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## THESIS

EVALUATION OF HEAD-UP DISPLAY FORMATS  
FOR THE F/A-18 HORNET

by

Leah M. Roust

March 1989

Thesis Advisor: Judith H. Lind

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Evaluation of Head-Up Display Formats for the F/A-18 Hornet

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## ABSTRACT

This study evaluates symbols and formats for the F/A-18 Hornet head-up display (HUD) and Attitude Directional Indicator (ADI) for use by pilots in recovering from unusual aircraft attitudes. Two surveys were conducted to collect pilot opinions on various symbols and formats, based on past experimental research and current recommendations. For the first survey, 60 F/A-18 pilots prioritized several types of HUD symbols according to the amount of information these symbols provide for the pilot while he is in an unusual attitude. In some cases, the pilots also were asked to choose their preferred symbols. The second survey was based on the results of the first and was administered to 56 F/A-18 pilots. These pilots selected their preferred HUD or ADI display formats, choosing one from two to five possibilities in each case. The specific symbols and formats that were evaluated are described in detail. Survey results are provided, and recommendations are made for display implementation and for further research and testing of symbols and formats.

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## LIST OF ABBREVIATIONS

ADI	- Attitude Directional Indicator
DDI	- Digital Display Indicator Multipurpose Display
F/A-18	- Fighter/Attack Aircraft, McDonnell Douglas Hornet
HUD	- Head-Up Display
NADC	- Naval Air Development Center
NATC	- Naval Air Test Center
TACAN	- Tactical Air Navigation
VFA	- Fixed Wing, Heavier Than Air Fighter Attack Squadron

## I. INTRODUCTION

### A. BACKGROUND

The Navy's F/A-18 Hornet aircraft represents a major step in the application of integrated controls and computer-controlled displays toward the reduction of pilot workload and enhancement of mission success (Figure 1). The Hornet crew station was designed to provide the capabilities of both the F-4 and A-7 aircraft. It is expected to perform both the fighter and attack roles in battle, and to be operable by one pilot. Mission reliability is increased by a combination of improved hardware reliability and functional redundancy. [Ref. 1:p. 82]

The head-up display (HUD) is the F/A 18 primary flight instrument for weapon delivery and navigation, including manual and automatic carrier landing modes (Figure 2). The HUD is a display which projects collimated symbol imagery onto a glass surface in the pilot's forward field of view. The technique results in the head-up presentation of flight control information, possibly combined with weapon delivery cues. Yet it does not interfere with external visual cues from the scene normally viewed through the windshield.

Attitude information, alphanumeric cues, and steering commands are projected on the HUD combiner. Pitch and roll

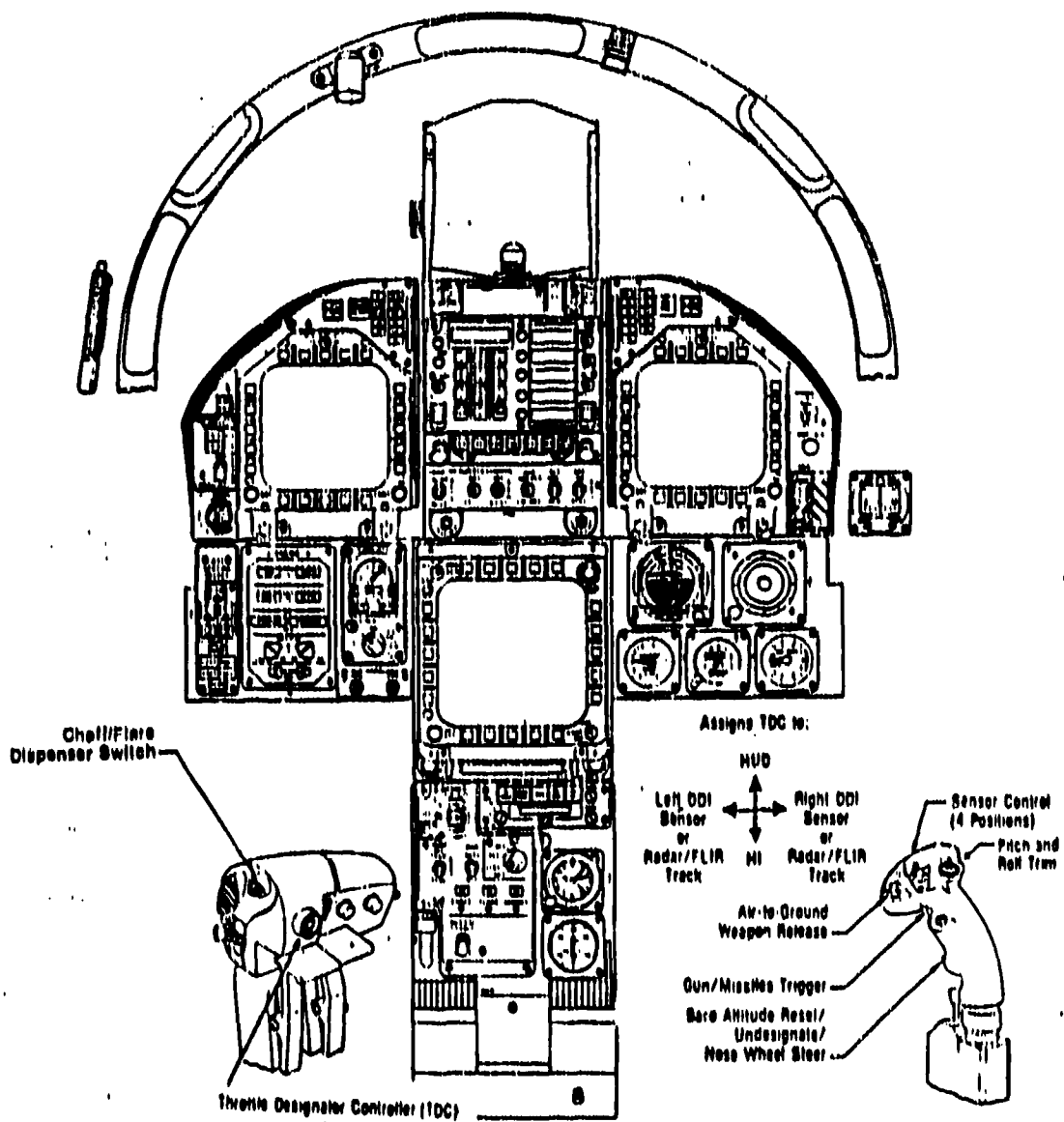
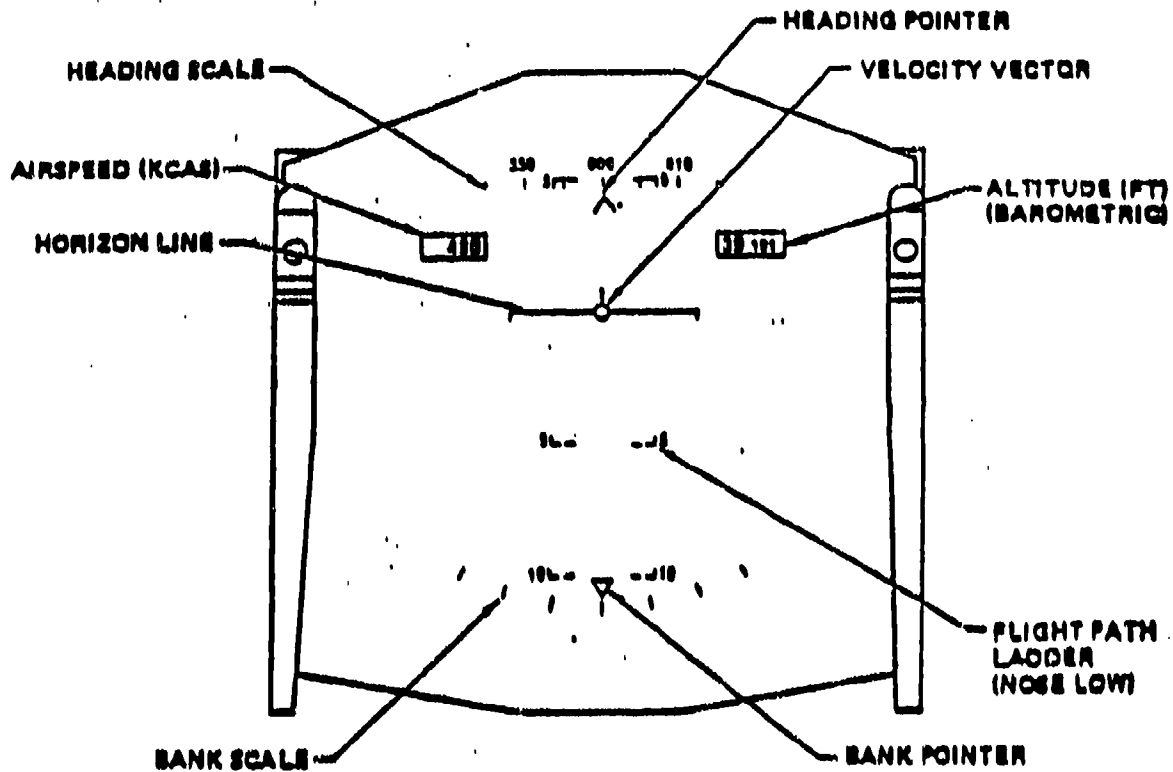


Figure 1. F/A-18 Main Instrument Panel [Ref. 1:pp. 2-23]



HUD BASIC SYMBOLOGY

Figure 2. F/A-18 Head-Up Display  
[Ref. 2:p. 8]

information is shown by a flight path ladder (also called a pitch ladder) and a bank scale. Airspeed and altitude are presented in a digital format. Heading is determined by use of a moving tape compass readout along the top of the display. Optics are focused at infinity for easy

assimilation by the pilot while scanning the area outside the crew station. [Ref. 2:p. 3]

Rapid recognition of aircraft spatial orientation is essential for the pilot when recovering from unusual, unexpected attitudes during aerobatic and emergency maneuvers. Under these circumstances, recovery of the desired attitude using aircraft instruments is strongly affected by display design factors. During any loss of situational awareness by the pilot, the HUD may not provide sufficient spatial orientation cues for quick recovery. [Ref. 3:p. 14-1]

Situational awareness encompasses awareness of both the "big" (tactical) picture and also the "small" (spatial orientation) picture. Spatial orientation refers to the aircrew's awareness of:

1. Aircraft attitude: pitch angle, pitch rate, bank angle, bank angle rate.
2. Aircraft energy state, airspeed, acceleration.
3. Proximity over terrain. [Ref. 4:p. 3]

Spatial orientation is gained through cockpit displays, outside-the-cockpit visual cues, aural cues, and tactile cues. It may be lost through distraction, disorientation, misorientation, and g-induced loss of consciousness. Disorientation occurs when conflicting sensory inputs are perceived and conflicts are not resolved. The common example of this is vertigo caused by visual illusions during instrument flight. Misorientation occurs when

incorrect sensory inputs are perceived and treated as correct. A common example of this is the pilot who unknowingly flies off a frozen or badly processed gyro. [Ref. 4:p. 3]

Since 1979, 14 F/A-18s have been lost in mishaps where loss of situational awareness, spatial disorientation, or unexplained flight into the surface are listed as confirmed or probable cause factors. This number represents 57% of all U.S. Navy and Marine Corps losses to date, plus, 50% of all Canadian and 100% of Royal Australian Air Force F/A-18 losses. [Ref. 4:p. 2]

Evidence points to inadequate or ambiguous attitude displays in the cockpit as a probable cause of situational awareness loss. A potential problem that has been identified is an inability of the pilot to recognize when he is in an unusual attitude and then recover while using the HUD and associated cockpit displays. [Ref. 4:p. 5]

#### B. HUD SYMBOLOGIES AND FORMATS

Of special concern for this study are HUD symbols and formats that may assist pilots in recovery from unusual attitudes. Some of the symbologies addressed here are currently in use on HUDs in operational Navy aircraft. Others have been proposed for use by various researchers who also have proposed modifications to the attitude direction indicator (ADI). Figures 3 to 8 illustrate

various HUD and ADI symbols and formats that are of interest. These are described below.

#### 1. Pitch Reference Frame

The position and format of the pitch scale or ladder are cues that may provide information to the pilot when he is in an unusual attitude. The pitch reference frame consists of the ladder plus other symbols, representing fixed angles in space. These symbols are used as references for aircraft pitch and velocity vector symbols (see Figure 2). They include

a. Horizon line: a horizontal line which represents zero pitch (the local horizontal) or the location of the real world horizon.

b. Pitch ladder (also called flight path ladder): a set of roughly parallel lines representing angular distances above and below the horizon, usually in 5-degree increments.

c. Pitch ladder tails: short vertical lines that can be present on the ends of the above-horizon and below-horizon pitch ladders indicating the direction toward the horizon.

d. Pitch ladder degree numerals: Numbers adjacent to the ladder tails representing angular distance above and below the horizon, in degrees. [Ref. 5:p. 4]

## 2. Fixed Aircraft Reference

The fixed aircraft reference symbol (sometimes called Theta or a waterline symbol) represents an extension ahead of the aircraft of the fuselage reference line or other longitudinal aircraft reference line (see Figure 3). The symbol usually is shaped like a "W". It indicates relative pitch and roll angles of the aircraft when compared to the horizon (either artificial or real world) or to a displayed pitch ladder. [Ref. 5:p. 4]

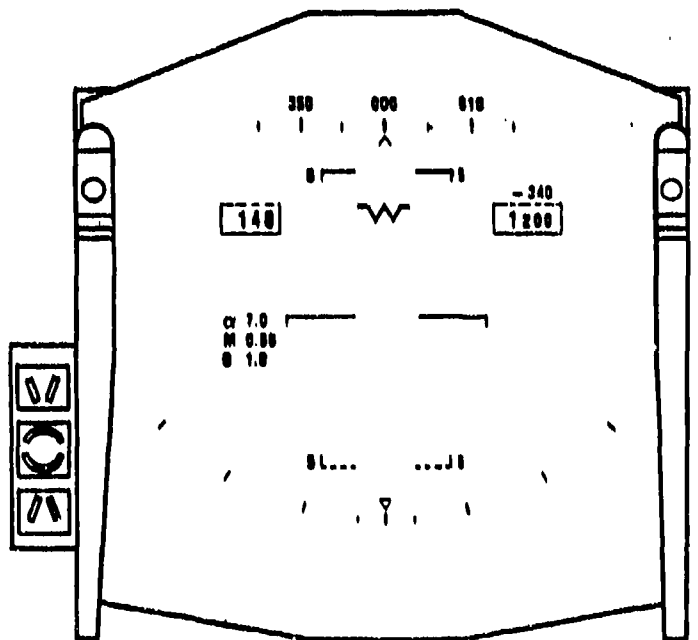


Figure 3. HUD With Waterline Symbol  
[Ref. 6:p.15]

## 3. Velocity Vector

The velocity vector (sometimes referred to as Gamma or the flight path marker) is a symbol indicating the



linear projection of a vector representing the aircraft velocity (see Figure 4). It usually resembles an aircraft, as seen tail-on. The vector originates at the aircraft center-of-gravity or some other well-defined location on the aircraft. A location forward of the aircraft center-of-gravity is sometimes used as origin to provide pitch rate quickening of the velocity vector symbol. [Ref. 5:p. 4]

#### 4. Air Mass Velocity Vector

The air velocity vector is a symbol that represents the linear projection of a vector indicating aircraft velocity through the air mass (see Figure 5). It resembles the lower half of the velocity vector. The inverse of this vector is the relative wind. [Ref. 5:p. 4]

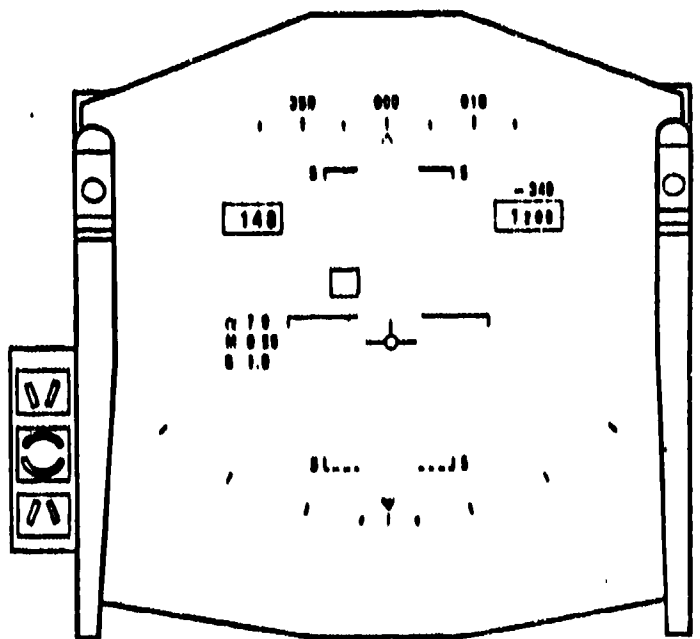


Figure 4. HUD With Velocity Vector Symbol  
[Ref. 6:p. ]

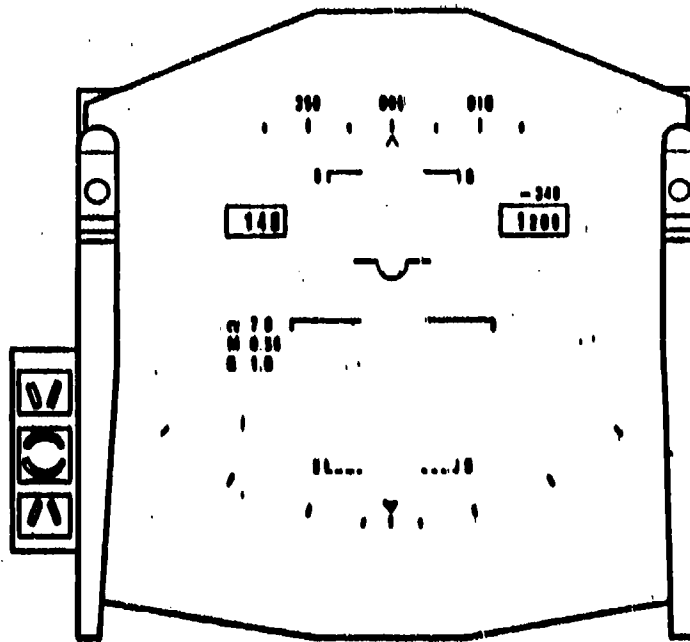


Figure 5. HUD With Air Velocity Vector

#### 5. Bank Indication

The aircraft's bank angle is the angle between true vertical above the earth's surface and the plane defined by the aircraft's vertical and longitudinal axes. The use of a bank index symbol on the HUD has been recommended for precision instrument flight. The index is an arrow pointing either at the sky or at the earth, attached to the velocity vector (see Figure 6). It is sometimes referred to as an Augie Arrow. The bank index reading must agree with that shown on head-down instruments. [Ref. 5:p. A2]

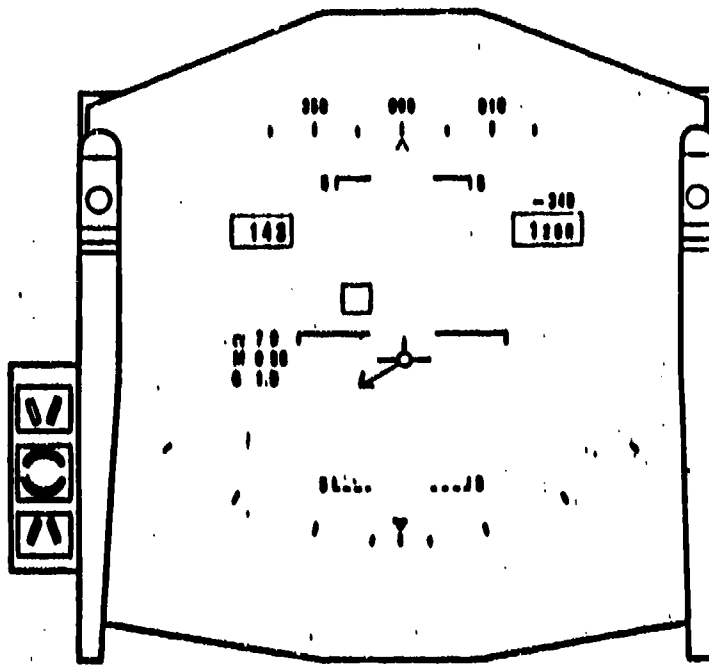


Figure 6. HUD With Augie Arrow

#### 6 Attitude Directional Indicator

The conventional attitude directional indicator (ADI) is a primary flight reference instrument for a variety of civil and military aircraft. The ADI provides an artificial horizon format for use during instrument flight (see Figure 7) that allows the pilot to control the pitch and roll of the aircraft without visual reference to the earth's horizon. Color coding maybe used on the ADI to differentiate pitch attitude above and below the representation of the horizon. [Ref. 2:p. 2]

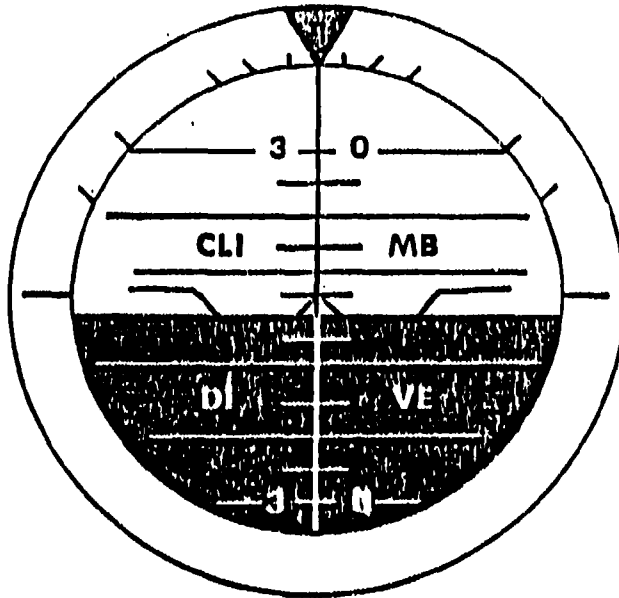


Figure 7. Standard Attitude Directional Indicator  
[Ref. 8:p. 7]

#### 7. Advisory Labels and Legends

Words on the HUD may give immediate information. An example includes descriptive words or commands such as "CLIMB" when the aircraft is at an extreme nose up position (see Figure 8). However, the actual words must be consistent with what the aircraft is actually doing.

[Ref. 7:p. 3]

#### 8. Symbol Color

HUD formats presently all are monochromatic. That is, green symbols are displayed on a clear background. Use

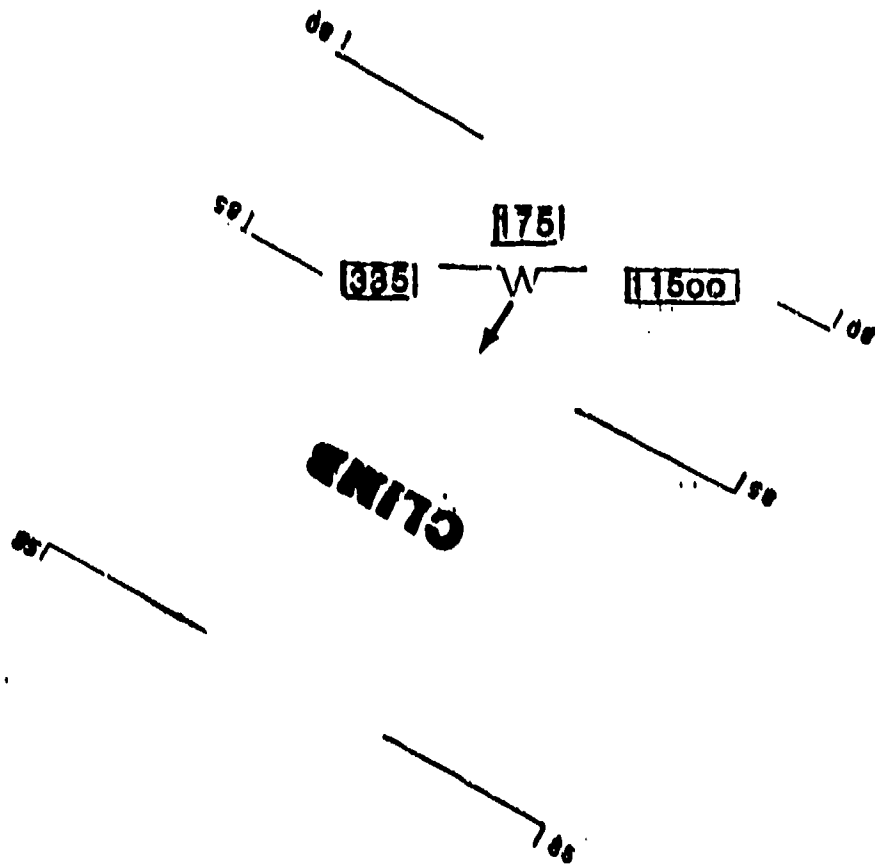


Figure 8. HUD With "CLIMB" Indicated  
 [Ref. 5:p. B7]

of other colors on the HUD has been proposed, but presents problems.

If colors are used on head-up formats they must be consistent in meaning with those used on head-down instruments. Each color used must be assessed for acceptable contrast against all likely background conditions. In a degraded or monochromatic mode, a color display must remain legible and unambiguous. Colors should only be used if an improvement over monochrome has been shown. [Ref. 7:p. 3]

## C. RELATED STUDIES

### 1. Head-Up Display Studies

There has been concern over HUD symbology since the 1970s when military pilots started using HUDs for routine instrument flight. In 1976 the Air Force Instrument Flight Center conducted a survey to determine the degree to which HUDs were used and problems that were encountered with them. The conclusions included concern over standardization of HUD formats and symbology when used as a primary flight reference. A pilot factors program was suggested to determine (1) whether HUDs are appropriate to use as a primary flight reference system and (2) what symbology and format are required for the HUD to be used as primary flight reference. [Ref. 9:p. 2] In a survey of 280 pilots flying HUD-equipped airplanes, a tendency of pilots towards disorientation was reported [Ref. 10:p. 1].

A related study at the Naval Air Test Center (NATC) evaluated the utility of a workload assessment device to measure pilot workload for approach and landing tasks. The study revealed a trend towards more mental reserve capacity when pilots were flying while using a predominantly pictorial and symbolic HUD configuration, compared to conventional HUD formats with graphical scales and alphanumeric information. [Ref. 11:p. 5]

Problems with recovery from unusual attitudes when a HUD is used have been recognized for many years. Several

studies comparing various HUD formats and symbology have been carried out by human factors engineers. These studies have included variables related to cognitive processes involved in perception as well as to HUD symbology.

Several military standards have been adopted related to HUD and other display symbology. Nonetheless, symbology variations continue to exist. The design of HUD pitch scales on the pitch ladder has been of major concern. HUD pitch scale symbols have been shown to have little pictorial realism based on studies at the Naval Air Development Center (NADC) [Ref. 8:p.3]. Redundant pitch cue combinations have been found to improve roll-recovery decision making. Horizon-pointing "tails" have been demonstrated to be superior to nadir-pointing "tails" on a pitch decision-making task [Ref. 3:p. 14-7].

To support standardization, four separate experiments were conducted with non-aircrew subjects evaluating pitch scale numerals, pitch bars, local versus global features (design of symbols attached to pitch bars), and roll and horizon interpretation [Ref. 3:p. 14-1]. The HUD formats and tasks studied were somewhat simpler than those actually used in aircraft. The formats presented only parts of the information normally displayed on HUDs; tasks performed by the operators were only a subset of pilot tasks, although they included a critical part of the operator's total HUD-related tasks. Pilot reactions to

unusual, unexpected attitudes were observed and evaluated in these studies. Experimental evidence from these studies supports adoption of the following HUD pitch scale design characteristics (see Figure 9):

1. Continuous positive above-the-horizon pitch bars and broken (dashed) negative below-the-horizon pitch bars.
2. Numerals on the sides of the pitch scales, above or below but not aligned with the pitch bar extremities.
3. Negative signs for negative pitch scale numerals.
4. Horizon-pointing tails and pitch bars sloping towards or away from the horizon, depending on attitude.

A combination of horizon-pointing tails and horizon-sloping pitch bars may be the safest and most effective design solution. [Ref. 3:p. 14-8]

In response to a questionnaire administered at NATC, one-third of the F/A-18 pilots queried gave below average ratings for the HUD as the primary attitude reference for quick interpretation of unusual attitudes [Ref. 12:p. 7]. More specifically, six pilots reported that the pitch bars on the pitch ladder were difficult to interpret in nose-high and nose-low attitudes. Reasons for this include the rapid movement of the pitch bars and the use of dashed pitch bars below the horizon line that look very similar to the solid lines above the horizon.

Further study was done by the Air Force in 1987 on recognition of and recovery from unusual attitudes. The experiment required pilots to recover from artificially








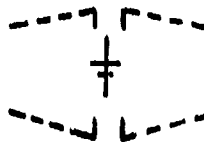
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| 1. |   | 3. | 1. Continuous Positive Above-the-horizon bars    |
|    |   |    | 2. Broken negative below-the-horizon bars        |
| 2. |   | 4. | 3. Numerals aligned above pitch bars extremities |
|    |  |    | 4. Negative sign for below-horizon scale         |
| 5. |   |    | 5. Horizon-pointing tails                        |
| 6. |   |    | 6. Horizon-pointing pitch bars                   |
| 7. |  |    | 7. Nadir-pointing pitch bars                     |

Figure 9. Recommended HUD Pitch Scale  
Design Characteristics  
[Ref. 3:p. 14-14]

induced unusual attitudes using various HUD formats. All the symbologies were compared to baseline F/A-18 HUD symbology. A post-flight questionnaire was also completed by each subject pilot, rating the display in terms of ease

of flying, ease of maintaining spatial orientation, and overall rating of the display [Ref. 7:p. 8]

The results of this Air Force study indicate that a two-to-one pitch scale compression is advantageous. Additional bank information and an upward pointing cue (Augie Arrow) on the velocity vector are effective. Slanted pitch ladder bars pointing toward the horizon enhance recovery from unusual attitudes. Automatic deletion of the velocity vector symbol at high angles of attack also enhances recovery. Five composite symbologies were recommended for further evaluation:

1. Composite I (Figure 10):

- a. F/A-18 style pitch ladder below the horizon and conventional pitch ladder above (pitch ladder modified to indicate heading when pitch exceeds +/-60 degrees; no pitch precession passing zenith or nadir).
- b. Compass heading on the horizon line with digital heading displayed above the waterline symbol.
- c. Bank index at the top of the display format free to move through 360 degrees (enhanced when bank exceeds +/-60 degrees).
- d. Automatic change to two-to-one pitch scaling and display of a roll arrow on the velocity vector symbol (or waterline) when pitch exceeds 30 degrees or bank exceeds 60 degrees.
- e. Deletion of velocity vector automatically at high angle of attack (if Augie Arrow or sky arrow is being displayed, display waterline symbol).

2. Composite II:

- a. Identical to Composite I except F/A-18 style pitch ladder with slanted pitch bars above and below horizon (pitch ladder modified to indicate

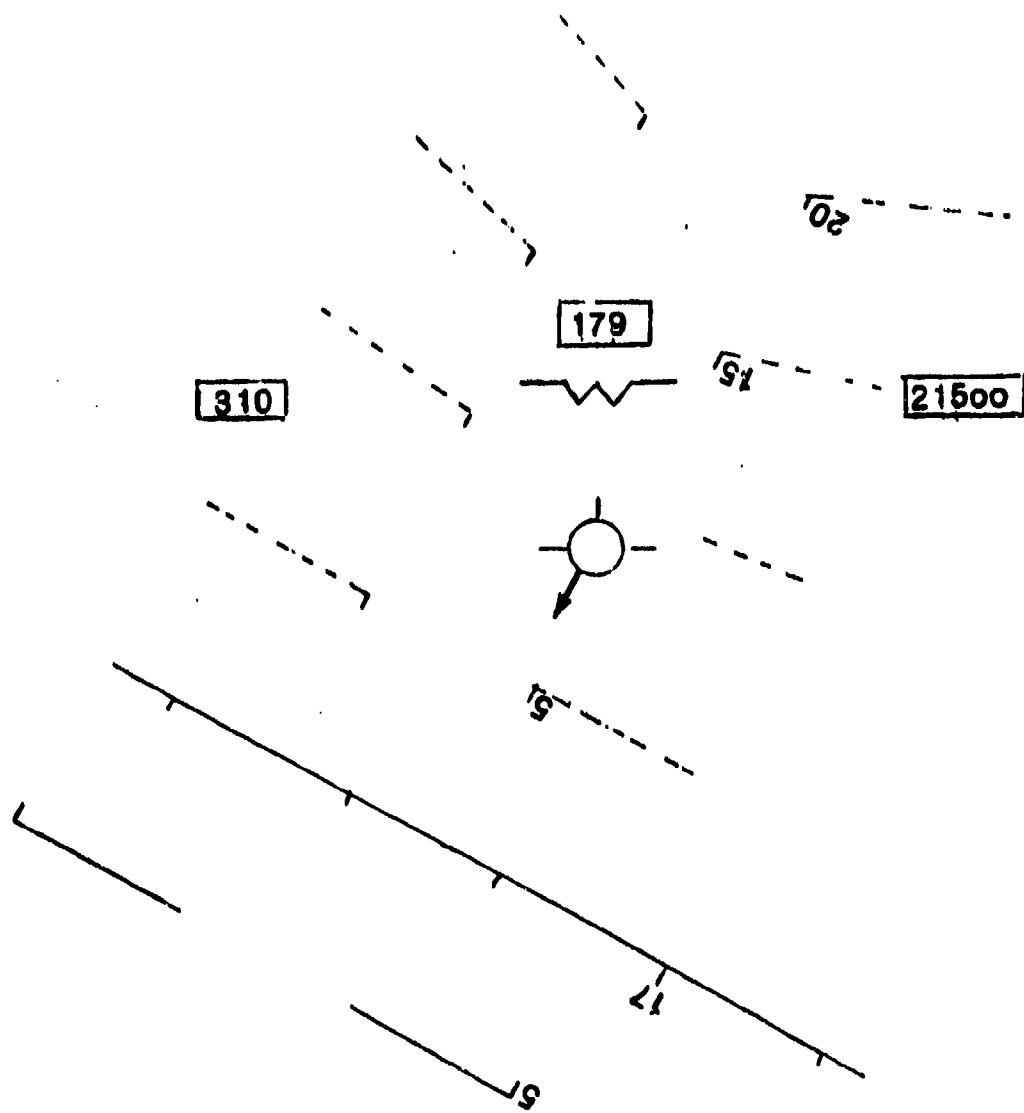


Figure 10. Composite Symbology I,  
 When Aircraft is Inverted  
 [Ref. 7:p. 43]

heading when pitch exceeds +/- 60 degrees; no pitch precession passing zenith or nadir).

3. Composite III:

- a. Identical to Composite I except fulltime one-to-one pitch scaling.

4. Composite IV:

- a. Identical to Composite I except fulltime two-to-one pitch scale compression.

5. Composite V:

- a. Identical to Composite I except fulltime Augie Arrow. [Ref. 7:p. 39]

2. Attitude Directional Indicator Studies

Discussions with pilots, psychologists, and engineers at NATC in April 1985 indicated that the Attitude Directional Indicator (ADI) ball is the preferred choice for attitude indicator instrument [Ref. 2:p. 3]. The current ADI ball in the F/A-18 is small and poorly located (near the pilot's right knee). Using this information and results from the Royal Air Force 1984 study [Ref. 3], NADC compared the F/A-18 HUD pitch ladder to an ADI for the length of time required to recover from unusual attitudes. Two experiments were conducted.

The first experiment, involving non-pilots, was a comparison of two pitch ladder formats and a pictorial representation of an ADI ball in a static display (see Figure 11). The ability of these formats to aid the subject in deciding how to recover from unusual attitudes was assessed.

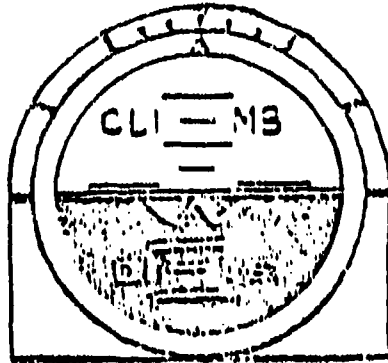


Figure 11. Static Display of Aircraft Attitude Directional Indicator Used in NADC Studies [Ref. 8:p. 8]

The second experiment, involving both non-pilots and pilots, tested the format of the current F/A-18 pitch ladder (Figure 12) and an ADI ball in a medium-fidelity, ground-based simulator in the Crewstation Evaluation Facility at NADC. The static display ADI ball resulted in significantly faster decision times and was superior to the pitch ladder in aiding recovery from unusual attitudes. A revised pitch ladder (Figure 13), based on the four concepts noted above for improved HUD displays, did not surpass the current pitch ladder in decision times.

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

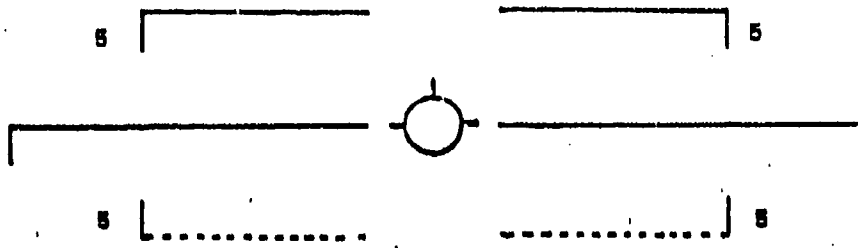


Figure 12. Current F/A-18 HUD Pitch Ladder Used in NADC Studies [Ref. 8:p. 8]

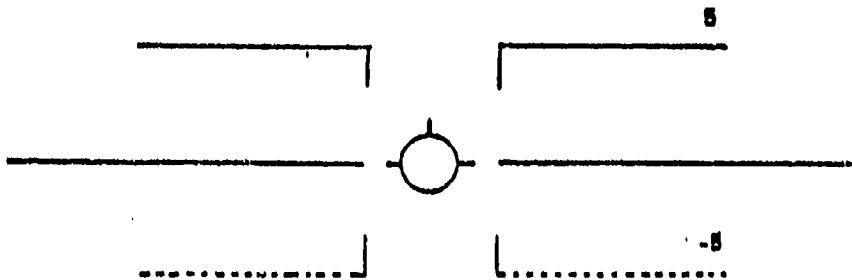


Figure 13. Revised F/A-18 HUD Pitch Ladder Used in NADC Studies [Ref. 8:p. 8]

translation to cross reference between the two displays. [Ref. 8:p. 23]

The results of both experiments suggest that the inclusion of an ADI located within the central field of view would aid in unusual attitude recovery and improve pilot spatial orientation.

NADC has performed research to determine whether the addition of an electronically-generated ADI, displayed directly below the HUD, would aid pilots in recovery from unusual attitudes. The study compared three display formats for their ability to aid pilots in recovery from unusual attitudes. The first format was the graphic representation of an ADI (Figure 11). The second format was that used on the F/A-18 HUD (Figure 12) [Ref. 8:p. 6]. The third format was the concurrent use of the HUD and the ADI. The electronically generated ADI again resulted in significantly faster recovery times, when compared with the current F/A-18 HUD format.

The reasons for this result might include:

1. The superiority of color coding on the ADI for denoting sky and ground, versus solid and dashed pitch bars on the HUD.
2. A slower, yet more controllable rate of movement of the pitch scale on the ADI, compared to the rapid movement of the HUD pitch ladder.

Other advantages of the ADI format include an easily distinguishable horizon line and ease in obtaining a snapshot assessment of the aircraft's attitude [Ref. 2:p. 26]. The concurrent use of the HUD and the ADI proved to be complementary during unusual attitude recovery. During recovery from extreme pitch attitudes, the strengths of each format compensated for the weaknesses in the other. The results of this study indicate that the addition of a centrally-located ADI display in the F/A-18 would improve

pilot performance during unusual attitude recovery. The ADI would allow pilots to conveniently crosscheck for attitude information displayed on the HUD.

Kennedy has proposed an enhanced ADI display, as shown in Figure 14. This would display ADI symbology on one of the F/A-18's two Digital Display Indicator (DDI) multipurpose displays. The enhanced ADI combines available ADI and HUD data in a location close to the pilot's primary instrument scan. The display provides a realistic, pseudo three-dimensional format similar to the 3-axis gyro used in flight training. [Ref. 4:p. 13]

The enhanced ADI combines information from two head-down displays into a single format. It provides nose attitude, bank angle, heading, turn and slip needle, altitude, airspeed, angle of attack, load factor (g), maximum g over 4.0, and horizon-pointing arrows based on a Swedish design. The improved ADI is expected to be useful during normal operations as well as for night and instrument flying.

#### D. OBJECTIVES OF STUDY

The purpose of this study is to determine the HUD design variables and overall display format that best assist F/A-18 pilots in maintaining or rapidly regaining spatial orientation.

Experimental studies have suggested various design variables and formats that assist decision-making



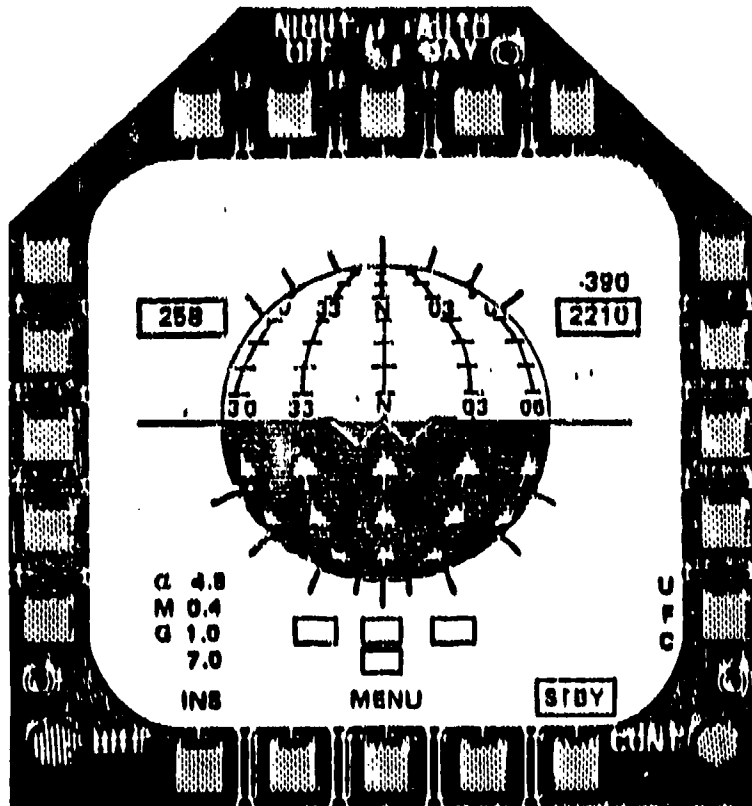


Figure 14. Enhanced Attitude Directional Indicator  
[Ref. 4]

performance. A survey of F/A-18 pilots has been conducted to assess their opinions on these design variables and formats in a static environment, based on their experience. It is hypothesized that key design variables and formats can be identified as a result of the survey. These can be recommended for simulation testing and as performance-based evidence for HUD standardization.

#### E. SCOPE

This study is limited to those specific design variables and formats that previously have been

hypothesized to have significant effects on decision-making performance when a pilot must recover from an unusual aircraft attitude. Opinions have been collected on specific variables that aid in situational awareness, as supported by experimental study. Due to unavailability of facilities, experimental testing of the favored formats in a dynamic flight simulation by F/A-18 pilots has not been carried out for this study.

## II. CONDUCT OF STUDY

### A. STUDY METHODOLOGY

Two surveys were conducted for this study. The purpose of Survey 1 (Appendix A) was to isolate specific symbols that are present or could be present on the HUD format that may assist pilots in recovery from unusual attitudes. Survey 2 then was conducted to obtain pilot views on display formats incorporating the preferred symbols.

#### 1. Survey 1

Survey 1 included questions on the pitch ladder tail formats and their location on the pitch ladder. The location is important since the pilot has time only for a quick look at the HUD symbols to determine his position while in an unusual attitude.

The pitch ladder bars and how they might be angled were examined. The pitch ladder bars provide visual cues for determining the aircraft's angle of attack with respect to the horizon.

A number is shown on each pitch bar to indicate the degrees above or below the horizon represented by that bar. The location and readability of the numbers are important due to the need to interpret them with only a quick look. Possible locations of the numbers were examined.

The usefulness of a negative sign adjacent to the below-horizon number also was examined. This additional visual cue may assist in determining attitude.

Various types of velocity vector symbols and the presence of an Augie Arrow were included in the survey. Pilots were asked how helpful each of these would be during recovery from unusual attitudes. The usefulness of words that might be present on the HUD when the aircraft is in extreme attitudes (CLIMB or DIVE) was the final area examined.

## 2. Survey 2

The purpose of Survey 2 (Appendix B) was to incorporate the preferred symbols from the results of Survey 1 into overall HUD display formats. Questions regarding the format of the ADI also were included.

The direction the Augie Arrow should point (toward the ground, horizon, or sky) was examined, because proper interpretation of the arrow during a quick look is necessary. The possible use of a contrasting color for the below-horizon pitch ladder symbols was examined. Color is a good visual cue, especially if the display is moving rapidly and the dashed lines become blurred.

Pilot opinions were collected concerning presentation of word cues on the HUD while the aircraft is at an extreme angle. Word cues can be presented as commands

(CLIMB or DIVE) or as information (NOSE UP or NOSE DOWN). A comparison of these types of descriptive wording was made.

Pilots were asked their preference for retaining or deleting the velocity vector while at extreme angles of attack. This factor was examined because of the importance of including only those symbols on the HUD that the pilots think are necessary, and decluttering the format by removing the rest.

Displaying the below-horizon pitch ladder as a "sawtooth" line has been proposed. Pilot opinions were solicited on this type of symbology and its usefulness as a visual cue in recovery from extreme attitudes.

Five possible ADI formats also were examined. Research and informal discussion with pilots and scientists indicate that the ADI provides good visual cues for recovery from unusual attitudes and for routine flight if the HUD does not function properly. Pilots were asked to indicate which of the five formats they would prefer to have, in conjunction with a standard F/A-18 HUD format.

#### **B. PILOTS SURVEYED**

The pilots surveyed were all F/A-18 operational pilots from VFA-125 and VFA-113 squadrons at Lemoore Naval Air Station, California. Sixty pilots responded to the first questionnaire. The average total flight hours for participants was 1000-2000 hours. The average tactical jet hours was 1000 hours. The average F/A-18 hours was less

than 500 hours. Four of the respondents had combat experience.

Fifty-six pilots responded to the second questionnaire. They averaged 1000-2000 total flight hours. The average tactical jet hours was 1000 hours. The average F/A-18 hours was less than 500 hours. Four of the respondents had combat experience.

### C. SYMBOLOGIES AND FORMATS EVALUATED

The symbologies and formats that were evaluated during this study are those that assist in maintaining situational awareness. That is, these symbols help the pilot recognize the status of his own aircraft and its relationship to the outside world. These are illustrated in Figure 3-8 and in Appendices A and B.

### D. SURVEY ADMINISTRATION

#### 1. Survey 1

The first survey was administered at Lemoore Naval Air Station on two separate occasions but under similar conditions. The first administration was to 15 pilots in the VFA-113 squadron. The second was to VFA-125, with 45 pilots responding. Appendix A provides the survey forms used.

Each format was illustrated on the survey form and also was presented visually via transparencies projected

from an overhead projection machine. Participants were not allowed to discuss the specific formats or the questions.

The first survey contained three questions regarding the pitch ladder tail formats, position of degree numerals, and velocity vector symbol cues. Pilots were required to rate the symbols, that is, to assign each of the illustrated instances to a ranked category, using categorical judgement. The descriptors that were associated with each category were related to the quality of information that each symbol possesses. These descriptions assisted the pilot with his task of rating those symbols.

The other questions on the first survey asked the pilots to choose their favored format, when given two options. The specific formats illustrated two kinds of pitch ladder bar angles, presence or absence of a negative sign associated with below-horizon pitch bars, and use of words as visual cues.

## 2. Survey 2

The second survey was mailed to VFA-113 and VFA-125 for administration by LCDR Dave Kennedy, Safety Officer, and LCDR Bob Woods, Training Officer, respectively. These officers were instructed to administer the survey in a fashion similar to that done with the first. The formats presented in the second survey were not presented visually from an overhead, but were illustrated in the survey forms (see Appendix B).

The questions in the second survey asked the pilots to choose between two or three possible HUD formats. The survey included questions on (1) where an Augie Arrow should point (toward the ground, horizon, or sky) if it were present on the HUD format, (2) whether the below-horizon pitch ladder should be color coded, (3) what types of descriptive wording should be used when the aircraft is in an extreme angle of attack, (4) whether the velocity vector should be present at extreme angles of attack, and (5) whether further research should be done on an experimental below-horizon pitch ladder.

The last question asked the pilots to choose between five ADI and HUD formats in combination. The ADI formats that were illustrated included the format that is currently used on the F/A-18 aircraft along with four other programmable options.



### III. DATA ANALYSIS

#### A. CATEGORICAL RATING ANALYSIS TECHNIQUE

The data analysis method used to analyze survey results for questions 1, 3, and 5 in the first survey is a scaling method which uses categorical ratings provided by judges. The technique constructs an interval scale based on these categorical ratings. The interval scale includes not only the instances but also the bounds between the categories. In this case, instances are the specific HUD symbols that pilots were asked to rate; these make up the rows of the frequency array. The rating categories define the possible levels of information quality that the various symbols provide for the pilot. [Ref. 13]

Five rating categories were used for this study: (1) Terrible Quality, (2) Poor Quality, (3) Fair Quality, (4) Good Quality, and (5) Excellent Quality. No assumptions are made about the relative interval sizes for the categories. The categories are understood to be a mutually exclusive set of successive intervals which collectively exhaust all possible responses.

The ten-step procedure constructs an interval scale that includes the instances and bounds between categories [Ref. 14:p.14]. The ten-step method requires several assumptions. The first assumption is that the pilot's

judgements about the scale value of an instance  $i$  can be expressed as a normally distributed random variable with mean  $\mu_i$  and variance  $\sigma_i^2$ .

The second assumption is that pilots view the continuum of values for instances as categories that are broken into successive intervals, each having an upper bound or boundary except the Excellent Quality category. The pilot's judgement about the category's upper bound is also expressed as a normally distributed random variable. Category  $j$  has a normally distributed upper bound with mean  $b_j^1$  and variance  $V_j^2$ .

The third assumption is that the pilot's judgements about the scale values of instances are stochastically independent random variables that have a correlation coefficient of zero for all pairs  $i$  and  $j$ .

The fourth assumption is that all category bounds have the same variance, that is,  $V_j^2 = c$  for all  $j$ . [Ref. 14]

#### B. TEN-STEP PROCEDURE FOR OBTAINING SCALE VALUES

The ten-step procedure described below is taken from Reference 14. It is a method that yields scaled numerical data for the pilots' categorical responses concerning the HUD variable types.

1. Arrange the raw frequency data in a table  $F_{ij}$  where the rows are instances  $i$  and the columns are categories  $j$ . The columns should be arranged in ascending order of category value, so that the last column to the right represents the most favorable category.

2. Compute relative cumulative frequencies for each row, and record these in a new table  $P_{ij}$  where  $P_{ij}$  is the proportion of pilots judging instance  $i$  in or below category  $j$ . The values in the right hand column of  $P_{ij}$  will equal one and that column may be omitted for computational purposes.
3. Compute the  $Z_{ij}$  array by treating the  $P_{ij}$  values as leftward areas under a Normal (0,1) curve and find the  $Z$  values for these areas in a table of values of the normal or Gaussian distribution.
4. Compute the row average  $\bar{Z}_i$  for each row  $i$  in the  $Z_{ij}$  array.
5. Compute the column average  $b_j$  for each column  $j$  in the  $Z_{ij}$  array. The  $b_j$  column averages are the upper bound values of category  $j$  on the scale.
6. Compute the grand average  $\bar{b}$  of all the values in the  $Z_{ij}$  array. This is done by averaging the column averages  $b_j$ .
7. Compute the sum of squares for the column differences:

$$B = \sum_{j=1}^{m-1} (b_j - \bar{b})^2.$$

8. Compute the sum of squares of the row differences:

$$A_i = \sum_{j=1}^{m-1} (Z_{ij} - \bar{Z}_i)^2.$$

9. Compute  $\sqrt{(B/A_i)}$  for each row to give an estimate of  $\sqrt{(\sigma_i^2 + c)}$ .
10. Compute  $S_i = \bar{b} - \bar{Z}_i \sqrt{(B/A_i)}$  for each row  $i$ . The  $S_i$  values are the scale values of the instances, and are on the same interval scale as the category bounds  $b_j$ . A linear transformation  $y = a + Bx$ ,  $B > 0$  may be performed to move the scale where it is desired. The same transformation must be used to move the instance values and the category bounds.

**C. OBTAINING SCALE VALUES FROM THE CATEGORICAL SURVEY DATA**

An example of the ten-step procedure for the pilot survey will be shown step by step for question 5 on Survey 1.

1. The scaling problem is broken into different problems because the  $Z_{ij}$  array must be complete, as described in reference 13.

1. The raw frequencies are given as illustrated in Table 1. The categories T, P, F, G, and E represent terrible, poor, fair, good, and excellent quality of information for each variable.

**TABLE 1. FREQUENCY DATA FOR PROBLEM 5,  $F_{ij}$ .**

(See Appendix A for illustrations of the symbols identified here as A, B, C, D, E, and F.)

Symbol	T	P	F	G	E
A	4	14	7	22	11
B	25	31	2	0	0
C	11	27	7	9	4
D	17	29	7	6	0
E	8	20	15	14	1
F	3	7	14	24	10

2. The relative cumulative frequencies are computed for each row, as illustrated in Table 2. The last column will always be a vector of ones and may be omitted.

**TABLE 2. RELATIVE CUMULATIVE FREQUENCY DATA,  $P_{ij}$ .**

Symbol	T	P	F	G
A	0.07	0.31	0.43	0.81
B	0.43	0.96	1.00	
C	0.19	0.66	0.78	0.94
D	0.29	0.79	0.88	
E	0.14	0.48	1.00	
F	0.05	0.17	0.41	0.83

3. The relative frequencies are then treated as leftward areas under a Normal (0,1) curve. The z values for the areas are recorded in Table 3. The values given in Table 2 are divided into two scaling problems because none of the pilots gave good or excellent ratings for three of the variables.

TABLE 3. Z VALUES FOR THE NORMAL DISTRIBUTION

Symbol	T	P	F	G
A	-1.48	-0.50	-0.17	0.88
C	-0.88	0.40	0.76	1.48
F	-1.63	-0.94	-0.22	0.94
B	-0.18	1.76	3.90	
D	-0.56	0.81	1.18	
E	-1.08	-0.05	3.90	

4. The row averages,  $\bar{z}_i$ , are computed, as shown in Table 4. The column averages,  $b_j$ , are also computed in Table 4.

TABLE 4. ROW AND COLUMN AVERAGES

$z_{ij}$	T	P	F	G	$z_i$
A	-1.48	-0.50	-0.17	0.88	-0.32
C	-0.88	0.40	0.76	1.48	0.44
F	-1.63	-0.94	-0.22	0.94	-0.46
$b_j$	-1.33	-0.35	0.12	1.10	
B	-0.18	1.76	3.90		1.83
D	-0.56	0.81	1.18		0.48
E	-1.08	-0.05	3.90		0.92
$b_j$	-0.60	2.52	2.99		

5. The grand average,  $\bar{b}$ , is computed. For this example, that calculation is:

$$b_{ACR} = (-1.33 + -0.346 + 0.123 + 1.1)/4 = -0.113$$

$$b_{BDR} = (-0.60 + 2.52 + 2.99)/3 = 1.64.$$

6. The sum of squares of the column averages, B, is calculated:

$$B = \sum_{j=1}^{m=1} (\bar{b}_j - b)^2$$

$$B_{ACR} = (-1.33 - -0.113)^2 + (-0.349 - -0.113)^2 + (0.123 - -0.113)^2 = 3.059$$

$$B_{BDR} = (-0.60 - 1.64)^2 + (2.52 - 1.64)^2 + (2.99 - 1.64)^2 = 7.61.$$

7. The sum of squares of the row averages is calculated for each row of the  $Z_{ij}$  array.

$$A_i = \sum_{j=1}^{m=1} (Z_{ij} - \bar{Z}_i)^2$$

$$A_A = (-1.48 - -0.318)^2 + (-0.50 - -0.318)^2 + (-0.17 - -0.318)^2 + (0.88 - -0.318)^2 = 2.84$$

$$A_C = (-0.88 - 0.44)^2 + (0.40 - 0.44)^2 + (0.76 - 0.44)^2 + (1.48 - 0.44)^2 = 2.926$$

$$A_R = (-1.63 - -0.463)^2 + (-0.346 - -0.463)^2 + (0.123 - -0.463)^2 + (1.1 - -0.463)^2 = 4.15$$

$$A_B = (-0.18 - 1.83)^2 + (1.76 - 1.83)^2 + (3.9 - 1.83)^2 = 8.32$$

$$A_D = (-0.56 - 0.48)^2 + (0.81 - 0.48)^2 + (1.18 - 0.48)^2 = 1.68$$

$$A_K = (-1.08 - 0.92)^2 + (-0.05 - 0.92)^2 + (3.9 - 0.92)^2 = 13.82.$$

8. The value of  $\sqrt{(B/A_i)}$  is calculated for each row:

$$A_A = (3.059/2.84)^{.5} = 1.04$$

$$A_C = (3.059/2.926)^{.5} = 1.02$$

$$A_R = (3.059/4.157)^{.5} = 0.86$$

$$A_B = (7.61/8.32)^{.5} = 0.96$$

$$A_D = (7.61/1.68)^{.5} = 2.13$$

$$A_K = (7.61/13.82)^{.5} = 0.74.$$

9. The scale values of the variable types are given for each row by the formula:

$$S_i = b - Z_i \sqrt{(B/A_i)}$$

The values for the  $S_i$ 's are as follows:

$$S_A = -0.113 - (-0.318)(1.04) = 0.217$$

$$S_P = -0.113 - (0.44)(1.02) = -0.56$$

$$S_T = -0.113 - (-0.463)(0.86) = 0.285$$

$$S_B = 1.64 - (1.83)(0.96) = -0.117$$

$$S_D = 1.64 - (0.48)(2.13) = 1.617$$

$$S_Z = 1.64 - (0.92)(0.74) = 0.952.$$

10. A linear transformation with the equation  $Y = a + \beta x$ , is then done to put the two sets of values for question 5 on the same scale. Transformed results are:

$$S_B = -1.638 + (-0.507)(-0.117) = -1.579$$

$$S_D = -1.638 + (-0.507)(-0.8198) = -2.45$$

$$S_Z = -1.638 + (-0.507)(0.952) = -2.12.$$

The ten-step procedure for scaling categorical data outlined above was applied to questions 1, 3, and 5 in Survey 1. The columns of the raw frequency data array with values of zero had to be grouped with adjacent columns so that the  $Z_{ij}$  array would not be incomplete. The scale values are found in Appendix C and in Figures 15, 16, and 17.

#### D. SURVEY 1 DATA ANALYSIS

The method described above was used to analyze the results from questions 1, 3, and 5 in Survey 1.

The remaining questions (2, 4, 6, and 7) in Survey 1 required the pilots to choose between two format variables. Such an "either/or" choice is representative of a discrete distribution. This distribution is hypothesized to be a Binomial Distribution in this case. If there is no preference for one or the other, it is hypothesized that, for each pilot, there is a 0.5 chance he will choose a given format variable. It follows that

$$\Pr(X = x) = \binom{n}{x} p^x q^{n-x}. \text{ [Ref. 15:p. 100]}$$

Results are included in Appendix C.

#### E. SURVEY 2 DATA ANALYSIS

All the questions in Survey 2 required the pilots to choose one from among two, three, or five format variables. Again, it is hypothesized that the responses have a Binomial Distribution. That is, unless pilots have a preference, there is a 0.5 chance of selection for each when there are two formats, a 0.33 chance for three formats, and a 0.2 chance for each with five formats. It follows that

$$\Pr(X = x) = \binom{n}{x} p^x q^{n-x}. \text{ [Ref. 15:p. 100]}$$

Results are included in Appendix D.



## IV. RESULTS

### A. SURVEY 1 RESULTS

Data from the first survey were analyzed according to the procedure outlined in the previous chapter, and are available in Appendix C. The results for each question are discussed in detail below.

#### 1. Pitch Ladder "Tail" Formats

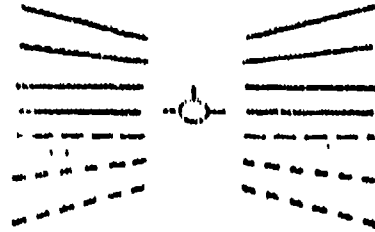
Question 1: Paying attention only to the HUD pitch ladder tail formats, rate each of the following tail positions according to the quality of information and cues they would give you during recovery from unusual attitude.

The first question asked the pilots to scale the five pitch tail formats on a rating scale. The rating categories, as described in the data analysis section, define the possible levels of information quality that the various symbols provide the pilot. The pilots rated each of five symbols.

The highest-rated pitch ladder tail format is that which places both tails (above the horizon and below the horizon) at the outer ends of the pitch ladder, pointing towards each other (see Figure 14). Analysis placed this symbol in the Good category (see Figure 15). A total of 34 of the pilots placed this symbol in the Good or Excellent



1. Pitch ladder with tails at outer ends, pointing toward each other.



2. Bars are level at horizon, with angle increasing with increased distance from horizon.

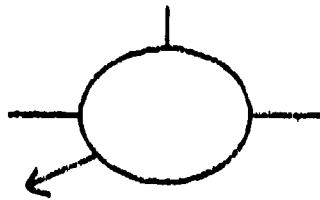


3. Degree numbers placed at both outer ends of both horizon bars.

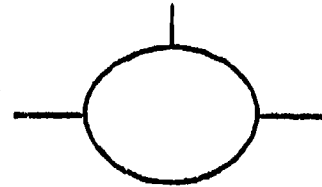


4. No negative sign present on below-horizon pitch bars.

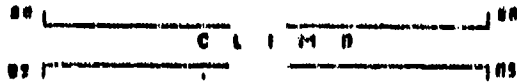
Figure 14. Symbols Favored on the First Survey



5. Velocity Vector with  
Angle Arrow.



5. Velocity Vector  
without Arrow.



6. Word "CLIMB"  
present.



7. Word "DIVE"  
present.

Figure 14. Symbols Favored on the First Survey (Continued)

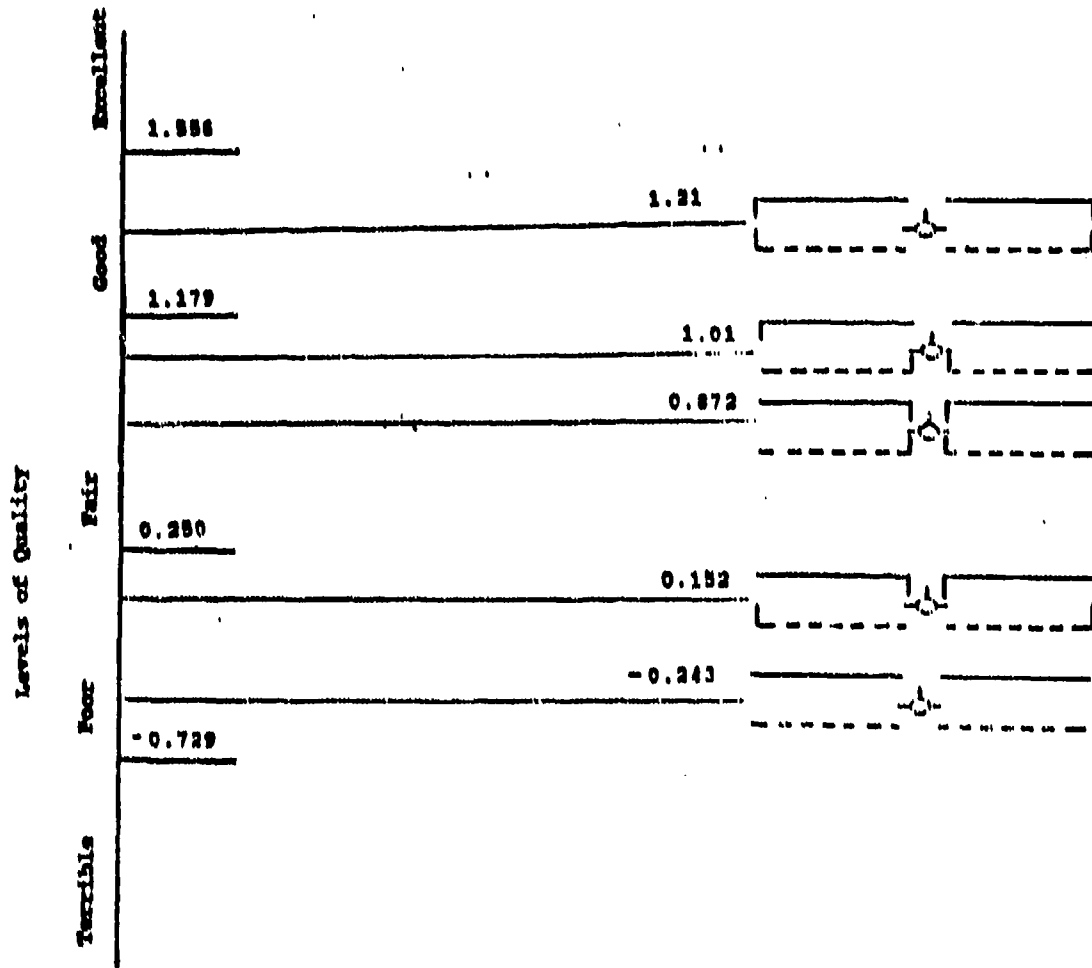


Figure 15. Scaling Results for the First Survey,  
Question 1

category. All other symbols rated only Fair or Poor. Other data values can be found in Appendix C.

Pilot comments included support for minimal clutter on the HUD, such as "Do not want too much clutter in the middle of the HUD".

## **2. Pitch Ladder Bar Angles**

**Question 2:** Paying attention only to the angle of the pitch bars, circle the format that would give you the better quality of information during recovery from unusual attitude.

The second question had the pilots choose their favored format when given two illustrated options. The preferred option (53 of the pilots) showed the pitch ladder bars level at the horizon, with the angle of the bars increasing with increased distance of the aircraft from the horizon (see Figure 14). The probabilities were determined by using the statistical package Minitab. The solution is limited to four significant figures. The probability of at least 53 out of 59 pilots choosing this format, given pilot indifference, is 0.0000.

## **3. Position of Degree Numerals**

**Question 3:** Paying attention only to the position of the numbers on the pitch ladder that represent degrees above and below the horizon, rate each of the following numeral positions according to the quality of information

and cues they would give you during recovery from unusual attitude.

This question asked the pilots to rate 18 different numeral positions on the pitch ladder. The same rating categories were used as in question one.

The highest-rated format included numerals shown at both outer ends of both the above the horizon and below the horizon pitch ladder (see Figure 14). Analysis placed this symbol in the Good category (see Figure 16). A total of 45 of the pilots placed this symbol in the Good or Excellent category. All other symbols rated only Fair or Poor.

Pilot comments on this question support the concept of less clutter in the center of the HUD. These included, "Don't want too much clutter in the middle of HUD" and "My eyes are focused to the outer ends for the "tails" and it is easier to see the numbers when they are located there".

#### 4. Negative Sign

Question 4: Paying attention to the below-horizon numbers on the pitch bars, circle the format which would give you the most information during recovery from unusual attitudes.

Pilots were asked to choose whether a negative sign should be displayed adjacent to the below-horizon number representing degrees. The option without the negative sign was preferred by 35 of the respondents (see Figure 14).

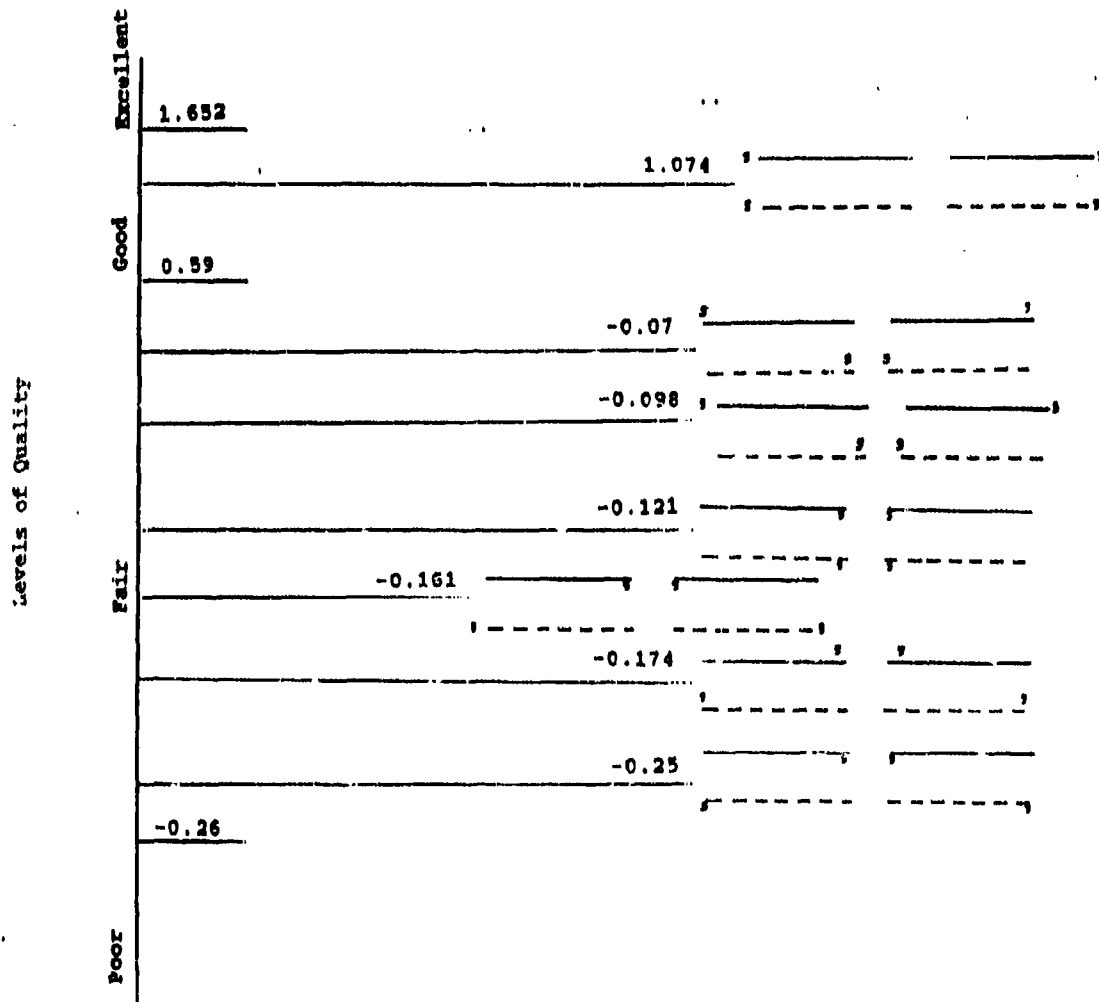


Figure 16. Scaling Results for the First Survey  
Question 3

The probability of at least 35 out of 60 pilots choosing this format, given indifference, is 0.0775.

Pilot comments regarding the negative sign included "Too much clutter" and "The dashed line of the below-horizon bar is enough without the negative sign". One respondent also noted that "The use of a two color display would be helpful".

#### 5. Velocity Vector Symbol Cues

Question 5: At high angles of attack, rate the following symbols according to the quality of information and cues they would give you during recovery from unusual attitudes.

The fifth question asked the pilots to rate five different velocity vector symbols, with and without an Augie Arrow. The same rating categories were used as in questions one and three.

The standard velocity vector or flight path marker, with and without an Augie Arrow, rated the highest of the symbols (see Figure 14). Analysis placed both the velocity vector with the Augie Arrow and the velocity vector without the Augie Arrow in the Good category (see Figure 17). A total of 11 pilots placed the velocity vector with the Augie Arrow in the Excellent category, while 22 rated it in the Good category. Without the Augie Arrow, ten placed the symbol in the Excellent category and 24 in the Good



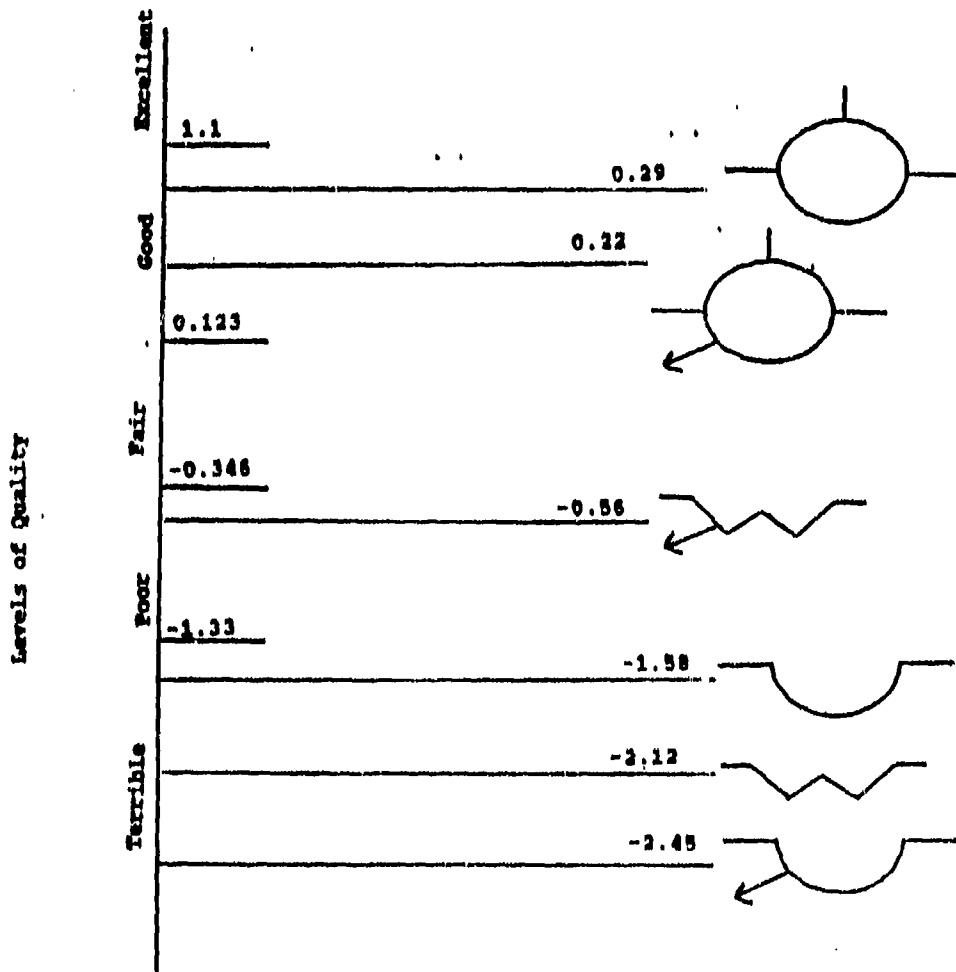


Figure 17. Scaling Results for the First Survey  
Question 5

category. Other analysis results can be found in Appendix C.

Pilot comments indicated concern as to whether an arrow would be informative or directive. Comments included, "Format needs to be directive; both arrows and words should indicate which way to recover", and "In low altitude, an arrow should show where the ground is".

#### 6. CLIMB As a Cue

Question 6: Circle the format which would give you the most information to make an efficient recovery, when your aircraft is at an unusual attitude.

For this question, pilots chose their favored format when given two options: the presence of the word "CLIMB" or no word on the HUD. Pilots choosing the format with the word "CLIMB" present totalled 34 (see Figure 14). The probability of at least 34 pilots out of 60 choosing this format, given indifference, is 0.1225.

Pilot comments indicate that a directive word would be helpful. They also noted that the format should remain unchanged, using the zenith and nadir symbols already present on the current HUD.

#### 7. DIVE As A Cue

Question 7: Circle the format which would give you the most information to make an efficient recovery, when your aircraft is at an unusual attitude.

The seventh question asked the pilots to choose whether the word "DIVE" should be present on the HUD, when appropriate. A total of 37 of the pilots preferred using the word "DIVE" (see Figure 14). The probability of at least 37 pilots out of 60 choosing this format, given indifference, is 0.0295.

## B. SECOND SURVEY RESULTS

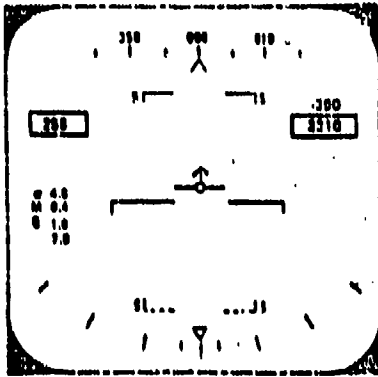
Data from the second survey were analyzed according to the procedure outlined in the previous chapter. Summary results are given in Figure 18. The data for each question are available in Appendix D. The results for each question are discussed in detail below.

### 1. Augie Arrow Direction

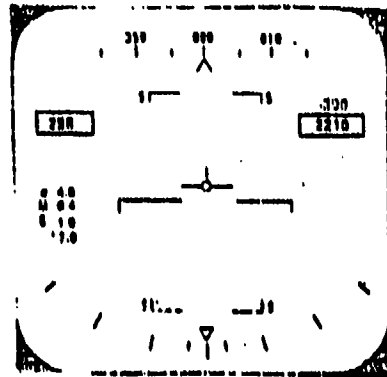
Question 1: If an arrow is present on the HUD format as displayed, what should it point to? Circle one.

The first question had the pilots choose which direction (ground, horizon, or sky) an Augie Arrow should point if it were present on the HUD. Forty-three out of 56 pilots chose the inclusion of an arrow. The "SKY" option was preferred by 23 of the 43 pilots (see Figure 18). The probability of at least 23 pilots out of 43 choosing this format, given indifference, is 0.0017.

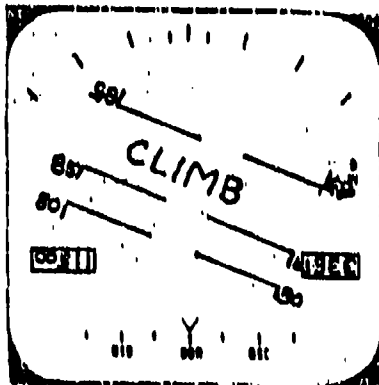
It should be noted that 13 of the pilots indicated that they do not want any arrow and chose none of the formats. Several comments on the surveys support the concept that an arrow may not be a good idea: "May make



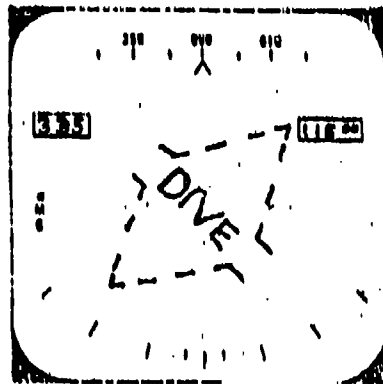
1. Augie Arrow pointed toward the sky.



2. Use of Color

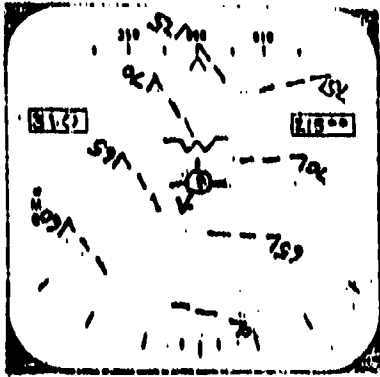


3. Word "CLIMB" used

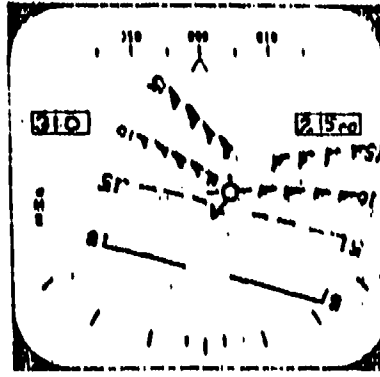


4. Word "DIVE" used

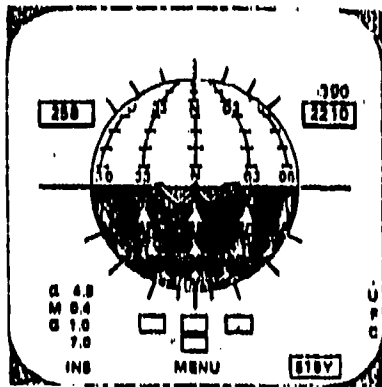
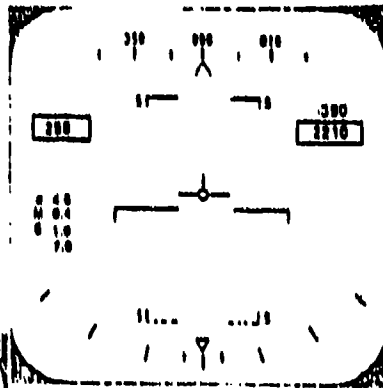
Figure 18. Formats Favored on the Second Survey



5. Velocity Vector with Augie Arrow.



6. "Sawtooth" Pitch Ladder.



7. Enhanced ADI with Standard HUD.

Figure 18. Formats Favored on the Second Survey (Continued)

the velocity vector harder to interpret (especially inverted)" and "The arrow may get confused with TACAN navigation".

Comments supporting the use of an arrow included, "The arrow needs to be directive for recovery", and "In a spin you always place the stick in the direction of the arrow. Following the same line of thinking, in the unusual attitude you would want to know where the sky is so as to pull that direction".

## 2. Color on HUD

Question 2: If the below-horizon pitch ladder were shown in a contrasting color to all other HUD symbology, e.g., red, would that assist in recovery from an unusual attitude?

A total of 39 of the pilots responded affirmatively to this question (see Figure 18). The probability of at least 39 out of 56 pilots choosing this format, given indifference, is 0.0009

The comments regarding the use of color included, "Use color that doesn't ruin night vision". The fact that color "would assist in unusual attitude recovery but may clutter up the HUD with more unnecessary information for a regular situation" also was noted.

### 3. Informational Cues When Nose is Up

Question 3: At extreme angles of attack, if words are used, what words would you prefer to be shown? Circle one.

Pilots were asked to choose between the words "CLIMB" and "NOSE UP" as informative cues describing the position of the aircraft. Thirty-eight out of 56 pilots chose the presence of words on the HUD. The word "CLIMB" was preferred by 26 out of the 38 (see Figure 18). The probability of at least 26 pilots out of 38 choosing this format, given indifference, is 0.0069.

A total of 18 of the pilots do not want any words, and did not choose either word. Several of the comments on the surveys support not adding a word cue on the HUD: "Prefer no words", "Not a good idea even though marked "CLIMB", and "Not sure words would help".

### 4. Informational Cues When Nose is Down

Question 4: At extreme angles of attack, if words are used, what words would you prefer to be shown? Circle one.

The fourth question asked the pilots to choose between the words "DIVE" and "NOSE DOWN" as informative cues describing the position of the aircraft. Thirty-seven out of 56 pilots chose the presence of words on the HUD. The word "DIVE" was preferred by 23 out of the 37 pilots

(see Figure 18). The probability of at least 23 pilots out of 37 choosing this format, given indifference, is 0.0494.

It should be noted that 19 of the pilots do not want any words and did not choose either word. Comments included, "Not a good idea, words take too much attention demand", "Prefer no words", and "Unnecessary clutter with words".

### **5. Velocity Vector as a Cue**

Question 5: At extreme angles of attack, greater than +60 degrees or less than -60 degrees, what format do you like best? Circle one.

The options were (1) having the velocity vector present, along with an Augie Arrow and the waterline symbol, or, (2) deleting the velocity vector and displaying only the Augie Arrow on the waterline symbol. A total of 45 of the respondents preferred retaining the velocity vector (see Figure 18). The probability of at least 45 pilots out of 56 choosing this format, given indifference, is 0.0000.

Pilot comments expressed concern with HUD clutter if many symbols are present. However, as one comment indicated, "The velocity vector with an arrow is a strong visual cue".

### **6. Experimental Pitch Ladder**

Question 6: It has been proposed that the below-horizon pitch ladder be displayed as a "sawtooth" line.



Should this display format be further tested to determine if it would assist in recovery from unusual attitudes? Circle one.

Approval for further experimental study was given by 32 of the respondents (see Figure 18). The probability of at least 32 pilots out of 56 choosing this format, given indifference, is 0.1144.

#### 7. ADI Formats

Question 7: Several ADI formats have been proposed for use on the F/A-18 DDI, with a standard HUD format present. Of the following HUD/ADI format combinations, circle the one you most prefer.

Pilots were asked to choose the one they prefer from five different HUD/ADI combinations. The ADI format illustrated in Figure 18 was strongly preferred (47 of the pilots). The probability of at least 47 pilots out of 56 choosing this format, given indifference, is 0.0000.

## V. CONCLUSIONS AND RECOMMENDATIONS

### A. CONCLUSIONS

The results of surveys carried out for this study show pilot support for the symbols currently used on the F/A-18 HUD. In order to provide additional visual cues while the aircraft is in an unusual attitude, pilots show moderate support for the use of the words CLIMB or DIVE (57%-62%), an Augie Arrow (57%), and color to designate below-horizon angles (70%).

Previous research on the use of words has investigated the use of "informative" words (such as NOSE UP or NOSE DOWN) to cue the pilot that he is in an extreme situation. A large proportion prefer that no words be used (33%-34%). If such cues are provided, more pilots prefer the use of "directive" words such as CLIMB or DIVE (41%-46%) to the previously proposed NOSE UP/NOSE DOWN terms (21%-25%).

The survey showed limited support for addition of an Augie Arrow symbol (57%). Preferred direction for the arrow to point is towards the sky (41%). Pilot comments indicate that an arrow would be most helpful in a directive role. The arrow should be allowed to be part of the declutter option, however, so that the large proportion of pilots who will not use it can remove the symbol from the HUD.

The survey showed strong support for the use of color on the HUD (70%). Concern over possible interference with night vision was expressed, however. Further research on use of specific unusual attitude recovery symbols on the HUD is supported by a majority of pilots (57%). The "sawtooth" below-horizon pitch ladder is expected to provide stronger visual cues to indicate that the aircraft is in an unusual attitude.

The strongest support for a crew station change is for a new format for the ADI when displayed on a DDI. A total of 84% of respondents prefer an ADI (used in combination with standard F/A-18 HUD formats) that gives a strong visual indication of above- and below-horizon angles. The ability to observe such an ADI format during normal instrument scan is deemed very important.

The use of a survey of military pilots has been informative for isolating areas for further research. It is apparent that the pilots surveyed are satisfied with the current F/A-18 HUD formats and symbols. It has been observed that the loss of aircraft due to loss of situational awareness may be due to training problems. Training command aircraft do not use the same HUD formats as do tactical aircraft. Thus pilots may not receive enough experience in HUD use prior to assignment to an F/A-18 squadron.

## B. RECOMMENDATIONS

It is recommended that the symbols and formats currently used on the F/A-18 HUD be retained. In addition, an Augie Arrow should be an option for the pilots to use if there is a possibility of being in an unusual attitude. Since color is a good visual cue (especially when the HUD symbols are moving rapidly), a color cue should be considered as a below-horizon indicator on the HUD and the ADI.

The pilots showed the strongest support for a change in the ADI format. The pilots comments and responses indicate that the HUD is satisfactory but the ADI display is a more useful visual cue in unusual attitudes. The enhanced ADI, as proposed, should be incorporated in the crew station as soon as possible.

Further experimental research should be carried out in the following areas:

1. The use of directive versus informative words when the pilot is in extreme situations.
2. The use of a sky pointer Augie Arrow.
3. The use of color on the HUD and ADI.
4. New formats for the ADI when displayed on the DDI.
5. Visually distinct pitch ladders.

All new formats should be tested dynamically in a ground-based simulator similar to the Crew Evaluation Facility at NADC. The dependent variables should include

pilot reaction time and time to recover from an unusual attitude for each of the independent variables.

## APPENDIX A. FIRST SURVEY FORM

### INTRODUCTION

**Background:** Several F/A-18s have been lost in mishaps where loss of situational awareness, spatial disorientation, or unexplained flight into the surface are listed as confirmed or probable cause factors. Evidence points to inadequate or ambiguous attitude displays available to the pilot. A potential problem may be an inability of the pilot to recognize when he is in an unusual attitude and then recover using the HUD.

**Objective of this study:** The purpose of this questionnaire is to determine what types of variables present on the HUD can best assist the pilot 1) to determine his current position during an unusual attitude and 2) to make an efficient recovery.

Please respond to the questions taking into account your experience while flying aircraft and using HUDs. I am interested in your recommendations for the HUD variables that would best assist you in unusual attitude situations.

F/A 18 Aircrew Survey on HUD Variables  
During Unusual Attitudes

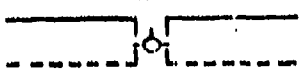
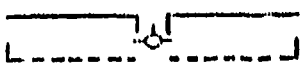
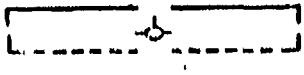
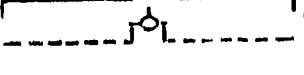
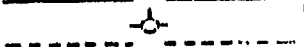
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Tac Jet Hours	<input type="checkbox"/> < 500	<input type="checkbox"/> 500 - 1000
	<input type="checkbox"/> 1000 - 2000	<input type="checkbox"/> > 2000
F/A 18 Hours	<input type="checkbox"/> < 500	<input type="checkbox"/> 500 - 1000
	<input type="checkbox"/> 1000 - 2000	<input type="checkbox"/> > 2000
Combat Experience	<input type="checkbox"/> YES	<input type="checkbox"/> NO
Service	<input type="checkbox"/> USN	<input type="checkbox"/> USMC

## HUD FORMAT CUES DURING UNUSUAL ATTITUDE

### PITCH LADDER "TAIL" FORMATS

1. Paying attention only to the HUD pitch ladder "tail" formats, rate each of the following tail positions according to the quality of information and cues they would give you during recovery from unusual attitude.

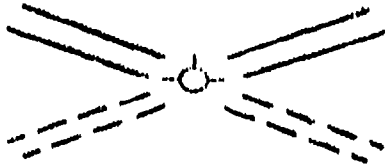
#### Quality of Information During Recovery From Unusual Attitude

	Terrible Quality	Poor Quality	Fair Quality	Good Quality	Excellent Quality
<p>A.</p> 	( )	( )	( )	( )	( )
<p>B.</p> 	( )	( )	( )	( )	( )
<p>C.</p> 	( )	( )	( )	( )	( )
<p>D.</p> 	( )	( )	( )	( )	( )
<p>E.</p> 	( )	( )	( )	( )	( )

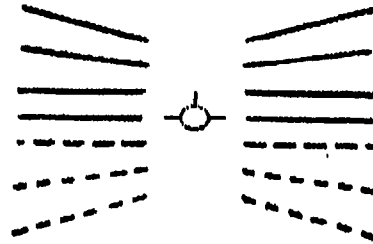


## PITCH LADDER BAR ANGLES

2. Paying attention only to the angle of the pitch bars, circle the format that would give you the better quality of information during recovery from unusual attitude.



Constant Angle  
Continuous Sloping



Bars are Level at Horizon,  
with Angle Increasing with  
Increased Distance from  
Horizon

## POSITION OF DEGREE NUMERALS

3. Paying attention only to the position of the numbers on the pitch ladder that represent degrees above and below the horizon, rate each of the following numeral positions according to the quality of information and cues they would give you during recovery from unusual attitude.

### Quality of Information During Recovery From Unusual Attitude

	Terrible Quality	Poor Quality	Fair Quality	Good Quality	Excellent Quality
A. <div style="display: flex; justify-content: space-between; border-bottom: 1px solid black; margin-bottom: 2px;"> <span style="width: 40%;"></span> <span style="width: 40%;"></span> </div> <div style="display: flex; justify-content: space-between; border-bottom: 1px dashed black; margin-bottom: 2px;"> <span style="width: 40%;"></span> <span style="width: 40%;"></span> </div>	( )	( )	( )	( )	( )
B. <div style="display: flex; justify-content: space-between; border-bottom: 1px solid black; margin-bottom: 2px;"> <span style="width: 40%;"></span> <span style="width: 40%;"></span> </div> <div style="display: flex; justify-content: space-between; border-bottom: 1px dashed black; margin-bottom: 2px;"> <span style="width: 40%;"></span> <span style="width: 40%;"></span> </div>	( )	( )	( )	( )	( )
C. <div style="display: flex; justify-content: space-between; border-bottom: 1px solid black; margin-bottom: 2px;"> <span style="width: 40%;"></span> <span style="width: 40%;"></span> </div> <div style="display: flex; justify-content: space-between; border-bottom: 1px dashed black; margin-bottom: 2px;"> <span style="width: 40%;"></span> <span style="width: 40%;"></span> </div>	( )	( )	( )	( )	( )
D. <div style="display: flex; justify-content: space-between; border-bottom: 1px solid black; margin-bottom: 2px;"> <span style="width: 40%;"></span> <span style="width: 40%;"></span> </div> <div style="display: flex; justify-content: space-between; border-bottom: 1px dashed black; margin-bottom: 2px;"> <span style="width: 40%;"></span> <span style="width: 40%;"></span> </div>	( )	( )	( )	( )	( )
E. <div style="display: flex; justify-content: space-between; border-bottom: 1px solid black; margin-bottom: 2px;"> <span style="width: 40%;"></span> <span style="width: 40%;"></span> </div> <div style="display: flex; justify-content: space-between; border-bottom: 1px dashed black; margin-bottom: 2px;"> <span style="width: 40%;"></span> <span style="width: 40%;"></span> </div>	( )	( )	( )	( )	( )

**Quality of Information During Recovery From Unusual Attitude**

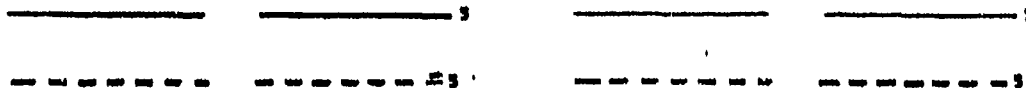
		<b>Terrible Quality</b>	<b>Poor Quality</b>	<b>Fair Quality</b>	<b>Good Quality</b>	<b>Excellent Quality</b>
<b>F.</b>	_____	( )	( )	( )	( )	( )
	_____					
<b>G.</b>	_____	( )	( )	( )	( )	( )
	_____					
<b>H.</b>	_____	( )	( )	( )	( )	( )
	_____					
<b>I.</b>	_____	( )	( )	( )	( )	( )
	_____					
<b>J.</b>	_____	( )	( )	( )	( )	( )
	_____					
<b>K.</b>	_____	( )	( )	( )	( )	( )
	_____					
<b>L.</b>	_____	( )	( )	( )	( )	( )
	_____					

Quality of Information During Recovery From Unusual Attitude

		Terrible Quality	Poor Quality	Fair Quality	Good Quality	Excellent Quality
M.	_____	( )	( )	( )	( )	( )
	-----					
N.	_____	( )	( )	( )	( )	( )
	-----					
O.	_____	( )	( )	( )	( )	( )
	-----					
P.	_____	( )	( )	( )	( )	( )
	-----					
Q.	_____	( )	( )	( )	( )	( )
	-----					
R.	_____	( )	( )	( )	( )	( )
	-----					

**NEGATIVE SIGN**

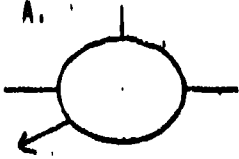




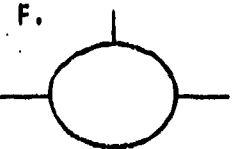
4. Paying attention to the below-horizon numbers on the pitch bars, circle the format which would give you the most information during recovery from unusual attitudes.



## VELOCITY VECTOR SYMBOL CUES

5. At high angles of attack, rate the following symbols according to the quality of information and cues they would give you during recovery from unusual attitudes.

### Quality of Information During Recovery From Unusual Attitude

	Terrible Quality	Poor Quality	Fair Quality	Good Quality	Excellent Quality
A. 	( )	( )	( )	( )	( )
B. 	( )	( )	( )	( )	( )
C. 	( )	( )	( )	( )	( )
D. 	( )	( )	( )	( )	( )
E. 	( )	( )	( )	( )	( )
F. 	( )	( )	( )	( )	( )



## APPENDIX B. SECOND SURVEY FORM

### Introduction and Instructions

**Background:** Several F/A 18s have been lost in mishaps where loss of situational awareness, spatial disorientation, or unexplained flight into the surface are listed as confirmed or probable cause. Evidence points to inadequate or ambiguous attitude displays available to the pilot. A potential problem may be an inability of the pilot to recognize when he is in an unusual attitude and then recover using the HUD.

**Objective of this study:** I am attempting to isolate HUD and other display variables that pilots prefer or recommend for use in recovery from unusual aircraft attitudes. I am most interested in determining what cues can best help the pilot, in order to prevent further mishaps. Results of this questionnaire will be used for further experimental study in a realistic environment.

This is the second of two questionnaires eliciting opinions on the best way to display information related to unusual aircraft attitudes. In the first (which you may have filled out), opinions were obtained on the preferred kinds of symbols for HUD displays. This second questionnaire takes into account the results of that first survey; the most-preferred symbols now have been incorporated into overall HUD display formats. Possible formats for an ADI also are included here.

Please respond to the questions, taking into account your experience while flying aircraft and using the HUD and the ADI. I am interested in your recommendations for the HUD variables, alone and in combination with the ADI, that would best assist you in unusual attitude situations.

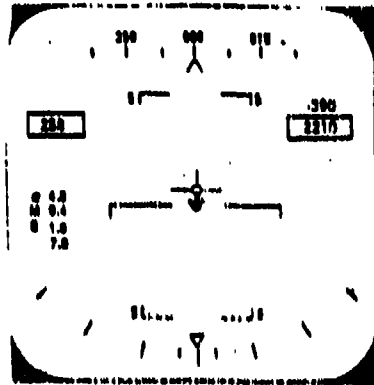


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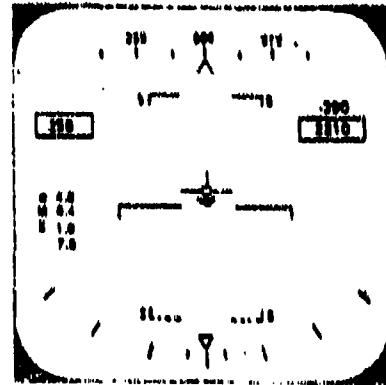
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Tac Jet Hours	<input type="checkbox"/> < 500	<input type="checkbox"/> 500 - 1000
	<input type="checkbox"/> 1000 - 2000	<input type="checkbox"/> > 2000
F/A 18 Hours	<input type="checkbox"/> < 500	<input type="checkbox"/> 500 - 1000
	<input type="checkbox"/> 1000 - 2000	<input type="checkbox"/> > 2000
Combat Experience	<input type="checkbox"/> YES	<input type="checkbox"/> NO
Service	<input type="checkbox"/> USN	<input type="checkbox"/> USMC

# AUGIE ARROW DIRECTION

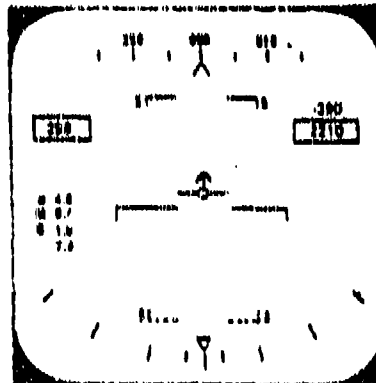
1. If an arrow is present on the HUD format as displayed, what should it point to? Circle one.



GROUND



HORIZON

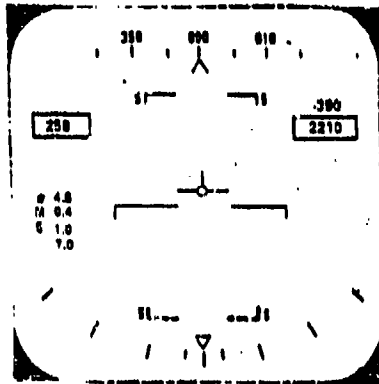


SKY

Comments:

COLOR ON HUD

2. If the below-horizon pitch ladder were shown in a contrasting color to all other HUD symbology e.g. red, would that assist in recovery from an unusual attitude? Circle one.



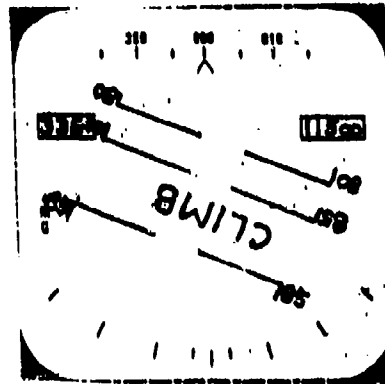
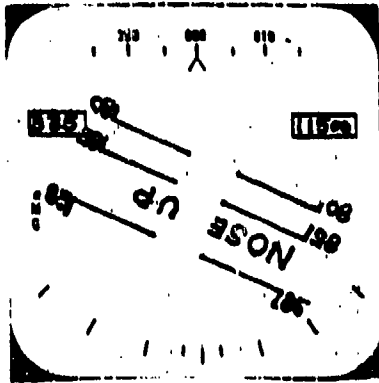
YES

NO

Comments:

WORDING OF INFORMATIONAL CUES

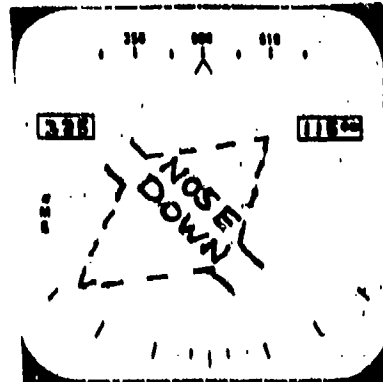
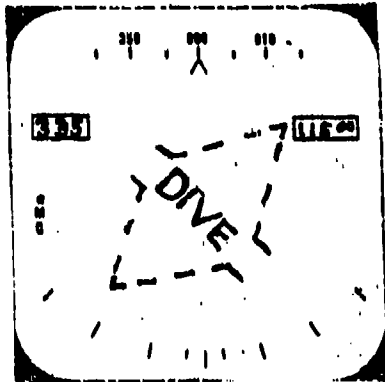
3. At extreme angles of attack, if words are used, what words would you prefer to be shown? Circle one.



Comments:

WORDING OF INFORMATIONAL CUES

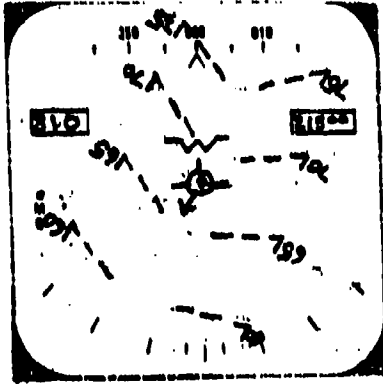
4. At extreme angles of attack, if words are used, what words would you prefer to be shown? Circle one.



Comments:

VELOCITY VECTOR AS A CUE

5. At extreme angles of attack, greater than +60 degrees or less than -60 degrees, what format do you like best? Circle one.



velocity vector present

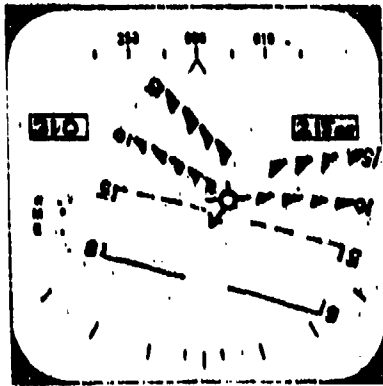


delete velocity vector

Comments:

**EXPERIMENTAL PITCH LADDER**

6. It has been proposed that the below-horizon pitch ladder be displayed as a "sawtooth" line. Should this display format be further tested to determine if it would assist in recovery from unusual attitudes? Circle one.



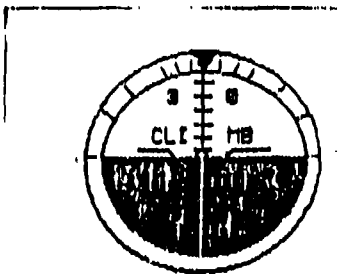
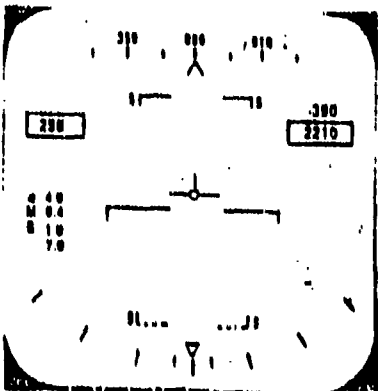
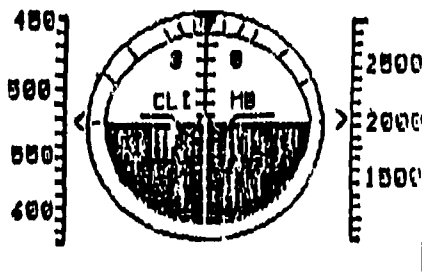
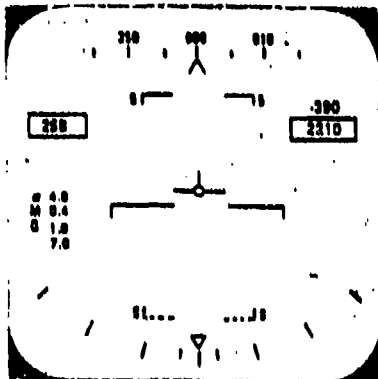
YES

NO

Comments:

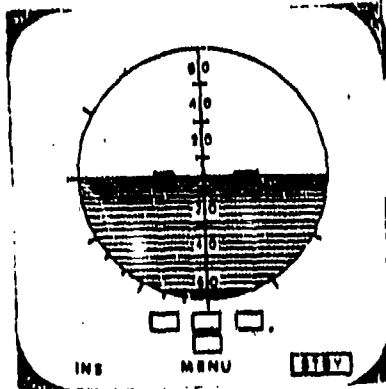
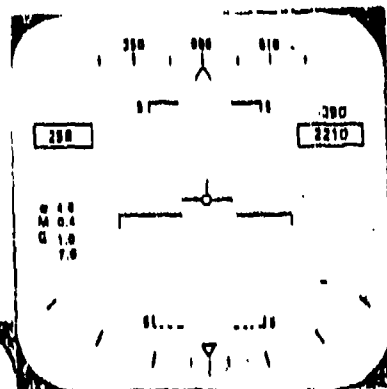
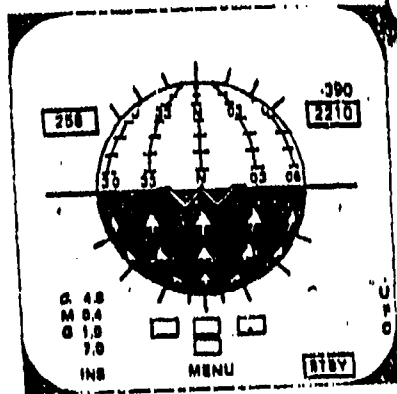
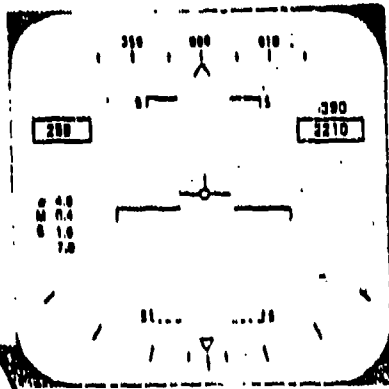
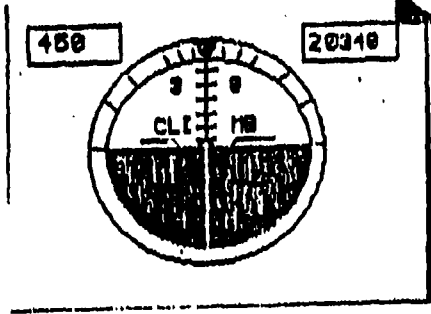
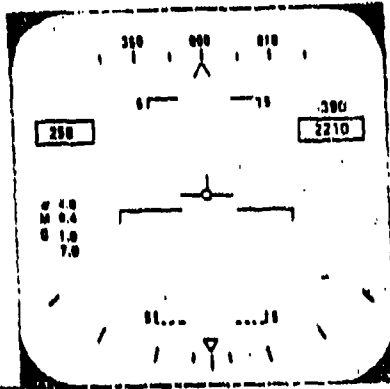
ADI FORMATS

7. Several ADI formats have been proposed for use on the DDI, with a standard HUD format present. Of the following HUD/ADI format combinations, circle the one you most prefer. Continues on following page.





7.



Comments:




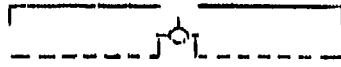
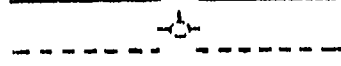
## APPENDIX C. FIRST SURVEY RESULTS

### HUD FORMAT CUES DURING UNUSUAL ATTITUDE

#### PITCH LADDER "TAIL" FORMATS

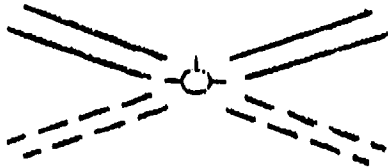
1. Paying attention only to the HUD pitch ladder "tail" formats, rate each of the following tail positions according to the quality of information and cues they would give you during recovery from unusual attitude.

Quality of Information During Recovery From Unusual Attitude

	Terrible Quality	Poor Quality	Fair Quality	Good Quality	Excellent Quality
	Number 8	25	13	9	4
	14%	42%	22%	15%	7%
	Scale Value 0.872				
	Number 6	24	20	6	0
	14%	41%	35%	10%	0%
	Scale Value 0.152				
	Number 4	12	9	25	9
	7%	20%	15%	43%	15%
	Scale Value 1.21				
	Number 4	21	16	14	3
	7%	36%	28%	24%	5%
	Scale Value 1.01				
	Number 21	17	13	7	1
	36%	29%	22%	12%	1%
	Scale -0.243 Value				

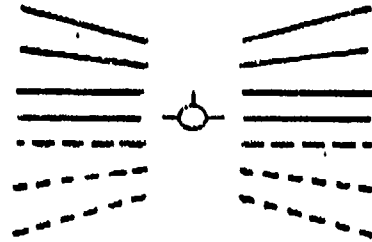
## PITCH LADDER BAR ANGLES

2. Paying attention only to the angle of the pitch bars, circle the format that would give you the better quality of information during recovery from unusual attitude.



Constant Angle  
Continuous Sloping

Number 6  
11%



Bars are Level at Horizon,  
with Angle Increasing with  
Increased Distance from  
Horizon

53  
89%

## POSITION OF DEGREE NUMERALS

3. Paying attention only to the position of the numbers on the pitch ladder that represent degrees above and below the horizon, rate each of the following numeral positions according to the quality of information and cues they would give you during recovery from unusual attitude.

**Quality of Information During Recovery From Unusual Attitude**

	Terrible Quality	Poor Quality	Fair Quality	Good Quality	Excellent Quality
_____	Number 10	18	19	15	2
-----		17%	30%	25%	3%
	Scale Value	-.098			
_____	Number 8	27	24	4	0
-----		8%	45%	40%	0%
	Scale Value	-0.36			
_____	Number 6	28	24	2	0
-----		10%	47%	40%	0%
	Scale Value	-0.46			
_____	Number 0	4	11	31	14
-----		0%	7%	18%	52%
	Scale Value	1.074			
_____	Number 9	33	16	2	0
-----		15%	55%	27%	0%
	Scale Value	-0.60			

Quality of Information During Recovery From Unusual Attitude

		Terrible Quality	Poor Quality	Fair Quality	Good Quality	Excellent Quality
_____	_____	Number 6	32	19	3	0
-----	-----	10%	53%	32%	5%	0%
		Scale Value -0.46				
_____	_____	Number 7	34	18	1	0
-----	-----	12%	57%	30%	2%	0%
		Scale Value -0.58				
_____	_____	Number 14	31	13	2	0
-----	-----	23%	52%	22%	3%	0%
		Scale Value -0.753				
_____	_____	Number 14	32	11	2	1
-----	-----	23%	53%	18%	3%	2%
		Scale Value -0.749				
_____	_____	Number 11	15	24	8	2
-----	-----	18%	25%	40%	13%	3%
		Scale Value -0.174				
_____	_____	Number 5	36	18	1	0
-----	-----	6%	60%	30%	2%	0%
		Scale Value -0.535				
_____	_____	Number 8	21	14	13	4
-----	-----	13%	35%	33%	22%	6%
		Scale Value -0.121				

Quality of Information During Recovery From Unusual Attitude

	Terrible Quality	Poor Quality	Fair Quality	Good Quality	Excellent Quality
Number 7	7	18	26	7	2
	12%	30%	43%	12%	3%
Scale Value -0.161					
Number 13	13	35	10	2	0
	22%	60%	17%	3%	0%
Scale Value -0.767					
Number 9	9	25	11	12	2
	15%	44%	16%	20%	3%
Scale Value -0.403					
Number 13	13	32	12	3	0
	22%	53%	20%	5%	0%
Scale Value -0.712					
Number 6	6	23	20	9	2
	10%	39%	33%	18%	3%
Scale Value -0.25					
Number 7	7	18	21	12	2
	12%	30%	35%	20%	3%
Scale Value -0.07					

**NEGATIVE SIGN**

4. Paying attention to the below-horizon numbers on the pitch bars, circle the format which would give you the most information during recovery from unusual attitudes.



Number 25

35

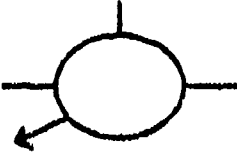




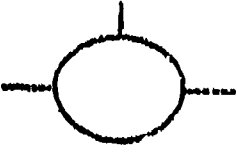
42%

58%

## VELOCITY VECTOR SYMBOL CUES

5. At high angles of attack, rate the following symbols according to the quality of information and cues they would give you during recovery from unusual attitudes.

**Quality of Information During Recovery From Unusual Attitude**

	Terrible Quality	Poor Quality	Fair Quality	Good Quality	Excellent Quality
	Number 4	14	7	22	21
	79	240	120	300	197
	Scale Value 0.22				
	Number 25	31	2	0	0
	434	540	30	00	00
	Scale Value -1.50				
	Number 11	37	7	9	6
	194	470	120	100	70
	Scale Value -0.56				
	Number 17	29	7	6	0
	254	490	120	100	04
	Scale Value -2.45				
	Number 8	20	35	14	1
	144	300	200	240	24
	Scale Value -2.12				
	Number 3	7	16	24	10
	80	120	265	420	170
	Scale Value 0.29				



WORDS AS CUES

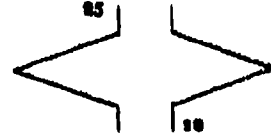
6. Circle the format which would give you the most information to make an efficient recovery, when your aircraft is at an unusual attitude.



Number 26  
43%

34  
57%

7. Circle the format which would give you the most information to make an efficient recovery, when your aircraft is at an unusual attitude.



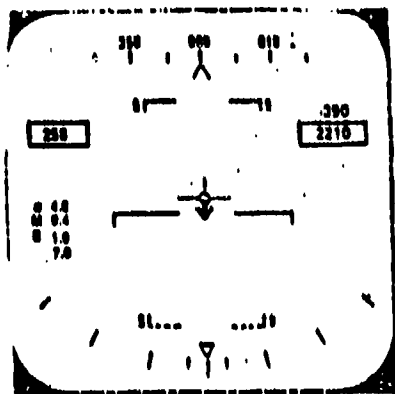
Number 37  
62%

23  
38%

APPENDIX D. SECOND SURVEY RESULTS

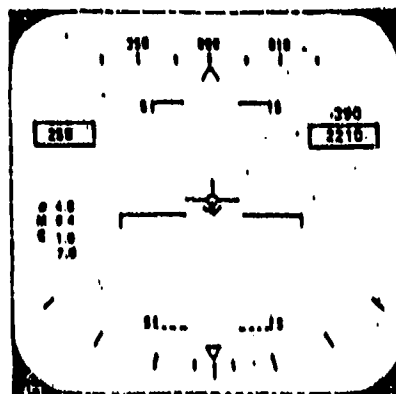
AUGIE ARROW DIRECTION

1. If an arrow is present on the HUD format as displayed, what should it point to? Circle one.



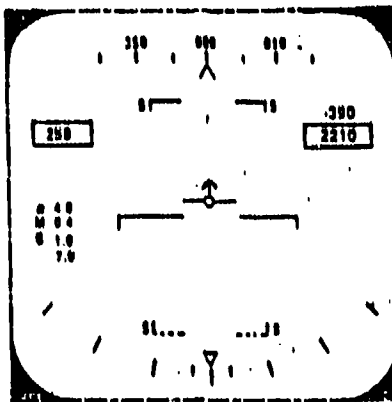
GROUND

Number 2  
4%



HORIZON

Number 18  
32%



SKY

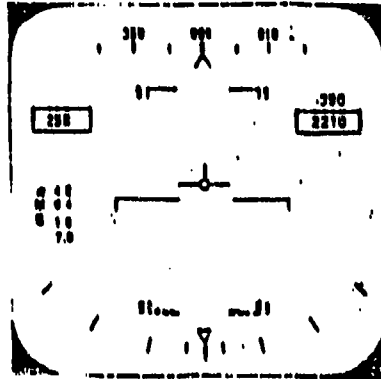
Number 23  
41%

No Arrow

Number 13  
23%

COLOR ON HUD

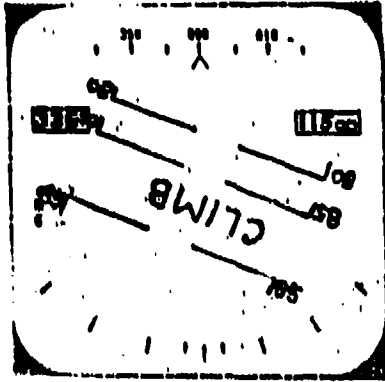
2. If the below-horizon pitch ladder were shown in a contrasting color to all other HUD symbology e.g. red, would that assist in recovery from an unusual attitude? Circle one.



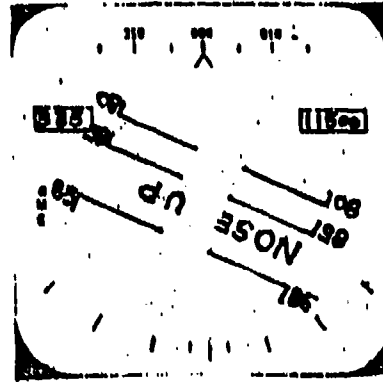
	YES	NO
Number	39	17
	70%	30%

WORDING OF INFORMATIONAL CUES

3. At extreme angles of attack, if words are used, what words would you prefer to be shown? Circle one.



Number 26  
46%



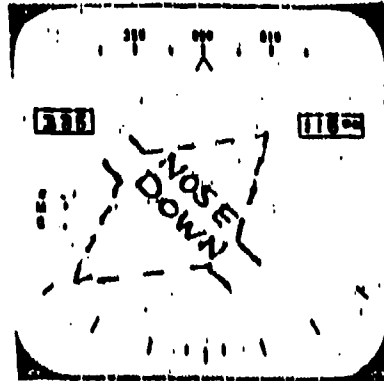
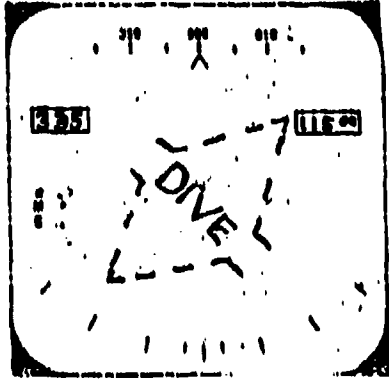
12  
21%

No Words

Number 18  
33%

WORDING OF INFORMATIONAL CUES

4. At extreme angles of attack, if words are used, what words would you prefer to be shown? Circle one.



Number 23  
41%

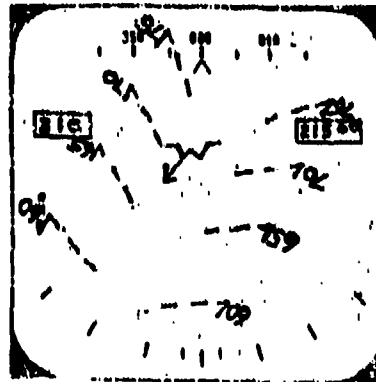
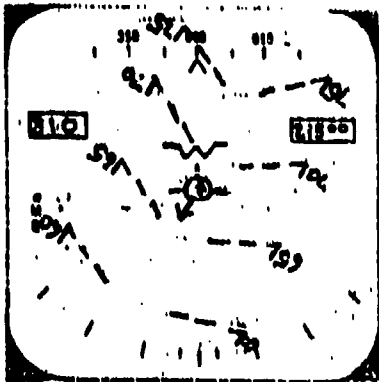
14  
25%

No Words

Number 19  
34%

VELOCITY VECTOR AS A CUE

5. At extreme angles of attack, greater than +60 degrees or less than -60 degrees, what format do you like best? Circle one.



velocity vector present

delete velocity vector

Number 45

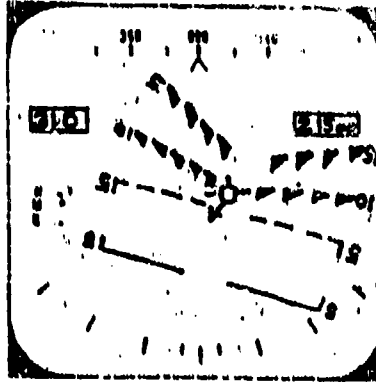
11

80%

20%

**EXPERIMENTAL PITCH LADDER**

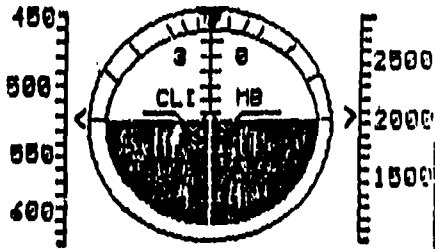
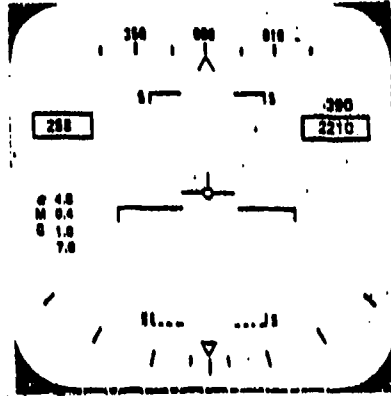
6. It has been proposed that the below-horizon pitch ladder be displayed as a "sawtooth" line. Should this display format be further tested to determine if it would assist in recovery from unusual attitudes? Circle one.



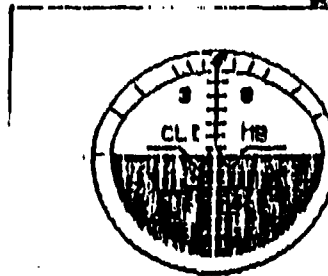
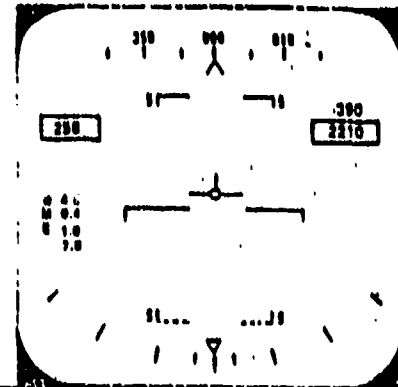
	YES	NO
Number	32	24
	57%	43%

**ADI FORMATS**

7. Several ADI formats have been proposed for use on the DDI, with a standard HUD format present. Of the following HUD/ADI format combinations, circle the one you most prefer. Continues on following page.



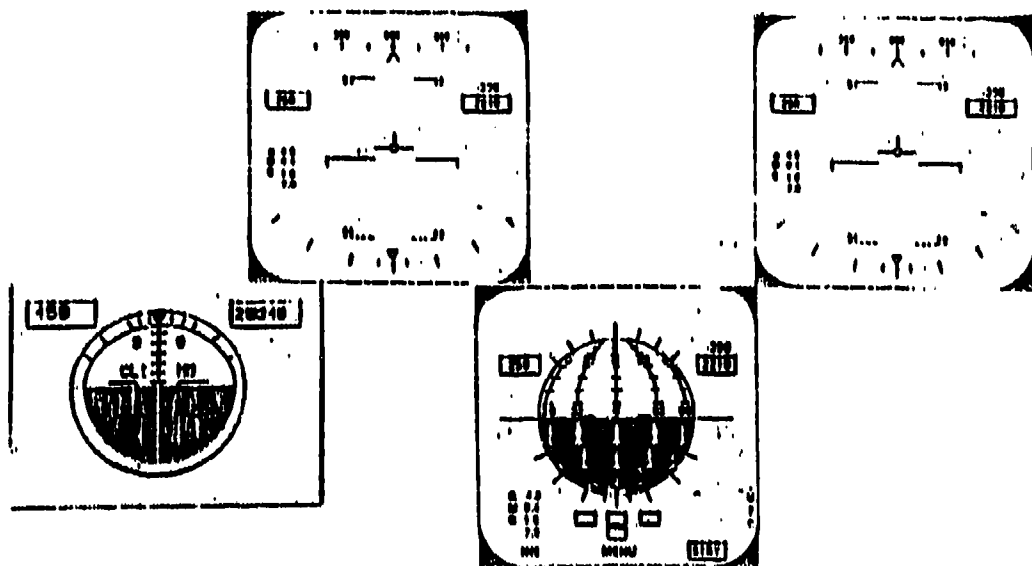
Number 0  
0%



Number 0  
0%

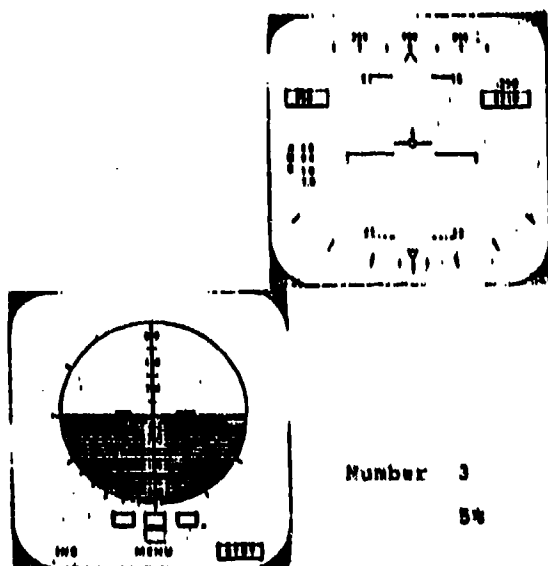


7.



Number 6  
11%

47  
84%



Number 3  
5%

## LIST OF REFERENCES

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2. Naval Air Development Center, Evaluation of the F/A-18 Head-Up-Display for Recovery from Unusual Attitudes, Aircraft and Crew Systems Technology Directorate, by J. Guttman, 1986.
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5. Air Force Wright Aeronautical Laboratories, Head-Up Display Design Guide. Improvement of Head-Up Display Standards Vol. I, by R. L. Newman, 1987.
6. McDonnell Douglas Corporation Report N60530-83-G-0227, Operation of the F/A-18 Avionic Subsystem For Aircraft with 85A Operational Flight Programs, July 1986.
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