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THE EFFECTS OF HEAD-UP DISPLAY (HUD) PITCH LADDER ARTICULATION, PITCH NUMBER LOCATION AND HORIZON LINE LENGTH ON UNUSUAL ATTITUDE RECOVERIES FOR THE F-16

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Crew Station Evaluation Facility
Human Factors Branch
ASD/ENECH

July 1990

Final Report for the period June 1989 through July 1990

Approved for public release; distribution is unlimited.

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

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The current trend in fighter cockpits is to provide flight references on the Head-Up Display (pitch ladder format), but because pitch ladder formats are superimposed on the outside world, pilots who reference them can become spatially disoriented. Presently, pitch ladder formats display abstract symbology to convey attitude information and to overcome the spatial disorientation problem. This evaluation examined such abstract coding for the F-16 aircraft. Specifically, the study focused on the effects of pitch bar articulation, pitch number location and horizon line length on the pilot's ability to recover from unusual attitudes. Performance data were collected for nose low and nose high attitudes. Also, Subjective Workload Assessment Technique (SWAT) and Subjective Workload Dominance (SWORD) data were collected to provide a measure of pilot mental workload. Pilot situation awareness was also evaluated. Three pitch ladder formats were evaluated; the F-16 Block 40 pitch ladder, a pitch ladder with articulated pitch bars in the lower hemisphere and a pitch ladder with articulated bars in the upper and lower hemisphere. Also, two locations for pitch numbers were evaluated. Results consistently

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showed that pitch bar articulation in the lower hemisphere yielded the most favorable results, while a "best" location for pitch numbers was not found. A horizon line that extended the entire width of the HUD was the favorite among pilots, but did not significantly improve performance.

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INTRODUCTION

The trend in fighter cockpits has been to provide flight reference information on Head-Up Displays (HUD) i.e. pitch ladder formats. The HUD is one place to present relevant flight information where it can be seen, while allowing the pilot to focus his attention outside the cockpit. Because the HUD is superimposed on the outside world, a problem arises when trying to determine which way is upright. USAF Colonel G.B. McNaughton (1985) stated that no clear distinction can be made between sky and surface on the HUD, so pilots must look to see if the pitch bars are solid (nose high) or dashed (nose low). He further states that this method of conveying aircraft attitude information is far from optimal and occasionally results in HUD related disorientation.

The inability of aircrews to recover from unusual attitudes has become a major concern in recent years. Disorientation is primarily caused by the display formats and symbology which do not allow for quick and clear interpretation by the pilot. Because they have 1:1 pitch scales, USAF pitch ladder formats provide a pitch display that is limited by the vertical field of view. This display can move very rapidly and be difficult to use in unusual attitude recoveries (Burns, 1986).

Despite problems associated with unusual attitudes, the HUD has many benefits. According to Burns (1986), the primary advantage of the HUD is that it presents information collimated, focused, and overlayed on the outside world. The HUD also gives pilots the capability to fly at night using real-time low-light-level television or Forward Looking Infrared (FLIR) sensor video integrated with Terrain Following Radar (TFR). Other advantages include an improved ability to conduct head-up operations and navigation, as well as improved weapon system effectiveness.

At the direction of the F-16 System Program Office (SPO), the Crew Station Evaluation Facility (CSEF) evaluated the effects of certain symbolic codes presented on the HUD. Specifically, the effects of three factors were examined: (1) pitch bar articulation (sloping pitch bars that funnel to the horizon), (2) pitch number location and (3) horizon line length. The SPO's goal was to find out which set of HUD symbology enhanced pilot performance the most.

Evaluation Phases

The HUD symbology was evaluated in an F-16 simulator. Evaluations were based on the pilot's ability to recover from unusual attitudes. Objective (performance) data included pilot reaction time, recovery time, correct/incorrect stick input (nose low attitudes only) and altitude gain/loss for each configuration. There were two phases to the evaluation.

The Phase I evaluation involved three pitch scale formats and two number configurations. All six configurations evaluated in this phase had a horizon line that extended the entire width of the HUD. The purpose of Phase I was to determine which pitch scale/number configuration resulted in the most acceptable recoveries from an unusual attitude. This phase was concerned with the effects that articulated pitch bars and pitch number location had on unusual attitude recoveries. Both objective and subjective data were collected in this phase.

Phase II examined the effects of horizon line length on unusual attitude recoveries. Two formats were evaluated. The pitch scale and number configuration were the same as the Baseline F-16 Block 40 HUD. The two horizon lines evaluated were (1) the F-16 Block 40 horizon line and (2) a horizon line that extended the entire width of the HUD. Objective and subjective data were collected during this phase.

PHASE 1

METHOD

SUBJECTS

Twelve Tactical Air Command (TAC) F-16 pilots took part in the evaluation. The pilots averaged 663 hours of flying time in the F-16 (standard deviation = 789.3) and 1,638 hours of total flying time (standard deviation = 667.6).

APPARATUS

Facility. The study was conducted at the CSEF which is an 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 CSEF government personnel are assigned by the Crew Systems Division (ASD/ENEC). The facility performs human engineering evaluations in support of a variety of System Program Offices (SPOs).

F-16 Simulator. The F-16C simulator was constructed using a salvaged single-seat F-16 cockpit, and includes the seat and canopy assemblies. The all digital design includes two 4X4 inch monochromatic Multi-Function Displays (MFDs), a Wide Field-of-View raster video HUD, an Integrated Control Panel, a Data Entry Display, Hands-on Throttle and Stick controls, and the LANTIRN avionics suite. The side control stick, throttle and flight controls are actual F-16 components. All other instruments and displays are simulated using locally available equipment. The aft section of the simulator, the area formerly occupied by fuel cells, now contains the microprocessor racks which encompass the Advanced Simulator Technology interface. Figure 1 shows the F-16 simulator system.

Computer Complex. The simulator is connected to a series of large and small computer systems. This computer complex includes five Gould series 32/7780, one Gould concept 32/8780, two PDP 11/34, three PDP 11/35, and two Silicon Graphics Iris 3100 Computer Aided Design stations.

Experimenter's Console. The experimenter's console was located approximately twelve feet from the simulator. It includes an intercom system which allows communication to and from the pilot. On the console are displays which replicate the visual scene, HUD, Data Entry Display and MFDs. The evaluator uses these displays to observe and monitor the pilot's performance, and to start, stop and reset the simulation as necessary.

Voice (Bogey) Warning. A "bogey" is defined as an enemy aircraft. Voice warnings of the bogey and the bogey's clock position were recorded on an Amiga micro computer by a female employee of the CSEF. The employee, who had a distinctive and mature mid-western voice, presented messages in a formal and impersonal manner. The Amiga used a high speed voice digitizer (Future

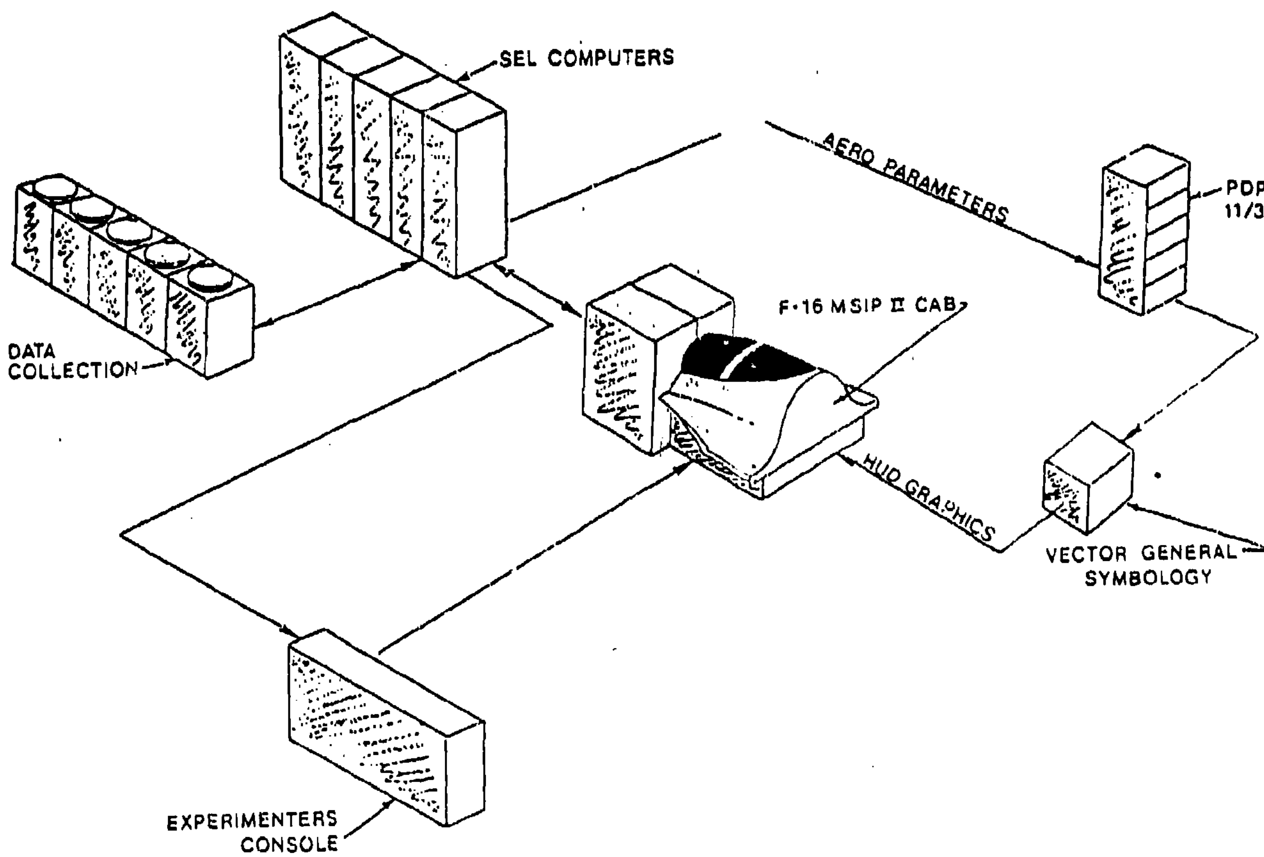

FIGURE 1. F-16 SIMULATOR SYSTEM

Sounds), with a sampling rate of 10,000 samples per second, to convert the messages from analog to digital format. The Amiga was then connected to the main frame computers using an RS-232 interface, and transmitted the messages to the pilot's head set (an ASTROCOM model number 20680 with MX-2508/a/c pads) through the intercom channel.

DESIGN

All performance data, subjective workload data and situation awareness data were analyzed using a repeated measures Analysis of Variance (ANOVA). The CSEF questionnaire data were analyzed using a Chi-square. The independent variables were pitch scale (3) and pitch number location (2). The following is a description of each.

Block 40 F-16. Figure 2 shows the current F-16 Block 40 HUD (excluding data blocks) with a longer horizon line. Pitch bars were five degrees apart, and the HUD displayed 20 degrees of vertical Field Of View (FOV). Horizontally, the HUD provided a FOV of 30 degrees. Figure 3 is identical to Figure 2 except the pitch numbers were presented above the outer end of the pitch ladders.

Partially Articulated Pitch Scale. Figure 4 shows the sloped (articulated) pitch bars below the horizon line which funnel to the horizon. Similar to the previous HUD, the horizon line was longer, pitch bars were five degrees apart, the vertical FOV was 20 degrees and the horizontal FOV was 30 degrees. The fourth configuration is shown in Figure 5. In this display, the pitch numbers were above the outer end of the pitch ladders.

Fully Articulated Pitch Scale. Figure 6 shows the articulated pitch bars above and below the horizon line. In both cases, the bars funnel to the horizon. As in the other pitch ladder formats, the horizon line extended the entire width of the HUD. Pitch bars were five degrees apart, the vertical FOV was 20 degrees and the horizontal FOV was 30 degrees. Figure 7 shows the same HUD with pitch numbers above the outer end of the pitch ladders.

Number Configuration. The effects of pitch indicator location were also evaluated. Two locations were manipulated: pitch numbers at the outer end and above the pitch ladders as shown in Figures 3, 5 and 7 and pitch numbers at the outer ends of the pitch ladder (shown in Figures 2, 4 and 6).

Each of the six configurations had a horizon line that extended the entire width of the HUD, but did not occlude the vertical altimeter and airspeed scales or the associated data blocks. Five levels of pitch angle (0, 15, -15, 55, -55) and four levels of roll angle (0, 45, 135, 180) were used. The order of presentation for the recoveries and display configurations was counterbalanced.

Two types of data were collected: objective and subjective. The dependent variables were reaction time, recovery time, correct response (nose low only) and altitude gain/loss. Reaction time was defined as the time from the onset of the HUD to the first stick input. Recovery time also began with

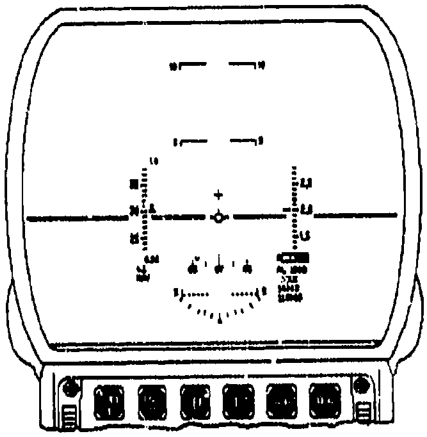

FIGURE 2. BLOCK 40 PITCH LADDER FORMAT WITH PITCH NUMBERS ON THE END.

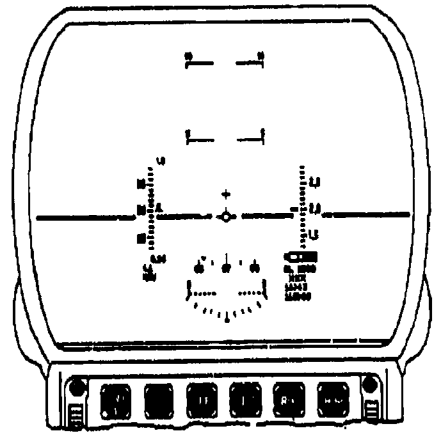

FIGURE 3. BLOCK 40 PITCH LADDER FORMAT WITH PITCH NUMBERS ABOVE.

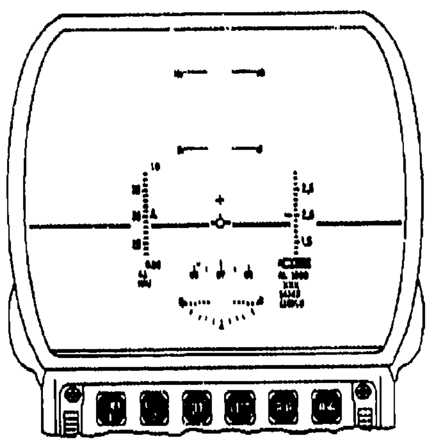

FIGURE 4. PARTIALLY ARTICULATED FORMAT WITH PITCH NUMBERS AT THE END.

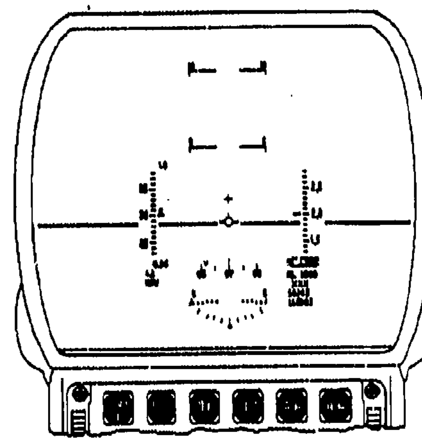

FIGURE 5. PARTIALLY ARTICULATED FORMAT WITH PITCH NUMBERS ABOVE.

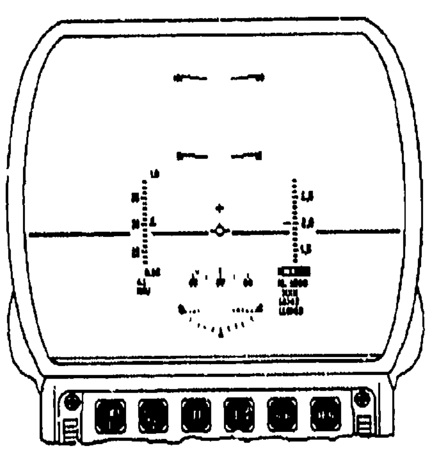

FIGURE 6. FULLY ARTICULATED FORMAT WITH PITCH NUMBERS AT THE END.

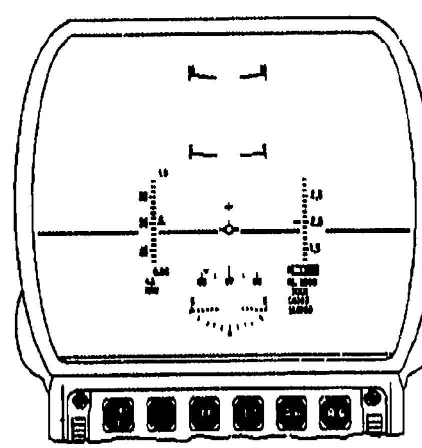

FIGURE 7. FULLY ARTICULATED FORMAT WITH PITCH NUMBERS ABOVE.

the onset of the HUD, but it continued until the pilot recovered the simulator to +10/-10 degrees of pitch and +10/-10 degrees of roll. A correct response was defined as an initial stick movement which caused the aircraft to take the shortest route to the upright and wings level position. Also, the pilot should not put G forces on the aircraft until it is within 60 degrees of bank. Altitude gain/loss was the amount of altitude gained or lost during the recovery.

The subjective dependent variables included Subjective Workload Assessment Technique (SWAT), Subjective Workload Dominance (SWORD) and Situation Awareness (SA) scores. The following section describes each of these subjective tools.

SWAT. SWAT has been used in the simulation environment for several years to assess pilot mental workload, and is comprised of two phases: a scale development phase and an event scoring phase. For a thorough description of the two phases, refer to the SWAT User's Guide (Reid et al., 1989). Once all event scores are collected, rescaled values are assigned to the pilot's SWAT rating (see Table 1). The result is a workload value ranging from 0 to 100. With these values, a mean SWAT score

Table 1. Rescaled SWAT Values.

EVENT SCORING		SWAT SCALE	
EVENT	RATING	CARD COMBINATION	RESCALED VALUE
1	2-2-1	111	0.0
2	2-1-3	112	24.4
3	1-1-1	113	51.4
4	3-1-2	121	7.6
5	1-3-3	122	32.0
6	2-3-1	123	59.0
7	2-1-2	131	27.7
8	1-2-2	132	52.1
9	3-3-3	133	79.1
10	3-2-1	211	6.5
		212	30.9
		213	57.9
		221	14.1
		222	38.5
		223	65.5
		231	34.2
		232	58.6
		233	85.6
		311	20.9
		312	45.2
		313	72.3
		321	[illegible]
		322	52.9
		323	79.9
		331	45.6
		332	73.0
		333	100.0

can be computed which indicates the amount of workload induced by flying with a particular HUD. Higher mean scores indicate higher workload. A 3 X 2 X 2 repeated measures design was used. The independent variables were three pitch scale formats, two pitch number locations and two types of task loading. The HUD configurations were previously described. The first type of task load dealt with the amount of difficulty the pilot had in recognizing or recovering from the unusual attitude. An easy attitude was one that was simple to recognize or recover from, while a difficult attitude was harder to recognize or recover from. A post hoc definition of attitude difficulty was made, and Table 2 shows how the attitudes were categorized. The second type of task load dealt with the presence or absence of

Table 2. Easy and Difficult Attitudes From Which to Recover

EASY		DIFFICULT	
Pitch	Roll	Pitch	Roll
0	0	0	180
0	45	-15	135
0	135	-15	180
15	0	55	135
15	45	55	180
15	135	-55	45
15	180	-55	135
-15	0	-55	180
-15	45		
55	0		
55	45		
-55	0		

a bogey. During the pre-flight briefing, pilots were told that a normal trial consisted of a mission flown in the weather in which the pilot becomes disoriented. Then, using the HUD, he was to recover the aircraft to wings level. On 18 random trials the bogey (voice) warning was presented. The pilot was instructed to execute an appropriate recovery, and then once the aircraft was at wings level, locate the bogey. SWAT event scores were collected after each bogey trial and the trial that succeeded the bogey trial (which had the same initial attitude). During data analysis, a direct comparison of pilot workload was possible for bogey/no bogey conditions. The dependent variable was the pilot's SWAT score.

SWORD. SWORD is a subjective workload tool developed by Dr. M. A. Vidulich at Armstrong Aerospace Medical Research Laboratory (AAMRL). With SWORD, pilots make relative judgements on a 17 point scale comparing displays as shown in Figure 8. Making SWORD ratings is

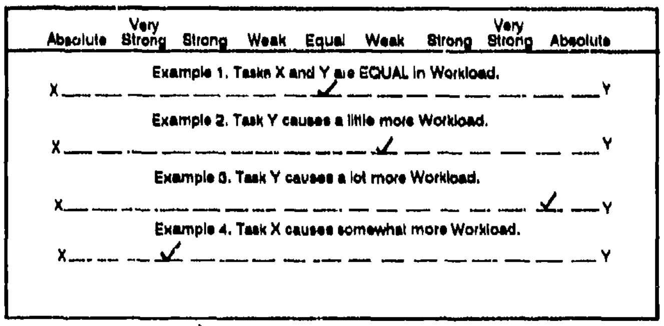

FIGURE 8. RELATIVE WORKLOAD JUDGEMENTS EXAMPLE SHEET.

very simple and is accomplished at the end of simulation. After numbers are assigned to the relative ratings, a computer is used to calculate the geometric mean SWORD score for each display. The display which induced the least amount of workload during flight will have a lower mean score, while the highest mean score indicates the display which induced the highest workload. A 3 X 2 X 2 (pitch scale X number location X task load) repeated measures design was employed. For SWORD, task load was defined as the amount of difficulty the pilot had in recognizing or recovering from the unusual attitude. An easy attitude (-15 degrees pitch and 60 degrees roll) was one that was simple to recognize or recover from, while a difficult attitude (-55 degrees pitch and 135 degrees roll) was more difficult to recognize or recover from. SWORD ratings were based upon the workload induced when the HUD was in one of these two attitudes. The dependent variable was the pilot's SWORD score.

Situation Awareness. A 3 X 2 X 2 (pitch scale X number location X task load) repeated measures ANOVA was used for the analysis of SA data. Situation awareness was assessed using a technique developed by Major M. Fracker at AAMRL. The SA rating instructions and scale are shown in Figure 9. Basically a statement is made concerning the pilot's SA when using a particular display, then during simulation, the pilot gives a rating based upon the amount that he agrees or disagrees with that statement. In this case the statement was "I experienced no confusion with this HUD configuration, and was easily able to recover to straight and level flight." Each pilot's SA rating was recorded following random trials. These trials were the same trials used to collect SWAT event scores. The ordinal level ratings given by pilots were converted to equivalent interval scale values (see Figure 9) using the Training and Human Factors Research on Military Systems: Questionnaire Construction Manual (Army Manual P-71-1). The interval level scale ranged from -2.76 through 2.77. The scale value that resulted was the pilot's situation awareness score and was used as a dependent variable.

PROCEDURE

Preflight Briefing

The pilots received a standardized briefing describing the procedures to use during simulation, the description of each pitch ladder and number format and SWAT card sort instructions. Additional instructions included SA data collection procedures, which were read to the pilot (refer to Figure 9).

Pilots were instructed to execute each recovery as they would during a normal F-16 flight while considering realistic positive and negative 'g' and energy management. For nose high attitudes, the pilot was told to roll to 90 degrees, let the nose of the aircraft fall and then roll to wings level near the horizon. For nose low conditions, pilots were instructed to roll to wings level and pull to the horizon. Pilots were briefed that they would fly 23 trials with each pitch scale and number configuration for a subtotal of 138 trials; 18 of which involved a bogey warning. The bogey warning was a verbal warning of a "bogey" and a specific clock position (i.e. BOGEY 4 O'CLOCK) and was intended to increase pilot workload. Following the preflight briefing, pilots were given time to

SUBJECTIVE PITCH LADDER RATING INSTRUCTIONS

In this evaluation, we are interested in how well different pitch ladder configurations affect your attitude awareness. A poor design may mislead you to initially pitch the wrong way, or you may pitch the right way but overshoot or undershoot. After certain trials, we will ask you to evaluate the pitch ladder configuration you just used. You will be asked to respond to the following statement: "I experienced no confusion with this pitch ladder configuration and was easily able to recover to straight and level flight." Simply indicate the extent to which you agree with the statement by giving a number from 1 to 9. Use the following scale.

9 - Decidedly AGREE
8 - Substantially AGREE
7 - Moderately AGREE
6 - Perhaps AGREE
5 - BORDERLINE
4 - Perhaps DISAGREE
3 - Moderately DISAGREE
2 - Substantially DISAGREE
1 - Decidedly DISAGREE

Scale Values for Descriptors:

9 - Decidedly agree........................2.77
8 - Sustantially agree....................2.10
7 - Moderately agree......................1.47
6 - Perhaps agree...........................0.52
5 - Borderline.................................0.00
4 - Perhaps disagree.....................-0.43
3 - Moderately disagree................-1.35
2 - Substantially disagree............-2.17
1 - Decidedly disagree.................-2.76

Source for scale descriptors and scale values: Babbit, B. A. & Nystrom, C. O. (1985). Training and human factors research on military systems: Questionnaire construction manual (Army Manual P-71-1). Fort Hood, TX: Army Research Institute for the Behavioral Sciences.

FIGURE 9. SA RATING INSTRUCTIONS AND SCALE.

perform the SWAT card sort (30-60 minutes).

Training

Pilots were trained on each of the configurations before any data were collected. Prior to flying each new configuration, one free-flight practice trial was flown until the pilot indicated that he felt comfortable with the display (maximum of five minutes).

Trial Procedure

The HUD was blanked out and the Horizontal Situation Indicator (HSI) and standby attitude indicator were frozen while an autopilot system flew the simulator into an unusual attitude. The Attitude Director Indicator (ADI) was removed for the entire simulation. Once the autopilot reached the unusual attitude, the pilot received the initial course heading and pulled the Display Management Switch (DMS), located on the stick, to the aft position. Activation of the DMS switch initiated the trial which made the HUD reappear and released the HSI and standby attitude indicator. The pilot flew the recovery to wings level. When the recovery was complete (+ 10/-10 degrees of pitch and + 10/-10 degrees of roll) the pilot pulled the trigger which ended the trial and reset the HUD, HSI and standby attitude indicator. Airspeed, altitude, vertical velocity and angle of attack were initially the same for each trial. For trials in which a bogey warning was presented, the warning was given 0.3 seconds after the pilot activated the Display Management Switch (DMS) to begin the trial. Pilots were instructed to remember the clock position, perform a recovery as they would in an actual bogey situation, and then, relative to their recovery heading, tell the evaluator where the bogey was located. For simulation purposes, the bogey did not move, however, while executing the recovery the pilot's heading may have changed, thus relative to the new heading, the bogey may have a new clock position. For the bogey trials and the trial immediately following it, the initial attitudes were identical. After these pairs of trials, SWAT event scores and situation awareness (SA) ratings were collected. Pilots were instructed to give SWAT scores and SA ratings via the intercom.

Debriefing

The evaluator used the debriefing to discuss observations made during simulation and to collect the SWORD data. There were two parts to the SWORD ratings; one part involved SWORD ratings based upon easy attitude deviations (-15 degrees pitch and 60 degrees roll) and the other part was based upon difficult attitude deviations (-55 degrees pitch and 135 degrees roll).

RESULTS

Objective Data

Two independent variables were examined as a function of reaction time, recovery time, correct response (nose low only) and altitude gain/loss in a 3 X 2 repeated measures ANOVA. Results are presented by attitude condition i.e. nose low or nose high. "Nose low" consisted of initial attitudes with degrees of pitch less than zero, while "nose high" were initial attitudes with degrees of pitch greater than or equal to zero.

The cockpit environment associated with the present simulation (and with the aircraft) is so diverse and dynamic that attempting to restrict the pilot's focus to one specific instrument is virtually impossible. Thus, while the objective of this study was to evaluate pitch ladder formats, most attitude related instruments were incorporated, resulting in a more complete mission scenario. This, in turn, decreased the level of experimenter control over the pilot's decisions and actions during the task performance. To avoid overlooking any significant effects between the different configurations during the evaluation, it seemed appropriate to assume a liberal stand in rejecting the null hypothesis by selecting a confidence level (p value) of less than, or equal to 0.10.

Nose Low Attitudes

Reaction Time. An ANOVA revealed no significant interaction between the pitch number location and pitch scale format for the mean reaction times, $F(2,22) = .02$, $p = .98$. The main effect of pitch scale format was significant, $F(2,22) = 1.06$, $p = .08$. An inspection of Figure 10 suggests that recoveries performed using the partially articulated format (0.37 seconds) resulted in the quickest mean reaction time, followed by the fully articulated configuration (0.46 seconds) and the Block 40 configuration (0.49 seconds). Significance was not found for the main effect of number, $F(1,11) = 1.07$, $p = .32$.

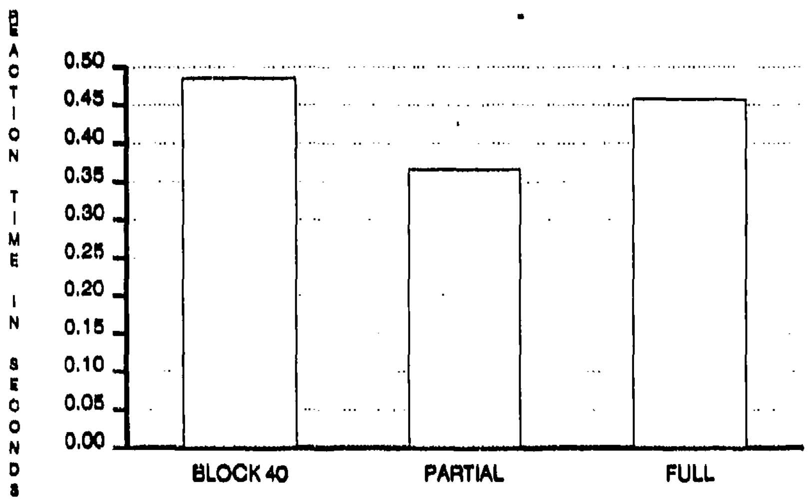

FIGURE 10. MEAN REACTION TIME AS A FUNCTION OF PITCH LADDER FORMAT (NOSE LOW).

Recovery Time. An examination of the three pitch ladder format X two pitch number location interaction (Figure 11) showed significance, with $F(2,22) = 2.59$, $p = .10$. The partially articulated pitch scale with pitch numbers presented above the pitch ladders resulted in the best mean recovery time (4.20 seconds). The longest recovery times occurred with the fully articulated format with pitch numbers at the ends of the pitch ladder (5.0 seconds). Neither the main effect of pitch scale ($F(2,22) = 2.59$, $p = .26$) nor pitch number location ($F(1,11) = .41$, $p = .54$) were found to be significant.

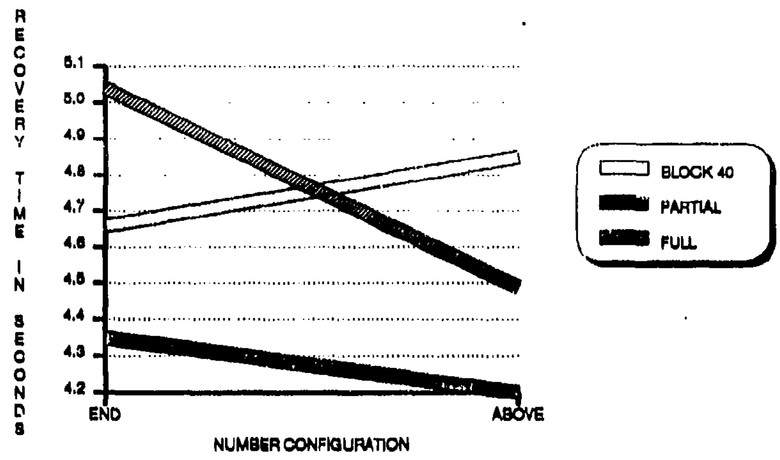

Figure 11. MEAN RECOVERY TIME AS A FUNCTION OF NUMBER CONFIGURATION AND PITCH LADDER FORMAT (NOSE LOW).

Correct Response. For nose low conditions only, the percentage of correct initial stick inputs was determined as a function of pitch scale format and number configuration. From Figure 12, it is obvious that flying with one configuration was essentially the same as flying with all configurations.

The percentage of correct responses for the four articulated pitch scales was nearly identical (either 70 or 72 percent). However, with the F-16 Block 40 configurations, the percentages ranged from 64 to 76 percent. These two configurations were exactly the same except for pitch number location. This result indicates that the pilots were basing their first stick input decision on the cue provided by number location.

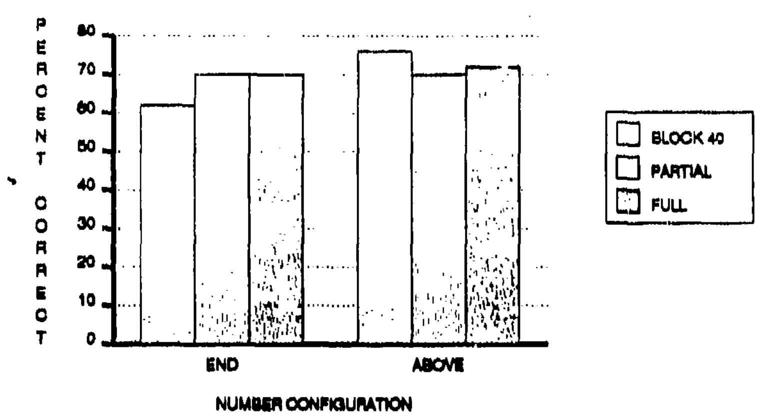

FIGURE 12. CORRECT RESPONSE PERCENTAGE AS A FUNCTION OF NUMBER CONFIGURATION AND PITCH LADDER FORMAT.

Altitude Loss. Another dependent variable used in this evaluation was altitude loss during the recovery. The interaction between pitch scale and pitch number location was not significant, $F(2,22) = 1.88$, $p = .18$. Furthermore, neither the main effect of pitch scale, $F(2,22) = 1.06$, $p = .36$, nor the main effect of pitch number location, $F(1,11) = .02$, $p = .89$, were significant.

Nose High Attitudes

Table 3 shows that none of the pitch scale format effects, pitch number location effects or their interactions were significant for any of the dependent variables: reaction time, recovery time or altitude gained.

Table 3. ANOVA Table for Phase I Nose High Attitudes.

Reaction Time

	DF	SS	F	P
A	2	.11740364	.17	.84
B	1	.87529150	1.56	.24
A x B	2	.13597874	.33	.72
A x S	22	7.53645969	1.22	.23
B x S	11	.87529150	3.13	.08
A x B x S	20	4.14911873	.74	.78

Recovery Time

	DF	SS	F	P
A	2	10.72316855	.45	.65
B	1	1.96179281	.15	.71
A x B	2	17.23978698	1.16	.33
A x S	22	263.84569645	1.69	.03
B x S	11	1.96179281	.28	.60
A x B x S	20	148.06707152	1.04	.41

Altitude Gained

	DF	SS	F	P
A	2	7249537.66321059	1.45	.26
B	1	25457.85770251	.01	.92
A x B	2	107027.37188489	.06	.94
A x S	22	54978824.83535654	1.29	.18
B x S	11	21820262.35766101	1.03	.42
A x B x S	20	17087634.57356517	.44	.98

A = PITCH LADDER FORMAT
B = PITCH NUMBER LOCATION
S = SUBJECT

Subjective Data

The following describes the SWAT, SWORD, SA and CSEF questionnaire results. For SWAT, the independent variables included three pitch scale formats and two types of task loading: bogey/no bogey conditions and easy/difficult attitudes from which to recover. For SWORD, three pitch scale formats, two number locations and two task loading levels were manipulated, and for SA, three pitch scale formats, two number configurations and two task loading levels were manipulated.

SWAT

Pilots can fly almost any display under normal flight conditions. However, given a situation where workload is significantly higher, the results of a poor HUD may be disastrous. For this reason, SWAT ratings were used to provide a measure of pilot workload for each of the pitch ladder formats. The ANOVA results for the various task loading levels will now be described.

The three-way interaction of pitch scale format, attitude difficulty and bogey condition was not significant for $F(2,22) = .75$, $p = .48$. Figure 13 shows the means for attitude difficultly and pitch ladder format. This interaction was significant, $F(2,22) = 9.12$, $p = .001$. For difficult attitudes the partially articulated pitch scale (mean SWAT score = 13.8) induced lower workload than the other two pitch scale formats. When recovering from easy attitudes, lower workloads were induced flying the fully articulated format (mean SWAT score = 8.4). Also, the partially articulated pitch ladder required

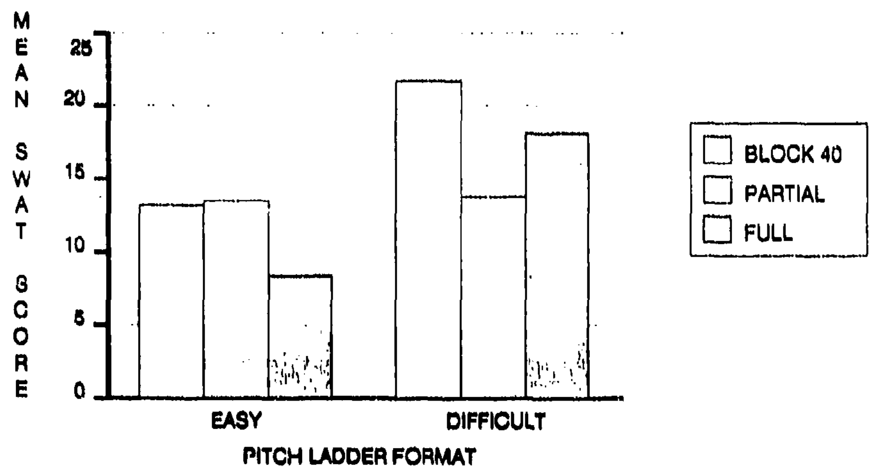

FIGURE 13. MEAN SWAT SCORE AS A FUNCTION OF TASK LOAD (DIFFICULTY) AND PITCH LADDER FORMAT.

essentially the same amount of workload regardless of attitude. Figure 14 illustrates the main effect of attitude difficulty. Clearly, the attitudes that were difficult to recover from induced significantly more workload (mean SWAT score = 17.9) than the easier recovery attitudes (mean SWAT score = 11.7), $F(1,11) = 18.66$, $p = 0.001$.

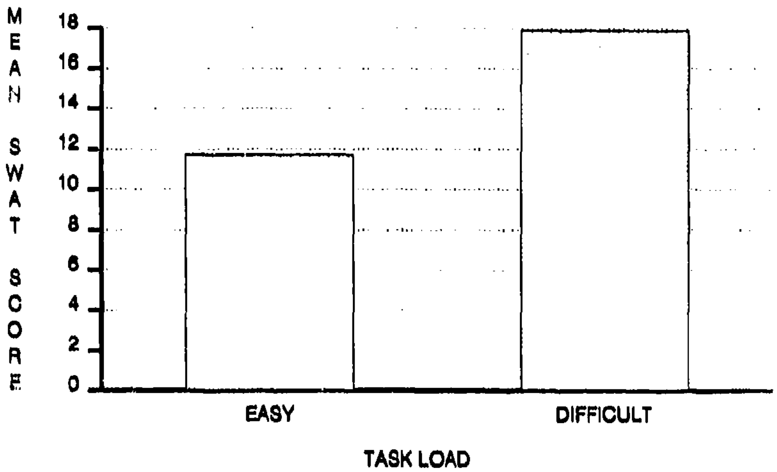

FIGURE 14. MEAN SWAT SCORE AS A FUNCTION OF TASK LOAD (DIFFICULTY).

Other analysis examined the interaction of pitch ladder format and bogey conditions. This interaction was not significant, $F(2,22) = .21$, $p = .81$ The main effect of the bogey warning was significant, $F(1,11) = 57.27$, $p = .0001$. Bogey warning conditions yielded a mean SWAT score of 22.2, while no bogey conditions had a mean SWAT score of 6.99. Figure 15 shows the SWAT scores for bogey and no bogey conditions. Finally, the main effect of pitch ladder format was not significant, $F(2,22) = 1.59$, $p = .23$.

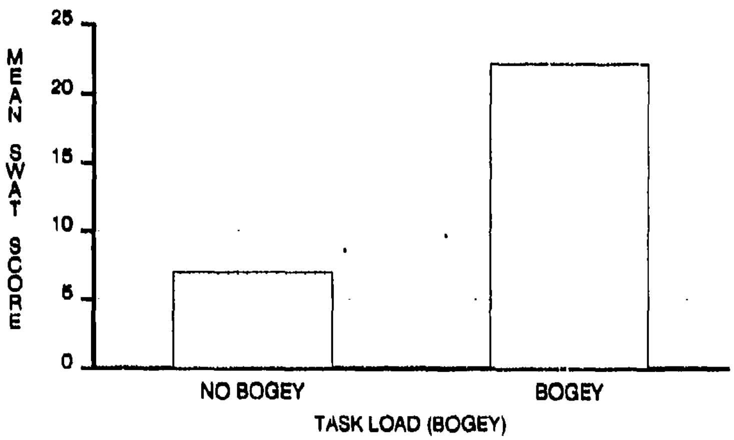

FIGURE 15. MEAN SWAT SCORES AS A FUNCTION OF TASK LOAD (BOGEY CONDITION).

SWORD

Following simulation, pilots performed two SWORD evaluations; one for relatively easy attitude adjustments (-15 degrees pitch and 60 degrees roll) and one for relatively difficult attitude adjustments (-55 degrees pitch and 135 degrees roll). Three pitch ladder formats and two number configurations were rated.

The three-way interaction of pitch ladder format X number location X attitude showed no significance, $F(2,20) = 1.44$, $p = .26$. An examination of the pitch scale X pitch number interaction, $F(2,20) = 1.80$, $p = .19$, yielded no significant differences either.The pitch ladder X attitude interaction showed significance, $F(2,20) = 3.95$, $p = .04$, and an examination of the means, shown in Figure 16, suggests that for difficult adjustments, the partially articulated pitch scale (mean SWORD rating = .0809) and the fully articulated pitch scale (.0898) induced significantly less workload then

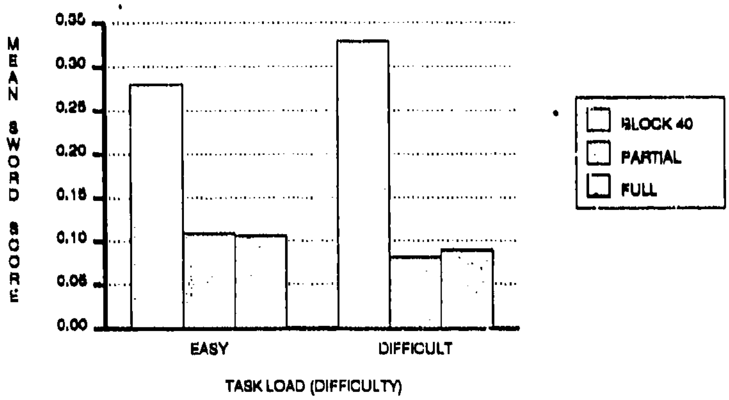

FIGURE 16. MEAN SWORD SCORE AS A FUNCTION OF TASK LOAD (DIFFICULTY) FOR ALL PITCH LADDER FORMATS.

Block 40 (.3291). The impact that attitude deviation and number configuration had on mean SWORD ratings was also examined, and the two way interaction was not significant, $F(1,10) = .02$, $p = .89$. The main effect of pitch ladder was significant, $F(2,20) = 31.05$, $p = .001$, with the means shown in Figure 17. The partially articulated format induced the lowest amount of workload (mean SWORD rating = .0950), followed by fully articulated (.0979) and Block 40 (.3069). The effect of pitch number configuration was also examined. The workload differences induced by pitch number location were not significant, $F(1,10) = .46$, $p = .51$.

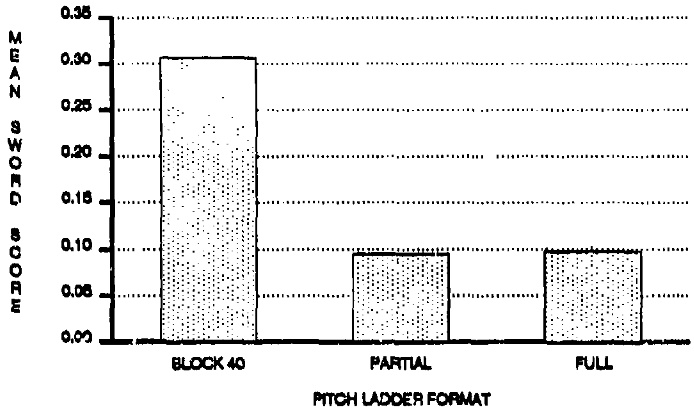

FIGURE 17. MEAN SWORD SCORE AS A FUNCTION OF PITCH LADDER FORMAT.

Situation Awareness

Each pilot's SA was recorded following selected random trials. The pitch ladder format X pitch number location X bogey interaction was not statistically significant for $F(2,22) = .04$, $p = .96$. Likewise, none of the two way interactions were significant; pitch ladder X pitch number, $F(2,22) = 1.32$, $p = .29$, pitch ladder X bogey, $F(2,22) = .11$, $p = .89$ and pitch number X bogey, $F(1,11) = .56$, $p = .47$ The main effect of number location was not significant, $F(1,11) = .36$, $p = .56$. Figure 18 shows the main effect of pitch scale format, $F(2,22) = 5.47$, $p = .01$, which was statistically significant. An examination of the means suggest that pilot SA was better when flying with the fully articulated pitch scale format (mean SA score = 2.04) and the partially articulated format (1.98) then with the F-16 Block 40 configuration (1.55).

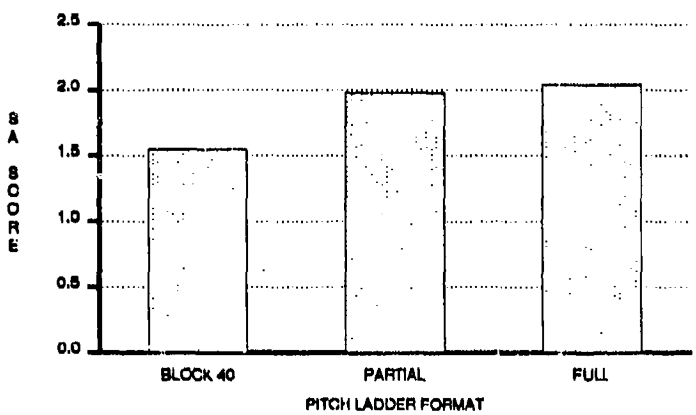

FIGURE 18. MEAN SITUATION AWARENESS SCORE AS A FUNCTION OF PITCH LADDER FORMAT.

Similar to the bogey results from the SWAT data, the SA main effect of bogey was significant, $F(1,11) = 34.82$, $p = .0001$. Figure 19 suggests that the bogey warning trials significantly reduced pilot situation awareness. Other SA results are discussed in Appendix A.

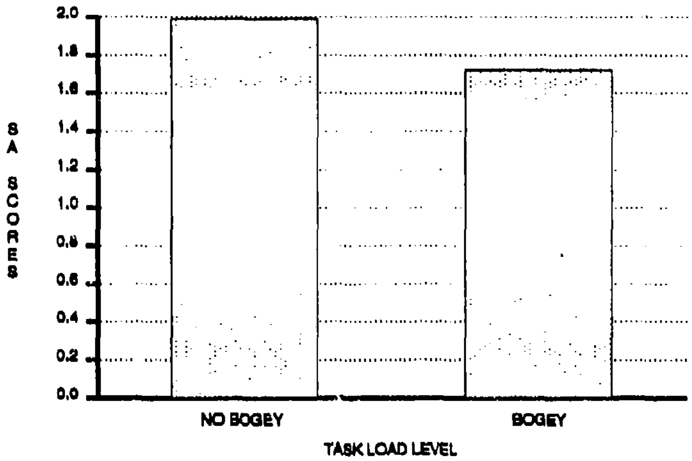

FIGURE 19. MEAN SITUATION AWARENESS SCORE AS A FUNCTION OF TASK LOAD (BOGEY).

CSEF Questionnaire

At the conclusion of Phase I simulation, part one of a CSEF questionnaire was given to the pilots. The questionnaire is shown in Appendix B. Individual Chi-Square tests were performed on the questionnaire data. For each question, response frequency was indicated, and if significant, graphed.

Pitch Ladder. As shown in Figure 20, the articulated pitch scales were preferred over the Block 40 pitch scale. Six pilots preferred the partially and six preferred the fully articulated pitch scales. The frequency analysis indicated that this preference was significant, $\chi^2 = 6.0$, $p < .05$.

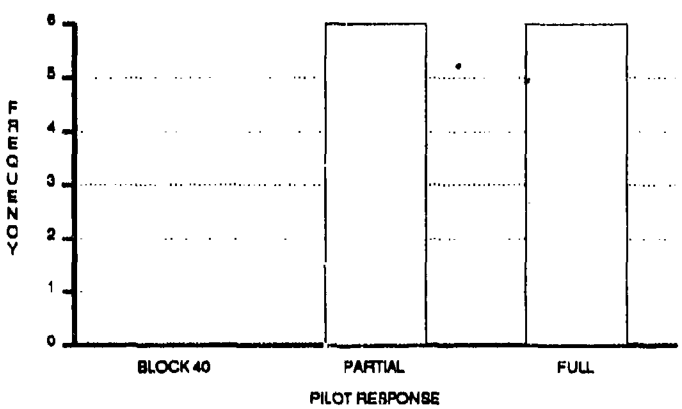

FIGURE 20. NUMBER OF PILOTS WHO PREFERRED EACH OF THE THREE TYPES OF PITCH LADDERS.

Pitch Number Location. The Chi-Square analysis of pitch number location yielded no significant differences between either of the alternatives ($\chi^2 = 1.43$, $p > .05$).

Flight Path Marker. Articulated pitch bars pose a special problem when trying to determine degrees of pitch. If the flight path marker is located between the upper ends of the pitch ladders, then should the pilot read degrees of pitch from that upper end? What if the flight path marker is located between the lower ends of the pitch bars, then does the pilot read degrees of pitch from that location? Pilots were asked this question but no significant difference existed between these two options, $\chi^2 = 1.34$, $p > .05$.

Spatial Disorientation. Seven of the 12 pilots had experienced spatial disorientation using the HUD. A Chi-Square of the frequencies showed no significant differences, $\chi^2 = .33$, $p > .05$.

Articulated Pitch Ladders. The following section includes a discussion of pilot responses to two, two-part questions concerning articulated pitch bars. The fully articulated pitch bar format helped pilots distinguish between nose up and nose down attitudes in eight out of 12 cases, however, this result was not significant, $\chi^2 = 1.33$, $p > .05$. With the partially articulated format, all 12 pilots were better able to distinguish between nose high and nose low attitudes, $\chi^2 = 12.0$, $p < .05$, (see Figure 21). Although articulation was very useful in distinguishing between nose low and nose high attitudes, the same was not true in determining roll. Seven pilots stated that both the fully ($\chi^2 = .33$, $p > .05$) and partially ($\chi^2 = .33$, $p > .05$) articulated pitch scales were helpful in determining roll, but these results were not significant.

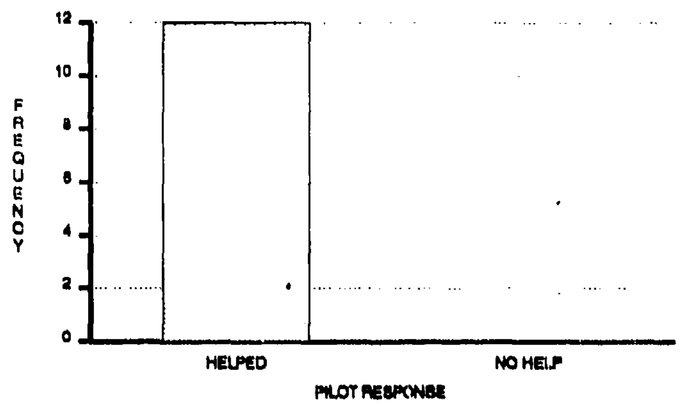

FIGURE 21. NUMBER OF PILOTS WHO FELT THAT THE PARTIALLY ARTICULATED PITCH BARS HELPED IN DETERMINING NOSE UP FROM NOSE DOWN.

Tails at the Ends of the Pitch Bars. The tails or "tic marks" at the ends of the pitch bars can either point to the ground (nadir) or the horizon. When asked their preference, all 12 pilots favored horizon pointing tails and the freqencies are shown in Figure 22, ($\chi^2 = 12$, $p < .05$). The results were significant.

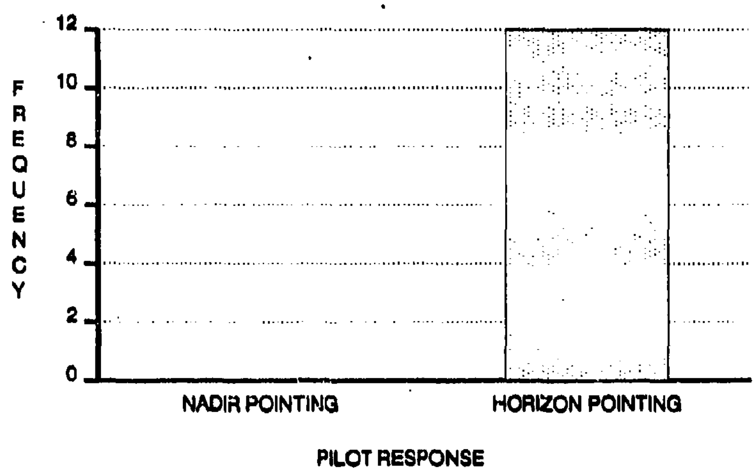

FIGURE 22. FREQUENCY OF PILOTS WHO PREFER NADIR AND HORIZON POINTING TAILS.

SUMMARY

Generally, the performance results indicated that the partially articulated format was the best HUD configuration. Subjective data tended to support this finding, particularly under high workload conditions. The performance and subjective results did not show that one pitch number location was better than the other.

PHASE II

METHOD

SUBJECTS

Pilots who participated in Phase I also participated in Phase II.

APPARATUS

The facility, F-16 simulator, computer complex and experimenter's console were the same as those used in Phase I and are described in the Phase I Method section.

DESIGN

Performance data were analyzed using a within subjects ANOVA, and a Chi-Square was used to analyze the questionnaire data. The only independent variable was horizon line length. Two horizon lines were evaluated. One horizon line was the F-16 Block 40 horizon line (Figure 23), while the other extended the entire width of the HUD as shown in Figure 24. The longer horizon did not occlude the vertical altimeter and airspeed scales or the associated data blocks. All other symbology was F-16 Block 40 symbology. Pitch and roll conditions were the same as those used in Phase I. This design resulted in 40 trials. The order of presentation for the recoveries and display configurations was counterbalanced. Dependent variables were reaction time, recovery time and altitude gain/loss as defined in the Phase I Design section.

PROCEDURE

Preflight Briefing

The preflight briefing for Phase II followed the Phase I debrief. All pilots were given the standardized briefing. The briefing included a description of the procedures to follow during simulation and a description of each format to be evaluated. Pilots were reminded to recover from the unusual attitude using the procedures briefed during Phase I.

Training

Training for Phase II was the same as Phase I training. Pilots were given the opportunity to fly each format before any data were collected. Prior to flying each new format a five-minute free flight practice period was provided to the pilot. After the training period, the simulation began.

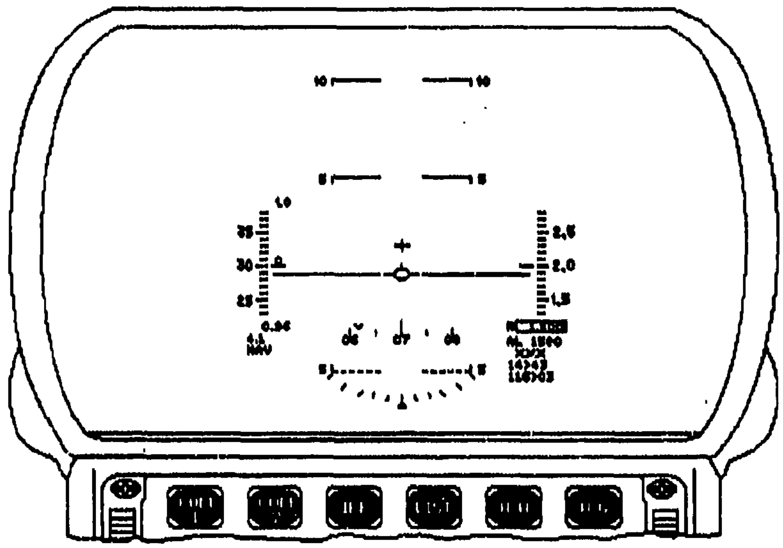

FIGURE 23. HEAD-UP DISPLAY WITH NORMAL HORIZON LINE.

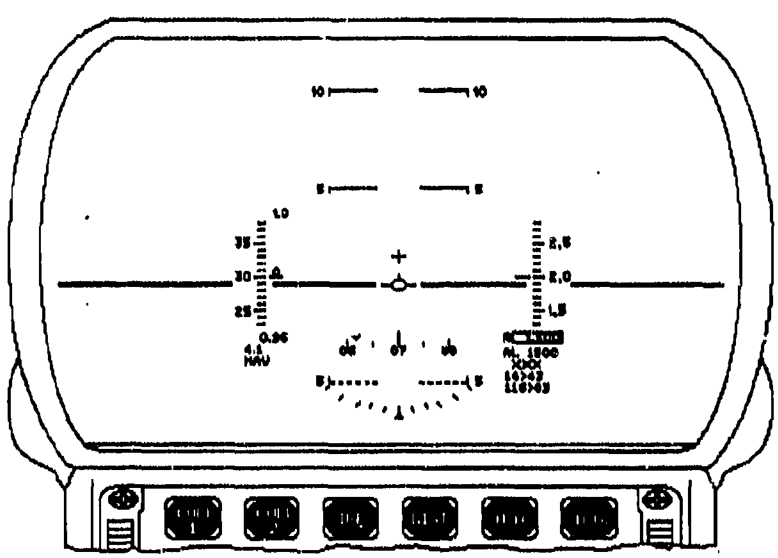

FIGURE 24. HEAD-UP DISPLAY WITH EXTENDED HORIZON LINE.

Trial Procedures

Similar to Phase I, pilots were required to recover from unusual attitudes. All trial procedures were the same except that the measures of workload and situation awareness were not used in Phase II.

Debriefing

Debriefings consisted of an informal interview in which the pilots discussed any problems encountered during simulation or with the simulator, and their opinion of the displays. The evaluation concluded with the pilots completing a CSEF questionnaire.

RESULTS

Objective Data

During Phase II performance data were collected on two horizon lines. Results are presented by initial attitude condition (nose low or nose high). Statistical significance was not found for any of the Phase II results. The ANOVA results are shown in Table 4.

Table 4. ANOVA Table for the Phase II Evaluation

Reaction Time

	DF	SS	F	P
A (Nose High)	1	.1826	.69	.43
A (Nose Low)	1	.06	.59	.46
A X S (Nose High)	9	2.39	1.38	.20
A X S (Nose Low)	9	1.07	.80	.63

Recovery Time

	DF	SS	F	P
A (Nose High)	1	.1846	.36	.56
A (Nose Low)	1	1.44	.31	.59
A X S (Nose High)	9	46.43	1.31	.24
A X S (Nose Low)	9	46.20	.98	.46

Altitude Gain/Loss

	DF	SS	F	P
A (Nose High)	1	1432135.70	1.36	.27
A (Nose Low)	1	373006.21	.17	.69
A X S (Nose High)	9	9459154.70	.61	.79
A X S (Nose Low)	9	22450998.03	.65	.77

A = Pitch Ladder Format
S = Subject

Subjective Data

The CSEF questionnaire for Phase II addressed the issue of horizon line length and the utility of the bank indicator for unusual attitude recoveries. Individual one-way Chi-Square tests were performed on the questionnaire data. For each question, response frequency was indicated and, if significant, graphed. The questionnaire is shown in Appendix D and pilot comments are provided in Appendix E.

Horizon Line. The frequency data for horizon line preference are shown in Figure 25. Eleven of the 12 pilots thought the longer horizon line was a good idea. This result was significant, $\chi^2 = 28.6$, $p < .05$.

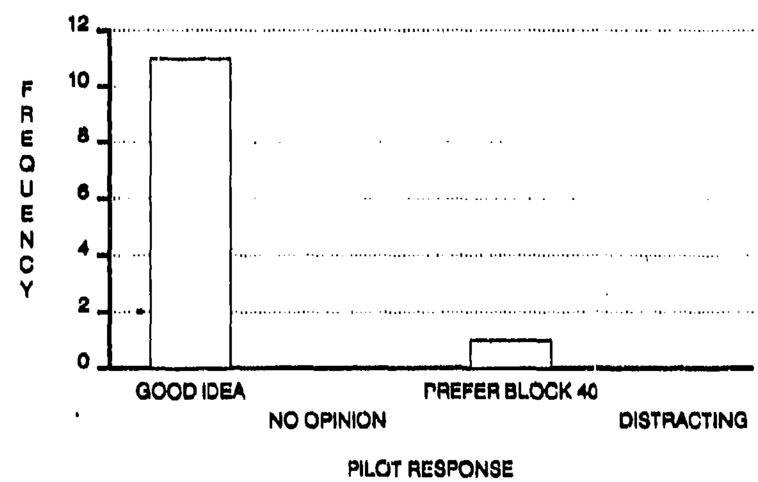

FIGURE 25. PILOT'S OPINIONS OF THE LONGER HORIAON LINE.

Bank Indicators. At the conclusion of the Phase II simulation, pilots were given the opportunity to fly with a bank indicator that had hash marks at 45 degree angles around the flight path marker (FPM). Then, pilots were asked their preference between the present bank indicator and the bank indicator around the flight path marker. Pilots favored having the bank indicator presently used significantly more than the other option, $\chi^2 = 5.33$, $p < .05$. Frequencies are shown in Figure 26.

Pointer on the Bank Scale. Pilots were asked their opinion of a ground pointer and a sky pointer on the bank scale. The frequencies are shown in Figure 27. Ten pilots favored the sky pointer and two favored the ground pointer. The results were significant, $\chi^2 = 5.33$, $p < .05$. The CSEF engineers were interested in pilot opinions of the bank scale for two reasons: (1) to determine what role, if any, the bank indicator played in unusual attitude recoveries and (2) to determine the most favorable features for a bank indicator. When recovering from unusual attitudes, nine of the pilots indicated that they did not use the bank indicator. This was expected because pilots are not trained to use the bank indicator for unusual attitude recoveries. This result was not significant, $\chi^2 = 3.0$, $p > .05$.

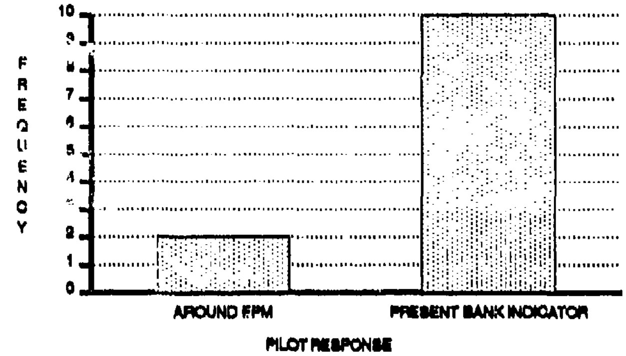

FIGURE 26. FREQUENCY AS A FUNCTION OF BANK INDICATOR.

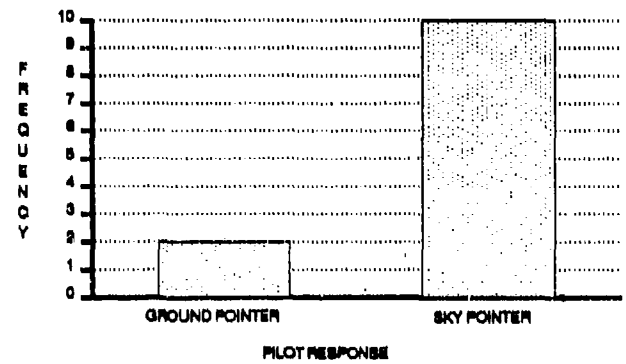

FIGURE 27. FREQUENCY AS A FUNCTION OF BANK SCALE POINTER.

Six of the pilots felt that a 360 degree bank indicator was a good idea, but statistical significance was not found, $\chi^2 = 6.67$, $p > .05$. Pilots were asked their opinion of having a bank pointer pointing up. In this case, significant differences were found; seven pilots felt that a bank pointer pointing up was of some use at low bank angles, one felt it was very helpful, two had no opinion and two felt it was of little use ($\chi^2 = 12.2$, $p < .05$). Figure 28 shows the frequencies for each response. Finally, six pilots felt that a bank pointer should be limited to +/- 45 degrees and six felt it should not. Significant differences did not exist, $\chi^2 = 0$, $p > .05$.

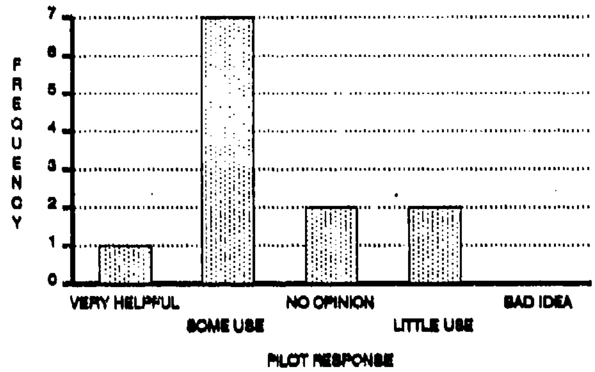

FIGURE 28. PILOT'S PREFERENCES REGARDING THE POINTER ON THE BANK SCALE.

DISCUSSION

This section discusses both phases of the present evaluation. Two general findings from the results were: (1) the Block 40 pitch scale was the worst format for both nose high and nose low conditions and (2) the partially articulated pitch scale was significantly better than the other pitch scales for nose low attitudes. This makes sense because the partially articulated pitch scale in a nose low attitude, gives the pilot instantaneous feedback concerning the aircraft's attitude.

Training effects may account for the quicker recovery times found flying the Block 40 with pitch numbers at the end (4.66 seconds), since F-16 pilots fly this format every day. Due to the pitch ladder symmetry found on the fully articulated HUD, a pilot must make a distinction between the solid bar (nose high) and dashed bar (nose low) to determine whether he is inverted. However, with pitch numbers above the pitch ladder, a pilot is immediately aware of his attitude (upright or inverted). This explains the reason for a quicker mean recovery time for the fully articulated pitch scale with pitch numbers above the pitch bars.

Both subjective workload measures yielded essentially the same results. Articulated pitch scales were significantly better than the Block 40 pitch scale. The partially articulated pitch scale was preferred in high workload conditions, but the fully articulated pitch scale was better under normal flight conditions. In Phase II, no differences were found in pilot performance between the two horizon lines. However, 11 of 12 pilots preferred the extended horizon line.

These results should prove useful to System Program Office engineers as they make decisions concerning the HUD. The results were exhaustive; performance data, subjective workload data and pilot opinion data were collected. Each source of data lead to the same conclusion, thus providing strong evidence to support the recommendations.

Follow on efforts should look further at alternative locations for the pitch numbers. Several pilots suggested placing the pitch numbers below the pitch bars in the upper hemisphere and above the pitch bars in the lower hemisphere. This option seems plausible because it gives the pilot an instantaneous indication of where the horizon is located. Future studies should investigate this possibility both with and without articulated pitch bars.

At least two questions remain that cannot be answered by the current effort. One area concerns the best location for pitch numbers. The follow on study mentioned above may answer this question. Another question concerns the horizon line; if pilots prefer the longer horizon line because it stands out more on the HUD, then why isn't their performance enhanced? These questions could be answered via more simulation.

CONCLUSION

The data collected in this evaluation suggest that articulated pitch bars yield better performance than the pitch bars presently used in the F-16. Specifically, the partially articulated pitch scale yielded quicker reaction times and in high workload scenarios, this pitch scale induced less work on the pilot. Of the 12 pilots, six preferred the partially articulated HUD, while six preferred the fully articulated configuration. Making a clear distinction between number configurations was not possible. The results were not significant and no trends in the data were apparent. Similarly, no discernible differences were found between the two horizon lines.

Based upon these conclusions, the following are recommended. First, replace the current F-16 Block 40 pitch ladder with a partially articulated format. Pilots reacted to the partially articulated format quicker and they know whether the aircraft is in a nose high or nose low attitude instantly. Second, maintain the current pitch number location. These results were not compelling enough to warrant a change. Third, extend the present F-16 Block 40 horizon line the full width of the HUD but do not occlude the altimeter, airspeed scale and data blocks. Pilots prefer the longer horizon line.

**Implementation of the third recommendation should be done only if recommendation one is implemented.

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APPENDIX A

SITUATION AWARENESS RESULTS

In the preflight briefing, the pilot was instructed to pull the trigger on the stick once he felt he had recovered to wings level. During simulation, the number of times that a pilot recovered to what he thought was wings level, but was actually inverted, was recorded. Out of over 1,700 trials, the pilots recovered inverted only 23 times. The results, however, are interesting. Fifteen of the 23 inverted recoveries occurred using the fully articulated pitch scale. Six occurred with the Block 40 pitch scale, and the remaining two occurred using the partially articulated format.

During the SA data analysis, a contradiction was found between the SA results and the inverted recovery results described above. The following is a description of the problem. The inverted recovery results contradict the previously stated SA conclusion that the fully articulated pitch scale was the best configuration (refer to Figure 18 on page 18). Figure 29 shows the percentage of inverted recoveries for each of the three pitch scale formats. Contrary to the SA results, the fully articulated pitch scale yielded the most (65.2 percent) inverted recoveries.

The results of this evaluation are clear. Based on the SA results, the pilots felt that their situation awareness was very good when flying with the fully articulated pitch scale while their performance unequivocally indicated the opposite. The inverted recoveries can be attributed to the pitch ladder symmetry found in the fully articulated pitch scale. Note, the partially articulated pitch scale (asymmetric pitch ladders) had the lowest number of inverted recoveries. These results indicate that, in its present form, the SA tool is not a sufficient indicator of pilot situation awareness.

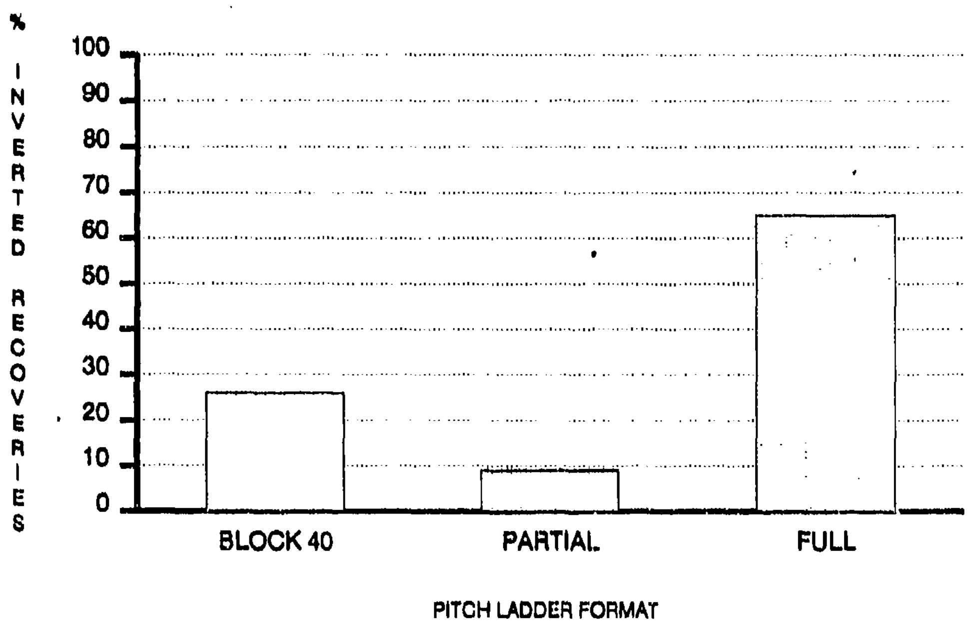


FIGURE 29. PERCENTAGE OF INVERTED RECOVERIES AS A FUNCTION OF PITCH LADDER FORMAT.

APPENDIX B

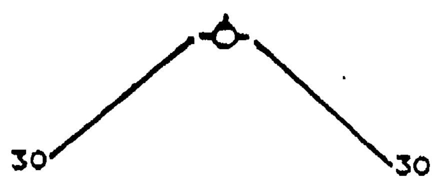
PILOT QUESTIONNAIRE - PHASE 1

1. Which pitch ladder format enhanced your ability to recover the most?
   a. Block 40 pitch ladder
   b. pitch ladder with articulated pitch bars in the lower hemisphere
   c. pitch ladder with articulated pitch bars in the upper and lower hemisphere

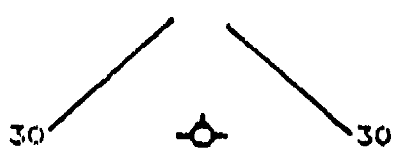
2. Concerning the numbers on the pitch scale, what characteristics are most useful? Choose all that apply.
   a. Positive numbers in the upper hemisphere and negative numbers in the lower hemisphere
   b. All positive numbers with dashed pitch bars in the lower hemisphere
   c. Numbers at the outer ends of the pitch bars
   d. Numbers at the outer ends and above the pitch bars

3. When articulated pitch bars are presented, would you prefer to read degrees of pitch when the flight path marker is presented at the top of the bars as shown in Figure A below, or at the bottom of the bars as shown in Figure B below? Pick the appropriate letter.

a.



b.



4. Have you ever experienced spatial disorientation using the HUD?

   a. Yes

   b. No

5. Did the articulated pitch bars help in determining nose up from nose down?

   Articulated bars in the upper and lower hemisphere

   a. Yes

   b. No

   Articulated bars in the lower hemisphere only

   a. Yes

   b. No

6. Were the articulated pitch bars helpful in determining roll attitude?

   Articulated bars in the upper and lower hemisphere

   a. Yes

   b. No

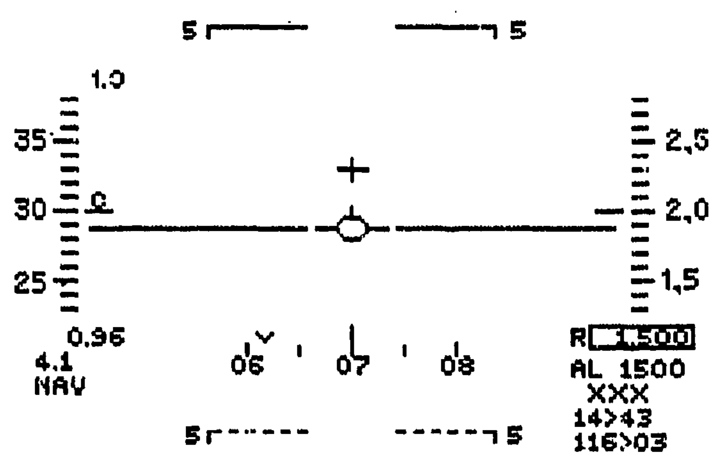
   Articulated bars in the lower hemisphere only

   a. Yes

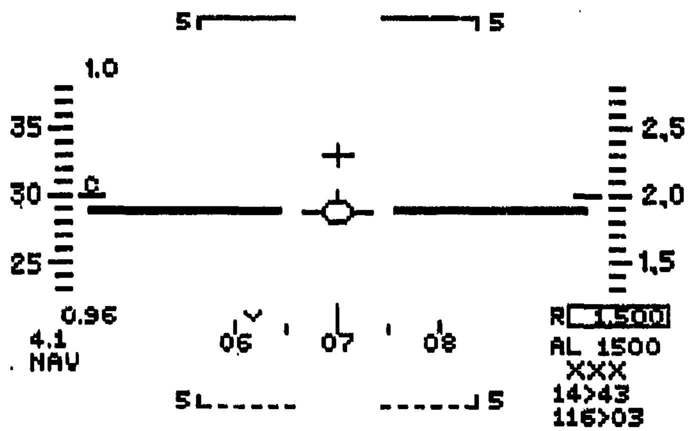
   b. No

7. For the following HUD features, pick the one that you prefer most.

   a. Nadir (ground) pointing tails



b. Horizon pointing tails



APPENDIX C

PILOT COMMENTS CONCERNING THE PITCH LADDERS AND PITCH NUMBER LOCATION

1. The following comments are related to pitch scale preference.

   A. Articulated pitch bars below the horizon are great. Articulated pitch bars above and below the horizon were confusing.

   B. Extreme nose high/low altitudes were easier to discern with articulated pitch bars below the horizon line.

   C. No comment.

   D. No comment.

   E. The best display was the partially articulated HUD.

   F. Only pitch bars below the horizon should be articulated.

   G. Fully articulated pitch bars were the best.

   H. Fully articulated configuration was easiest to quickly determine which direction to the horizon.

   I. No comment.

   J. Fully articulated HUD gave instant feedback on which way to pull to the horizon.

   K. No comment.

   L. Definite difference using the full articulation.

2. The following comments are related to the numbers on the pitch scale.

   A. Number location really doesn't make too much of a difference.

   B. With a partially articulated pitch scale number location does not matter, but with a fully articulated scale, positive numbers in the upper hemisphere and negative numbers in the lower hemisphere is the best choice.

   C. No comment.

   D. No comment.

   E. The best choice is to locate the pitch numbers below the pitch bars in the upper hemisphere and locate pitch numbers above the pitch bars in the lower hemisphere.

   F. Would like to see negative numbers in the lower hemisphere.

   G. No comment.

   H. Numbers at the end tend to obscure the tic mark at the end of the pitch bar especially in unusual attitudes.

   I. No comment.

   J. Easier to read when numbers are above the bar. Also, this reinforces which way is up and which way is down.

   K. No comment.

   L. The number placement currently used is fine.

3. These comments concern pilot opinions of the flight path marker location with an articulated pitch scale.

A. Easier to set and hold desired pitch attitudes by placing FPM between two lines rather than between two numbers.

B. Having the degrees of pitch read between the pitch bars distorts pitch change rate.

C. No comment.

D. No comment.

E. Having the degrees of pitch read between the pitch numbers would be confusing.

F. No comment.

G. No comment.

H. When dive angle is critical, the pilot's crosscheck does not allow enough time to estimate the dive angle by looking at numbers. The pilot will note how much he is above or below the pitch line and correct from there.

I. No comment.

J. Easy to think about pulling to put the FPM in the funnel.

K. More logical to "fly" FPM through the funnel and have the "wings" of the FPM point to pitch angle.

L. No comment.

4. The following comments concern the utility of articulated pitch bars in determining nose up from nose down.

A. No comment.

B. Articulated pitch bars below the horizon provides on immediate distinction between nose high/low attitudes.

C. No comment.

D. Both are good in nose low.

E. Difficult to tell what is up and what is down with fully articulated HUD. Partially articulated made it easy.

F. With partially articulated you get a positive first glance indication of horizon position.

G. Articulated below the horizon works the best.

H. Both are better than Block 40 HUD.

I. No comment.

J. No comment.

K. I would like to see partially articulated with numbers reinforcing pointing rails by being on the horizon side.

L. Articulation was big help.

5. The following comments concern the utility of articulated pitch bars in determining roll attitude.

A. No comment.

B. No comment.

C. No comment.

D. No comment.

E.They would help in assessing the initial aircraft attitude and determining which way to roll.

F. No comment.

G. No comment.

H. No difference among all three displays.

I. No comment.

J. No comment.

K. No comment.

L. No comment.

6. The following comments concern pilot opinions of the tic marks (tails) located on the outer ends of each pitch ladder.

A. No comment.

B. Horizons are more important than the direction of the ground.

C. No comment.

D. Very useful when articulation was not available.

E. Easier to see horizon pointing tails.

F. No comment.

G. No comment.

H. No comment.

I. No comment.

J. Easier to think that the tails are always pointing to the horizon.

K. Have pitch numbers on horizon side of pitch ladder to reinforce pointing tails.

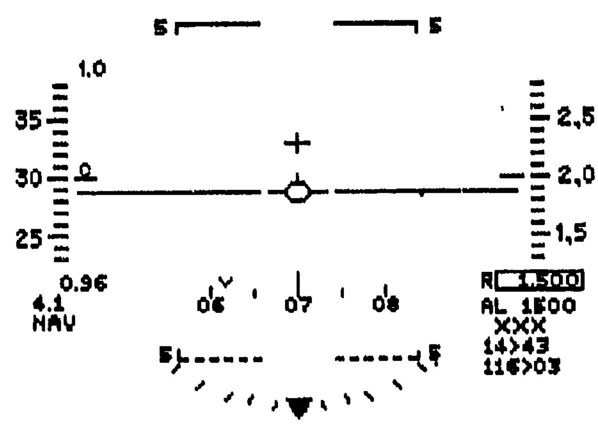
L. No comment.

APPENDIX D

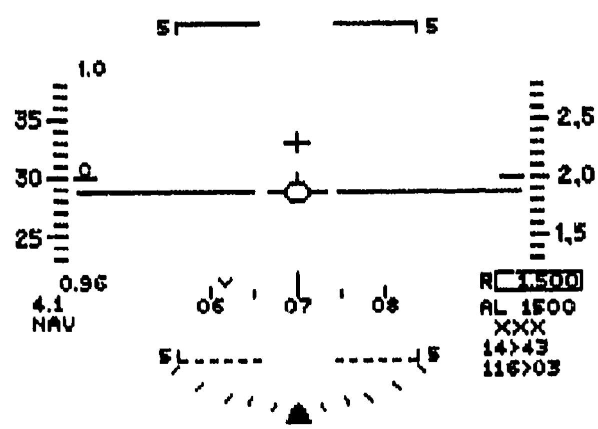
PILOT QUESTIONNAIRE - PHASE II

1. What do you think of the longer horizon line?
    a. Good idea
    b. No opinion
    c. Prefer the normal Block 40 horizon line
    d. Very distracting - take it out

2. For the following HUD features, pick the one that you prefer most.
    a. A ground pointer on the bank scale

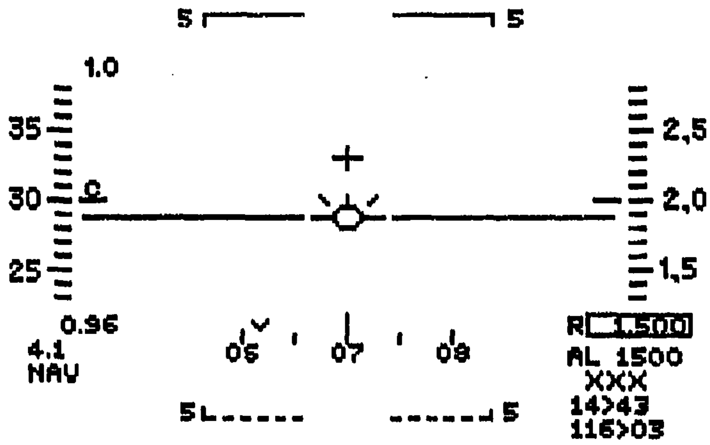


b. A sky pointer on the bank scale

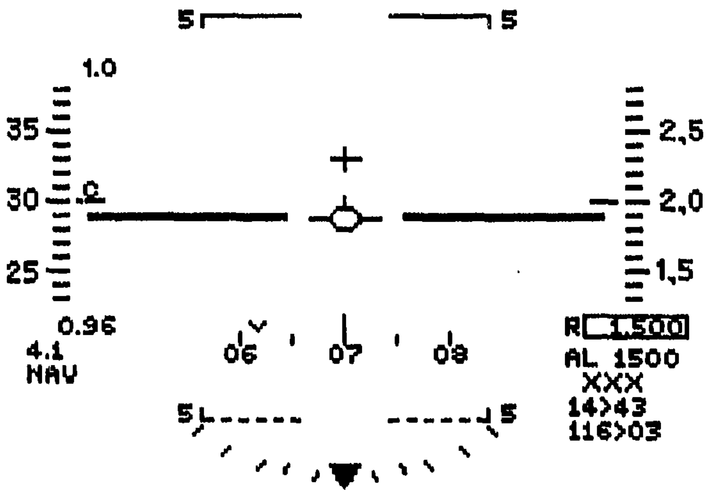


3. For the following HUD features, pick the one that you prefer most.

a. 45 degree bank indicators around the flight path marker



b. The bank indicator presently used



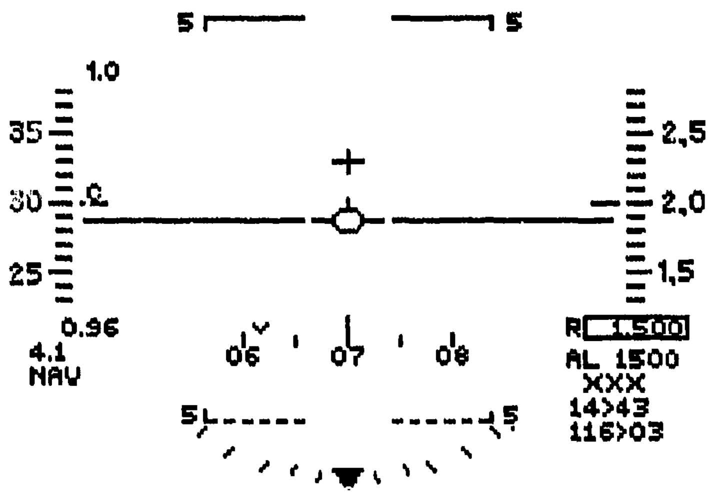
4. On the bank scale shown below, the pointer rotates through 360 degrees; what is your opinion of this bank scale?

a. Good idea

b. No opinion

c. Prefer another bank scale, (which one________________)

d. Would be very distracting



5. Did you find the bank scale/pointer useful in UA recoveries?

a. Yes

b. No

6. How do you feel about the pointer on the bank scale pointing up?

a. Very helpful

b. Of some use at low bank angles

c. No opinion

d. Of little use

e. Bad idea

7. Should the bank pointer be limited to +/-45 degrees of bank?

a. Yes

b. No

APPENDIX E

PILOT COMMENTS CONCERNING THE HORIZON LINE AND THE BANK INDICATOR

1. The following comments include pilot opinions of the long horizon line.

   A. Good idea but not helpful.

   B. Should revert back to a normal horizon line in any weapons mode.

   C. No comment.

   D. No comment.

   E. Gives a feeling of rolling faster than you really are so current horizon line is better.

   F. Better reference to level flight

   G. Good idea but normal horizon is good enough.

   H. Easier to pick up with peripheral vision.

   I. Not important in day-to-day operations. Would prove to be more useful at night or in weather.

   J. Very nice.

   K. No comment.

   L. Makes it easier to distinguish.

2. Pilot comments related to the pointer on the bank scale are summarized below.

   A. No comment.

   B. A sky pointer always points to the horizon and is a positive indication of upright/inverted flight.

   C. No comment.

   D. No comment.

   E. No comment.

   F. No comment.

   G. No comment.

   H. No comment.

   I. Now make the Bank indicator 360 degrees.

   J. No comment.

   K. No comment.

   L. No comment.

3. The comments below concern pilot opinions of two different bank indicators.

A. No comment.

B. Bank indication is a minor concern.

C. No comment.

D. The Block 40 bank indicator is very useful in gear down ILS approaches.

E. The Block 40 Bank indicator is good.

F. No comment.

G. No comment.

H. No comment.

I. Bank indication around FPM only necessary with Block 40 HUD.

J. No Comment.

K. Bank indication around FPM would be nice for flying in the weather.

L. Bank indication around the FPM would be better if the indications were bigger.

4. These comments concern pilot opinions of the 360 degree bank scale.

A. Too distracting.

B. Bank indication is not so important that it requires this much space on the HUD.

C. No comment.

D. Make it optional or incorporate it into the gear down symbology.

E. Prefer current scale.

F. No comment.

G. Prefer bank indication around FPM.

H. Prefer pointer below the scale pointing up.

I. No comment.

J. No comment.

K. No comment.

L. No comment.

5. The following are pilot comments related to limiting the bank pointer to +/- 45 degrees of bank.

A. Limit bank, otherwise it would unnecessarily clutter HUD.

B. Do not limit bank, 360 degrees of bank or nothing.

C. No comment.

D. Displays go unnoticed or lost in bank angles greater than 45 degrees.

E. Limit Bank, a 360 degree bank indicator would be more confusing

F. No comment.

G. No comment.

H. Useless for normal flying.

I. No comment.

J. A 360 degree display would be nice.

K. We seldom use 45 degrees. A scale ranging from + or - 30 degrees would be better.

L. No comment.