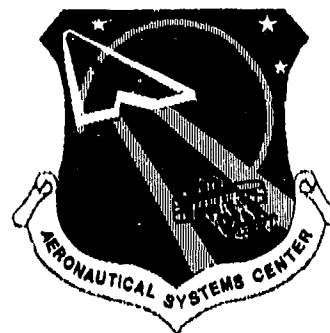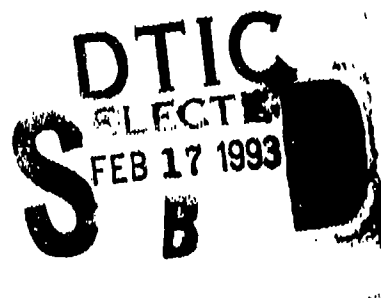# AD-A260 280

ASC-TR-92-5017

ATTITUDE AWARENESS ENHANCEMENTS FOR THE F-16 HEAD-UP DISPLAY

Scott M. Cone
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Crew Station Evaluation Facility
Crew Station and Human Factors Section

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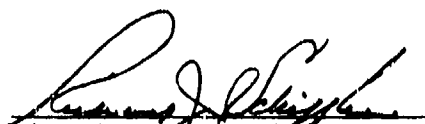
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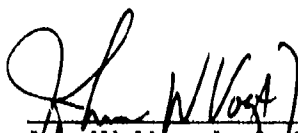
This technical report has been reviewed and is approved for publication.

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13. ABSTRACT (Maximum 200 words)

In an effort to reduce the Collision With Ground (CWG) and Spatial Disorientation (SDO) mishaps, the F-16 System Program Office has initiated an effort to improve F-16 C/D HUD symbology. In support of this effort, the SPO identified a set of attitude awareness enhancements for potential incorporation into the aircraft. These were (1) extended horizon, (2) ghost horizon, (3) articulated nose down pitch bars, (4) removal of 2:1 pitch scale compression, (5) moving nose down pitch bar tic marks to the inside of the pitch bars, (6) modified bank angle indicator, and (7) modified zenith/nadir symbols. Prior to the incorporation of these enhancements, the Crew Station Evaluation Facility performed a simulation evaluation to assess the improvement in attitude awareness provided by these changes. Fifteen pilots flew a series of unusual attitude recoveries and mission demonstration tasks during which reaction time, error rate, and subjective ratings were collected. Results showed faster reaction times, especially in nose-down conditions, and strong subjective preference for the modified HUD format. Based on these results, the CSEF recommended the incorporation of the extended horizon, ghost horizon, modified pitch ladder, and modified zenith/nadir symbols (low priority). Ratings for the bank angle indicator were mixed. It is recommended that the bank angle indicator be evaluated in instrument flying conditions before being considered for incorporation into the F-16 HUD.

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INTRODUCTION

Spatial Disorientation (SDO) and Collision With Ground (CWG) events constitute a significant percentage of F-16 mishaps (Ward, 1990). These events occur when the pilot loses awareness of the aircraft position/orientation with respect to the earth. A variety of factors can cause this loss of attitude awareness, including confusing information presentation and high workload/distracting conditions (e.g., target fixation).

In an attempt to reduce the probability of these events in the future, the F-16 SPO initiated a program to improve F-16 C/D symbology. Incorporating more intuitive attitude symbology should aid recognition and recovery from these events. Specifically, the goals of the program are to (1) reduce mishaps associated with CWGs and SDO and (2) provide for unambiguous recognition of, and recovery from SDO and CWG events. There is no current plan to make the HUD in F-16 C/Ds a primary flight reference. In support of this effort, the F-16 SPO conducted a review of previous HUD symbology research, flight testing, and other HUD-equipped aircraft. Based on this review and a consideration for commonality with recent F-16 A/B HUD upgrades, a set of proposed attitude awareness enhancements (referred to as "nuggets") to the F-16 C/D HUD were identified. Prior to pursuing a formal development effort, the F-16 SPO has tasked the Crew Station Evaluation Facility (CSEF) to assess the spatial awareness benefits provided by these nuggets. This report describes the methods and results of this evaluation. If shown to be beneficial, these nuggets will be incorporated into Software Capability Upgrade 2 (SCU-2), an avionics upgrade program for existing F-16 C/D aircraft.

TEST OBJECTIVES

The primary objective of this evaluation was to assess attitude awareness benefits provided by the symbology nuggets. To accomplish this objective, pilot performance and attitude awareness were compared across two HUD formats: (1) the current F-16C/D format and (2) the F-16 C/D format that incorporates the proposed symbology changes. The specific enhancements evaluated included (1) extended horizon, (2) ghost horizon, (3) modified bank angle indicator (move to location around flight path marker), (4) nose down articulated pitch bars with tic marks on the inside (noncompressed conformal scaling, numbered every five degrees), and (5) modified zenith and nadir symbols.

The evaluation employed five simulator tasks, each flown with an F-16C/D HUD and the Nugget HUD format. The five tasks were (1) Unusual Attitude Recovery (UAR), (2) Air-to-Air tracking (AAT), (3) Air-to-Ground (A-G) Mission Demonstration, (4) Air-to-Air (A-A) Combat Demonstration, and (5) Familiarization Demonstration. The procedures for these tasks are defined more fully in the methods section. Pilot performance, attitude awareness data, and subjective questionnaire data were collected throughout the evaluation.

METHOD

Subjects

Fifteen pilots participated in the evaluation: 10 operational F-16 pilots, three locally available pilots with extensive F-16 experience, and two pilots who recently completed Undergraduate Pilot Training and have no F-16 or HUD experience. Five of the pilots had experience in the F-16A model and eight of the pilots had F-16C experience (three of these pilots also had F-16A experience). Overall F-16 flying hours ranged from 180 through 2000 and averaged 775. Total flying hours ranged from 750 to 5000 and averaged 2003.

Simulation Test Bed

Crew Station Evaluation Facility

The study was performed at the CSEF, an Air Force simulation facility that belongs to the Crew Station and Human Factors Section (ASC/ENECS) in the Crew Systems Branch (ASC/ENEC). The branch is part of the Support Systems Engineering Division (ASC/ENE) contained within the Directorate for Integrated Engineering and Technical Management (ASC/EN). The facility supports System Program Offices in their acquisition engineering through pilot vehicle interface evaluations using man-in-the-loop simulation. Currently, the CSEF has the capability to perform full and part mission simulations for a variety of aircraft including the F-16, F-111, F-22 and KC-135.

F-16 Simulator

The CSEF F-16C simulator was constructed using 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 undercarriage was removed, and the floor panel section sits on small canister-type wheels. The simulator does not employ a motion base. The cockpit controls and displays are configured to the F-16C Multi-National Staged Improvement Program (MSIP) F-16 C/D design which includes two 4x4 inch multifunction displays (MFDs), an Integrated Control Panel (ICP), a Data Entry Display (DED), Hands-on Throttle and Stick (HOTAS) controls, centralized flight instruments and F-16 C/D avionics suite. The side control stick, throttle, HUD and flight controls are actual F-16 components. All of the other instruments, controls, and displays will be simulated using locally available equipment. All head-down flight displays were disabled during the evaluation, forcing the pilots' reliance on the HUD. A photograph of the F-16 simulator cockpit is shown in Figure 1.

External Visual Scene Generation

An IMAGE IIIT Visual System was mounted directly in front of the F-16 simulator. The IMAGE IIIT system presents collimated computer generated imagery representing the outside world to the pilot. Three monitors presented a contiguous 120° visual scene directly in front of and to the left and right of the pilot's seated position. The IMAGE IIIT system has the capability to provide a variety of special effects including weather, time of day, texture, and airfield lighting. For the data collection tasks, a daytime Instrument Flight Rules (IFR) scene with no discernible horizon was shown. For the mission demonstrations, a Visual Flight Rules (VFR) visual scene was shown.

HUD Graphics Generator

The HUD symbology was generated using a Vector General symbol generator, while a PDP 11/34 computer mapped and controlled the HUD's position. The PDP computers were in turn driven by flight parameter information provided by Gould 32/7780 and 32/8730 mainframe computers.

Experimenter's Console

The experimenter's console included a complete intercom system for up to four test engineers/observers and the simulator pilot. The console duplicated cockpit displays and provided "quick-look" feedback on pilot performance. From the console, the test engineer controlled simulator operation and selected test parameters (test subject number, test conditions, etc.).

F-16C/D Head-Up Display Format

The two HUD symbology formats used in the evaluation are shown in Figures 2, 3 and 4. The baseline symbology used in this evaluation, representing the current F-16 C/D HUD format, is shown in Figure 2. The specific symbols and mechanizations are described below. These descriptions address only flight information provided by the HUD. Weapon symbology and other specialized information presentations are not relevant to the current study.

1. **Boresight Cross.** The boresight cross is a "+" sign 13 mr wide and 13 mr tall and represents the fuselage reference line. The cross is displayed at 0 degrees in azimuth in all modes.

2. **Roll Indicator.** The HUD roll indicator displays tic marks positioned around reference circle centered 50 mr below the center of the total field of view. The tic marks are aircraft stabilized and spaced 10 degrees apart. A ground stabilized reference caret is displayed immediately below the tic marks. Roll is read by referencing the caret to the stationary scale. The roll indicator is removed in selected modes.

3. **Flight Path Marker.** The Flight Path Marker consists of a 10 mr circle with 10 mr "wings" that are aircraft-stabilized and a 5 mr tail extending up from the circle. The position of the flight path marker represents the current velocity vector of the aircraft and can be read in reference to the pitch ladder. When the FPM is limited to the HUD field of view (FOV), an "X" symbol is superimposed over the marker symbol.

4. **Air Speed Scale.** The air speed scale shows velocity in tens of knots at 50-knot increments. Airspeed is obtained by reading the fixed index mark relative to the moving scale, as well as via the digital readout presented next to the index mark.

Figure 1. CSEF F-16 simulator cockpit

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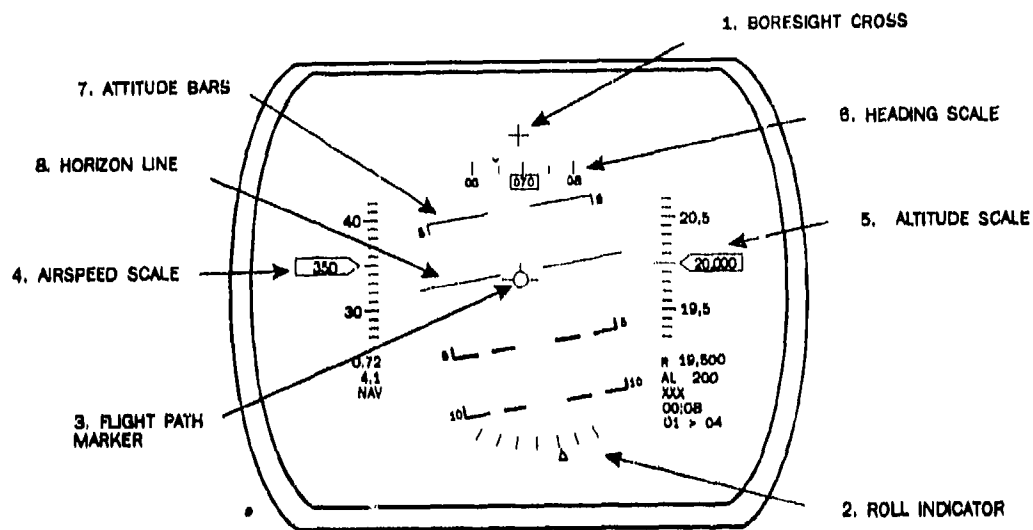
Figure 2. F-16 C/D HUD format.

1. BORESIGHT CROSS
6. HEADING SCALE
5. ALTITUDE SCALE
2. ROLL INDICATOR
7. ATTITUDE BARS
8. HORIZON LINE
4. AIRSPEED SCALE
3. FLIGHT PATH MARKER
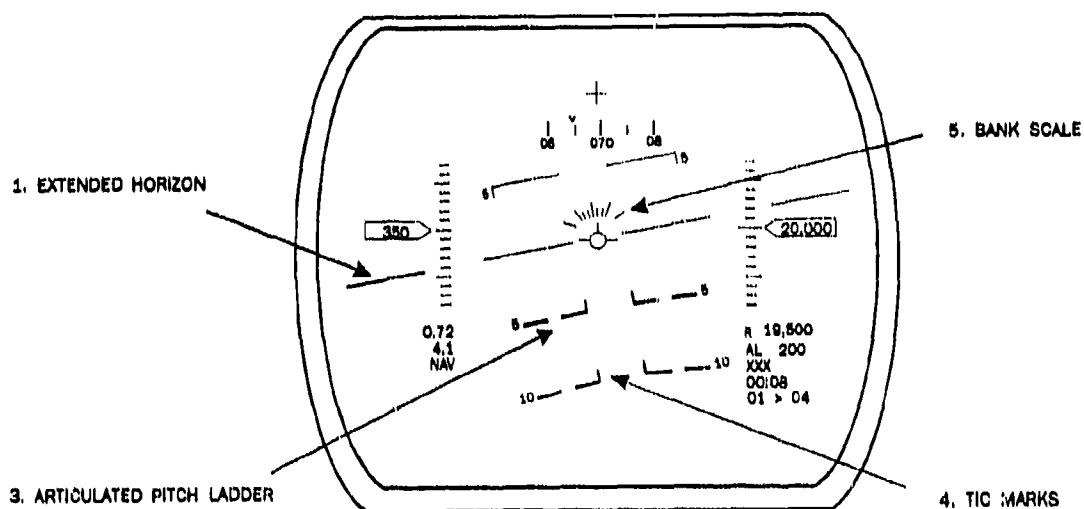
Figure 3. Nugget HUD format.

5. BANK SCALE
1. EXTENDED HORIZON
3. ARTICULATED PITCH LADDER
4. TIC MARKS

Figure 4. Nugget HUD format showing ghost horizon.

2. GHOST HORIZON

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Calibrated, true and ground speed scales are selectable on the HUD remote panel.

5. Altitude Scale. The altitude scale displays barometric or radar altitude in hundreds of feet with a digital read-out at 500 foot intervals. Reference tics are provided every 100 feet. Altitude is read by reading the fixed index mark relative to the moving scale, as well as via the digital 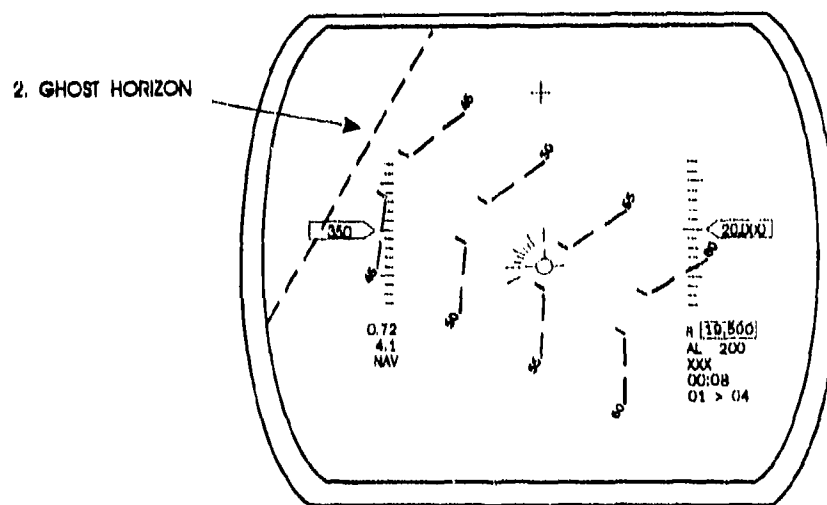representation presented next to the index mark. A digital presentation of radar altitude is shown below the altitude scale.

6. Heading Scale. Heading is displayed in tens of degrees at 10-degree increments. Reference tics are provided every five degrees. Heading is read via the digital readout shown below the moving scale. Magnetic or groundtrack heading scales are individually selectable. During landing, the scale is displayed either 50 mr above the FPM or just below the boresight cross, whichever position is lower.

7. Attitude Bars and Horizon Line. Attitude bars are displayed conformally with the real world in 5-degree increments. Between zero and 60 degrees, the bars are labeled in 5- degree increments with numbers positioned on both sides of each line. Beyond 60 degrees, pitch bars are also spaced at 5 degree increments, but are labeled and mechanized to represent 10 degree changes in attitude. This design constitutes a 2:1 compression scheme beyond 60 degree climbs/dives. When the aircraft is climbing, the attitude bars are solid and tic marks on the outside ends point downward toward the horizon. When the aircraft is diving, the attitude bars are dashed and tic marks on the outside ends point upward toward the horizon. Both the attitude bars and horizon line have a gap in the middle for the FPM. The entire pitch ladder is roll stabilized, and therefore stays parallel to the horizon. Attitude and roll angle can be determined by reading the pitch ladder with reference to the flight path marker.

8. Horizon Line. The horizon line is solid and slightly wider than the attitude bars. As with the attitude bars, it contains a gap in the middle for the FPM. The horizon line remains stabilized to the real horizon at all times.

9. Zenith and Nadir Symbols. The zenith and nadir symbols presented with the C/D format were unique to the CSEF HUD. The aircraft has no zenith/nadir symbols. Instead, pitch ladder bars

continue through the zenith and nadir. The zenith symbol represents a 90 degree climb position, and was a circle surrounding an "X." The nadir represents a 90 degree dive attitude and was an open circle. The symbols are shown in Figure 5.

Figure 5. CSEF simulator zenith and nadir symbols.

More detailed specifications of the F-16 C/D HUD format can be found in the F-16 C/D Avionics System Manual, Block 40 Production Tape 3 (General Dynamics, 1991).

F-16 Nugget Head-Up Display Format

The Nugget HUD format is shown in Figures 3 and 4. The Nugget format contains the following changes from the current C/D HUD format. The symbology descriptions below reflect the design used throughout the evaluation.

1. Extended Horizon Line. The horizon line is lengthened from the C/D horizon line to the entire HUD field of view. In addition, it is drawn at all times when the real horizon is within the HUD FOV, including when the pitch ladder is not (e.g., during high-g maneuvers).

2. Ghost Horizon. The ghost horizon appears as a dashed line, in place of the extended horizon line, when the real horizon line moves out of the HUD total field of view. It is displayed tangent to an 8 degree radius circle in the center of the HUD and remains parallel to the true horizon at all times. It provides both relative position of the real horizon and a roll indication. The ghost horizon in Figure 4 shows that the real horizon is above and to the left of the aircraft nose (i.e., the aircraft is diving and in a slight right roll).

3. Articulated Pitch Ladder and tic marks. For nose-up conditions, the nugget HUD pitch ladder is identical to the F-16 C/D HUD pitch ladder. Below the horizon, the nugget HUD pitch bars are dashed

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and articulated (or angled) by half of the indicated angle. For example, at 10 degrees dive, the pitch bars are angled 5 degrees; at 80 degrees dive, the pitch bars are angled at 40 degrees. The increasing articulation provides a gross indication of dive angle. The articulated pitch ladder (or bendy bars), taken together, suggest a funneling effect for nose down conditions. This effect can be seen in Figure 4. Performing a nose-down unusual attitude recovery only requires the pilot to "fly up the funnel." For each pitch bar, the indicated dive angle is located at the intersection of the tic marks and pitch bar. Pitch bars are presented every 5 degrees throughout the entire range of attitudes, thus removing the 2:1 compression from the C/D HUD. The Nugget HUD pitch ladder is completely conformal with the real world.

4. Tic marks. For the nugget HUD, the tic marks at the ends of each pitch bar were moved from the outside ends to the inside of the bar, on either side of the flight path marker gap. This provided additional asymmetry between nose-up and nose-down conditions and was intended to enhance the discriminability of the tic marks. Their inside placement also enhanced the "funneling" effect produced by the angled pitch bars.

5. Bank Angle Indicator. For the nugget HUD format, the C/D roll indicator was removed, and replaced with a bank angle indicator that is displayed with reference to the flight path marker. The scale consisted of tic marks displayed at 0, 10, 20, 30, and 60 degrees positioned on a reference circle that encircles (and follows) the FPM. The scale is roll stabilized and is read with reference to the "tail" of the FPM.

6. Zenith/Nadir. The nadir symbol is a circle with a line extending from the circumference in the direction of the nearest horizon and is positioned at the -90 degree angle on the pitch ladder. The circle had five solid lines inside it which are always parallel to the pitch ladder lines. The zenith indication is a "star" shaped symbol with one elongated point, which always points the closest direction to the horizon. The symbol is placed at the +90 degree angle on the pitch ladder. The symbols are shown in Figure 6.

Two "orange peel" conceptual display designs were included in the study for quick-look evaluation only.

These concepts are not currently being considered for incorporation into the F-16.
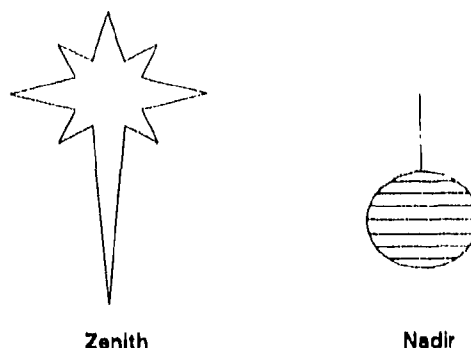
Zenith   Nadir
Figure 6. Nugget HUD zenith and nadir symbols.

Orange Peel Displays

1. Small Orange Peel. The orange peel concept is shown in Figure 7. At straight and level flight, it consists of a semicircle wrapped around the lower half of the FPM. The orange peel remains referenced to, and moves along with, the FPM at all times. A dive condition is represented by an increase in the length of the orange peel. The orange peel wraps around a greater portion of the FPM as dive angle increases. A climb condition is represented by a shrinking of the orange peel; as climb increases, the length of the orange peel decreases.

2. Large Orange Peel. The large orange peel (shown in figure 8) mechanization is similar to that of the small orange except that it is referenced to the airspeed and altitude boxes, is much larger in size, and remains stationary around the outer circumference of the HUD FOV. Straight and level flight is indicated when the tic marks on the orange peel are aligned with the airspeed and altitude boxes. As with the small orange peel, it lengthens to show a dive and shrinks to show a climb.

Questionnaires. Questionnaires were developed to obtain subjective ratings/evaluations of the proposed symbology changes. A copy of the questionnaire along with all subject's responses is included as Appendix A.

Procedure

Pilots participated in the study for two half-day sessions. After an initial training session, the pilots

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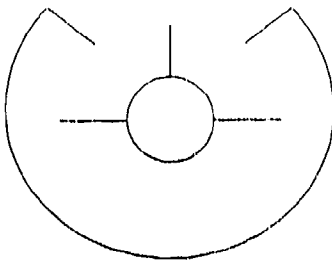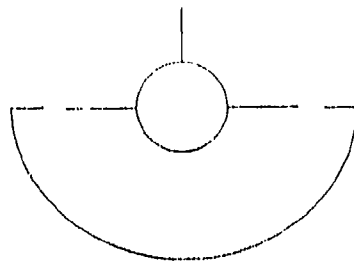
Dive condition   Straight and level flight   Climb condition

Figure 7.   Small Orange Peel Concept.
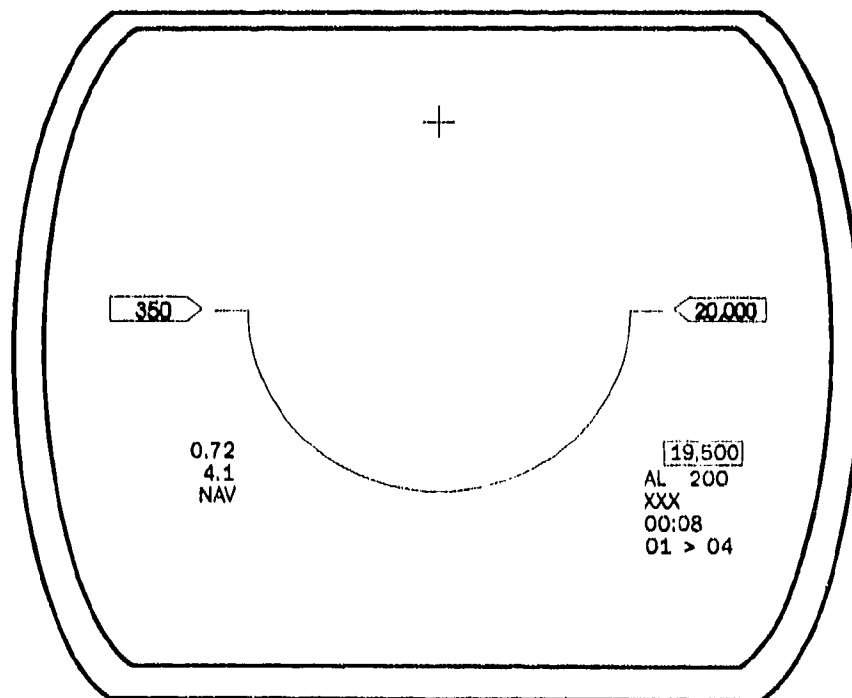
Figure 8.   Large Orange Peel concept showing level flight.

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flew a series of data collection / subjective evaluation tasks along with several mission demonstrations.

Evaluation Tasks

The evaluation employed five tasks, each flown with an F-16C/D HUD and the Nugget HUD format. The five tasks were (1) Unusual Attitude Recovery, (2) Air-to-Air tracking, (3) A-G Mission Demonstration, (4) A-A Mission Demonstration, and (5) Familiarization Demonstration. The tasks are described below:

Unusual Attitude Recoveries. Each UAR trial began with the HUD blanked and the throttle set to a mid-range position (80%). The simulator was then set to the desired unusual attitude conditions (gamma, phi, airspeed and altitude) and frozen. The pilot initiated the trial by pressing the cage/uncage switch on the throttle. Upon pressing the switch, the HUD display appeared, the stick became active, and the pilot recovered to straight and level flight as quickly as possible. The trial automatically terminated once the pilot achieved and maintained level flight for 5 consecutive seconds. Level flight was defined as +/-5° gamma and +/-8° phi. Upon termination, the HUD symbology was blanked and the next trial was set up.

Test subjects were instructed to use AFM 51-37 (1992) procedures during the recovery from unusual attitudes. Back pressure on the stick was not to be applied until a positive lift vector had been achieved, (i.e., aircraft within 90° of the horizon). For purposes of data collection, pilots were instructed to pull when within 90° of the horizon regardless of whether the simulator was climbing or diving. Pilots were also instructed to use the throttle and speedbrake as appropriate.

For the UARs, Flight path angles of 30, 60, 80, -30, -60 and -80 degrees were completely crossed with roll angles of 0, +/-45, +/-90, +/-135 and 180 degrees (half were right bank and half were left bank) for a total of 30 combinations. Each pitch/roll condition was repeated 3 times for each HUD format for a total of 6 (pitch conditions) x 5 (roll conditions) x 2 (HUD formats) x 3 (repetitions) = 180 recoveries. Altitude, airspeed and crosswind conditions were randomly selected for each trial. Each pilot flew two sessions of UARs, one with the F-16 C/D HUD format and one with the enhanced HUD format.
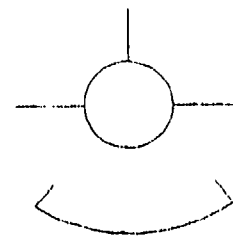
Air-to-Air Tracking Task. This task required the pilot to fly in trail to an "adversary" while keeping the boresight cross aligned on it. The "adversary" was driven by an interactive robot pilot, that was sufficiently dynamic to induce substantial pilot workload. Only standard navigation symbology was shown during this task, and the visual scene provided no discernible horizon. For purposes of the task, the pilot was instructed to maintain awareness of all aircraft parameters throughout the task. When the "adversary" led the test pilot a preselected attitude condition, and at least on inute of time had passed, the simulator was frozen and the HUD was blanked. A computer workstation display located next to the cockpit presented multiple choice options for ownship flight parameters and information about the "adversary's" flight parameters and relative location. The pilot then selected the options that matched aircraft parameters at the time of freeze. After the options were selected, the HUD and visual scene reappeared to provide feedback of conditions at the time of freeze. Twelve AAT runs were performed for each HUD format.

This task was part of an exploratory effort to identify alternative tasks to UARs that could be used to assess differences in attitude awareness across display formats. Whereas the UAR assesses attitude recognition in relatively static conditions, AAT was an attempt to assess pilot maintenance of attitude awareness in dynamic, high workload conditions. The task had two primary goals. First, it required the pilot to maintain attitude awareness with the HUD display during high workload and distracting conditions. Very often, it is in high workload conditions, when the pilot is task saturated or target fixated, that the highest potential for loss of attitude awareness exists. Second, it provided pilots experience with the HUD formats in very dynamic conditions, and therefore was valuable for subjective evaluation. Although error data were collected during AAT runs, time constraints precluded an adequate number of runs for a valid statistical analysis. Therefore, this task was used primarily as a demonstration of the HUD formats in dynamic conditions.

Symbology Familiarization. Pilots performed a take off and flew maneuvers including straight and level flight, shallow dive, steep dive, steep climbs and high-g turns. In addition, the pilot was given time to fly any other maneuvers he desired to

exercise and demonstration the symbology. The C/D format, Nugget format, and orange peel displays were flown during the symbology familiarization task. Approximately 20 minutes were available for this task.

A-G Weapon Delivery. Pilots flew two A-G delivery scenarios using the CCIP A-G delivery mode. The scenarios consisted of a low level ingress, pop up and dive weapon delivery. Pilots were given approximately 15 minutes per HUD for these scenarios.

The mission profiles consisted of three targets and five waypoints. The pilot was instructed to follow the steering cue from waypoint to waypoint maintaining 300 ft Above Ground Level (AGL) and approximately 480 KTS. When approaching a target area the pilot was instructed to action-off to the right 30°, climb at 30° to 4000 ft and roll left to the target at 135°. Upon acquiring the target, the pilot switched to CCIP mode using the symbology to deliver his weapon. After release the pilot egressed to the left, switched back to NAV mode and proceeded to the next waypoint. Once the pilot had released his weapon on the final target, the simulator was reset and re-established at the initial conditions for the next mission.

Each pilot flew at least one mission with the C/D format, the Nugget HUD format, and the small orange peel. Throughout the mission demonstrations, pilots subjectively evaluated the symbology for such issues as confusion and clutter.

Air-to-Air Scenario. Pilots flew a simple A-A scenario using the current F-16 C/D HUD format, Nugget HUD format, and the large and small orange peel displays. When using the orange peel displays, the pilots were instructed to declutter the pitch ladder symbology. When using the C/D and Nugget HUD formats, pilots were instructed to use the symbology as they would in operational conditions. Most pilots retained the pitch ladder during the A-A scenarios, except when in the dogfight mode, in which the pitch ladder was automatically decluttered. Some pilots used the symbology for "snap-look" verification of their conditions, in which the pitch ladder symbology was brought up in the HUD for a short time period but decluttered throughout most of the scenario.

In each scenario, the pilot engaged three interactive enemy aircraft driven by a pilot decision logic algorithm. After downing the three adversaries, the pilot returned the aircraft to straight and level flight, and the simulation ended. The primary focus of this task was to demonstrate the potential interference between flight and weapon delivery symbology.

Pilot Training

During the first day of participation, each pilot was taken through a two phase training program. First, pilots were briefed on the purpose of the simulation, HUD symbology changes being evaluated, evaluation task descriptions, and suggested strategies for performing the tasks. Second, pilots received hands-on familiarization with the simulator, symbology and task procedures. The hands-on training included (1) flying maneuvers as desired to illustrate the modified symbology and provide familiarization with the CSEF simulator, (2) 30 practice UARs with reaction time/error feedback after each trial, and (3) 12 practice A-A tracking task runs. The test engineer gave the test subject verbal feedback as needed throughout the training sessions.

Data Collection Session

After completion of training, data collection began. The data collection session required a total of seven hours and was divided equally over the first and second days of participation. Each half-day session consisted of 90 UARs, 12 A-A tracking demonstrations, A-A combat demonstration, and A-G combat demonstration. The same HUD format was used throughout the entire half-day session.

Experimental Design

A repeated measures design was used to compare the two HUD formats. Order of HUD presentation was randomized across subjects. All subjects completed all data collection using one HUD format before beginning data collection with the second format. For UARs, pitch and roll conditions were completely crossed and their presentation order was randomized with the constraint that one repetition of all 30 conditions had to be completed before another repetition could be started.

Data Collection

Three dependent measures were collected for the UAR task. *Reaction time* was defined as the time in milliseconds between the HUD presentation and the first correct pitch or roll input. *Error rate* was defined as the percent of trials in which the first pitch or roll input was incorrect (i.e., not in accordance with AFM-51-37). *Altitude loss* was defined as the difference between altitude at the start of the recovery (i.e., always 15,000 feet) and the altitude at the end of the recovery (i.e., the pilot had reached straight and level flight).

After all of the experimental tasks were completed, each pilot completed a comprehensive questionnaire. Rating scales provided the pilots the opportunity to compare the Nugget HUD format to the C/D format on a symbol by symbol basis. Pilots were also encouraged to provide comments and explanations for their responses. A copy of the questionnaire and the pilots' responses are provided in Appendix A.

RESULTS

Unusual Attitude Recoveries

For the unusual attitude recovery task, performance reaction time data were analyzed with a 5 (roll angle) x 6 (pitch angle) x 2 (HUD format) repeated measures Analysis of Variance. The main effect for HUD was not statistically significant, $F(1, 14) = 4.01$, $p = 0.0651$, although the trend suggests that reaction times were faster with the Nugget HUD format. A significant HUD format by Pitch interaction was found, $F(5, 70) = 4.74$, $p = 0.0009$. Post-hoc analyses showed that reaction times were significantly faster for the Nugget HUD than the C/D format in nose-down conditions. In nose-up conditions, a trend showed consistently faster reaction times for the Nugget format. The reaction time results are shown in Figure 9.
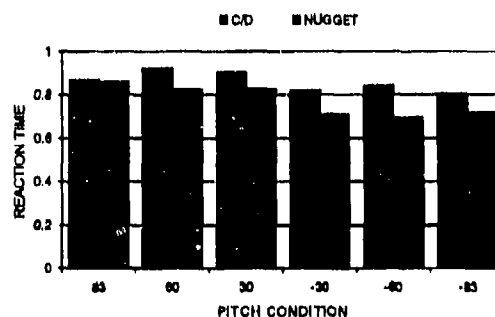
Figure 9. Reaction times for C/D and Nugget HUD formats for different pitch conditions.

The ANOVA also showed a main effect for roll conditions, where mean reaction times in the $0°$ and $180°$ (0.85 sec and 0.84 sec, respectively) were significantly larger than those for the 45, 90 and 135 roll conditions (0.81, 0.78, and 0.81 seconds, respectively), $F(4, 56) = 7.47$, $p = 0.0001$. Since this main effect gives no information regarding performance differences between HUD formats, it is not of significant interest in this evaluation. However, it does isolate roll angle as a "nuisance" variable that should be considered in future similar research. None of the other interaction effects were significant.

The error rate data were also analyzed with a 5 (roll angle) x 6 (pitch angle) x 2 (HUD format) repeated measures Analysis of Variance. No significant differences in error rates were found between HUD formats. Average error rates are shown in Figure 10.
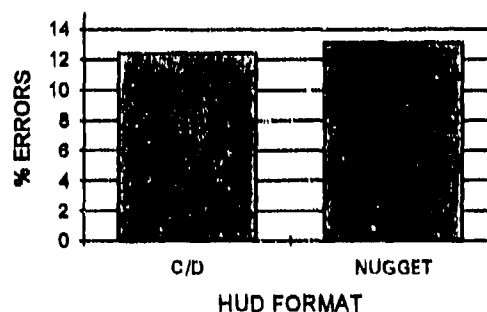
Figure 10. Stick input error rates for the C/D and Nugget HUD formats.

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Altitude lost was analyzed for nose-down UAR conditions with a 2 by 3 by 5 (HUD by Pitch by Roll) ANOVA, which showed a significant main effect for HUD format, $F(1,14) = 7.27$, $p = 0.003$. Average altitude lost for the Nugget and C/D HUD formats were 2902 ft and 3185 ft, respectively. The ANOVA also showed a three-way interaction for HUD by Pitch by Roll. Table 1 shows the altitude losses for different pitch and roll conditions for both HUD formats. In all but one condition, less altitude was lost when pilots were using the Nugget HUD format. Altitude loss information should be interpreted with caution because a variety of confounding factors can impact the measure, such as throttle and speedbrake settings.

Pitch	Roll	Nugget	C/D
-83	0	4321	4396
-83	45	3643	4132
-83	90	3417	3659
-83	135	4524	4832
-83	180	4888	5160
-60	0	2820	3287
-60	45	2204	2555
-60	90	2911	3464
-60	135	2728	3413
-60	180	4605	5129
-30	0	1240	1183
-30	45	1181	1250
-30	90	1438	1737
-30	135	1457	1808
-30	180	1923	2104

Table 1. Altitude loss comparison between Nugget and C/D HUD formats for different pitch and roll conditions.

Questionnaire Results

Frequencies and mean ratings were calculated for all questionnaire items employing rating scales. Complete responses to all rating scales and open ended questions as well as other pilot comments collected via the questionnaire are included in Appendix A. Significant results of the questionnaire responses will be summarized below.

The first part of the questionnaire allowed pilots to perform a symbol by symbol comparison of the Nugget and C/D HUD formats. Pilots were instructed to consider their experience with the UARs, AAT task, mission demonstrations, as well as their operational experience when answering the questions. Frequency distributions were generated for all of the symbol comparisons. Figure 10 shows the frequency distribution for the comparison between the overall Nugget and C/D formats. The rating scale represented a continuum of preference between the two symbols being compared, with the center representing a "neutral" rating. Movement towards the extreme left or right side of the scale represented increasing strength of preference for the symbol being evaluated. The same graph format was used for all of the symbol comparisons. As shown in Figure 11, unanimous preference was expressed for the overall Nugget format. Pilots felt that the Nugget HUD features were a significant improvement over the C/D format. Several pilots commented that the attitude information in the Nugget HUD could be interpreted more quickly and easily than that in the C/D HUD. Individual symbol comparisons are discussed below:
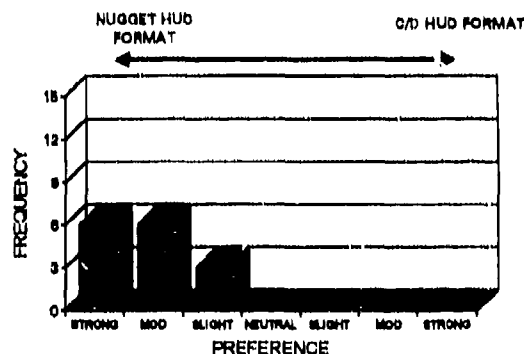
Figure 11. Subjective comparison of the overall Nugget and C/D HUD format

Extended Horizon. All pilots rated the extended horizon as slightly, moderately or strongly preferred, compared to the current C/D horizon line (Figure 12). Comments indicated that it provided a much improved quick-look attitude reference that could be viewed with peripheral vision. Also, pilots felt that it was a more prominent horizon indication than the current line, especially in dynamic conditions.
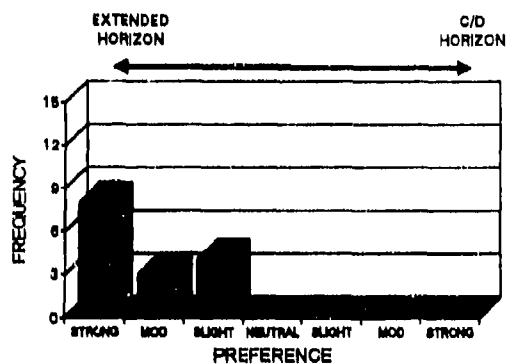
Figure 12. **Subjective comparison of the extended and C/D horizon lines.**

Ghost Horizon. All but one pilot felt that the ghost horizon was beneficial, compared with not having it presented at all (Figure 13). It was particularly useful for UARs, since it provided a full time reference of the direction to the real horizon. Comments also indicated some concerns with the ghost horizon. Several pilots mentioned that it was frequently outside the instantaneous field of view during the UARs and other maneuvers, thereby reducing its utility. One pilot felt that the ghost horizon was not sufficiently discriminable from the real horizon and provided a misleading indication that the aircraft was near level flight when it was actually at an extreme climb or dive.
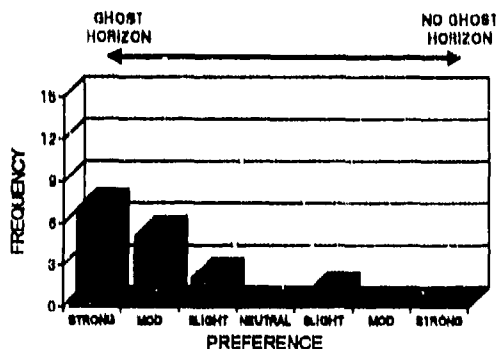
Figure 13. **Subjective comparison of the ghost horizon and no ghost horizon.**

Articulated Pitch Ladder. As shown in Figure 14, strong preference was shown for the bendy bars by most pilots. Pilots commented that the bendy bars were the most powerful improvement to the C/D HUD and provided an instantaneous indication of a diving condition. During unusual attitude recoveries, pilots were able to use the "funneling

effect" for a quick-look indication of the direction to the horizon.
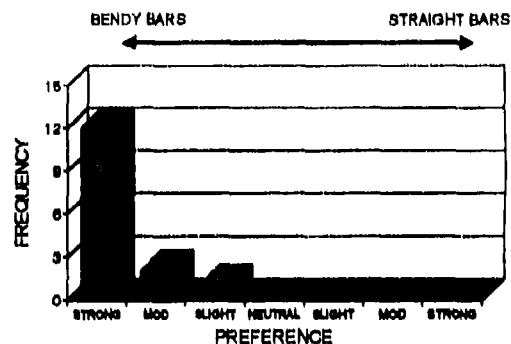
Figure 14. **Subjective comparison of bendy bars versus straight pitch ladder bars.**

Tic Marks on Inside of Pitch Ladder. Once again, unanimous agreement was shown for tic marks on the inside position of the pitch ladder (Figure 15). Comments indicated that these tic marks aided the perception of a "funnel" to fly up during UARs. Also, the inside tic marks were more prominent that outside tic marks because they did not blend in with the pitch ladder numbering.
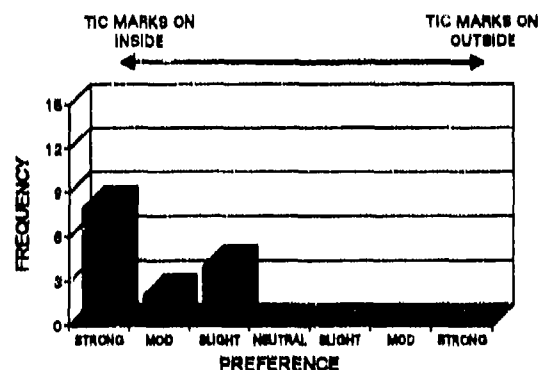
Figure 15. **Subjective comparison of inside and outside positions for pitch bar tic marks.**

Removal of Compression. While the majority of pilots agreed that compression should be removed, 5 pilots were neutral (Figure 16). Four pilots commented that removal of compression was desirable because it provided 1:1 conformance of the pitch ladder with the real world over all pitch attitudes. However, pilots also indicated that its removal would not be very noticeable, since most flying is performed at climb and dive angles of less than 60 degrees.

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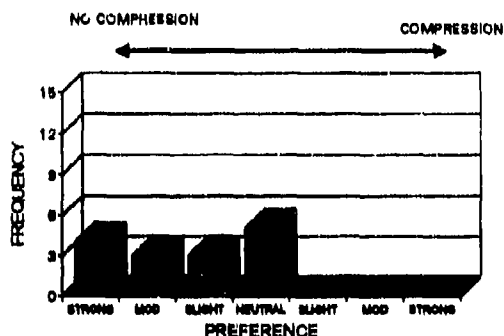
Figure 16. Subjective comparison of HUD formats with and without pitch ladder compression.

Bank Angle Indicator. Mixed results were obtained on the ratings of the modified bank angle indicator (Figure 17). Many pilots indicated that, although they had little need for it during the simulation, it might be useful for instrument flying. During the simulation, general bank information was available from the pitch ladder and the horizon line. Three pilots strongly to moderately preferred the C/D roll indicator format. Nearly all pilots commented that the bank angle indicator caused excessive clutter, particularly in weapons modes.
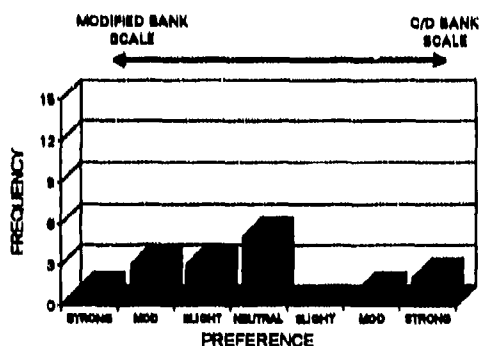
Figure 17. Subjective comparison of the modified bank angle indicator and the C/D roll scale.

Modified Zenith and Nadir Symbols. Both the modified zenith and nadir symbols were generally preferred over the symbols in the C/D HUD format. However, over half the pilots were neutral on the question. Comments indicated that, although the modified symbols were superior, they were rarely needed or used. Subjective preferences for the zenith and nadir symbols are shown in Figures 18 and 19.
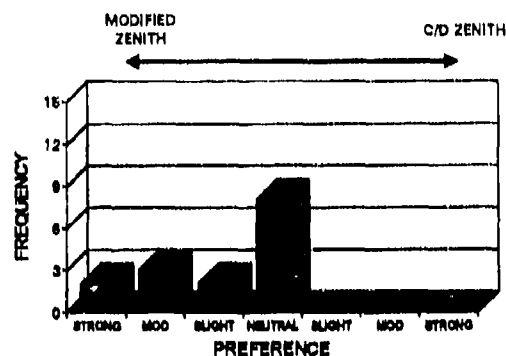
Figure 18. Subjective comparison of the modified and C/D zenith symbol.
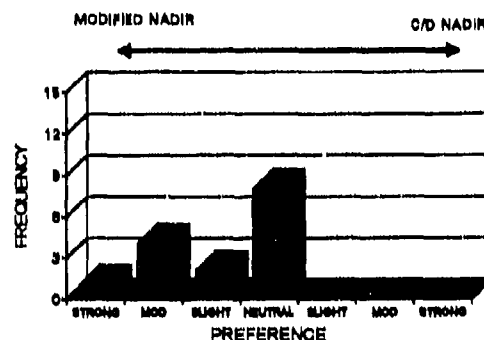
Figure 19. Subjective comparison of the modified and C/D nadir symbol.

Additional questions asked pilots to rate the effectiveness of the two HUD formats for providing quick and accurate attitude recognition and attitude awareness in static and dynamic conditions. The responses once again showed that the Nugget HUD provided superior attitude cues in nose up, nose down, and highly dynamic conditions.

The differences between the HUDs allowed pilots to use significantly different strategies during the UARs. In the C/D HUD, pilots tended to determine whether the pitch ladder was solid or dashed, and then used the pitch ladder numbering to determine which way to roll. If nose down, pilots rolled to make numbers appear upright. If nose up, pilots rolled to make numbers appear inverted. Once the proper roll input was chosen, pilots pulled to the horizon.

For the Nugget HUD, pilots could more easily determine nose-up versus nose-down by using the

bendy bars. If bendy bars were present, pilot could simply fly up the funnel. Recoveries from nose up unusual attitudes were similar to those for the C/D HUD, except that many pilots used the ghost horizon line to determine the correct roll direction. Pilots felt that the global cues provided by such modifications as bendy bars, ghost horizon, and extended horizon allowed quicker and easier determination of the proper stick input to achieve straight and level flight.

Pilots were asked to rate the acceptability of the Nugget HUD format in Air-to-Air, Air-to-Ground and Navigation master modes. In all three modes nearly all pilots who responded to the questions felt the Nugget HUD was either "moderately" or "completely" acceptable. The major complaint with the Nugget HUD in these modes was that the bank scale tended to add excessive clutter to the HUD while not providing useful information.

Figure 20 shows responses to the question, "Would you like to see these changes incorporated into the F-16 HUD?" A clear majority of pilots felt that the extended horizon, bendy bars, inside tic marks, ghost horizon, and removal of compression should be incorporated into the F-16 HUD. Less than half of the pilots felt that the modified zenith/nadir symbols and the bank scale should be incorporated. In the case of the zenith / nadir, these results most likely reflect the fact that pilots did not expect to use the symbols in operational conditions. In the case of the bank scale, the results are most likely due to the added clutter produced by the bank scale, along with the fact that bank information can be obtained from other HUD symbology, such as the extended horizon.
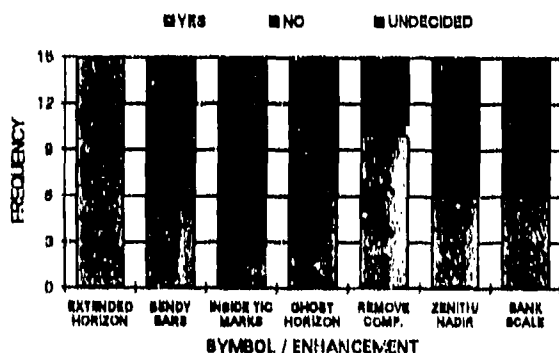
Figure 20. Responses to the question, "Would you like to see these changes incorporated in the F-16 HUD?"

Finally, pilots were asked if the incorporation of these modifications would reduce CWG and SDO events. Twelve pilots answered "yes" to this question. Comments tended to stress that a more intuitive indication of attitude, as provided by the Nugget HUD, may reduce time to recognize unusual attitudes, aid recovery, and reduce the probability of misreading the HUD. Comments from the three pilots who responded "no" or "undecided" indicated that improved HUD symbology will not aid in recognizing that an unusual attitude exists, and therefore will probably not reduce CWGs or SDOs, particularly in high workload conditions.

Orange Peels

Both orange peels were evaluated in the A-A scenario and in the navigation mode. The small orange peel was also evaluated in the A-G scenario. Ratings of the effectiveness of the small and large orange peels for providing attitude awareness information were mixed. Six pilots rated the small orange peel as "moderately effective" or "very effective," while three pilots rated it as "moderately ineffective" or "very ineffective." Three pilots were neutral on the question. Common criticisms of the small orange peel were that it moved around the HUD too much (since it was referenced to the flight path marker), was too small, and caused clutter in A-A scenarios. Three pilots mentioned that they had insufficient experience with the symbol to make a good judgment.

Seven pilots rated the large orange peel as "moderately" or "very" effective while three pilots rated it as "moderately" or "very" ineffective. Five pilots' comments showed they felt that it was a strong cue for a "rough" attitude reference. Those who like it felt that it would be most useful in A-A dogfight modes. Criticisms included difficulty of interpretation. Three pilots felt they had insufficient experience with it to make a good judgment.

DISCUSSION

The primary purpose of the evaluation was to assess the ability of the Nugget HUD modifications to improve attitude awareness in the F-16. Objective data showed consistently faster reaction times with the Nugget HUD format. These differences were

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statistically significant in nose-down conditions. The lack of differences in error rates between the formats suggest that the performance differences do not reflect a speed-accuracy tradeoff. Subjective data showed strong agreement with the performance results, with unanimous preference for the Nugget format.

These results can be interpreted in light of HUD design principles suggested by Taylor (1985). Based on a systematic evaluation of HUD symbology design options, Taylor concluded that HUD formats conforming to Gestalt psychology principles should yield faster performance in critical conditions. These principles suggest that global or macroscopic characteristics of complex displays are processed more rapidly than local or detailed information.

Traditional HUDs, such as the F-16 C/D format, require pilots to read detailed information to determine many flight parameters, including severity of climb/dive (pitch ladder numbering), direction to horizon (tic marks and number orientation, number pattern) and, to some extent, a determination of climb/dive (dashed versus solid lines).

The Nugget HUD, on the other hand, provided more global cues for some of this same information. The articulated pitch ladder combined with the inside tic marks formed a very large "arrow" or "funnel" which provided an immediate indication of dive conditions, severity of dive, and direction to the horizon. The ghost horizon provided a redundant cue of direction to horizon and roll angle. The extended horizon line provided a global horizon cue that was very prominent and distinctive from the rest of the pitch ladder. In addition to providing global cues, the bendy bars and inside tic marks in the Nugget HUD add two dimensions of asymmetry between nose-up and nose-down conditions.

In the simulation, these differences between the HUD formats led to different UAR strategies that can account for the faster reaction times for the Nugget HUD format. It is likely that these differences will also be of benefit to the pilot in real-world conditions, particularly in highly dynamic conditions, where detailed information and local cues may not be readable.

The results found here are consistent with those from previous similiar research. For example, Vidulich, Ward and Schueren (1991) compared various HUD formats employing the Subjective

Workload Dominance Technique (SWORD), and found a statistically significant preference for HUD displays with articulated pitch ladders. A trend was also shown for improved pilot performance with those same displays. Ercoline, Gillingham and Greene (1989) found improved reaction time, in a static attitude recognition task, for displays with bendy bars above and below the horizon. However, a display that only had articulation below the horizon was subjectively preferred because of the added asymmetry the bendy bars provided between nose-up and down conditions and provided improved percent correct over the other formats. Subjective preference and / or performance improvements with articulated pitch ladders have also been found by Taylor (1984) and Deaton, Barnes and Lindsey (1989).

While the current experiment was not designed to isolate the relative contributions of various nuggets to attitude awareness, the symbol by symbol subjective comparison showed that most pilots felt the bendy bars (with tic marks), extended horizon and ghost horizon were the most effective improvements in the HUD. Removal of compression and the zenith/nadir modifications were generally considered improved designs but of limited significance in most operational flight conditions. The bank angle indicator, while possibly useful for instrument flight, was seen to add clutter in weapons modes. Further, general roll information could be obtained from other sources in the HUD, such as the extended horizon and pitch ladder.

Note that, while the zenith/nadir symbols will not be presented on the HUD the vast majority of the time, the improved symbols may be of significant value in certain critical conditions. In an unexpected severe nose down condition, the improved nadir symbol may increase the speed and accuracy of the pilot's control inputs. Both speed and accuracy would be crucial to a successful recovery from such a condition.

Based on pilot comments, the design and mechanization of most symbols was acceptable as shown in the simulation. One exception was the ghost horizon, which was not in the instantaneous field of view a significant percentage of time. Modification, such as movement toward the center of the HUD FOV may be required before the ghost horizon is incorporated into the HUD. However, clutter tradeoffs would need to be considered if the ghost horizon were moved.

Operational Conditions

A similar pattern of pilot performance to what was shown in the simulator would be expected in operational conditions. While absolute reaction times may be larger to reflect a greater emphasis on accuracy, it is reasonable to assume they would still be faster with the Nugget HUD format.

The actual improvements in reaction time were rather small from an operational standpoint. They are significant, however, from the standpoint of human information processing. The faster reaction times indicate that the Nugget HUD can be interpreted easier and quicker than the C/D HUD. The human performance improvement associated with this HUD may be a very significant benefit to the pilot in high workload or very dynamic conditions.

At first glance, error rates appeared quite high for both HUD formats. However, it should be recognized that an erroneous stick input does not necessarily indicate that the UAR was unsuccessful. Rather, it indicates that the pilot made a momentary incorrect stick input that was usually corrected a short time later. Error rates in operational conditions would probably be lower, since both speed and accuracy are critical.

Orange Peel displays

The orange peel evaluation was a low priority objective in the current study. As mentioned previously, orange peel ratings were mixed, which may reflect a lack of training and familiarization with the symbols and their mechanization. However, some comments are warranted. The orange peels were originally conceived to provide a gross attitude reference in selected A-A modes, where pitch ladder symbology is not presented. However, the small orange peel, being referenced to the FPM, moved around the HUD in dynamic conditions. In high-g maneuvers, it was often completely out of the HUD FOV. Another criticism raised by pilots was that it interfered with the use of the missile reticle, which was a similar size and shape to the orange peel.

The large orange peel was developed in an effort to address these concerns with the small orange peel. Being referenced to static components of the HUD, it remains stationary in all flight conditions. Being very large and presented nearer the edge of the FOV,

it may reduce interference with missile symbology. Even with these modifications, the ratings were mixed. The orange peel concepts require further development and evaluation, where pilots are given more training and experience with the symbols, before any strong conclusions can be drawn.

CONCLUSION & RECOMMENDATION

In conclusion, the simulation showed improved pilot performance, particularly in nose-down conditions, for the Nugget HUD format over the C/D format. The results also showed strong subjective preference for the Nugget format, with bendy bars (with inside tic marks), extended horizon and ghost horizon appearing to provide the most significant enhancements to the current C/D HUD format. While the ghost horizon was desired by most pilots, it may require modification if it is to be incorporated into the current HUD. Removal of compression and the modified zenith/nadir symbols were considered improved designs, but were not considered operationally significant by most pilots in most flight conditions. The modified bank angle indicator added unnecessary clutter, particularly in weapons modes, but may be useful in instrument flying conditions.

If the F-16 SPO plans to pursue modification of the C/D HUD format, recommend that the following nuggets be incorporated:

a. Extended horizon

b. Ghost horizon

c. Pitch ladder changes (bendy bars, removal of compression, inside tic marks

d. Modified zenith and nadir symbols (low priority)

The bank angle indicator requires further evaluation in instrument flying conditions before it should be considered for incorporation into the F-16 C/D HUD. Finally, the orange peel concepts show potential, and current results justify further development and evaluation.

REFERENCES

Department of the Air Force, (1986). Instrument Flying. (AFM 51-37). Washington, DC.

Deaton, J. E., Barnes, M., Lindsey, N., Green, J., and Kern, J. (1989). The effect of windscreen bows and HUD pitch ladder on pilot performance during simulated flight. In *Proceedings of the Human Factors Society 33rd Annual Meeting* (pp. 33-37). Santa Monica, CA: Human Factors Society.

Ercoline, W. R., Gillingham, K.K, Greene, F. A., and Previc, F. H. (1989). Effects of variations in head-up display pitch ladder representation of orientation recognition. In *Proceedings of the Human Factors Society 33rd Annual Meeting* (pp. 1401 - 1405). Santa Monica, CA: Human Factors Society.

General Dynamics, Fort Worth Division, (1991). F-16 C/D Avionics System Manual, Block 40 production tape 3. (16 PR 4729). Fort Worth, TX.

Taylor, R. (1984). Some effects of display format variables on the perception of aircraft spatial orientation. Presented at the NATO AGARD Medical Panel Symposium, Williamsburg, Va.

Taylor, R. (1985). HUD Pitch scale design and evaluation. In Aircraft Attitude Awareness Workshop, October 8-10, 1985. Wright Patterson Air Force Base: Flight Dynamics Laboratory.

Ward, G. F., (1990). *Human Factors in F-16, F-15, F-111, F-4 and A-10 Mishaps*. (CSEF-TR-90-ATF-01). Wright-Patterson AFB, OH: Crew Station Evaluation Facility.

Ward, G. F., and Hassoun, J. (1990). *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*. (Tech Report ASD-TR- 90-5008). Wright-Patterson AFB, OH: Crew Station Evaluation Facility.

APPENDIX A

QUESTIONNAIRE RESULTS AND PILOT COMMENTS

F-16 HUD Symbology Evaluation

Questionnaire

Section I. The following questions address the symbol enhancements.

1. Circle your preferences for the following symbols using the scale below:

a. Extended Horizon:

Strongly Prefer Extended Horizon	Moderately Prefer Extended Horizon	Slightly Prefer Extended Horizon	Neutral	Slightly Prefer F-16 C/D Horizon	Moderately Prefer F-16 C/D Horizon	Strongly Prefer F-16 C/D Horizon
8	3	4	0	0	0	0

Pilot #1: Easier to see, more prominent.

Pilot #3: Good because it gives pilot a slightly better bank cue. Bad because it adds to HUD clutter.

Pilot #4: Especially useful with lots of HUD symbology and drift off to one side

Pilot #6: Seemed to enhance the view of the horizon especially when rapidly rolling and pulling G's. Made the horizon more identifiable and seemed more natural.

Pilot #7: Gives more of a "Global" picture.

Pilot #8: Increased visual impact.

Pilot #9: With an extended horizon, its almost no doubt where the horizon in the HUD is, so that's nice. It's something that you can notice in your peripheral vision.

Pilot #10: Provided slightly higher S.A. of where the horizon is, especially when taking quick, snapshot looks at the HUD during air-to-air engagements (assuming the avionics were in a mode to display the horizon)

Pilot #11: In dynamic situations allows quicker reference to where "real" horizon is. Especially with lots of bank angles.

Pilot #12: Almost seemed to go beyond HUD. Helped me to draw an imaginary horizon in the sky. Stayed in view even when I wasn't staring at the HUD.

Pilot #13: I think the extended horizon does increase attitude awareness somewhat over the current F-16 C/D horizon line. I can not think of any disadvantages in having it displayed.

Pilot #14: It gives a better feel for where horizon is. It distinguishes it from the pitch lines.

Pilot #15: Much better spatial orientation using peripheral vision.

Pilot #16: Excellent modification to the HUD because the extended horizon makes horizon recognition quicker and easier for the pilot. Normally a quick look for the horizon in the C/D HUD can be confused with pitch ladders.

b. Ghost Horizon

Strongly Prefer Ghost Horizon	Moderately Prefer Ghost Horizon	Slightly Prefer Ghost Horizon	Neutral	Slightly Prefer No Ghost Horizon	Moderately Prefer No Ghost Horizon	Strongly Prefer No Ghost Horizon
7	5	2	0	1	0	0

Pilot #1: Needed when "real" horizon not visible.

Pilot #3: Helps some during unusual attitude recoveries.

Pilot #4: Somewhat difficult to see at extremely high pitch attitudes. Too low in the HUD FOV.

Pilot #6: It was useful as a quick check while doing the recovery when all the pitch lines and numbers are zipping by. One draw back was that it didn't stand out. It seemed to be difficult to focus on immediately. Maybe a thicker dashed line would help for recoveries even though it will tend to clutter the HUD

Pilot #7. It gives you a reference to pull your A/C to even when no "visible" (VFR) reference exists.

Pilot #8: Constant confirmation of here the horizon is.

Pilot #9: I really liked the Ghost horizon the best. When you would see it, you could always tell where the horizon was. I started using this exclusively when doing unusual attitudes recoveries.

Pilot #10: This was a great tool if it could always be present in the instantaneous FOV. I understand why the flight path marker can "push" the ghost horizon from the HUD FOV but I think the F.P.M. and ghost horizon relationship should be ignored; i.e. I know the F.P.M. is where the jet is going (velocity vector) regardless of where the ghost horizon is. As a technique, if either the horizon or ghost horizon were always present in the instantaneous F.O.V., one can simply roll to put the "Horizon" at the top of the HUD, pull until the FPM is on the horizon, and then if inverted, roll upright.

Pilot #11: It's okay. I'd rather have it than not at all, but at times its too far away from the flight path marker.

Pilot #12: When it was in view - most often for me during nose low attitudes it gave me an instant direction to pull during recoveries. During nose high attitudes, I didn't always see it. Which is fine because nose high attitudes don't usually kill people.

Pilot #13: The ghost horizon was somewhat disorientating during unusual attitude recoveries. It seemed to give me a false indication that I was slow to differentiate the ghost horizon from the actual one. It also normally appeared to be slightly outside the usable field of view in the HUD.

Pilot #14: A lot of times its close to the edge and out of sight from my seating position. However, it still helps in recoveries.

Pilot #15: Gives basic info. re: where horizon is with pitch attitude when real horizon is not in HUD FOV. Definite requirement! Although put it 6° from FPM vice 8°.

Pilot #16: Excellent modification to give the pilot an idea as to where the horizon is at high pitch attitudes. I recommend it not be displayed unless pitch attitude exceeds +30 degrees pitch as it is a clutter item below that. Additionally I'm not convinced I even noticed it in nose low recoveries - rather I just flew up the funnel. Didn't like the ghost horizon disappearing under high G's.

c. Bendy Bars

Strongly Prefer Bendy Bars	Moderately Prefer Bendy Bars	Slightly Prefer Bendy Bars	Neutral	Slightly Prefer Straight Pitch Bars	Moderately Prefer Straight Pitch Bars	Strongly Prefer Straight Pitch Bars
12	2	1	0	0	0	0

Pilot #1: "Down" is more readily apparent.

Pilot #3: This was my best reference for initiating nose low unusual attitude recoveries. Articulated ladder was a great help in reducing reaction time and making the initial input in the correct direction.

Pilot #4: Best! Most powerful symbol.

Pilot #5: Much better cue to direction of horizon.

Pilot #6: Great for nose down more than 20 degrees or so. The idea of flying up the funnel is great for large down pitch. No need to think. The trouble comes with nose high when you have to remember technique for the C/D. Slight nose down looked like slight nose up because the lines weren't bent much and I was getting tired at the end. My eyes weren't focusing quickly so I was going to simplified strategy and was prone to mistakes. Over all, very useful.

Pilot #7: Quicker determination/reaction time.

Pilot #8: Increased ability to determine attitude in short period of time.

Pilot #9: Just one more indication at nose high/low attitude. It's easier to distinguish than solid/dashed lines.

Pilot #10: These were great!! Made it very easy to tell when I was diving compared to the straight pitch ladder. I don't recommend articulating the climb portion of the ladder though. Worst case for a pilot is not recognizing a nose low unusual attitude and impacting the ground or having the airspeed increase to unacceptable ejection parameters.

Pilot #11: Much better!! Tremendously increases situation awareness on dive angles. I especially like how dive angles bend pitch ladder more as dive angle increases.

Pilot #12: The funnel effect and horizon pointer ties toward the center help a lot. I've always recovered on the round dials because when things go tango uniform, I have a difficult time distinguishing between solid and dashed lines.

Pilot #13: The articulated pitch ladder was great for doing unusual attitude recoveries. It made nose low recognition faster and the recovery easier by flying up the funnel. However, in all my F-16 hours, I've never had to do a recovery for real, and am usually not using the HUD for attitude orientation during close in air-to-air engagements. I'm referencing outside visual clues. In a no discernible horizon situation, I think the articulated pitch ladder would improve S.A.. The times that I routinely use the nose low pitch ladders, such as in air-to-ground weapons delivery and instrument penetrations and approaches, I think the articulated pitch ladder might be some what harder to use than the straight ones. I don't think I'd ever be able to solely refer to the articulation for pitch degrees. I probably would have to reference the numbers as well. Additionally, holding a constant pitch attitude as in a penetration maybe slightly harder with the articulated ladder particularly if not on a line.

Pilot #14: Quicker than tic marks.

Pilot #15: "Funnels" or points to horizon gives very strong indication of dive, especially at steep dive angles.

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Pilot #16: Strongly recommend only in below the horizon pitch attitudes as I believe it is an excellent aid to nose low recoveries when time and altitude are critical. In nose high situations where time and altitude are increasing for recovery -leave straight pitch ladders. Also, the pilot knows he is nose low immediately when he sees the articulated pitch ladders. If they are used in both nose up and nose down, brain bites will be used to determine in which direction (up or down) I'm going, instead of being obvious right away. What have we gained?

d. Modified Zenith

Strongly Prefer Modified Zenith	Moderately Prefer Modified Zenith	Slightly Prefer Modified Zenith	Neutral	Slightly Prefer C/D Zenith	Moderately Prefer C/D Zenith	Strongly Prefer C/D Zenith
2	3	2	8	0	0	0

Pilot #1: Ok, but I wasn't straight down or up long enough to really use.

Pilot #3: Didn't make much difference to me.

Pilot #4: Good confirmation of correct direction to pull to the horizon.

Pilot #6: Good for telling up from down, but in the vertical the gyro tumbled so I couldn't see it sit still enough to see which way it pointed. I suppose it doesn't matter much how well it points to the nearest horizon, but the odd shape made it obvious what it was and all you have to do is roll away from it.

Pilot #7: Modified is better, but I didn't use it that much.

Pilot #8: Not significant. Actually probably degrades overall (computer) system since it increases required drawing time.

Pilot #9: I didn't really use any one over the other. I didn't use it to determine which way to go to the horizon.

Pilot #10: Never really noticed the old symbols before. The only time I come close to seeing the zenith symbol is during BFM while going pure vertical, and then I'm usually spending most of my time looking outside the cockpit.

Pilot #11: Didn't use it.

Pilot #12: Honestly, I rarely see it.

Pilot #13: Easier to differentiate from the nadir symbol. May help differentiate extreme nose high attitudes from extreme nose low ones. To be honest though I never noticed the old ones. The pointers on the modified symbols are good idea and might aide in making an appropriate recovery.

Pilot #14: Don't care.

Pilot #15: More distinctive and includes pointer towards closest horizon.

Pilot #16: It's okay, but I'm not looking through the HUD pitch ladders in an air-to-air mode going straight up. In fact I'm either outside looking at the target or looking at my airspeed to determine my maneuver capability. I'd never be going straight up in the weather intentionally. - Long story short - It's better, but how often I would need it or use it - not much.

e. Modified Nadir

Strongly Prefer Modified Nadir	Moderately Prefer Modified Nadir	Slightly Prefer Modified Nadir	Neutral	Slightly Prefer C/D Nadir	Moderately Prefer C/D Nadir	Strongly Prefer C/D Nadir
1	4	2	8	0	0	0

Pilot #1: Ok, but I wasn't straight down or up long enough to really use.

Pilot #3: Didn't make much difference to me.

Pilot #4: Not as strong as zenith but bendy bars do not need this as much to confirm attitude condition.

Pilot #6: It didn't stand out as too different from the C/D, but it made it obvious that it stood for the ground.

Pilot #7: Modified is better, but I didn't use it that much.

Pilot #9: I didn't really use any one over the other. I didn't use it to determine which way to go to the horizon.

Pilot #10: Never really noticed the old symbols before. The only time I come close to seeing the zenith symbol is during BFM while going pure vertical, and then I'm usually spending most of my time looking outside the cockpit.

Pilot #11: Didn't use it.

Pilot #12: Honestly, I rarely see it.

Pilot #13: Easier to differentiate from the zenith symbol. May help differentiate extreme nose high attitudes from extreme nose low ones. To be honest though I never noticed the old ones. The pointers on the modified symbols are good idea and might aide in making an appropriate recovery.

Pilot #14: Don't care.

Pilot #15: More distinctive and includes pointer towards closest horizon.

Pilot #16: Better modification to the fact that normally, when I'm flying straight down I am looking at the HUD to determine airspeed and altitude, I would see it, but again, in nose low I would recover using the funnel.

f. Modified Bank Scale:

Strongly Prefer Modified Bank Scale	Moderately Prefer Modified Bank Scale	Slightly Prefer Modified Bank Scale	Neutral	Slightly Prefer C/D Roll Indicator	Moderately Prefer C/D Roll Indicator	Strongly Prefer C/D Roll Indicator
1	3	3	5	0	1	2

Pilot #1: I only need this if I can't find the horizon line.

Pilot #3: Only slight benefit. Not useful for extreme unusual attitudes.

Pilot #4: Would use this only for Nav. and instrument approaches. Too much clutter.

Pilot #5: Less clutter, easier to read.

Pilot #6: I didn't do any precision turns or instrument flight procedures which is when they are most critical for precise flight. I really didn't have an opinion, but having the bank scale in the center made it easier to see and remember to use for turns.

Pilot #7: Much easier to use because you only have to look at one thing - takes one item out of my cross-check.

Pilot #9: I really use the ADI for bank.

Pilot #10: Not easily noticed for unusual attitude recoveries. It, however, would be useful for instrument flying.

Pilot #11: Didn't really use it.

Pilot #12: The modified is too close to the flight path marker and it clutters up the HUD. Truthfully, I set bank with the round ADI. Plus, I just know what 30, 45, and 60 degrees look like based on flight path marker to horizon line relationship.

Pilot #13: I found that it was not in my cross-check at all during unusual attitude recoveries or for attitude awareness during air-to-air tracking. But, I do think it would be easier to use during instrument flying; i.e. easier cross-check.

Pilot #14: Didn't use it much - good for LANTIRN.

Pilot #15: It is closer to central FOV, but I would not want it in ILS mode. (And, it wouldn't be consistent to have it in NAV., and not ILS); and definitely not in WPNS modes.

Pilot #16: Didn't really use it - adds to clutter. Where I really like it is on instrument final to give me an idea of my bank angle. I felt the C/D HUD bank indicator is better for slow speed instrument approaches but if displayed full time would be added clutter as well.

g. Tic marks, inside of pitch ladder (nose down only):

Strongly Prefer Inside Tic Marks	Moderately Prefer Inside Tic Marks	Slightly Prefer Inside Tic Marks	Neutral	Slightly Prefer Outside Tic Marks	Moderately Prefer Outside Tic Marks	Strongly Prefer Outside Tic Marks
8	2	0	0	0	0	0

Pilot #1: Good distinguishing feature.

Pilot #4: Strengthens the funnel effect.

Pilot #5: Really doesn't matter, except that pitch angle labels are too close to the marks when on outside. Move the numbers and answers would be neutral.

Pilot #6: It helped with the notion of flying up the funnel With the straight pitch ladder it would bother more than it helps.

Pilot #7: Makes it slightly easier to differentiate.

Pilot #8: Never noticed difference.

Pilot #9: It differentiates it from the nose high, so to me that's good.

Pilot #10: Made it real easy to "fly the funnel" during a nose low recovery and coupled with the bendy bars, made nose low situations easier to recognize than standard F-16 C/D HUD.

Pilot #11: Easier to use since you put flight path marker in middle of HUD, the tic marks on the inside of the pitch ladder are closer to flight path marker and overall it makes unusual attitude recoveries easier.

Pilot #12: Combined with bendy bars helps a lot.

Pilot #13: They were much easier to pick out on the inside. The outside tic marks took a little longer to pick out being so close to the numbers. In fact, I felt some times like I was using the numbers orientation up or down rather than the tic marks for initial roll to horizon. The inside tic marks in combination with the articulated pitch ladders made it much easier to recognize nose low unusual attitudes, although I was using funnel and not tic marks for recoveries. You could probably eliminate the tic marks on nose low ladder and it wouldn't change anything.

Pilot #14: That way they don't meld with the numbers.

Pilot #15: ʌ   ɔ[s to accentuate "funnel" effect of bendy-bars.

Pilot #16: Excellent - adds definition to the funnel.

h. No Compression (Modified HUD):

Strongly Prefer No Compression	Moderately Prefer No Compression	Slightly Prefer No Compression	Neutral	Slightly Prefer Compression	Moderately Prefer Compression	Strongly Prefer Compression
4	3	1	4	0	0	0

(The F-16 CD HUD pitch ladder has 2:1 compression beyond 60 degrees of climb or dive. All compression has been removed in the Modified HUD.)

Pilot #1: Compression distorts reality.

Pilot #6: It seems that the pitch rate decreases at the near vertical nose high and nose low eliminating the need for compression. However, I don't know of any maneuver which requires precise pitch values at high pitch angles. Also, the compression scale makes the scale easier to focus on because it doesn't go whizzing by. Overall - I didn't really have a preference.

Pilot #7: Didn't notice in simulator.

Pilot # 9: Didn't use it at all.

Pilot #10: Seemed to make the HUD more usable at nose high/low conditions. Was easier to find pure vertical and fly pure "over-the-top" maneuvers. Not much utility though for unusual attitude recoveries.

Pilot #11: Didn't really notice.

Pilot #12: Having the flight path marker pass through altitudes smoothly (without the pause) gives me a warm fuzzy.

Pilot #13: Honestly never noticed a problem with 2:1 compression in the current HUD due to the limited reference to the HUD during extreme pitch attitude. However, no compression would seem to improve S.A., particularly if concerned with determining nose track rate.

Pilot #14: More realistic.

Pilot #15: Gives _true_ indication of pitch rate. Definitely required out-of-control situation when nose high and slow, where pilot may think his nose has slowed (with compression) and it really has not.

Pilot #16: I like things symmetric!

i. Overall "Nugget" Format:

Strongly Prefer Nugget Format	Moderately Prefer Nugget Format	Slightly Prefer Nugget Format	Neutral	Slightly Prefer C/D Format	Moderately Prefer C/D Format	Strongly Prefer C/D Format
6	6	3	0	0	0	0

Pilot #1: Easier to interpret when disoriented.

Pilot #3: Generally a good improvement. Articulation is the best feature.

Pilot #4: Great improvement - Stronger inherent clues and global references. Lowered the cognitive processing load (This is important in a single sea cockpit).

Pilot #5: Articulated pitch scales greatest difference.

Pilot #6: Overall the nugget format seemed to make much simpler to interpret information. Took less time to digest the information presented.

Pilot #9: The ghost horizon and the articulated ladder are nice additions. There aren't many times when a pilot finds himself in an unusual attitude but when he does it's nice to have a good HUD.

Pilot #10: Did not detract from flying the jet or weapons delivery. Significantly increases at least the possibility of discriminating between extreme nose high and nose low conditions. (Hope the data substantiates this).

Pilot #11: Overall, I like it better. UARs are easier to recover from. The tic marks n the inside of pitch ladder were especially helpful and greatly increased overall awareness.

Pilot #12: Other than the bank scale, I like it.

Pilot #13: All the features should improve general attitude awareness and recovery from unusual attitudes. I didn't like the ghost horizon but with more familiarization with it, it might also be an aide. The nugget format would be most helpful in a no discernible horizon, over the water, or night type situation My only concern is that the nugget format in a normal day VFR situation might make setting precise dive attitudes for weapons delivery hard. The funnel created by the articulated pitch ladders was a great aide in recovering from nose low unusual attitudes and might be considered for nose high ladders as well. The straight (nose high) vs slanted (nose down) does give one more clues besides the solid vs dashed lines of your orientation though.

Pilot #14: Better in most respects.

Pilot #15: Better cues as to attitude and direction to roll.

Pilot #16: Strongly recommend: (1) articulated pitch ladders nose low with tic marks inside, (2) Extended horizon, and (3) Ghost horizon.

2. Were there any conditions or tasks in which the symbol interfered with other symbology, caused confusion, was misinterpreted, or caused excessive clutter? Consider the UARs, Air-to-Air tracking tasks, A-A mission demos, and A-G mission demos when you answer this question.

	Yes	No
a. Extended Horizon	2	12
b. Ghost Horizon	3	11
c. Articulated Pitch Ladder	0	14
d. Modified Bank Scale	9	5
e. Modified Zenith Symbol	1	13
f. Modified Nadir Symbol	0	14
g. Large Orange Peel	2	11
h. Small Orange Peel	8	5

Pilot #1: Sometimes I lost the horizon in the scales. The modified bank scale tends to clutter the area around the FPM.

Pilot #3: a & b - Minor clutter added. g & h - clutter added. I didn't get to use these very much.

Pilot #4: d & h - Too much clutter for air-to-ground and air-to-air.

Pilot #5: Modi ::~d bank scale clutters display and is hard to read. Orange peels seem difficult to interpret, but didn't get that much exposure to them.

Pilot #6: Being a banked pilot, I didn't understand much about the symbols to begin with. I couldn't make useful inputs to this question.

Pilot #8: b - Move ghost horizon closer to center of FPM in HUD on each side. Since no pilot sits at design eye the position of ghost horizon must be visible at most locations the pilot will sit.

Pilot #9: It seems like the bank scale might have interfered with some air-to-air modes of the radar from what I can remember. In air-to-ground or air-to-air modes the bank scale is worthless and just clutters the scope.

Pilot #10: d - Makes HUD a bit too busy in weapons delivery modes (e.g. strafing). e - Large arrow, FPM and modified bank scale make 90° nose high condition too cluttered. h - Too busy for air-to-air employment. Interferes with missile and gun symbology.

Pilot #11: In air-to-air mode with the missile reticle present the small orange peel makes the HUD much too cluttered.

Pilot #12: d & h - To close to the FPM and too small. Its an "eye test" and irritating to look at.

Pilot #13: As mentioned before I thought the ghost horizon was some what confusing during UARs. It did not seem to aide in rolling to the nearest horizon and misinterpreting it with the solid horizon gave a snap feel that I was closer to level flight than actual. With more familiarity it might be useful.

Pilot #14: d - Bank scale interfered with target during tracking at times. It probably wouldn't if target was locked up.

Pilot #15: d - During air-to-air tracking and air-to-ground modes demo. h - During air-to-air tracking and air-to-ground modes demo. Additionally, small orange peel was out of the FOV sometimes, and therefore not accurate. -- his would create a single reference that would provide both a horizon reference (i.e. which way to roll) and an attitude reference (i.e. a "sky pointer").

Pilot #16: d - Adds to clutter. g - Didn't like it. Marginally useful in the clear; i.e. VFR - unusable in IMC. h - Didn't use it. Didn't really like it.

3. Is the current design of the ghost horizon (dashed line) sufficiently discriminable from the true horizon?

__12__ Yes   __3__ No

Pilot #4: Keep it close to the middle of the HUD FOV. Gets too low in the HUD.

Pilot #5: Need to be displayed all the time. If concerned about relationship of ghost horizon and FPM, delete FPM when there is a conflict.

Pilot #6: But - It typically was too subdued to notice. A thicker line which stands out more like the examples shown on paper would make it easier to find when things change fast.

Pilot #9: It could be improved by putting the ghost horizon a little closer to the center of the HUD so one doesn't have to move the head to see it.

Pilot #11: Move it closer to the FPM!

Pilot #13: It tended to be outside my tunnel (narrow) cross check near the FPM. So in my peripheral vision it was hard to discriminate and seemed to draw my attention away from the other attitude cues. It was obviously dashed when I looked at it but to far from the center for quick reference. Moving it closer to the center of HUD field of view might help but I personally think it might always be more disorienting than helpful. It seemed most confusing in large banks when stuck down in a corner.

Pilot #15: Need to put it at 6^0 from FPM (i.e. closer to central FOV). Additionally, need to further accentuate it as well as use it as "sky pointer" by making it a series of triangles or small arrows like: _ _ _ _ _ _ _   or   _ _ _ _ _ _
_ _ '

4. What numbering scheme do you prefer for the articulated pitch ladder?

OPTION 1   10 _ _ _ _ _ _ | L _ _ _ _ _ 10

OPTION 2   10 _ _ _ _ _ | L _ _ _ _ _ 10

OPTION 3   10 _ _ _ _ _ | L _ _ _ _ _ 10

OTHER (SKETCH)   _ _ _ _ _ | L _ _ _ _ _ '

<u> 4 </u>   Option 1
<u> 6 </u>   Option 2
<u> 1 </u>   Option 3
<u> 0 </u>   Option 4
<u> 4 </u>   No Preference

Pilot #5: Move degree numbers further away from ladder.

Pilot #6: Chose option 1 because for the 5° and 10° ladder lines they will be able to be quickly interpreted by the same means as the nose up lines.

5. Other options are being considered for zenith symbology. Which of the following do you prefer?
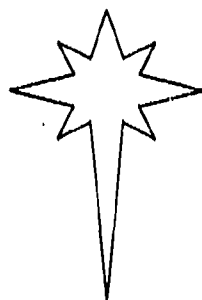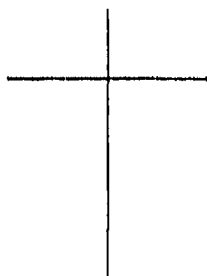
OPTION 1	OPTION 2	OPTION 3	OPTION 4	OTHER (SKET
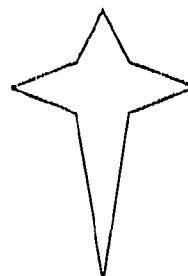
<u> 8 </u>   Option 1
<u> 0 </u>   Option 2
<u> 0 </u>   Option 3
<u> 0 </u>   Option 4
<u> 2 </u>   Other
<u> 5 </u>   No Preference

Pilot #5: Don't use anyway, don't knock yourself out!

Pilot #6: Don't use option - it would not stand out enough.

Pilot #8: Horizon pointers are not important. When you're this close to zenith/nadir it takes longer to roll to "correct" location than just to pull through. Takes too much draw time.

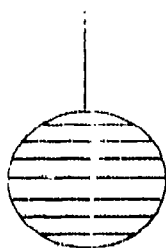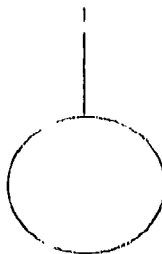**6. Other options are being considered for _____ symbology. Which of the following do you prefer?**

OPTION 1   OPTION 2   OTHER (SKETCH)

__8__ Option 1
__2__ Option 2
__1__ Other
__4__ No Preference

Pilot #5: Don't use anyway, don't knock yourself out!

Pilot #8: Horizon pointers are not important. When you're this close to zenith/nadir it takes longer to roll to "correct" location than just to pull through. Takes too much draw time.

7. The block 40 F-16s already have a bank scale indicator that is presented around the flight path marker. Which design do you prefer?
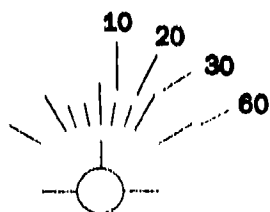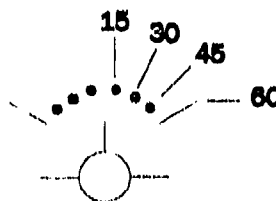
MODIFIED BANK SCALE   BLOCK 40 BANK SCALE

__4__ Strongly Prefer Modified Bank Scale (F-16 A/B)
__6__ Moderately Prefer Modified Bank Scale (F-16 A/B)
__2__ Slightly Prefer Modified Bank Scale (F-16 A/B)
__1__ Neutral
__1__ Slightly Prefer F-16 Block 40 Bank Scale
__1__ Moderately Prefer F-16 Block 40 Bank Scale
__0__ Strongly Prefer F-16 Block 40 Bank Scale

Pilot #3: I would rather have this:

Pilot #5: Moderately prefer Modified Bank Scale (F-16 A/B) but really prefer top/bottom of HUD

Pilot #15: Don't like either (See answer for question #1 on Modified Bank Scale). However, if chosen, the "dots" seem more distinctive than the lines.

8. How effective was the <u>F-16 C/D HUD format</u> at providing:

a. quick and accurate attitude *recognition* in nose up conditions?

_0_	Very Effective
_6_	Moderately Effective
_3_	Neutral
_4_	Moderately Ineffective
_2_	Very Ineffective

b. quick and accurate attitude *recognition* in nose down conditions?

_1_	Very Effective
_6_	Moderately Effective
_2_	Neutral
_4_	Moderately Ineffective
_2_	Very Ineffective

c. maintaining accurate attitude awareness in dynamic conditions (i.e. as you recovered from unusual attitudes, A-A tasks)?

_0_	Very Effective
_6_	Moderately Effective
_4_	Neutral
_5_	Moderately Ineffective
_0_	Very Ineffective

Pilot #1: Some mental processing time is required to interpret the information.

Pilot #3: Not to bad.

Pilot #4: Forced to read and interpret numbers. It was not inherently obvious whether I was 90° up or down. Need something more dramatic/obvious.

Pilot #5: Difference is location of the tic marks too close to pitch scale numbers in nose-up condition.
Pilot #6: Once I estimated a technique to rapidly identify which way to roll and pull to get to the horizon, I didn't worry too much whether I was nose high or low. This delayed my power
input, but was highly effective in the sim. In a real aircraft it will make a big difference to know quickly if I am nose high or low. The articulated lines will help with "true Recognition".

Pilot #7: There is not much to differentiate between ground and sky, especially if you become task saturated. Perhaps a different color scheme from ground and sky would help.

Pilot #9: Sometimes its easy to confuse extreme nose up/down conditions in C/D. All you had basically is a dashed vs solid line. It took some brain cells to determine this, maybe a little more so than the modified HUD.

Pilot #10: Just not enough ambiguity between nose up and down

Pilot #12: I am a firm believer in using the round dials for unusual attitude recoveries. However, when I looked at the HUD pitch ladders racing across the FPM all look alike - dashed or solid line. The full horizon line was the only one I could really _instantly_ recognize.

Pilot #14: The tic marks aren't large enough.

Pilot #16: Moderately ineffective in nose low attitudes.

9. What was your strategy for unusual attitude recoveries with the F-16 C/D HUD format?

Pilot #1: (1) Find the FPM, (2) Find the scales, (3) Interpret scales; up or down by looking at the numbers or dashes, (4) maneuver.

Pilot #3: (1) Look at pitch ladder to determine nose high/nose low, (2) Look at pitch ladder to determine direction to roll followed by roll and pull, (3) Look at HUD airspeed to determine throttle setting required.
Pilot #4: Picked up on numbers and the dashed pitch lines. The pitch lines were not very powerful however, in triggering my mind to positive or negative pitch.

Pilot #5: (1) \check direction of tic marks, (2) Roll aircraft to make tic marks point up, (3) pull, (4) Determine nose up/down and airspeed, (5) Adjust throttle/speed brakes to maintain as near 350 KIAS at max G in nose low situations.

Pilot #6: Being a banked pilot with no experience, my strategy evolved. It started with identifying nose high or low by whether the pitch ladder was solid or dashed. Coupling this with reading the numbers for pitch I could determine which way to go. Then I learned about the tic marks pointing to the horizon. This posed two problems: first the tic marks were hard to see when I became fatigued, second for nose low it was obvious which way to go, but for nose high I had to take time to think whether the arrows were sky pointers or horizon pointers. I finally transformed to thinking of the ladder lines and numbers as forming brackets for the horizon. This didn't even require the time to focus my eyes and was very accurate. After rolling I would worry about whether I was nose high or low and change power accordingly.

Pilot #7: I would first determine if I was below or above the horizon by looking for dashed or solid lines. I would next look at the numbers (pitch angle). If I was nose low, I would turn the numbers right side up and pull through the numbers. If I was nose high, I would turn to put the numbers upside down and pull through to the horizon.

Pilot #8: (1) Determine nose high or low by looking at solid vs dashed lines., (2) If nose high, roll to put pitch numbers upside down then pull, (3) if nose low, roll to put pitch numbers right side up then pull.

Pilot #9: Looked at the dashed/solid lines, then the numbers to determine which way I had to roll.

Pilot #10: Try to find pitch ladder and look for solid vs dashed lines for nose vs nose down, then try to determine where the horizon was by the slant in the pitch ladder; once determining these, I applied 51-37 procedures for recovery.

Pilot #11: (1) determine aircraft attitude, (2) find the horizon, (3) if nose down roll to horizon and pull, idle, speed breaks, or (4) if nose up, roll toward horizon, add power and pull gently to get nose tracking below horizon.

Pilot #12: I tried to immediately focus on whether the lines were dashed or solid. Dashed meant I pulled power to idle then made the numbers read up right, then pull. Solid meant push the power up, roll till the numbers were upside down, then pull.
Pilot #13: First to recognizing that an unusual attitude exists my initial focus went to the FPM then determined nose low vs nose high attitude with dashed/solid lines. Then referenced tic marks/numbers orientation to

determine correct direction to roll to nearest horizon. Once roll and pull was initiated I'd cross check airspeed and severity of dive to determine if a throttle change from mid-range was appropriate.

Pilot #14: I would look at a combination of the tic marks and orientation of the numbering to find the horizon.

Pilot #15: (1) Determine which way "tic marks" (or the outside ends of the ladder) were pointing, (2) Roll to pull that way, (3) Check for solid/dashed pitch ladder, (4) Check altitude, (5) Check airspeed, and (6) Throttle-set as required.

Pilot #16: (1) Recognize where my nose is - up or down, (2) Confirm attitude and airspeed - climb or dive, (3) Recover by roll and pull to nearest horizon. Easier at lower pitch attitudes, regardless of HUD.

10. For the C/D HUD format, rank the symbols (1 through 9) in order of importance for attitude awareness?

Horizon line	4-1s, 2-2s, 3-3s, 3-5s, 1-7s, 2-9s
Overall asymmetry nose-up/down	4-1s, 1-2s, 1-3s, 3-4s, 4-7s
Dashed/solid pitch ladder	4-1s, 8-2s, 1-3s, 2-4s
Pitch Ladder Numbering	3-2s, 8-3s, 3-4s, 1-5s
Zenith/Nadir	1-1s, 1-3s, 1-5s, 2-6s, 1-7s, 5-8s, 1-10s, 3-N/As
Bank Scale	1-1s, 1-4s, 1-5s, 3-6s, 2-7s, 3-8s, 1-9s, 1-10s, 2-N/As
Airspeed	1-2s, 2-4s, 2-5s, 3-6s, 2-7s, 2-8s, 2-9s, 1-10s
Altitude	2-4s, 3-5s, 2-6s, 3-7s, 1-8s, 2-9s, 1-N/As
Tic marks	2-1s, 1-2s, 1-3s, 2-4s, 2-5s, 3-6s, 1-8s, 1-9s, 1-10s, 1-N/A
Pitch ladder compression	1-2s, 1-4s, 4-9s, 6-10s, 3-N/As

Pilot #15 - Pitch ladder compression is more likely to affect performance awareness vice attitude awareness.

11. How effective was the <u>Modified HUD format</u> at providing:

a. quick and accurate attitude *recognition* in nose up conditions?

3	Very Effective
11	Moderately Effective
0	Neutral
1	Moderately Ineffective
0	Very Ineffective

b. quick and accurate attitude *recognition* in nose down conditions?

11	Very Effective
4	Moderately Effective
0	Neutral
0	Moderately Ineffective
0	Very Ineffective

c. maintaining accurate attitude awareness in dynamic conditions (i.e. as you recovered from unusual attitudes, during A-A tasks)?

5	Very Effective
8	Moderately Effective
2	Neutral
0	Moderately Ineffective
0	Very Ineffective

Pilot #3: Articulation of pitch ladder for nose low was very effective.

Pilot #4: Marked improvement in inherent recognition attributes.

Pilot #5: Bent nose-low pitch ladder improved awareness in nose low recoveries.

Pilot #7: Nose-low recovery was very easy - just follow the funnel to the horizon. Nose high took time to think about. There was no quick device (a no-brainer) to show you which way the horizon was.
Pilot #9: I'm not convinced the modified HUD will reduce CWG, etc., but it was an improvement over the C/D HUD. One still has to recognize the unusual attitude exists. I'll just say the modified HUD was a bit easier/quicker to determine what one had to do to get back to level flight.

Pilot #10: More changes in up-vs-down made the task much easier, however; it was equally as tough to determine back (i.e. which way to initially roll). This is where the ghost horizon could help out. Most cases it was not in the instantaneous F.O.V..

Pilot #12: Again, I could immediately recognize the bendy bars in a nose low attitude.

Pilot #13: The articulation and inside tic marks contributed to a quick recognition of a nose low condition. It might be good to move the nose high tic marks to the inside as well.

Pilot #14: I feel the tic marks could be moved to the inside in nose-up attitudes OR the pitch lines could be bent when nose up also.

Pilot #16: (A) Not much better over current HUD if ghost horizon not in view, and (B) Air-to-air tasks are more prioritized toward target and weapon employment rather than attitude/airspeed/altitude awareness. So I didn't really notice my performance.

12. What was your strategy for unusual attitude recoveries with the Modified HUD format?

Pilot #1: (1) Find FPM, (2) Find horizon line, (3) Pull to it or, if no horizon line, read ladder, (4) interpret attitude (Straight bars vs bent/dashed ones), (5) pull to capture horizon line.

Pilot #3: Same as F-16 C/D HUD but it was easier for nose low recoveries with this HUD.

Pilot #4: Funnel (bendy bars) characteristic was the first trigger to my mind. Followed by confirmation information from numbers - ghost/extended horizon, zenith/nadir.

Pilot #5: (1) If pitch ladder is bent, roll to align "Funnels", if not, roll to point tic markers up, (2) pull for max. "G", (3) verify nose-up/down and check airspeed, (4) adjust throttles/speed breaks to maintain as near 350 KIAS as possible in nose-low situations.

Pilot #6: For nose down it was simple to see the funnel, roll & fly up it. Nose high was confusing because it requires a different set of mental rules from the nose low. It did, however, make it easy to see if the situation was nose high or low. For nose high & slightly nose low, I used the same thought that the ladder lines & numbers bracketed the horizon. The ghost horizon was good for a sanity check once I was starting the recovery, but it was not easy enough to find to for use as the initial indicator of which way to go.

Pilot #7: For nose low recoveries, first pulled toward the "tunnel". For nose high, I used the same method as with the C/D HUD, but it was still quicker because I didn't have to determine if I was nose above or below the horizon (no tunnel" - then I was above). There was still no (no-brainer) quick reference on which way to turn.

Pilot #8: (1) Find ghost horizon line, (2) put at top of HUD, (3) pull. If ghost horizon line not seen revert to normal C/D recovery.

Pilot #9: I started to use the ghost horizon exclusively. When the HUD appeared, I looked to see where the ghost horizon was and rolled/pulled to get to it.

Pilot #10: Try to find articulated pitch ladder and look for solid vs dashed lines for nose vs nose down, then try to determine where the horizon was by the slant in the pitch ladder; once determining these, I applied 51-37 procedures for recovery.

Pilot #11: Same as basic HUD but with a few differences. I used the tic marks on the inside of the pitch ladder to act as a "funnel" to get me to the horizon. I didn't have to think about where the horizon was, it "drew" me a picture. The orange peels were slightly helpful, but not near as much as the tic marks.

Pilot #12: If bendy bars, fly the funnel. Also, the ghost horizon was my clue if that came in view first. Often the ghost horizon was visible first in all nose low situations and extreme nose high attitudes. 30° nose high, wings level, I did not see the ghost horizon. It gave me an instant reference point to roll and pull, the funnel provided me info to fine tune my recovery.

Pilot #13: Nose high was no different than C/D HUD. I'd go from the FPM, determine nose high with the solid lines then use the tic marks/numbers to roll to the nearest horizon (put them pointing up [tic marks] in the HUD) and then initiate a pull down to the horizon. In general always advanced throttle to mil. power. - Nose low was much easier. Recognized the nose low condition by the articulated/dashed line combination then rolled and pulled to the nearest horizon with a wider overall view of the "funnel" pulling up the funnel to the horizon. Cross checking A/S, pitch severity to determine if throttle change was appropriate.

Pilot #14: If nose down (through dashed line recognition) I would fly up funnel. If nose up, I would look at a combination of tic marks and numbering. Lastly I used the ghost horizon.

Pilot #15: (1) Find horizon/ghost horizon, or dive "funnel" (which was more commanding than horizon), (2) Roll to pull that way, (3) Check solid straight vs dashed bendy lines, (4) Check altitude, (5) Check airspeed, and (6) Throttle - set as required.

Pilot #16: Nose low - follow the funnel - easy and quick. Nose high - find the ghost horizon and follow it. Big concern is that pilot's will filter it out of their cross check over time because we won't see it to use it in a dynamic environment.

13. For the **Modified HUD format**, rank the symbols (1 through 11) in order of importance for attitude awareness?

Extended horizon	3-1s, 2-4s, 3-5s, 2-6s, 1-7s, 1-8s, 1-9s, 1-10s, 1-N/As
Ghost horizon	3-1s, 4-2s, 2-3s, 2-6s, 1-7s, 1-10s
Overall asymmetry nose-up/down	2-1s, 1-2s, 2-3s, 2-4s, 1-5s, 1-6s, 1-7s, 1-9s, 1-11s, 2 - N/As
Pitch ladder numbering	1-2s, 2-3s, 4-4s, 3-5s, 3-6s, 2-7s
Dash/solid pitch ladder	2-1s, 3-2s, 3-3s, 3-4s, 1-5s, 1-6s, 2-8s
Modified Zenith/Nadir	1-1s, 1-5s, 3-7s, 1-8s, 3-9s, 1-10s, 2-11s, 3-N/As
Articulated pitch ladder	5-1s, 5-2s, 3-3s, 1-5s, 1-11s
Modified Bank Scale	1-1s, 1-5s, 1-6s, 2-7s, 2-8s, 1-10s, 1-11s, 4-N/As
Airspeed	1-2s, 1-4s, 1-5s, 2-6s, 1-8s, 2-9s, 3-10s, 3-11s, 1-N/A
Altitude	1-2s, 1-4s, 2-5s, 2-7s, 1-8s, 2-9s, 2-10s, 2-11s, 2-N/A
Tic marks on inside of pitch ladder	1-1s, 2-3s, 1-4s, 1-5s, 2-6s, 1-7s, 2-8s, 1-9s, 1-10s, 1-11s, 2-N/As

14. Would you like to see the following symbology modifications incorporated into the F-16 C/D?

Symbol modification	Yes	No	Undecided
a. Extended Horizon	15	0	0
b. Modified Bank Indicator	6	5	4
c. Ghost Horizon	13	2	0
d. Improved zenith and nadir	6	4	5
e. Articulated Pitch Ladder	14	0	1
f. Inside placement of tic marks	13	0	2
g. Removal of pitch ladder compression	10	1	4

Pilot #5: In F-16, nose up/down UARs basically the same. Finding nearest horizon most important (more so than whether nose is up or down). Moving all tic marks to inside would make them easier to find (you'd know immediately where to look and wouldn't be distracted by pitch angles and labels). Make the spacing wider between the pitch angle labels and the tic marks.

Pilot #6: Each of the above are beneficial. The ghost horizon needs to be more obvious, maybe thicker. The last two, inside tic marks and pitch ladder compression, I feel neutral about.

Pilot #8: Zenith/Nadir unimportant as to what symbol used. When they are in the FOV it is usually faster or just pull through rather than trying to find the "correct" azimuth.

Pilot #9: Item b.- Still will use ADI for bank no matter if its in the HUD or not. Item c.- One of the better improvements. Item d.- Just didn't use these symbols to determine what to do only the fact that I was very nose high/low. Items e & f.-Removes confusion (instantaneous) as far as pitch ladders go concerning nose up/down. Item g.- Hardly made any difference as far as I was concerned.

Pilot #10: These changes are definitely needed and a step in the right direction.

Pilot #13: The articulated pitch ladder is particularly helpful in getting a quick recognition of attitude. My concern, and I think it should be looked at closely is whether it would be harder to use in normal air-to-ground delivery situations.

15. Do you think that adding these modifications to the F-16 C/D HUD will reduce Collision With Ground (CWG) and Spatial disorientation incidents?

__12__ Yes   __1__ No   __2__ Don't Know

Pilot #1: If we train to use this HUD correctly, it's easier to interpret.

Pilot #3: Would only reduce C.W.G. by a very small percentage. Most guys hit the ground for reasons other than spatial disorientation while looking at HUD. I think to really reduce S.A. and C.W.G with F-16 we need a peripheral horizon indicator.

Pilot #4: Faster and easier recognition of attitude reduces demands on the pilot. This is especially important during high workload mission segments. Pilots must have an inherently obvious indication of their attitude that requires little or no interpretation to make it useful in all stress conditions. Low level/night/air-to-air/instruments.

Pilot #5: In F-16, nose up/down UARs basically the same. Finding nearest horizon most important (more so than whether nose is up or down). Moving all tic marks to inside would make them easier to find (you'd know

immediately where to look and wouldn't be distracted by pitch angles and labels). Make the spacing wider between the pitch angle label and the tic marks.

Pilot #6: It will reduce the opportunity to incorrectly read the symbology or the thinking 180° off when searching for which way is up. It also helps re-enforce pilots mind, what the situation really is and what the instruments are saying when spatially disoriented. It can be hard to convince yourself that you are reading the HUD correctly when you don't trust what you see.

Pilot #7: It's easier to notice that you're heading toward the ground without consciously thinking about it.

Pilot #8: These assist recovery. The real problem is recognition that an unusual attitude exists or that C.W.G. is imminent. Once I recognize that the best gage in the world is the ADI. HUDs needs to warn pilots.

Pilot #9: Still depends upon pilot to pick something to use in the HUD. I think it will reduce confusion by a little and save maybe 1 - 2 seconds at best. If 1 - 2 seconds is all a pilot's got, he's in bad state.

Pilot #10: It won't effect CWG incidents that aren't induced by spatial disorientation (e.g. CWG during low altitude OPS in mountainous terrain).

Pilot #11: Better awareness of where horizon is and "How I get there from here".

Pilot #12: I know for a fact, being safety school trained, that guys have rolled and pulled the wrong way during extreme nose low and nose high conditions and not lived to tell about it.

Pilot #13: Only if spatial disorientation is recognized and then the HUD is used as the primary reference to recognize and recover from the disorientation.

Pilot #14: A small percentage are probably from misreading the HUD.

Pilot #15: Better S.A. regarding direction to maneuver.
Pilot 16: Particularly nose low recoveries where time and altitude are extremely critical.

16. In real-world A-A combat, what strategies do you use to maintain attitude awareness?

Pilot #1: I use outside references. The real sky, real ground, real horizon, clouds, etc. Unless I punch into clouds or the horizon is obscured, then if I'm unsure I'll check the ADI or pitch ladder.

Pilot #3: Look out the window. Check ADI during extreme nose high/nose low situations.

Pilot #4: Altimeter mainly - especially on hazy days or over water. This is because the HUD field of view is so narrow in the Block 10 F-16 A/Bs.

Pilot #5: HUD not used for this task, since required to have discernible horizon and good visibility for air-to-air. It's all done by outside references.

Pilot #6: N/A. Sorry, just a banked pilot.

Pilot #7: N/A. Banked pilot.

Pilot #8: Altitude and airspeed change. Precise attitude is unimportant. altitude and airspeed are. They tell me whether I'm approaching the ground and what my energy is. All that's important.

Pilot #9: Outside horizon - peripheral vision.

Pilot #10: Use the real world - clouds, sky, H_2O, ground. We do need something in the dogfight position instead of a "blank" HUD. A horizon/ghost horizon would be appropriate. This would also give more flexibility for avionics use on low levels. Currently almost everyone runs inboard (MLS OVRD) so they have a horizon in the HUD. This pretty much dictates that he runs RWS inboard. Most guys used to run RWS outboard with ACM inboard.

Pilot #11: Kill bandit and I won't have to worry about it! Mostly pitch ladders and airspeed.

Pilot #12: If over land, that's easy. But honestly to improve S.A., I fly with the RWS in missile override until I'm ready to gun the guy. So I definitely use the pitch ladders and scales. When I go for guns, I already have an idea of where I am in relation to the ground.

Pilot #13: I normally am not using HUD symbology for orientation. I do cross check altitude and airspeed in the HUD but use outside visual reference to the real world for attitude awareness. If I was suddenly in IMC etc. I would probably revert to old habit of referencing the head down ADI to recover to level flight not the HUD (previous F-4 & T-37 experience).
Pilot #14: Outside horizon - I never use the HUD consciously.

Pilot #15: (1) Outside references, (b) Main ADI.

Pilot #16: Outside visual reference - I hardly even notice what the HUD is telling me except for airspeed and altitude.

17. Please rate the acceptability of the following:

	Completely Acceptable	Moderately Acceptable	Borderline	Moderately Unacceptable	Completely Unacceptable
a. Modified HUD in A-G Modes	6	6	0	0	0
b. Modified HUD in A-A modes	6	5	1	0	0
c. Modified HUD for Navigation	7	5	0	0	0
d. Small Orange peel for A-G Modes	2	1	1	3	3
e. Small Orange peel for A-A Modes	2	0	1	2	6
f. Small Orange peel for NAV modes	2	0	5	3	1
g. Large Orange peel for A-A modes	4	2	1	3	1
h. Large Orange peel for A-G modes	0	3	2	3	2
i. Large Orange peel for NAV modes	0	2	4	3	2

Pilot #1: I only need the orange peel in those air-to-air mode where no other reference is available, then the large peel is better as its not in the way in air-to-ground or NAV modes. The pitch ladder is better as its more accurate.

Pilot #4: Items d. & e. - too much clutter and follows FPM.

Pilot #5: HUD used primarily for weapons symbology in air-to-air and air-to-ground.

Pilot #6: With no experience I really would only serve to cancel the quality of results if I were to answer these.

Pilot #9: The modified HUD was completely acceptable. It didn't change the way I did business in air-to-air or air-to-ground modes. The small orange peel in conjunction with the modified HUD was good. The one I really didn't like was the large orange peel. I didn't like that at all.

Pilot #10: Item b. - see pilot #10 comment on question number 16. Item c. - Too cluttered with all the other "circular" symbology. Item g. - A bit too hard to interpret, however that would get better with using it. Moderately acceptable for clutter.

Pilot #11: Items d. & e. - Makes HUD too cluttered. Item f. -Move it up higher, closer to center.

Pilot #12: The large orange peel in dogfight only is a definite S.A. builder. When that thing starts to close around my FPM, it's time to check altitude and airspeed carefully. Also, I like how it gives me an immediate pull direction to wings level.

Pilot #13: I don't anticipate any problems in air-to-air with modified HUD. With the very limited exposure to the small/large orange peel I don't think I can make any intelligent determination-tion one way or the other. The small orange peel tended to be out of the HUD FOV, being tied to the FPM. The large orange peel stayed in FOV, but I would probably use it about as much as the range and overtake information on the gun sight; i.e. never. Might be useful with better familiarity but probably more clutter than worth.

Pilot #14: Item e. - It was never in view. Large orange peel was better, but I don't see a real need to add it to the HUD.

Pilot #15: Item h - Don't need large orange peel for A-G modes since it doesn't dive exact dive angles. It may be useful if a digital dive/climb angle was added to the display, at the ends of the "peel". Item i - Not real useful in Nav. modes unless I find myself in an unusual attitude.

Pilot #16: Didn't really like orange peel - Adds to clutter - not needed for a visual delivery.

18. Rate the effectiveness of the small orange peel for providing attitude awareness information.

    __2__   Very Effective
    __4__   Moderately Effective
    __3__   Neutral
    __2__   Moderately Ineffective
    __1__   Very Ineffective

Pilot #1: But, the only situation that I'll use it for is air-to-air, in which case it's in the way.

Pilot #4: Too much movement around HUD when attached to FPM. Too much clutter in this part of HUD. Too small to be globally effective.

Pilot #5: Could have had more experience with it.

Pilot #8: Very effective when combined with pitch ladder.

Pilot #9: Basically it's a quick look symbol but I'd have to go to the round dials or something else to get more detailed information.

Pilot #10: Very good for nose low conditions (in fact probably the best thing overall for knowing which way to roll and pull stick in nose low). Not very useful in nose high conditions.

Pilot #11: Too small, too much concentration to read it with other tasks.

Pilot #12: It works but it clutters up the HUD and diverts my attention away from my altitude and airspeed cross check.

Pilot #13: Not enough use to judge.

Pilot #14: It would take getting used to.

Pilot #15: It moves all over the HUD, sometimes off the HUD, and is too small.

Pilot #16: It's effective if I want it, but I didn't use it in the scenario provided.

19. Rate the effectiveness of the Large orange peel for providing attitude awareness information.

__4__	Very Effective
__3__	Moderately Effective
__2__	Neutral
__1__	Moderately Ineffective
__2__	Very Ineffective

Pilot #1: It seems to be a very good "quick" reference and not in the way in Air-to-air mode. Please check against AIM - 120 symbology. Also, I'd like to evaluate it in a guns track scenario using EEGS with the target low in the HUD. If the orange peel interferes with either, it would be of limited value.

Pilot #4: Liked its stationary position in the HUD FOV. Very powerful impression to me of my attitude. Strongest in air-to-air mode.

Pilot #5: Could have had more experience with it.

Pilot #9: Didn't like it at all.

Pilot #10: About the same as above only the size seemed to make it harder to process what it was representing.

Pilot #11: Really liked it in dogfight mode only. Didn't like it in center position (air-to-air) or MSL override.

Pilot #12: I liked it.

Pilot #13: Not enough use to judge.

Pilot #14: It would take getting used to.

Pilot #15: Global effects is excellent, but only in general attitude vice exact climb/dive angle. Still need pitch ladders for A-G modes and out-of-control pitch rate info.

Pilot #16: Better than small one; unusable in IMC, didn't use it.

20. Assuming the modifications are incorporated, what declutter options would you like to see in the following modes?

Flight Path Marker   Airspeed Scale
Attitude Bars   Altitude Scale
Roll Indicator   Vertical Velocity Scale
Ghost Horizon   Heading Scale

a. A-G Modes:

Pilot #5 - Options of displaying: Airspeed, Altitude, FPM or airspeed & altitude only for strafing.
Pilot #8 - VVI
Pilot #9 - Roll indicator, VVI scale.
Pilot #10 - Roll indicator, ghost horizon, vertical velocity scale.
Pilot #11 - Roll indicator, VVI.
Pilot #12 - Ghost horizon, roll indicator, vert. velocity.
Pilot #13 - Roll indication.
Pilot #14 - Roll indicator & Vertical velocity.
Pilot #15 - Roll indicator & Vertical velocity
Pilot #16 - Roll indicator/ VVI

b. A-A Gunnery Modes:

Pilot #4 - Large orange peel provided strongest reference for me here.
            Ghost horizon was sometimes too low in the HUD FOV to be seen easily.
Pilot #5 - Options of displaying: Airspeed, Altitude, FPM or airspeed & altitude only for strafing.
Pilot #8 - Attitude bars, roll indicator, VVI, Heading scale.
Pilot #9 - Roll indicator, VVI scale.
Pilot #10 - FPM, Altitude bars, Roll Indicator, Ghost horizon, VVI, Heading scale.
Pilot #11 - Roll indicator, Altitude bars, VVI. Keep/re-incorporate heading into "dogfight" position
Pilot #12 - Roll indicator, VVI, Altitude bars (already done).
Pilot #13 - Roll indicator.
Pilot #14 - Roll indicator.
Pilot #15 - Roll indicator, Vertical velocity, Attitude bars, & FPM
Pilot #16 - Roll indicator & VVI

c. A-A Missile Modes:

Pilot #4 - Large orange peel provided strongest reference for me here.
            Ghost horizon was sometimes too low in the HUD FOV to be seen easily.
Pilot #5 - Options of displaying: Airspeed, Altitude, FPM or airspeed & altitude only for strafing.
Pilot #8 - Attitude bars, Roll, VVI, HDG.
Pilot #9 - Roll indicator, VVI.
Pilot #10 - FPM, Altitude bars, Roll Indicator, Ghost horizon, VVI, Heading scale.
Pilot #11 - Roll indicator, VVI.
Pilot #12 - Roll Ind., VVI.
Pilot #13 - Roll Indicator.
Pilot #14 - Roll Indicator.
Pilot #15 - Roll indicator, Vertical velocity, Attitude bars, & FPM
Pilot #16 - Roll indicator & VVI

a. NAV Modes:

Pilot #4 - Roll indicator is only needed in this mode. Should be decluttered from others.
Pilot #5 - Can declutter VVI.
Pilot #8 - VVI.
Pilot #9 - Roll indicator, VVI.

Pilot #10 - Vertical velocity scale.
Pilot #11 - Roll indicator, ghost horizon, VVI, Heading.
Pilot #12 - Vert. Velocity.
Pilot #14 - Keep all.
Pilot #15 - Roll indicator & Vertical velocity
Pilot #16 - Roll indicator & VVI.

21. What changes, if any, would you recommend making to the current mechanization of the declutter options on the remote HUD control panel?

Pilot #1: Can't think of any.

Pilot #3: Works OK as is.

Pilot #5: Not enough experiences with it for comments. A/B model seems good.

Pilot #6: Too inexperienced to answer intelligently.

Pilot #10: It would be great if the HUD had a declutter option page similar to the MFD's. That way guys could "program" their own options for each of the above modes, plus it would get rid of the HUD remote control panel.

Pilot #11: Currently okay but get rid of roll indicator in HUD, except for LANTIRN ops.

Pilot #13: I normally don't declutter other than VVI. This is always off.

Pilot #16: For manual banks - be able to declutter HUD symbology completely in primary reticle.

22. Do you have any suggestions for other symbology changes that could reduce SDO and/or CWG mishaps?

Pilot Comments:

Pilot #3: If you could tint the nose high portions of the HUD blue or clear and tint the nose low portion of the HUD green or brown, it would give the pilot instant recognition of nose high/low and rough gage bank for pitch attitudes near level.

Pilot #5: Put extra large arrow pointing to horizon whenever low-speed warning horn comes on or whenever, say, 4 Gs required in 5 seconds to avoid hitting ground.

Pilot #7: For nose up attitudes, place on arrow showing what way the horizon is (no brainer).
Pilot #9: Symbology to me is not necessarily the key. A good training program is. To me, it can be done with either the new or old HUD.

Pilot #10: Maybe instead of the ghost horizon tie a symbol to the FPM when the horizon is out of view.... Don't know how usable it would be. See drawing. Symbol would consist of a small piece of the way most guts draw the ground (horizontal line with slashed marks underneath) and it would rotate around the FPM the same way the pitch ladder does. My real suggestion is to give us a larger, 3-D, ADI similar to the one displayed on the console.

Pilot #11: How about tie marks in the inside of pitch ladders while climbing also. That way you always have a "funnel" picture directing you to where the horizon is. The tie marks on outside of climbing pitch ladders aren't really noticeable. When I do UARs I'm centering my attention around the FPM and tie marks should be closer (inside).

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