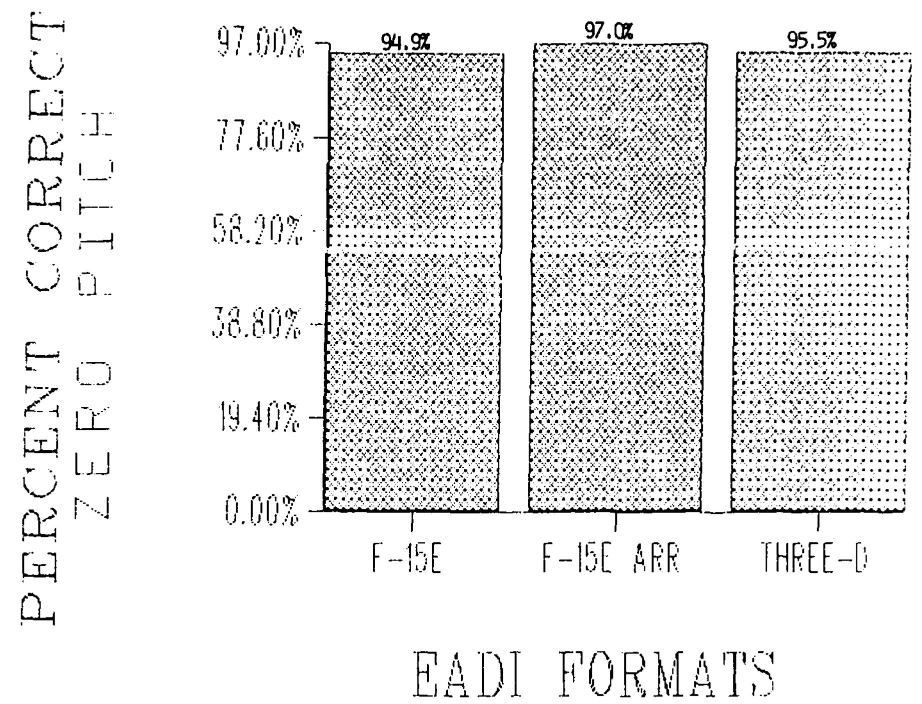

Figure 10. Percent correct for zero pitch attitude conditions

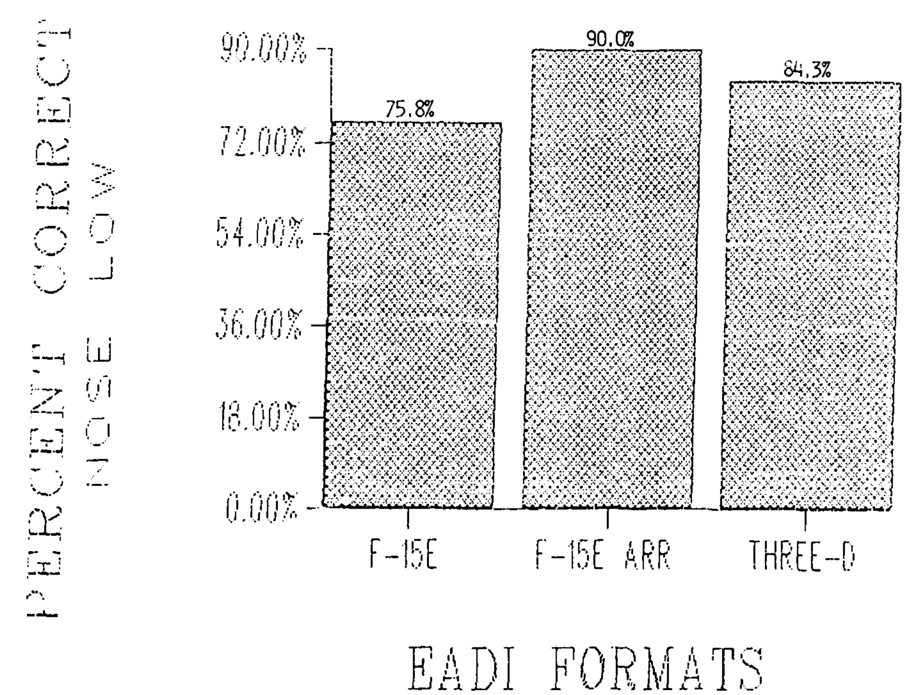

Figure 11. Percent correct for nose low attitude conditions

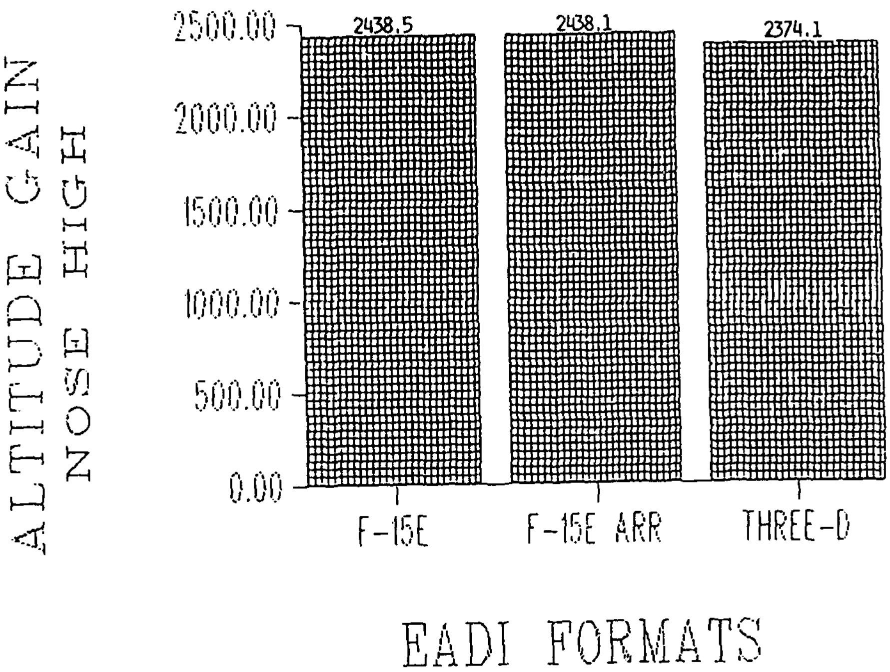

Figure 12. Altitude gain for nose high attitude conditions

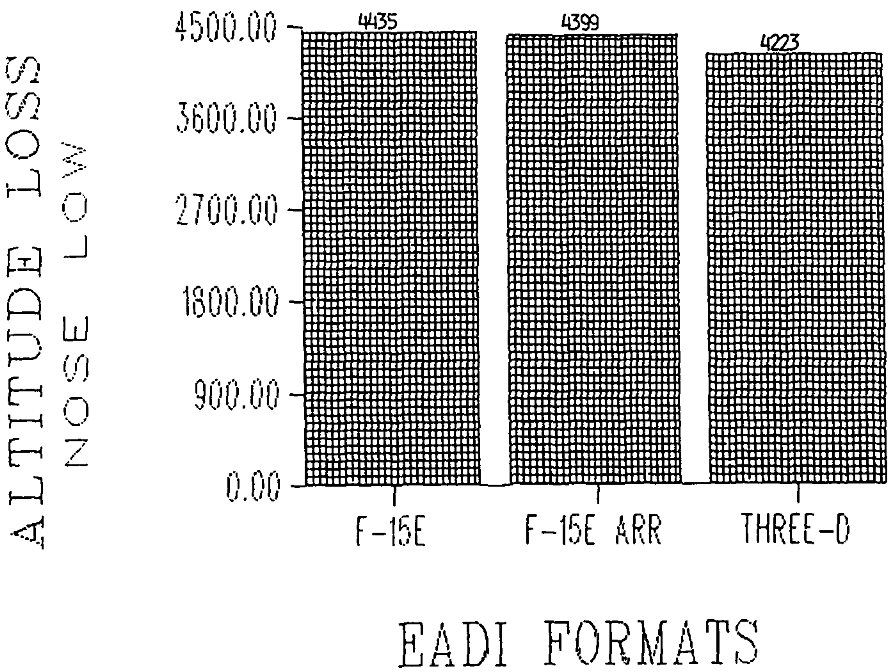

Figure 13. Altitude loss for nose low attitude conditions

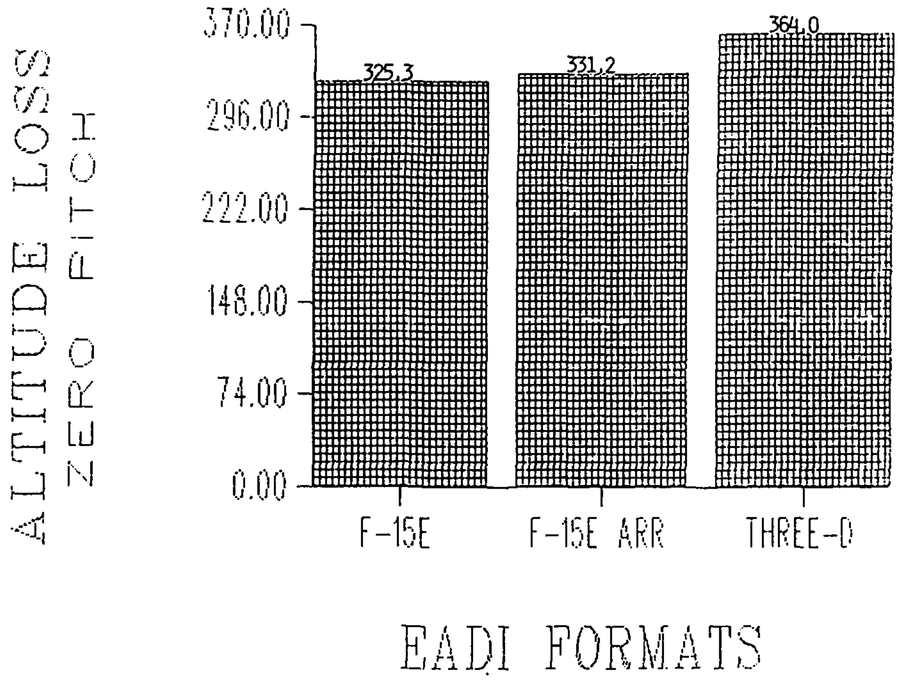

Figure 14. Altitude loss for zero pitch attitude conditions

SUBJECTIVE RATINGS

Modified-Cooper-Harper Ratings. MCH ratings were given for each display for nose high and nose low attitude conditions. Overall, the three-dimensional display was rated as the most desirable display (MCH rating = 1.821), followed by the F-15E with arrows (2.518) and the baseline F-15E display (2.964). (See Figure 15 for a description of the Modified-Cooper-Harper ratings.) The MCH ratings were subjected to ANOVA and the three-dimensional display was found to be significantly more desirable than the other two displays (See Figure 16), $F(2,26) = 5.9$, $p < 0.01$. The data were then separated by attitude condition and analyzed. For the nose high ratings (Figure 17), the three-dimensional display (1.857) was again found to be significantly more desirable than both the baseline F-15E display (3.143) and the F-15E display with arrows (2.893), $F(2,26) = 6.2$, $p < 0.01$. But for the nose low ratings (Figure 18), while the baseline F-15E display (2.786) was still found to be significantly less desirable than the three-dimensional display (1.786), $F(2,26) = 5.2$, $p < 0.01$, the F-15E display with arrows (2.143) was not found to be significantly different from either of the other two displays.

MCH ratings were also given for the digital vertical velocity, altitude, and airspeed displays. For recovery and level flight, the digital vertical velocity was rated 7.0 The digital altimeter was rated 6.3 for recovery and 5.2 for level flight. The digital airspeed was rated 3.8 for recovery. Digital airspeed was not rated for level flight as there was no requirement to maintain airspeed.

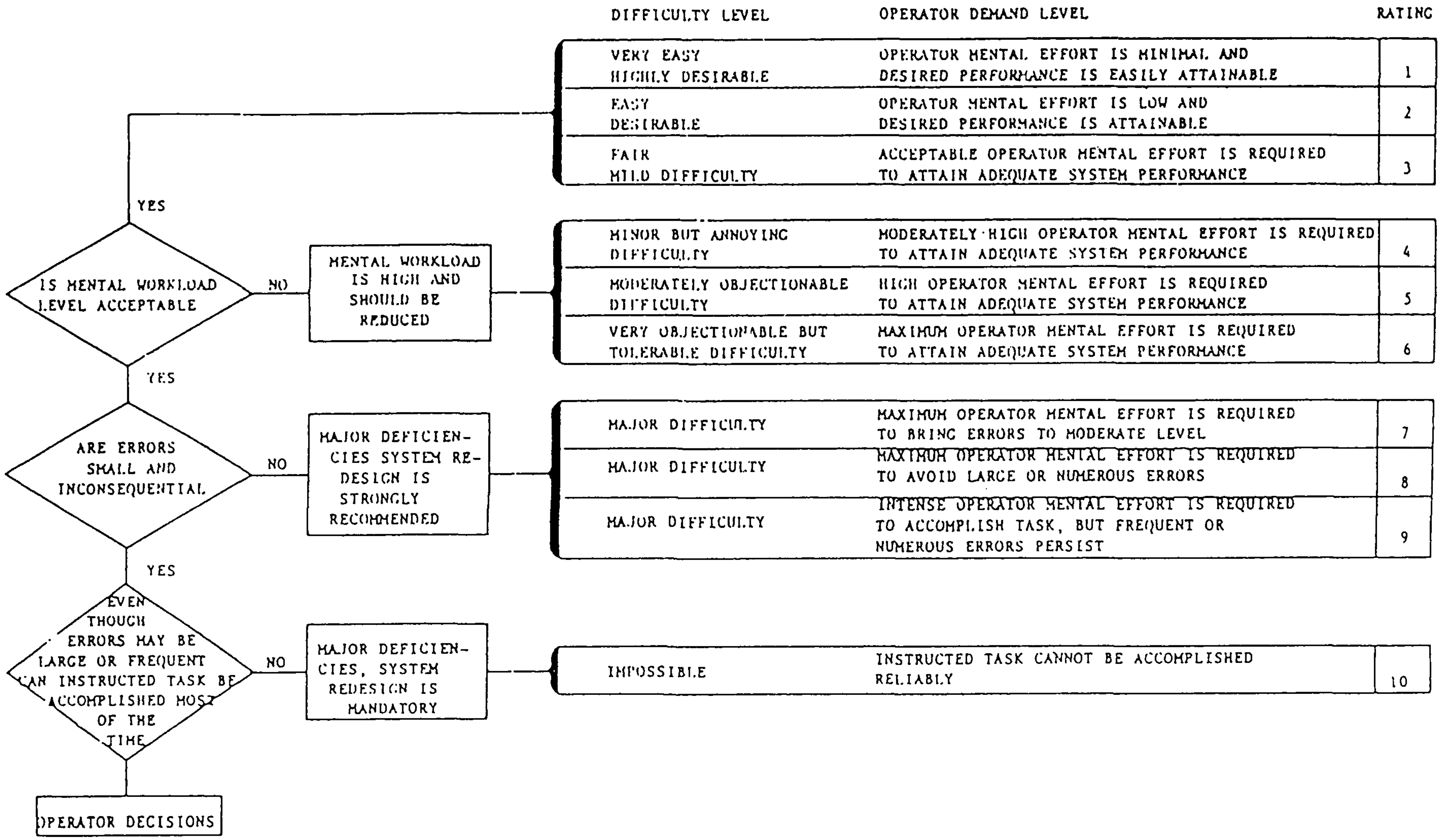

FIGURE 15. Modified Cooper-Harper Rating Scale

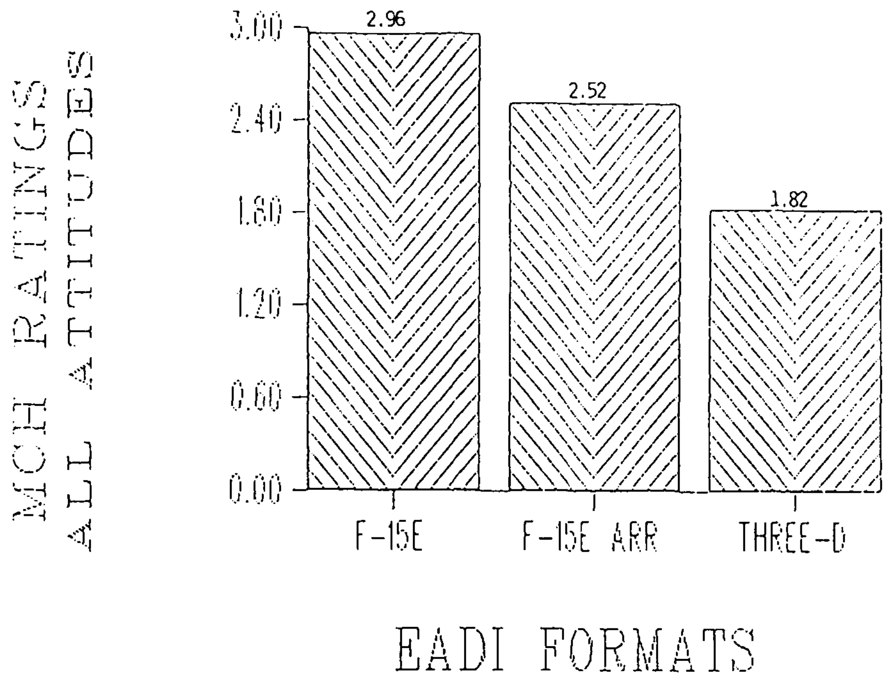

Figure 16. MCH ratings for all attitudes

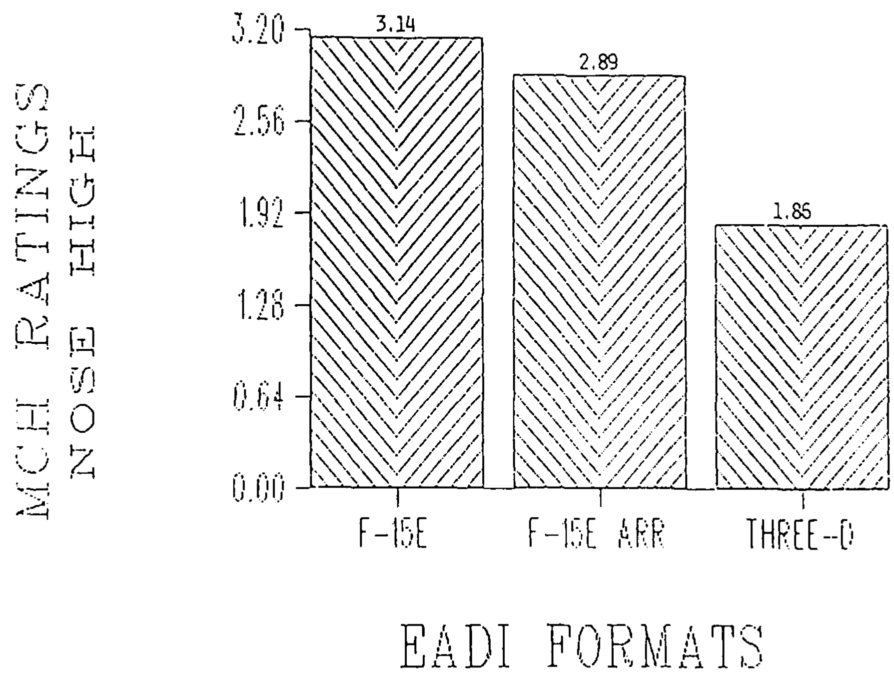

Figure 17. MCH ratings for nose high attitude conditions

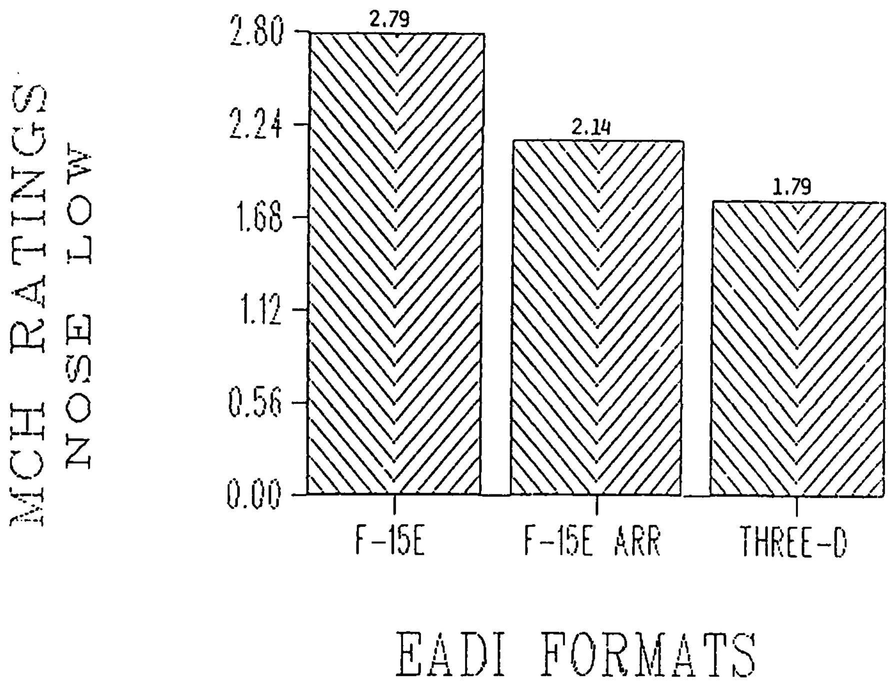

Figure 18. MCH ratings for nose low attitude conditions

SUBJECTIVE QUESTIONNAIRE DATA

At the completion of the experiment, all 14 subjects responded to a questionnaire which was designed to address the particular topics covered in the study. The following paragraphs briefly summarize the pilots' responses and comments from the questionnaire data. A copy of the questionnaire can be found in Appendices A and B.

Display Preference. Seven out of 14 subjects preferred the three-d display; five preferred the F-15E with arrows; 1 preferred the baseline; and 1 reported a toss-up between the two arrow displays.

Field-of-view versus arrows. Eight out of fourteen subjects preferred the increased field of view provided by the three-dimensional display. The other six selected the arrows as the most important feature.

Baseline F-15E display. When asked what features they liked most about this display, three subjects indicated the color of the display and three subjects mentioned the readibility and simplicity of the display. Other individual comments included the expanded pitch scale (more precise attitude control); less clutter; easily recognizable pitch and bank; and the ground pointer is always a ground pointer. Conversely, two reported that they did not like the display at all; two reported that the ground pointer is not easy to see against the color of the ground and the pitch numbers; two reported that the narrow field of view makes it difficult to tell up from down; two reported that there are no easily distinguishable sky/ground pointers; one reported that it is a flat display with little rate information; one reported that only the color differentiates between up and down while the numbers differentiate between upright and inverted; and another stated that it does not have good references at large positive or negative pitch angles.

F-15E with arrows. When asked what features they liked most about this display, thirteen subjects reported that the arrows really help to identify the nose down attitude and the required roll direction; one individual commented that it eliminates the processing problems associated with the baseline F-15E display. Conversely, one reported that the sky pointer arrows are distracting and confusing; two reported that there are no ground arrows for nose high attitudes; 4 reported that there are too many sky arrows which causes a distraction from the pitch values; and two reported that the narrow field of view makes it hard to get oriented.

Three-dimensional display. When asked what features they liked most about this display, thirteen out of fourteen pilots indicated the large field-of-view was a positive feature. Some of the comments were: this display provides an excellent perception of aircraft attitude; it is intuitive/there is constant situation awareness; it has a better big picture ability instantaneously; there is better situational awareness and ease of use for unusual attitude recoveries; it provides excellent visualization of aircraft attitude in relation to external reference planes; pitch attitude is instantly recognizable; good attitude information remains at very low light levels; this display makes large pitch attitudes (positive and negative) much easier to handle; and the horizon is almost constantly in view - easy to determine where horizon is even when it is out of view. When asked what features they liked least, five subjects reported that fine pitch adjustments were more difficult; one reported it takes longer to get used to the display and interpret information; three reported that bank information is poor and hard to interpret at high bank angles; three reported that the black numbers and aircraft pitch reference symbol had poor contrast and were hard to use (white could not be used because of the conflict with the white arrows); three reported there were too many arrows (arrows tended to predominate and fill up the display, drowning out the artificial aircraft); one reported that the nadir symbol was confusing with arrows pointing in every direction; two reported that it should have translated about the horizontal axis, i.e., a 3-axis attitude indicator; and one reported that it does not give the pilot the sense of 'urgency' that the ground is coming up fast (when nose-low).

DISCUSSION

OBJECTIVE DATA

The results of this evaluation show that the F-15E display with arrows yielded the fastest and most accurate responses for unusual attitude recovery. Although decision times for the F-15E display with arrows were not significantly different from the baseline display, accuracy with the baseline display was significantly poorer. This finding suggests that sky pointer arrows can facilitate decision making judgments during recovery from unrecognized unusual attitudes.

Figure 7 shows the total time taken to recover from nose low pitch attitudes. The half-second difference shown in Figure 7 between the three-dimensional display and the other two may be due to the larger field-of-view of the three-dimensional display. Although the three-dimensional display had the longest decision times (both nose-low and especially nose-high), there was also an interesting trend in performance in the nose-low and nose-high conditions relative to minimum altitude loss (and gain) with the three-dimensional display (See Figures 12 and 13). Although altitude mean differences were not significant at the $\underline{p} = 0.05$ level in this experiment, i.e., statistically they were the same, the means should be considered relevant because they were at a minimum with the three-dimensional display despite significantly slower decision times. This trend, i.e., slow but still more effective in minimizing altitude gains and losses, was attributed to the display's ability to provide the big picture instantaneously. The situation awareness provided by this display allowed pilots to perform the most efficient recovery, despite the slower decision times. Observations during the experiment indicated that pilots more often pulled and rolled simultaneously with the three-dimensional display, as opposed to rolling almost wings level before pulling, as was primarily the case with the other two displays. If two of the proposed modifications to this display were incorporated (i.e., reduce the number of arrows; and change the contrast of the numerals and aircraft reference symbol), and several hours of training provided to allow the pilots to become intimately familiar with this type of display, decision time should decrease thus resulting in a significant improvement in altitude performance. The poor altitude performance in the zero pitch condition might best be summarized by one of the pilot comments made in the questionnaire: "This display does not give the pilot the sense of urgency that the ground is coming up fast." In the zero pitch conditions, coupled with the low pitch resolution of the 180 FOV, pilots were probably not as sensitive to a minor pitch low condition and thus not concerned with altitude performance in zero pitch conditions.

SUBJECTIVE DATA

EADI Displays. Figure 17 shows the MCH ratings for the nose high pitch conditions. The three-dimensional display was rated significantly more desirable than the other two displays in the study. This was most likely due to the difference in fields-of-view. In the nose-high conditions, the two F-15E displays were physically identical to each other. The fact that the ratings for the F-15E display with arrows were a little lower than the baseline F-15E display was probably due to the subjects' knowledge that this display had the sky pointer arrows present below the horizon. These arrows would come into view as the pitch decreased to less than 30 degrees nose high. However, in the nose-high conditions, the horizon was always present in the three-dimensional display.

In the nose-low conditions, subjective ratings for the F-15E display with arrows were substantially better than the baseline F-15E display (see Figure 18). Although the drop was not significant, the difference between the ratings for the two displays, as compared to the difference in the nose-high conditions, suggests that the arrows were what influenced the ratings. Again, the three-dimensional display was rated significantly more desirable than the baseline F-15E display. However, the three-dimensional display was not significantly different from the F-15E display with arrows. This was not expected, especially since the horizon is always in view with the three-dimensional display, thus contributing to better situation awareness. This result might best be explained by the fact that 6 of the 14 subjects selected the arrows as a more important feature than the 180 degree field-of-view (see Results section, Field-of-view vs arrows).

The results from the MCH ratings and the questionnaire data indicate that the pilots definitely prefer the sky pointer arrows over the baseline display format. With a few modifications, both of the displays with arrows (the F-15E display with arrows and the three-dimensional display) have a lot of potential for use in military aircraft with electronic attitude displays.

Pitch scaling. Several pilots commented on the relatively compressed pitch scale on the three-dimensional display. The scale, of course, had to be compressed to show the full 180 degree picture in the available viewing area (a 5-inch display was used). The fact that three-dimensional perspective was used, however, expands scaling in the area of the miniature aircraft and compresses it near the top and bottom of the display. This expanded scaling in the center of the perspective display may not have been as noticeable as the difference in field-of-view between the perspective (180 degrees) and the other two displays (60 degrees).

Problems with scaling do exist if the display is used in context with the fundamental principles of precision instrument flight in an IMC environment. Additionally, these problems are exaggerated by the fact that the digital vertical velocity display is essentially useless as a supporting display parameter for achieving and maintaining level flight or for achieving and maintaining any given rate of descent. Overall, we feel that the scaling problem will be greatly diminished by the presence of a flight path marker on the EADI, an analog flight path scale or vertical velocity scale presented on the same CRT display but adjacent to the EADI format.

Arrows. Several comments were made with regard to the number of arrows shown in extreme nose low attitudes. In both displays incorporating this feature, as many as 18 (for the F-15E display with arrows) or 27 (for the three-dimensional display) could be in view at approximately 60 degrees nose low. More concern was shown with the three-dimensional format because as the number of visible arrows increased, they began to point left, right, and even down. With very little practice, however, evaluators found that this became much less of a problem; but some initial concern was noted and reported. Probably 50 percent of the arrows could be removed from both displays without adversely affecting display utility.

Digital Displays. Performance parameters of airspeed, altitude, and vertical velocity were displayed in digital format on all three displays evaluated. Past experience in the use of similar displays has shown that this information is difficult to use in digital form due to the lack of useful trend information. When used in context with precision instrument flight, digital displays might increase pilot workload. The MCH ratings obtained during this evaluation, and described in the Results section, substantiate the concern in this area. The ratings for the digital vertical velocity, airspeed, and altitude indicate that the digital format is not desirable for use in unusual attitude recoveries. Rate information, which is not available in the digital format, is very desirable for use during recoveries and maintaining level flight. The fact that the digital airspeed was rated better than the other two digital displays was probably due to either infrequent use during each recovery trial (there was no requirement to maintain airspeed during the recovery task) or because airspeed changes more slowly than altitude and vertical velocity.

CONCLUSIONS

The objective data gathered in this experiment suggest that sky pointer arrows help during recovery from unusual attitudes. Although decision times for both arrow displays were not significantly lower from the baseline F-15E display, there was a significant improvement in correct responses at nose low attitudes, a critical factor in unusual attitude recovery, especially at low altitudes. Although results with the three-dimensional display were not conclusive, it is evident that it has a lot of potential, given altitude loss and altitude gain were less for the nose low and nose high conditions, respectively, despite significantly longer decision times. This finding of a more efficient recovery suggests that situation awareness and the ability to recover from unusual attitudes is enhanced by a display where the horizon is essentially always in view (180 degree field-of-view). The subjective data supports this conclusion. Note also that the Swedish have already incorporated sky pointer ADIs in some of their military aircraft (Frieberg and Holmstrom (1986)).

Specific conclusions are:

1. The subjects in this study preferred the three-dimensional display, but recommended at least two modifications, fewer arrows and white pitch numerals/aircraft reference symbol. Figures 19-20 show the display with these modifications incorporated. For the F-15E display with arrows, it was commented that all the arrows in a row and the same length were confusing. When nose low and inverted, the arrows tended to blend together. Figure 21

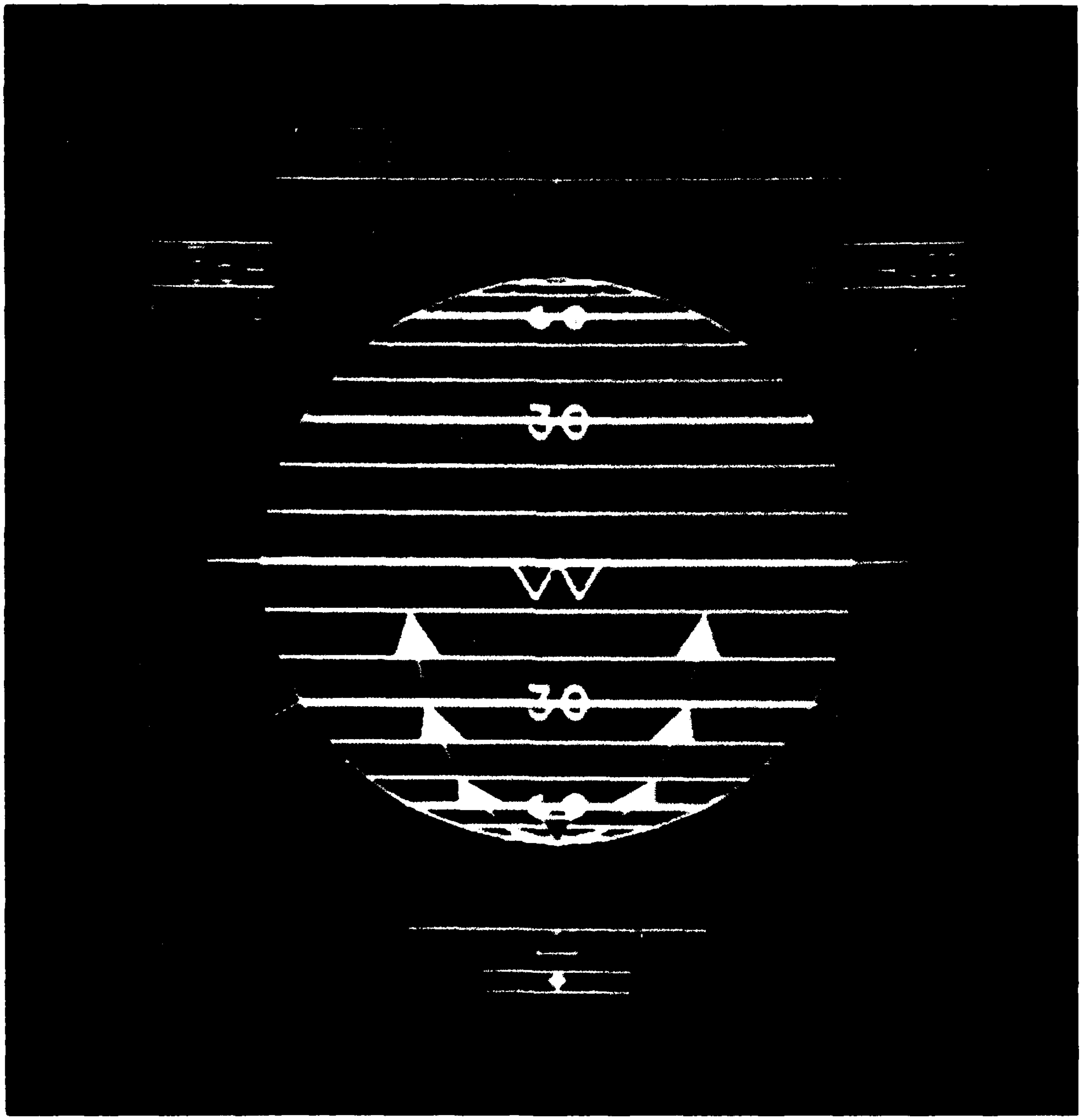

Figure 19. Modified three-dimensional display in wings level attitude

Figure 20. Modified three-dimensional display in nose low attitude

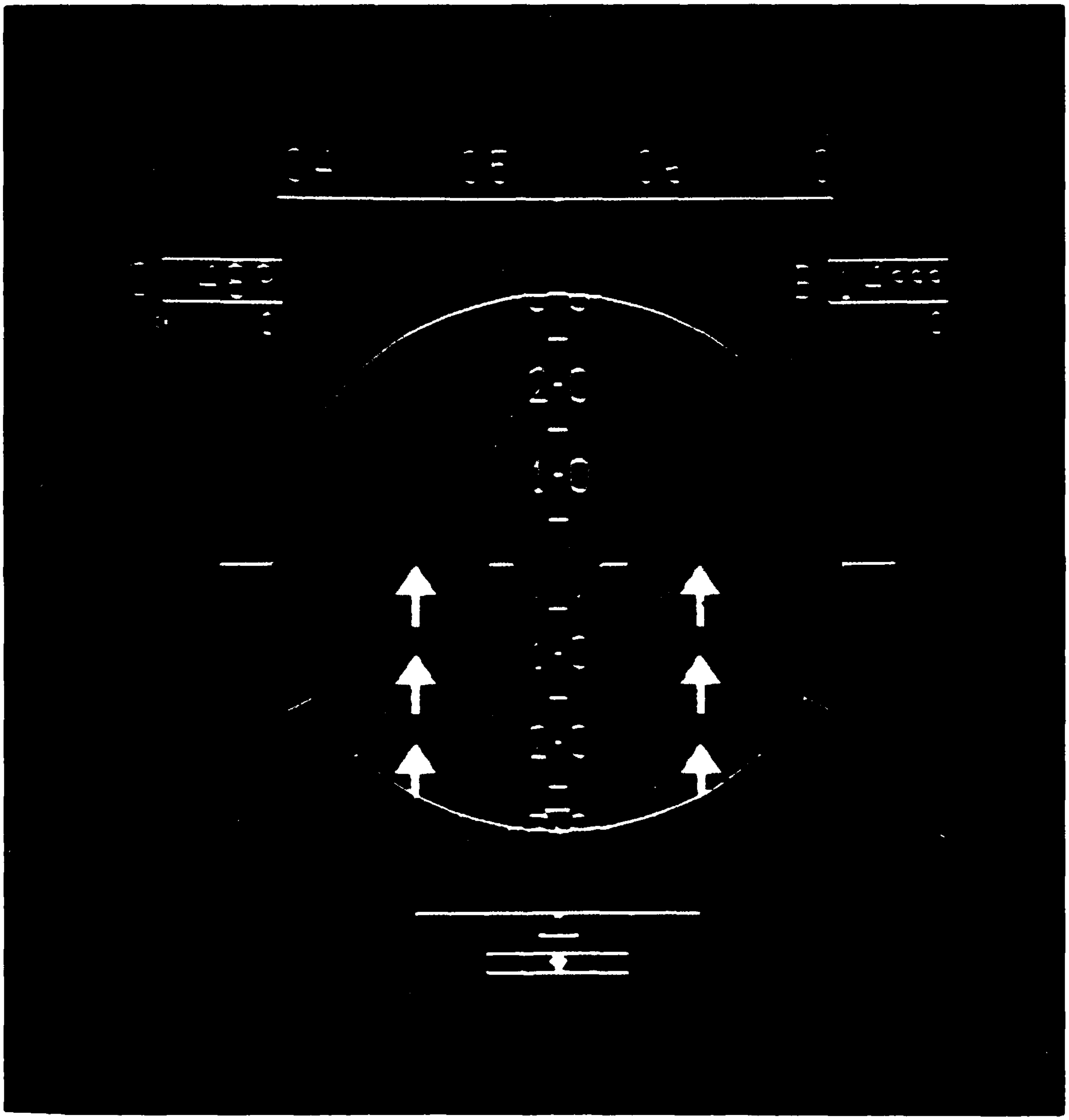

Figure 21. Modified F-15E display with fewer arrows

shows a modified display with 2 rows of arrows instead of 4 rows and the stems of the arrows have been thinned to make the arrowheads more prominent.

2. The arrows and the increased field-of-view benefit recovery/attitude awareness.

3. Digital vertical velocity and altitude were not liked for unusual attitude recoveries. It was suggested that a flight path marker, flight path scale or vertical velocity scale would improve the EADI displays. McAir plans to incorporate a flight path marker on their proposed F-15E display. This mechanization should be evaluated in all phases of flight to ensure that new problems are not introduced with a dual reference (aircraft reference symbol and flight path marker) attitude display.

4. It should be noted that the addition of sky pointers to an electronic attitude display will require new techniques for unusual attitude recovery. Specifically, for nose high attitudes, a recovery technique using a ground pointer will be the opposite of nose low recovery techniques with sky pointers. In this case, pilots should be trained to use the pitch numbers in nose high recoveries and to use the ground pointer only as an index for the bank scale during routine flight maneuvers.

RECOMMENDATIONS

1. Encourage development of a three-dimensional 180 degree FOV capability for the F-15E cockpit.

2. Conduct additional research to optimize both of the arrow displays. Specifically:

a. Consider expanding the field-of-view of the current F-15E display (about 110 degrees) and implementing it as an unusual attitude recovery indicator. This display would be used in addition to a reduced field-of-view EADI display which could be used for landings, etc., where precise pitch control is necessary. These two displays could be preprogrammed as a function of phase of flight with the other display available as a secondary choice, if necessary.

b. Improve the miniature aircraft reference symbol and pitch numerals on the three-dimensional display.

c. Reduce the number of arrows on both displays.

d. Look at a 3-axis three-dimensional 180 degree FOV display.

3. Consider the problem of interpreting a blue/brown color display when display illumination is at very low levels. This color scheme could be very difficult to interpret in nighttime viewing conditions. The addition of sky

pointer arrows below the horizon should be considered immediately for the baseline F-15E display. This would aid the pilot in recognizing nose low attitude conditions when the display is at low illumination levels.

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APPENDIX A

MCH RATING SCALE QUESTIONNAIRE RESULTS

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In terms of pilot workload, please rate (using the MCH scale) the baseline F-15E EADI in its application to:

a. Nose-high attitude recoveries

Rating: 3, 4, 1, 4, 2, 1, 4, 5, 2, 3, 3, 3, 3, 6

b. Nose-low attitude recoveries

Rating: 3, 5, 1, 4, 2, 1, 5, 4, 1, 2, 4, 1, 2, 4

Comments:

Subject #1. I rated this slightly lower than the other two because in a purely inverted position, it took a moment to decide which way was up. The arrows on the other displays help, but I think there are too many, esp. on the 3-d display. One or two are fine. The ones off center on the 3-d display seem to detract a little bit.

Subject #2. Worst case is at the extremes of the pitch scale when you can not see the horizon displayed. I find I have to read the pitch numbers (where aircraft is at), see which way is lower number and roll or pull as appropriate to recover. I question what effect, extreme lighting conditions play. For example, if I have been using EADI as primary instrument, I can readily tell that brown is down and blue is up. When I have to come to EADI as primary 'recovery' instrument, I must be able to tell which color I have, and how far down/up I have, and then recover.

Subject #3. Using the numbers on the nose low recoveries helps orient yourself and the ground pointer is always the ground pointer. There is no confusion between sky and ground pointers. Both nose high and nose low easy to recognize and use.

Subject #4. Extreme attitudes, both high and low took a second or so to determine which way to roll. It took 'cognitive' time to interpret which way the numbers would be smaller when there was no ground or sky to contrast with when the display was all blue or all red (no horizon line). On one occasion I rolled the wrong direction before I figured it out (nose high). I must admit, however, that I did not use the ground pointer on any recovery. It probably would have helped determine which way to roll.

Subject #5. No comments.

Subject #6. Had no problem immediately seeing where I was relative to the horizon using both color and number orientation. The brown 'earth' and horizontal lines worked well but there was some hesitation effect, like my eyes took longer to focus. Nose high, no problem with the light blue.

Subject #7. Either nose high or nose low, when at extreme attitudes (horizon not visible) it takes concentration to tell the attitude. This extra concentration caused me to several times, delay proper power/drag usage. The bank steering arrow (in this case, a ground pointer) is too small to be useable for immediate orientation. The only method to tell attitude is to look at the digits for pitch attitude and judge whether they are right-side up or upside down - not desirable for immediate warm fuzzies. This indicator was much easier (as compared to the 3-d) to use for precise instrument flying - due to the expanded pitch scale with 5 degree ticks.

Subject #8. Same comment on digital readouts as indicated on 3-d questionnaire. At low pitch attitudes, high contrast around horizon with blue sky makes orientation easy. Nose low - I miss the arrows. You must read numbers at steep nose low attitudes to know which way to maneuver - just like steep nose high attitudes. The red lines help determine wings level. Nose high - GRIM as with F-15E display with arrows - Same comments. Orientation is more difficult, especially at large + or - pitch angles with small angular coverage of display with no lines of latitude.

Subject #9. On two nose high recoveries with all blue (45-60 degrees, some bank), interpretation seemed to take a bit longer than usual.

Subject #10. Nose high inverted with blue only showing was confused once for nose low inverted. Relied on pitch scale numbers to determine flight attitude as either upright or inverted when only one color (blue or brown) was visible due to exaggerated nature of flight attitude. Validity of data degraded by lack of my familiarity with F-16 flight controls and tendency of autopilot to resist my control inputs. Pushing against (down) the stick to prevent the nose from rising resulted in an unintentional roll at the completion of many recovery maneuvers. Result was an unrealistic delay in achieving level flight.

Subject #11. No comments.

Subject #12. Did not seem to use the ground pointer to determine attitude. Display was easy to read and determine attitude quickly. Did not like digital VVI, too much change.

Subject #13. No comments.

Subject #14. Used the numbers exclusively for sky, and ground pointer for all ground or all sky unusual positions. Need some other pointers to make horizon location easier to identify.

In terms of pilot workload, please rate (using the MCH scale) the F-15E EADI with arrows in its application to:

a. Nose-high attitude recoveries

Rating: 2, 4, 1, 3, 3, 1, 4, 5, 1, 2, 3.5, 2, 3, 6

b. Nose-low attitude recoveries

Rating: 2, 4, 3, 2, 3, 1, 3, 3, 1, 1, 2, 1, 2, 2

Comments:

Subject #1. Identifying the displayed attitude was relatively easy. Other cues such as airspeed/altitude/VVI were more difficult to crosscheck, simply because of the digital (vs analog) display. You ought to compare the settling time between displays with digital vs analog altitude/VVI readouts.

Subject #2. Better than baseline, worse than 3-d. Like the arrows. THis ADI is a compromise. Would not recommend it or the baseline display. Would rate 3-d one point better on Cooper-Harper.

Subject #3. I don't like digital VVI - I use round dial and pointer movement/reversal to give me instant or trend information. Digital is to precise and I can't judge dial movement to give me the info I want. Digital altitude is annoying, but I think I could get used to it. Again - the dial movement helps me alot as opposed to the precise altitude readout.

For some reason, I had to concentrate on nose low recoveries and had to think about which way to turn, pull etc. Whether is was lack of experience with attitude indicator or changing from ground to sky pointer, I can't say, but a completely brown picture caused me to hesitate before recovering. Any blue in attitude picture was easy to recognize and I had no problem/hesitation with nose high recoveries, I could instantly recognize my attitude and recover.

Subject #4. I used the ground pointer for nose high recoveries this time and found that it was much easier to determine which way to roll toward the horizon. It still took a little bit of thinking to decide to follow it though. The nose low recoveries were easier with the arrows than without when the horizon was out of view. However, when the attitude was inverted, nose low, it was still very similar to erect, nose low (with the horizon out of view), because the arrows tended to blend into one long solid line. I wonder if fewer, larger headed arrows would work better. When the horizon was in view, the arrows (and ground pointer) were of no added value and seemed to clutter the display enough to detract from reading the numbers on the scale. Also, the black ground pointer virtually disappeared in the black lines of the red ground display.

Subject #5. A round dial altimeter would be desirable to fine tune the level off.

Subject #6. No change on nose high recoveries from baseline display. Primary difference with arrows is it's easier to get nose low picture, and quicker. Also, easier to nail wings level pull because all arrows help align lift vector. Extra white on brown seemed to tire my eyes less.

Subject #7. Nose low much better than without arrows. Nose high - no change. Suggest changing the bottom arrows by only making one column on each side of center (vs two columns), also delete the first two rows as they are unnecessary and clutter the display. This method should be mirrored to the blue section so that arrows would always point to the horizon line. The large number of arrows on the bottom scale end up being too bright.

Subject #8. Same comments regarding digital readouts as on 3-d questionnaire. High contrast around horizon makes horizon easily recognized. Blue sky helps orientation. Nose low - the arrows help find the horizon at all pitch angles but since there are no 30 degree/60 degree lines or no variation in the arrows, you must read the numbers to determine pitch attitude. The red lines in the ground help to determine wings level at large pitch down. Nose high - GRIM, especially at high pitch angles. It's easy to go the wrong way. You must read the numbers, determine if they are right side up or not, and then roll. Your only vertical reference is the row of numbers and the short lines along with them. The smaller angular coverage of the display makes it harder to get oriented.

Subject #9. Nose low extremely easy to recognize attitude and where horizon is. Felt I was faster on nose low recognition than nose high. Possible that the nose low display has more contrast overall between #s/arrows on background vs light white #s on blue background nose high.

Subject #10. No brainer nose low. Nose high requires mental processing to determine if the pitch scale numbers are right side up or down. Learning curve really leveled off during this trial - significant for me due to lack of familiarity with F-16 controls and autopilot. Once I learned to fly the simulator, I did much better than the display choice alone should account for.

Subject #11. Initial attitude quickly conveyed in most cases. Very nose high required interpretation of climb/dive numbers to assess altitude, however, nose up attitude was easily apparent from display 'plain-ness'. I cued on lack of arrows vs color primarily. Required maneuvers (bunt vs letting nose fall through) was much less apparent than 3-d EADI. Nose low case required much less interpretation than 3-d, however, dive steepness required going to ADI numbers.

Subject #12. Arrows were helpful in that they reinforced the feedback you received from the EADI.

Subject #13. Arrows help. Nose high is skimpy.

Subject #14. Arrow pointers greatly improve nose low attitudes. Might try arrows for ground horizon pointers. Now, all you need is better representation of airspeed and altitude, i.e., a reference airspeed and altitude that is shown as lower or higher than desired.

In terms of pilot workload, please rate (using the MCH scale) the 3-D EADI in its application to:

a. Nose-high attitude recoveries

Rating: 2, 3, 2, 1, 1, 1, 1, 1, 3, 2, 3, 2, 2, 2

b. Nose-low attitude recoveries

Rating: 2, 2, 1, 1, 1, 2, 2, 1, 3, 2, 3, 1, 2, 2

Comments:

Subject #1. It was slightly easier to identify the magnitude of the initial correction to make with this display. Once or twice, I had to stop and think about the direction of my correction when I encountered nose high attitudes.

Subject #2. No doubt as to which way is up, and how far above or below you are. Gives 'quantum leap' more rate information for roll rates, pitch. Gives no information on ADI, of your heading rate changes...must be read digitally or refer to bottom of presentation for ball deflection. Get less pitch accuracy, since scale is reduced. I really like being able to see the whole world. Gives the big picture instantly. No anticipated lighting problems based on contrast or illumination changes. Need to add headings to vertical lines. I like the arrows on the vertical lines. Need to fold this information into typical tactical mission profile to simulate loss of HUD.

Subject #3. The arrows on the nose low recoveries helped alot to determine bank and pitch, especially with the star at the 90 degree nose down position. When that was in view, it was very easy to determine bank and attitude. Nose high had no easily recognizable bank indicator and the dot for nose up was too nondescript to pick out at a glance and determine bank and pitch instantly. When both sky and ground were visible, it was easy to instantly determine pitch and bank.

Subject #4. The magnitude of the attitude was easily discernable. Extreme nose low attitudes were especially obvious and made to look serious with all the arrows pointing up. The only difficulty I saw with the display was fine tuning level flight since the symbology displacement was so small around the aircraft symbol.

Digital airspeed information was no problem and I found the trend/rate change display acceptable, since I was interested only in general values. The altitude display was less useful, because it was normally changing so fast I paid little attention to it. The magnitude of altitude change displayed by the VVI was also minimally useful, because it took cognitive time. I just looked for values +/- 2000 fpm and whether it was decreasing or increasing. The nonchanging 1,000's (and 10,000's) digits (altitude) gave an initial sense of security that probably shouldn't have been present though. Attaining zero VVI was extremely difficult, if not impossible, since it could not be referenced with peripheral vision and attention was diverted away from the attitude. A flight path marker would eliminate the need for using VVI to level off though.

Subject #5. This display would become much easier to work with once the pilot becomes familiar with the system. I would prefer the other ADIs for instrument approaches.

Subject #6. Always had very clear picture of where the nose was pointing. The scale (outer space perspective with small area equating to large degrees) seemed to detract from the recovery process. Also, I found it more difficult to nail the lift vector and would overshoot.

Subject #7. Nose low attitude - On one occasion from a very nose low attitude, there was a brief second of confusion as the sky pointers were pointing both to the left and right. Even though it was clear that the middle arrow was the correct one to follow, there was a slight hesitation. Attitude indicator in general - The pitch scale is too small for precise attitude instrument flying. It is difficult to make 1 - 2 degree pitch changes. Difficult to see them hold and be able to repeat to attain the same pitch attitude. Difficult to precisely zero the VVI because of this. Overall, quite easy and natural to use, would be super if it had heading scale and rotated like a sphere (like the F-4 ADI). VVI and altimeter - Must have a lag line type indication to see trends. Extremely difficult to zero VVI.

Subject #8. THe display is high contrast and the arrows make it very easy to determine the direction to the horizon and wings level. I find I can easily tell nose down pitch attitude by the number of rows of arrows below the horizon. The blue on the upper part of the ball makes the sky obvious. Numbers and lines on the upper part of the ball are easy to see. Those on the bottom are harder to see but the arrows provide the same information. Black numbers on red provide little contrast. Being able to see more of the ball makes large +/- pitch attitudes much easier to handle. Digital airspeed/altitude/VVI with no analog information is hard to use since no good rate information is available. The ground pointer is hard to see but is not necessary. The arrows provide the same information. I had brightness turned down after the evaluation and good attitude information remained until the whole display washed out.

Subject #9. ADI in center portion is distracting with line breakup. Black 'W' hard (very hard) to distinguish in nose low situations. Resolution of ADI on this large scale causes #s/lines to be fuzzy. Some tendency to overcontrol more in bank.

Subject #10. As a 3-d display with a full 180 degree perspective, there are two features that are somewhat disorienting: 1) The ball translates along the vertical axis, but not the horizontal axis; and 2) When flying through the vertical, either 90 degrees up or down, the display rotates 180 degrees instead of simply continuing the translation down the backside of the display. Nose up attitudes took a little more concentration to evaluate but that's the way it should be. White arrows pointing up on the bottom half of the display extremely persuasive. Not sure black for the 'W' symbol is the best choice. I think it should be the brightest character on the display.

Subject #11. Overall, very easy to interpret initial attitude. Very nose high required longer to interpret but nose up attitudes allow some indecision. Arrows very helpful in nose low attitude except in very nose low where multi-directional arrows required some interpretation (I used the greater number of arrows to determine where horizon was). Color did not seem to be an important discriminator to up or down. Arrows were.

Subject #12. Tendency to use the sphere almost totally during initial recovery and not look at altitude or airspeed until close to recovery.

Subject #13. Takes a couple of minutes to get used to, but then its great. Overall, a flat display is better for bank information because of the straight pitch lines. For pitch, the 180 degree FOV 3-d display with curved lines is best.

Subject #14. Ground pointer never used, doubt if needed. Aircraft frequently hard to find among display clutter. Maybe have display lines less dominant and aircraft more pronounced. Large black degree numbers stand out more than necessary. Overall, display far easier to read and intuitively understand than other two displays.

APPENDIX B

END OF EVALUATION QUESTIONNAIRE RESULTS

PILOT QUESTIONNAIRE

F-15E EADI EVALUATION

18-26 APRIL 1988

CREW STATION DESIGN FACILITY

WRIGHT-PATTERSON AFB, OHIO

1. Please rank order each display in terms of ease of use for unusual attitude recovery (1 = most preferred, 2 = next preferred, 3 = least preferred).

Rank Order -	#1	#2	#3
Baseline F-15E EADI	1	3	10
F-15E EADI with arrows	5	8	1
3-D EADI with arrows	8	3	3

2. For the two modified EADIs, there are two distinct features, the increased field-of-view and the arrows. Please rank in order of importance these two features relative to unusual attitude recovery (1 = most important).

Rank Order -	#1	#2
Increased Field of View	8	6
Arrows (Sky pointers)	6	8

3. What features do you like most about the baseline F-15E EADI display?

Subject #1. Less clutter, more room for other stuff like flight path.

Subject #2. Not much. Variation in color.

Subject #3. Bank and pitch easily recognizable. Ground pointer is always ground pointer.

Subject #4. Color.

Subject #5. Simple, clean display. I'm used to it.

Subject #6. Basic, neutral.

Subject #7. Expanded pitch scale, more precise attitude control.

Subject #8. Blue sky in contrast to red ground. Red lines in ground.

Subject #9. Most like standard ADI.

Subject #10. Large "W" symbol.

Subject #11. Readibility and simplicity.

Subject #12. See previous rating scale questionnaire.

Subject #13. No comment.

Subject #14. The color sky and colored ground versus black for both.

4. What features do you like least about the baseline F-15E EADI display?

Subject #1. Limited FOV. Difficulty telling up from down.

Subject #2. Flat display, little rate information.

Subject #3. Narrow field of view.

Subject #4. Ground pointer disappears in ground (red black display). Digital altitude and VVI. No flight path marker.

Subject #5. At times, I could use more information displayed.

Subject #6. See question #1.

Subject #7. No sky/horizon pointer.

Subject #8. At large + or - pitch angles, you have no good reference and it's easy to go the wrong way.

Subject #9. Narrow pitch gradient line, i.e. 10
20

Subject #10. Color processing required to discern up from down. Numeral processing required to determine upright from inverted.

Subject #11. Only color differentiates between nose-up and nose-down attitude.

Subject #12. Digital VVI.

Subject #13. Nothing in sky but numbers.

Subject #14. There are no easily distinguishable sky/ground pointers. The ground pointer is hidden among the pitch down numbers.

5. What features do you like most about the F-15E EADI with arrows?

Subject #1. The arrows but there are too many.

Subject #2. Eliminates one step in figuring out which way up is.

Subject #3. Pitch and bank easily recognizable.

Subject #4. Arrows give constant direction to horizon.

Subject #5. The arrows can be helpful.

Subject #6. Arrows really help. See question #2.

Subject #7. That there are arrows.

Subject #8. Helps to find horizon if nose low.

Subject #9. Easily distinguishable where horizon is!

Subject #10. Solves both processing problems described in question #4.

Subject #11. Additional cue to identify 1) nose down attitude and 2) required roll direction.

Subject #12. See previous questionnaire.

Subject #13. Good presentation of bank info.

Subject #14. The sky arrows.

6. What features do you like least about the F-15E EADI with arrows?

Subject #1. Too many arrows, limited FOV. Why not scale pitch ladder to decrease space between marks as you get further from center?

Subject #2. More pitch sensitive due to larger pitch scale.

Subject #3. The sky arrows distract and confuse. A conscious effort must be made to judge if you are reacting to a sky pointer or a ground pointer.

Subject #4. Too many arrows all in a row that distract from pitch values (degree numerics). See comments on rating scale questionnaire.

Subject #5. Display becomes cluttered when not doing an unusual attitude recovery.

Subject #6. Almost too many arrows, but become used to it very quickly.

Subject #7. Too many arrows on the bottom and no arrows on top.

Subject #8. See comments on rating scale questionnaire.

Subject #9. Nothing.

Subject #10. +/- 30 degrees of possible display coverage. Too limited.

Subject #11. Overall, no outstanding objections.

Subject #12. Digital VVI.

Subject #13. Not so good with pitch info nose high.

Subject #14. No ground arrows for nose high attitudes.

7. What features do you like most about the 3-D EADI?

Subject #1. Wide FOV.

Subject #2. Like curved vertical lines. Better big picture ability instantaneously.

Subject #3. Wide FOV, pitch instantly recognizable, Star at bottom is instant indicator that you are in trouble! Most of time sky and ground visible making unusual attitude recognition instant!

Subject #4. Intuitive, constant situation awareness. Constant (almost) horizon in view. Easy to determine where horizon is even when out of view.

Subject #5. It gives me the big picture.

Subject #6. Orientation, big picture.

Subject #7. Better situation awareness. Ease of use for unusual attitude recoveries. Too many sky pointers.

Subject #8. See previous questionnaire.

Subject #9. No comment.

Subject #10. +/- 90 degrees of display coverage AND arrows.

Subject #11. Provides excellent visualization of aircraft attitude in relation to external reference plane.

Subject #12. Excellent perception of aircraft attitude.

Subject #13. Good pitch info.

Subject #14. Broad field of view.

8. What features do you like least about the 3-D EADI?

Subject #1. Too many arrows pointing in several directions - I just want to know which way is up!

Subject #2. Needs heading lines to move like F-4 ball did.

Subject #3. Bank at high pitch attitudes is not instantly recognizable.

Subject #4. Too small a display to precisely control pitch.

Subject #5. It does not give the pilot the sense of urgency that the ground is coming up fast (when nose low).

Subject #6. Scale.

Subject #7. Pitch scale much too small for precise attitude control.

Subject #8. Black numbers.

Subject #9. Can't be fine tuned in pitch, tendency to roll more (use of bank), bottom seems cluttered.

Subject #10. 1. Did not translate about horizontal axis. 2. Rotates 180 degrees when transiting the vertical. 3. Black "W" symbol. 4. Fine pitch adjustments more difficult.

Subject #11. In the very nose low attitude, I found the rosette of arrows confusing.

Subject #12. Takes longer to get used to display and interpret information.

Subject #13. Poor bank info at large pitch angles.

Subject #14. Lines, arrows and numbers are too predominant. Tend to fill up display and drown out artificial aircraft.

9. Did you find anything in the three display formats that was confusing? For example, colors used for the EADI, sky pointers (arrows), bank pointer/bank scale, perspective cues, etc.

	Subject #
yes	1, 2, 3, 4, 7, 8, 9, 11, 14
no	5, 6, 10, 12, 13

10. On which display(s) did this appear?

	Subject #
a. Baseline F-15E EADI	1, 2, 8
b. F-15E EADI with arrows	1, 3, 4, 8
c. 3-D EADI	1, 7, 9, 11, 14

Specifically, what did you find confusing?

Subject #1. Displays a, b, and c. Need sky and ground pointers.

Subject #2. Display a. Had to think when horizon was not in FOV.

Subject #3. Display b. No comment.

Subject #4. Display b. All arrows in a row and same length. When nose low inverted, they tended to blend together.

Subject #7. Display c. A little too many sky pointers on one occasion.

Caused confusion as they all pointed in different directions.

Subject #8. Displays a and b. See previous questionnaire.

Subject #9. Display c. See previous questionnaire.

Subject #11. Display c. The arrow rosette.

Subject #14. Display c. The black pitch degree in the 3-d display tended to blend with the aircraft. In nose low, this bothered me more than nose high.

11. If yes, did this appear:

	Subject #
a. All the time?	1
b. In nose high attitudes?	2, 8(Displays a,b)
c. In nose low attitudes?	2, 3, 4, 7, 8(Display a), 9, 11, 14

12. Rate the utility of the digital altimeter in its application to:

a. Unusual attitude recovery

Ratings: 10, 4, 5, 8, 7, 2, 10, 7, 10, 7, 2, 2, 10, 4

b. Maintaining level flight

Ratings: 10, 4, 4, 4, 10, 2, 6, 5, 4, 4, 4, 2, 10, 4

Use the Modified-Cooper-Harper (MCH) Scale

13. Rate the utility of the digital vertical velocity indicator in its application to:

a. Unusual attitude recovery

Ratings: 10, 7, 9, 4, 5, 2, 10, 9, 10, 4, 4, 10, 10, 4

b. Attaining and maintaining level flight

Ratings: 10, 6, 6, 8, 8, 2, 9, 7, 5, 7, 6, 10, 10, 4

Use the Modified-Cooper-Harper (MCH) Scale

14. Rate the utility of the digital airspeed indicator in its application to unusual attitude recovery.

Use the Modified-Cooper-harper (MCH) Scale

Ratings: 9, 5, 1, 2, 4, 2, 3, 4, 4, 4, 2, 2, 7, 4

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