USAF IFC-TR-91-01

REPORT ON HEAD-UP DISPLAY SYMBOLOGY STANDARDIZATION

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PREFACE

This report (USAF IFC-TR-91-01) is the summation to date of a USAF Instrument Flight Center (IFC) effort to develop a standard set of symbols and their mechanizations for all USAF head-up displays which will be used as primary flight references. This project was initiated at the request of HQ USAF/XOO and validated by a study indorsed by CSAF.

The IFC participated in the devclopment of the simulated flight tests contained in this report, but the administration of the tests and recording and analysis of the data were performed by outside agencies.

This technical report has been reviewed and is approved.

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USAF INSTRUMENT FLIGHT CENTER REPORT

ON

HEAD-UP DISPLAY SYMBOLOGY STANDARDIZATION

1 NOVEMBER 1990

1. **INTRODUCTION**. This report describes the USAF Instrument Flight Center (IFC) current position regarding Air Force standard head-up display (HUD) symbology and the use of a HUD as a primary flight reference. When symbology development is complete, the IFC position will be incorporated into Mil-Std 1787, *Aircraft Display Symbology*, and appropriate procedural guidance and techniques will be included in AFM 51-37, *Instrument Flying*.

2. **BACKGROUND**. In 1987 the IFC was tasked by HQ USAF/XOO to "develop specific cockpit instrumentation standards" including display formats for a "single-source instrument reference." In 1989 Air Force Chief of Staff General Welch endorsed a study conducted by a team of MAJCOM representatives which verified the need for standard USAF instrument flight symbology. The IFC focused its efforts on HUD symbology because pilots are using HUDs more and more extensively for instrument flight, and because the cockpit designs of new weapons systems, such as the ATF and C-17, are based on using the HUD as the primary flight reference.

3. **IFC PHILOSOPHY**. The IFC approach consists of identifying the best symbols and mechanizations currently in use (or that are showing strong qualities in mature research) and combining them in one format. It is not our intent to design a completely new HUD symbology suite from scratch. That will be left to researchers who can demonstrate a significant improvement over the standard we set forth now. This approach should allow for beneficial creative freedom while still providing a proven benchmark from which to begin.

4. **PROGRESS**.

a. The IFC has engaged in extensive research involving HUDs, multifunction displays, helmet/head-mounted displays, etc. This research was conducted with the help of the Aeronautical Systems Division (Crew Station Evaluation Facility and Wright Research and Development Center), the Human Systems Division (USAF School of Aerospace Medicine), similar agencies within the US Army and Navy as well as in US allied nations. NASA-Ames

Research Center, and operational subject pilots from the MAJCOMs.

b. From this research we have derived a strong position on symbology form, location, and mechanization as described in the following paragraphs. We still need to resolve a few attitude awareness issues (which will require further research), but we expect to begin inflight validation of our present simulator conclusions in early 1991 after airworthiness certification of our HUD-modified T-38 is complete.

5. **PRIMARY FLIGHT REFERENCE (PFR).**

a. **Need**. During the research mentioned above, it became apparent that any flight instrumentation standard put before the aviation community must be based on the concept of a primary flight reference (PFR). Such a reference must be defined in terms of information required to ensure safe flight in all weather conditions.

b. **Philosophy**. We at first hoped to define the requirements for a single-source PFR but have determined it presently infeasible to require every item of information needed for a particular phase of flight to be presented on a single display medium. While we strongly support including as much information as is practicable on the PFR, we recognize there are some inherent limitations and now establish the PFR as follows.

c. **Definition**. A primary flight reference is a single display medium which continuously provides the pilot the information necessary to maintain attitude, airspeed, and altitude awareness and recognize and recover from an unusual attitude.

d. **Use of the PFR in a Particular Phase of Flight.** When applicable, the PFR can also provide the information required to accomplish a specific mission segment, but such additional information must not detract from the pilot's ability to maintain attitude, airspeed, and altitude awareness and recognize and recover from an unusual attitude. Operational MAJCOMS determine the weapons employment phase requirements to be added to the PFR. Additional instrument flying requirements are addressed in paragraph 5f(2) below.

e. **Primary Flight Reference Presentation**.

(1) **Concepts**.

(a) While the PFR must be contained on one display medium, it need not remain the same medium throughout the flight.

(b) As cockpits become missionized, we must still recognize that the ability to maintain attitude awareness and to transition to instrument flight or recover from an unusual attitude is a full-time mission requirement; hence, the need for a PFR to be present full-time. This means that a pilot who declutters the HUD and leaves only tactical symbology needs a PFR present in the head-down space. Conversely, if all the head-down displays are missionized, the HUD needs to provide the PFR data.

(2) **Requirements**.

(a) When the HUD is the PFR, a head-down PFR must also be available from only one switch action by the pilot. This requirement ensures the pilot has an unambiguous attitude source in the event of HUD failure, HUD washout from external lights, or any condition which has resulted in unmanageable spatial disorientation.

(b) None of the information denoted in paragraph 5f may be split between the head-up and head-down regions because of the risk of confusion and spatial disorientation such a crosscheck would generate.

(3) **Location**. A head-up PFR will subscribe to location criteria for head-up displays. A head-down PFR must be centrally located within the pilot's normal scan pattern of the instrument panel. Vertical stacking on top of the primary navigation display (HSI/HSD) is preferred; however, a side-by-side arrangement with the PFR on the left is acceptable. If both a head-up and head-down PFR are available, the head-down PFR will be located on the instrument panel as previously described and within 15° of the horizontal axis of the center of the HUD FOV. A head-down PFR will not be placed in the upper or lower quadrants of the head-down space. It will always be centrally located. See Figures 1 and 2.

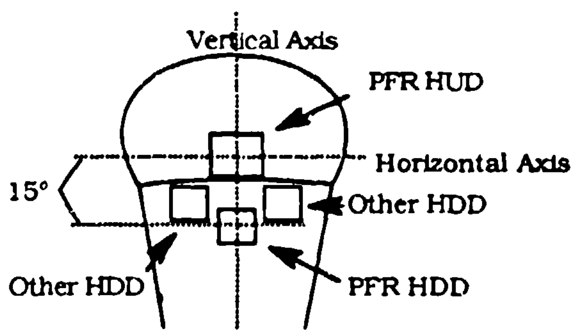


Figure 1. Preferred Location of Head-down PFR when Head-up and Head-down PFRs are Available.

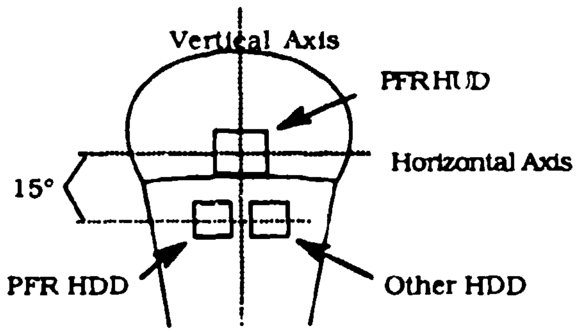


Figure 2. Alternate Location of Head-down PFR when Head-up and Head-down PFRs are Available.

f. **Required Data**. Descriptions of the symbology representing the data referenced below are in Appendix A. Not all the symbols described in Appendix A are required in all phases of flight, as mentioned in paragraph 5d above. However, when the flight data those symbols represent is required, those symbols will be used to display it.

(1) **Critical Flight Data**. The PFR must continuously provide the following critical flight data in all phases of flight:

(a) Climb/dive angle.

Note - If the display can mark climb/dive angle with a single symbol, i.e., the Climb/Dive Marker (CDM), then it will be used in place of pitch and vertical velocity. This symbology is desired because the CDM graphically represents the climb/dive angle traditionally calculated from pitch and vertical velocity (see paragraph 8). However, if the CDM is unavailable or invalid, it must be replaced by pitch and vertical velocity. Finally, pitch and vertical veloc[illegible] must be added to the display in those high angle of attack, sinking conditions specified [illegible] the flight manual which would be worsened if the pilot attempted to raise/lower the CDM rather than lower/raise the pitch attitude.

(b) Bank.

Note - Precise bank angle, i.e., a bank scale and pointer, is not required in all phases of flight. See paragraph (2) and Table 1 below for specific maneuvers which require precise bank angle.

(c) Altitude.

(d) Airspeed.

(2) **Additional Flight Data for Instrument Flight**. See Table 1 below for the minimum additional data required to be presented on the PFR when it will also be used as the primary reference for a particular instrument maneuver. More than the minimum data, or attention-getting enhancements, such as highlighting or flashing critical parameters, may be included within the constraints of paragraph 5d. We encourage the presentation of as much information as practicable to diminish the necessary crosscheck.

NOTE: The format, mechanization, and location of additional information not included in Table 1, i.e., power indication, altimeter setting, selected course, and those items which are not required by Table 1 to be on the PFR, will be addressed in a future report on head-down standardization. USAF IFC's position will almost surely be to require a layout which follows the basic "T" arrangement and supports a crosscheck that is within reasonable limits. This means, for example, that a crosscheck between a PFR HUD and a head-down Horizontal Situation Indicator (HSI) to perform an arc-to-radial intercept would be acceptable as long as the HSI is within the displacement angle to be determined.

g. **Failure Indications.** Failure of any data presented on the PFR will be indicated on the PFR.

Table 1. Data Required on the PFR during Specific Maneuvers when the PFR will be used as the Primary Reference for Instrument Flight.

Required Data	Maneuver									
	Climb	Cruise	Fix-to-Fix	Hold	Pen	Arc	NPrec	Prec	Flt Dir App	Cat II/III
Climb/Dive Angle [1,2]	X	X	X	X	X	X	X	X	X	X
Precise Bank Angle	X	X	X	X	X	X	X	X	X	X
Barometric Altitude	X	X	X	X	X	X	X	X	X	X
Airspeed	X	X	X	X	X	X	X	X	X	X
Heading	X	X	X	X	X	X	X	X	X	X
Horizontal Flt Path [3]							X	X	X	X
Bearing	S	S	S	S	S	S	S	S	S	S
Distance	S	S	S	S	S	S	S	X	X	X
Lateral Deviation	X	X		X	X		X	X	X	X
Vertical Deviation					M/G			X [5]	X	X
Flight Director									X	X
Timing				S	S		S	S	S	X
Absolute Altitude										X
Angle of Attack [4]	X	X	X	X	X	X	X	X	X	X
Yaw [4]	X	X	X	X	X	X	X	X	X	X
Long. Acceleration	R	R	R	R	R	R	R	R	R	X
Speed/AOA Deviation	R	R	R	R	R	R	R	R	R	X

Legend:
X = Always required for this maneuver.
M/G = Required only for MLS or GPS curved path procedure.
S = Required only if this data is not in view elsewhere in the cockpit (single source).
R = Strongly recommended but needs further research before becoming a requirement.

Notes:
1. Replaced by pitch and vertical velocity when the climb/dive marker is invalid or unavailable.
2. Pitch and vertical velocity are added to the display when the aircraft is in a high AOA, sinking condition.
3. Required only on displays which conform to the outside scene, e.g., HUDs, overlaying FLIR on an MFD, etc.
4. Only for aircraft which require this data (airframe limitations, asymmetric drag/thrust, etc).
5. Not required for PAR approaches.

6. **HUD SYMBOLOGY FORM, LOCATION, AND MECHANIZATION**. Appendix A is a draft symbology standard which reflects our current position on symbology form, location, and mechanization. The terminology of some of the symbols mentioned may be somewhat unfamiliar. This is another aspect of standardization we are addressing since each weapon system uses its own descriptive terms. We have named the symbols according to either the function they actually perform or the parameter they represent.

a. The symbols in Appendix A were selected based on either scientific, comparative simulator studies or the experience of our team of symbology experts representing air-to-air, air-to-ground, bomber, and strategic and tactical airlift missions. Not all of the symbols could be derived through pure, scientific means due to the excessive time and cost involved. The following is a summary of our findings which were derived through comparative simulator trials as of September 1990.

(1) In November 1989, we asked the USAF School of Aerospace Medicine (USAFSAM) to determine if there was any significant difference in noticing and correcting errors between five separate airspeed and altitude displays. Of the five displays the analog, circular dial type "counter-pointer" format proved significantly better both in objective performance measurement and in subjective pilot preference. Appendix B is a report of this study.

(2) Also in 1989, we contracted with ASD/ENECH (Crew Station Evaluation Facility) at Wright-Patterson AFB to document significant differences in performing instrument climbouts, unusual attitude recoveries, precision approaches, and non-precision approaches using eight different formats. The fighter aircraft portion of the study is complete, and again the counter-pointer airspeed and altitude presentation performed better as did a dual-cue (split needle) flight director. Additionally, pilots' subjective comments supported a tapered climb/dive ladder (gradually shortened climb/dive lines) and symbology which was introduced for longitudinal acceleration and course/glideslope deviation (raw data). New symbology for bearing and speed/AOA error had mixed reviews but were generally supported in concept. A **preliminary draft** of the results of the fighter portion of the study is in Appendix C. A final report will incorporate both fighter and transport category results after analysis of the transport portion is complete.

(3) In February and March 1990, we participated in a tri-service effort conducted at NASA - Ames Research Center to find the best presentations and mechanizations for attitude awareness. Analysis of the objective data is still ongoing, but the pilot subjective comments tend to support an asymmetric, variably compressed climb/dive ladder and a dampened CDM. The variable compression allowed movement of the C/D ladder at a rate that permitted it to be read at high pitch rates while preserving horizon correlation at climb/dive angles close to the horizon. Dampening removed CDM "bobbing" and resulted in a stable display.

b. As a result of our simulator studies, we plan to require a PFR HUD to incorporate a variably compressed, asymmetric climb/dive ladder; a dampened CDM; counter-pointer airspeed and altitude presentation; and a dual-cue flight director. While we feel strongly about the other symbols in the draft standard, we do not have comparative, analytical support of them and will wait until flight validation to fully endorse them. Meanwhile, we plan to seek further simulator study of the climb/dive ladder to investigate full-time drift stabilization and the best means of achieving asymmetry.

7. **INFLIGHT VALIDATION**. Our T-38 which has been equipped with a programmable HUD is scheduled to complete airworthiness certification near the end of this calendar year. Early next year we will begin flight validation of the symbols and mechanizations which have shown promise in the simulator trials. The elements we will initially evaluate include the following:

a. Symbology.

(1) Airspeed and altitude.

(a) Counter-pointer.

(b) Digital.

(c) Vertical scale with digital.

(2) Climb/dive ladder.

(a) Non-tapered, bent climb and dive bars.

(b) Non-tapered, straight climb bars and non-tapered, bent dive bars and vice-versa.

(c) Tapered, straight climb bars and non-tapered, bent dive bars and vice-versa.

(3) Bank scale.

(a) With vs without bank scale.

(b) Bank scale placement .

(4) Heading scale placement.

(5) Longitudinal acceleration cue

(6) Speed /AOA deviation cue

b. Mechanization.

(1) Climb/dive ladder.

(a) Fully drifting with a flight path marker to represent aircraft flight path (horizontal and vertical components).

(b) Caged (non-drifting) with a CDM representing aircraft climb/dive angle and a separate flight path marker to represent aircraft flight path.

(c) 1:1 conformality to the real world throughout the ladder.

(d) 1:1 ratio from 0° to 5°, then steadily increasing compression which reaches a maximum 4.4:1 ratio at ± 85°.

(2) Climb/dive marker.

(a) Dampened.

(b) Non-dampened.

c. We will evaluate the format, mechanization, and placement of navigation data immediately following the validation of the attitude awareness information listed in paragraph 7.

8. **VECTOR VERSUS ATTITUDE INSTRUMENT FLYING**. In the same 1987 HQ USAF/XOO tasking referenced in paragraph 2, the IFC was directed to investigate the related issue of flying instruments by reference to the flight path vector rather than following the conventional attitude instrument flying concept. These are our findings to date:

a. All of our research of electronic display symbology has centered around the concept of "vector" flying and has shown it to be quite effective. The premise that attitude flying is obsolete is somewhat flawed, however, because the flight path vector symbol (flight path marker/fpm or velocity vector/vv) incorporates the pitch attitude of the aircraft in its positioning while the flight path ladder indicates roll attitude. Since the fpm/vv graphically and immediately presents the resolution of the comparison of pitch attitude, vertical velocity, and airspeed that the attitude instrument flying technique calls for, it seems appropriate to use the fpm/vv as the central reference for controlling the aircraft.

b. There are some problems with the manner in which our current flight path markers/velocity vectors are mechanized, i.e., their "swimming" around the display field of view and lagging control inputs. In short, the display is not stable. Also, the fpm/vv is inappropriate to use in a high AOA, sinking flight condition. However, the mechanization liabilities are eliminated by stabilizing, or caging, the symbol in the horizontal plane and dampening it in the vertical. The problem of using a flight path vector symbol (now we can call it the climb/dive marker since it's stabilized horizontally) to control the aircraft in a high AOA sink can be resolved by providing a pitch reference for use in that situation.

c. By stabilizing the CDM horizontally, a separate symbol for indicating actual flight path is still needed in those phases of flight which require that information. Our initial findings suggest this arrangement is acceptable, even desirable, to enhance the pilot's maintenance of spatial as well as positional orientation.

d. These concepts will also be validated in flight, along with the items in paragraph 7, upon receipt of our T-38 test vehicle. However, our strong opinion now is that all aircraft should take advantage of the capability of presenting dampened, caged climb/dive information and use it as the symbol with which to control the aircraft. Correspondingly, all other symbols relating to the CDM should be referenced to it, e.g., flight director steering and speed error.

9. **NEED FOR FURTHER RESEARCH.**

a. Much progress has been made in establishing a viable Air Force flight symbology standard, but further research is required to sufficiently ensure the selected symbology is safe to use in all weather conditions.

b. While most of the critical flight data symbols described in this report have been evaluated thoroughly, questions still remain regarding the intuitiveness of the climb/dive ladder. Some important aspects of the navigation data still need to be validated, i.e., the utility of the longitudinal acceleration and speed deviation cues. Also, promising new symbols for aiding attitude awareness, such as a "ghost "horizon line and an "up" arrow, are being investigated by various government agencies and industry contractors. As they mature we will need to evaluate them for a later upgrade to the standard.

c. To date, the standardization work accomplished has required a longer-than-desired time span. The slow pace is mostly due to difficulty in securing funds to add onto existing research programs. Efficient and timely evaluation of the remaining issues can only be accomplished through appropriate program funding and prioritizing.

10. If you have comments or questions concerning this report please direct them to Majors Rick Evans or Foster Bitton, USAF IFC/IS, for issues pertaining to symbology research, and Lt Col Ed Saflarski, USAF IFC/FO, regarding the T-38 flight evaluation, at DSN 487-3077, Commercial (512) 652-3077, FAX (512) 652-4904.

STANDARD UNITED STATES AIR FORCE

HEAD-UP DISPLAY SYMBOLOGY

FOR

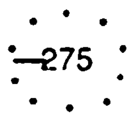
ATTITUDE AWARENESS AND INSTRUMENT FLIGHT

Introduction. This appendix reflects the current USAF Instrument Flight Center position on HUD symbology form, location and mechanization as of 1 November 1990. It is written in a format similar to that of MIL-STD 1787, *Aircraft Display Symbology*, since the descriptions will be included in that MIL-STD to identify USAF standard HUD symbology. Not all the symbols described are required in all phases of flight, as mentioned in paragraph 5d of the report. However, when the flight data these symbols represent is required, these symbols will be used to display it. See the body of the report to note which symbols have been selected based on comparative simulation study and those which were chosen from subjective evaluation. All symbols and mechanizations will be validated in flight before being included in MIL-STD 1787 as the Air Force standard. Weapons systems employment symbology will be determined by the operational major commands.

Symbol Definition. Symbols for the functions described will have the geometry shown in the same or similar figures in MIL-STD-1787B, *Aircraft Display Symbology*. Where applicable, equations of motion for mechanizing these symbols will also be included in MIL-STD 1787B.

1.0 **Airspeed Display.** Airspeed is displayed on the left side of the instantaneous field-of-view (IFOV). It is fixed in a constant position up and to the left of the climb/dive marker (see paragraph 6.0 for climb/dive marker) and moves vertically with it. The airspeed display is fixed relative to the pitch reference symbol (see paragraph 17.0) if the climb/dive marker is unusable. The type of airspeed displayed (indicated or calibrated) will be that with which the aircraft is normally flown and will not include any associated letter(s). This display is presented full-time on the primary flight reference (PFR).

1.1 Basic Format. Airspeed is displayed in a counter-pointer format. The format consists of a digital readout of the current airspeed to the nearest knot surrounded by a circle of ten dots equally spaced around the periphery, and an index placed inside the circle pointing to the position representing current airspeed . A full circle represents 100 knots and each dot indicates ten knots. Speed increases in the clockwise direction.



1.2 Command airspeed cueing. Command airspeed is displayed in one of two formats, based on airspeed error. When the difference between current airspeed and command airspeed is less than 40 knots, a caret is placed on the outside of the airspeed circle (figure 1). The caret points to the center of the circle. When the difference between current airspeed and command airspeed is greater than 40 knots, the caret is removed and the command airspeed is shown by a digital readout above and to the left of the circle (figure 2). The two different modes are necessary to prevent confusion between the caret's indicating a need to increase rather than decrease speed and vice-versa. The 40 knot differentiation allows the caret to always be closer to the pointer in the direction of the required change. If more than one caret or digital value can be displayed at one time, each will be tagged with a single letter or digit to delineate the airspeed they represent. The 40 knot differentiation rule applies to each caret/digital value. When digital values are tagged, a space will be placed between the last digit and the identifier. The following identifiers will be used as required. Additional identifiers may be used for aircraft-specific paramenters, but will not conflict with those listed below.

1 = First reference speed during takeoff, i.e., $V\ ref_1$

2 = Second reference speed during takeoff, i.e., $V\ ref_2$. and so on.

R = Rotate speed

F = Flap retract/extend speed

S = Slat retract/extend speed

G = Gear retract/extend speed

A = Final approach speed

When a reference speed is past and is no longer of use, it should be removed from the display.

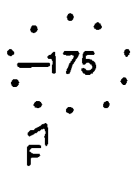


Figure 1.

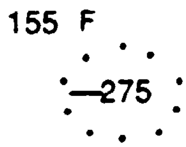


Figure 2.

1.3 Digits. All digits are equal in size and leading zeroes are omitted.

1.4 True airspeed. True airspeed can be displayed immediately below the counter-pointer indicated/calibrated airspeed in the digital format described in paragraph 1.3. The letter "T" and a space will be placed to the left of the digital value.

T 580

1.5 Groundspeed. Groundspeed may be displayed immediately below the counter-pointer indicated/calibrated airspeed in the digital format described in paragraph 1.3. The letter "G" and a space will be placed to the left of the digital value.

G 475

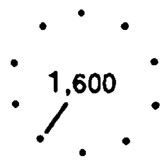
2.0 **Altimeter Setting**. This display is in the lower left corner of the HUD FOV. It is displayed in a traditional four digit manner with a decimal point after the first two digits.

30.02

3.0 **Bank Angle Scale and Pointer**. This fixed scale and moving pointer arrangement displays precise bank angle in degrees. It is located at the top or bottom of the IFOV. The open, moving pointer points up or down with respect to true vertical. Constant tick marks represent 10°, 20°, and 30°. The 30 ° tick mark is longer and bolder than the 10° and 20° marks. Long and bold tick marks representing 45° and 60° are enabled on both sides of zero bank when the roll attitude is greater than or equal to 25°. Long, bold 90° tick marks are enabled when roll attitude is greater than or equal to 55°. The bank pointer moves 360° around the IFOV. At bank angles greater than 60° the pointer doubles in size. If yaw information is required, the yaw indicator (paragraph 23.0) will be the bank pointer.

4.0 **Barometric Altitude Display.** The barometric altitude display is on the right side of the IFOV, directly abeam the airspeed display.

4.1 Basic Format. Barometric altitude is displayed in a counter-pointer format consisting of a digital readout surrounded by a circle of ten dots equally spaced around the periphery and an index placed inside the circle pointing to the position representing current altitude. A full circle represents 1000 feet and each dot indicates 100 feet. Altitude increases in the clockwise direction.



4.2 Command Altitude Cueing. Command altitude is displayed in one of two formats, based on magnitude of error. When the difference between current altitude and command altitude is less than 400 feet, a caret is placed on the outside of the altitude circle (figure 1). The caret points to the center of the circle. When the difference between current altitude and command altitude is greater than 400 feet, the caret is removed and command altitude is shown by a digital readout above and to the right of the circle (figure 2). The two different modes are necessary to prevent confusion between the caret's indicating a need to increase rather than decrease altitude and vice-versa. The 400 feet differentiation allows the caret to always be closer to the pointer in the direction of the required change. If more than one caret or digital value can be displayed at one time, each will be tagged with a single letter to delineate the altitude they represent. The 400 feet differentiation rule applies to each caret/digital value. The following letter identifiers will be used when needed:

L = level off (climb/descend to)
F = flap level off
S = stepdown
M = minimum descent altitude
D = decision height

When a reference altitude is past and is no longer of use, it should be removed from the display.

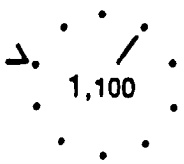


Figure 1. Command altitude less than 400 feet from present altitude

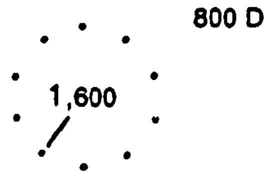


Figure 2. Command altitude greater than 400 feet from present altitude

4.3 Digits. Large digits indicate tens of thousands and thousands of feet; smaller digits indicate the hundreds, tens, and units values in feet. A comma is placed after the thousands digit. The unit digits are indicated as a zero, i.e., the resolution of the display is ten feet. Leading zeroes are blanks.

5.0 **Bearing Pointer**. This pointer indicates relative bearing to the selected NAVAID or waypoint. It is located in the upper right corner of the display and referenced about a digital readout of the radial on which the aircraft is located. Two horizontal indices are included on either side of the radial readout to represent ±90° of the aircraft heading.

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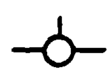
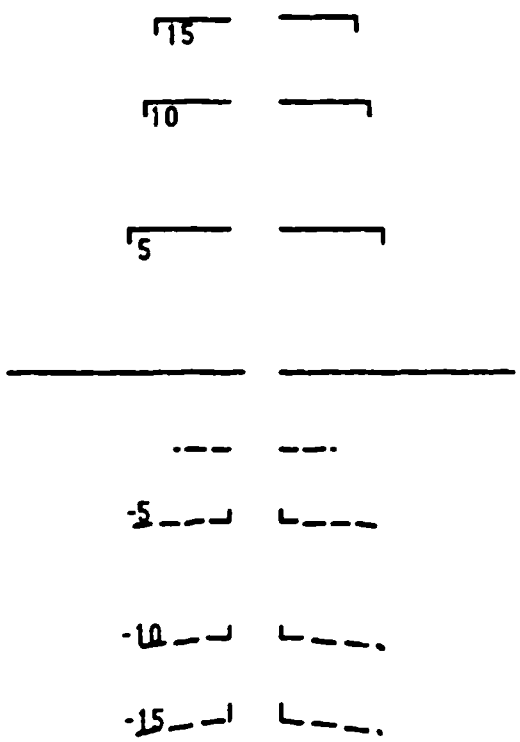
6.0 **Climb/Dive Marker (CDM).** The CDM is centered in azimuth and moves vertically to indicate aircraft climb or dive angle when referenced to the C/D ladder (see paragraph 7.0 for C/D ladder). The CDM is the vertical component only of the traditional flight path marker/velocity vector. Optimally, the CDM is ground-referenced, but can be air mass-referenced if ground referencing is not possible. A dampening constant is added to the positioning equation to allow the CDM to be more stable. Dampening the CDM prevents its "bobbing" when the nose of the aircraft is moved in the vertical plane. It can then be used as the primary aircraft control symbol. Specific dampening algorithms must be tailored to each aircraft. (See MIL-STD 1787B, *Aircraft Display Symbology*, for a representative equation). The CDM is limited to the HUD IFOV. When the CDM is limited the fin will be removed. When the aircraft enters (or is about to enter) a high angle of attack, sinking condition, as denoted in the flight manual, the CDM will flash to advise the pilot to transition to the pitch reference symbol in order to recover (see paragraph 17.0 for pitch reference symbol).



7.0 **Climb/Dive (CD) Ladder**. The C/D ladder, when read against the CDM, displays horizon-referenced aircraft climb or dive angle in 5 degree increments between -30° and +30° and 10 degree increments at angles greater than ±30°. The C/D ladder is centered on, and rotates about, the CDM. When no CDM is displayed, the ladder is centered on, and rotates about, the aircraft pitch reference symbol, indicating true fuselage reference line pitch attitude. Gross roll attitude is provided with respect to the aircraft-stabilized wings of the CDM.

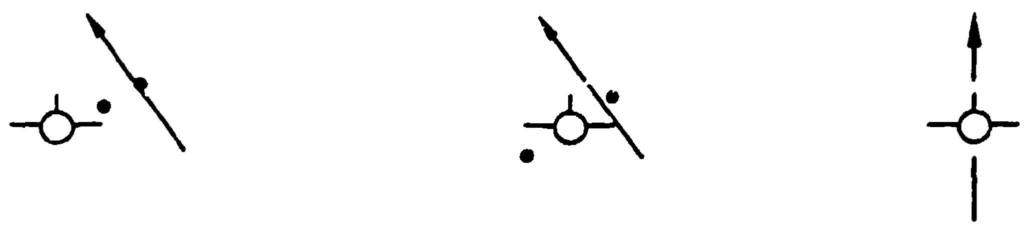
7.1 Format. The ladder consists of sets of solid lines for positive (climb) angles to 80° and dashed lines for negative (dive) angles to 80° which are separated in the center by a gap slightly larger than the CDM. Zenith and nadir symbols are displayed at + 90° and - 90°, respectively, and no bars are written past these symbols (see paragraph 16.0 for the nadir symbol and paragraph 24.0 for the zenith symbol). During the landing phase of flight, unlabeled 3° glide slope reference lines appear 3 ° below the horizon. (If the capability exists to manipulate the glideslope reference lines, the lines will be labeled on the left side with the exact dive angle in the same manner as the other C/D lines). Numerics are displayed under the outer left edge of the climb lines and above the outer left edge of the dive lines. A negative algebraic sign precedes all negative C/D numerics. The numerics rotate in roll with the C/D ladder. Tabs connected to the ladder lines point to the horizon. The tabs are located on the outside of the positive lines and their numerics and on the inside of the negative lines. Dive lines angle down half the number of degrees they are representing (i.e. -5 degree dive lines angle down at 2.5 degrees, -10 degree lines slant 5 degrees, etc.). The -3° glideslope reference lines are not slanted. Climb lines parallel the horizon and taper (shorten) as the climb angle increases. The lines shorten linearly at a 4:1 ratio so that the +85° line (which is not written) would be 25% as long as the +5° line. As the climb lines taper, the numerics shrink correspondingly (unable to show shrinking numerics in the figure below). The C/D ladder is scaled vertically at a 1:1 ratio to the horizon line between 0° and ±5°. After ±5° the ladder is variably compressed linearly to achieve a 4.4:1 ratio to the horizon line at the zenith/nadir.



7..2 Presentation. The C/D ladder moves in relation to the CDM so that the climb/dive angle represented by the CDM is always conformal to the real world. An occlusion "window" appropriate to the specific HUD FOV is placec around the CDM so that a maximum of 4 climb/dive lines are displayed.

NOTE: Consideration is being given to modifying the asymmetric aspects of the C/D ladder in light of recently surfaced concerns regarding the above described C/D ladder's attitude awareness and unusual attitude recovery attributes. Specifically, bent lines are in question for aiding roll recognition and reaction. Another arrangement would be to place the bent lines in the climb portion of the C/D ladder and the straight ones in the dive portion where rolling in the correct direction is paramount. Also, the bending angle of the climb or dive lines may need to be reduced and held constant to minimize confusion in roll recognition. These configurations will be researched further in the near future.

8.0 **Course Deviation Indicator (CDI).** This symbol presents the lateral and angular displacement of the aircraft from the selected course in the same manner as the CDI and course arrow in a conventional horizontal situation indicator. The CDI consists of a course arrow and four dots displayed relative to the CDM. The head of the arrow points in the horizontal plane to the selected course. The angle between the course arrow and the fin of the CDM represents the aircraft's angle of intercept to the course relative to the heading. Dots are displayed between the CDi and CDM to indicate magnitude of deviation from the desired course. A maximum of two dots are presented at one time. When the deviation is more than 1 1/2 dots, two dots will be shown on the same side of the CDM as the CDI. When the lateral deviation is less than 1 1/2 dots but more than 1/2 dot, a dot will be displayed on both sides of the CDM. As the deviation is reduced to less than 1/2 dot, all dots disappear. The CDI does not occlude the CDM.



Deviation greater than 1 1/2 dots | Deviation less than 1 1/2 dots, but greater than 1/2 dot | Deviation less than 1/2 dot

9.0 **Desired Course**. Desired course is displayed in the lower left corner of the HUD FOV. A three letter indication of the navaid source (i.e. ILS, TCN, VOR, GPS, MLS) precedes the actual course number which is displayed in three digits.

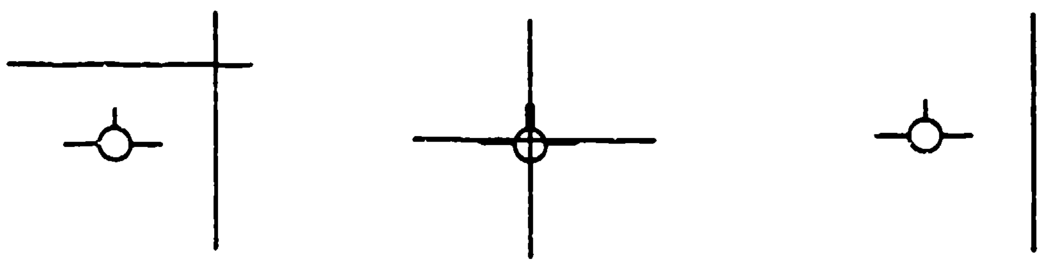
ILS 010

10.0 **Distance**. TACAN DME, GPS range, or waypoint distance is displayed in digital form below the bearing pointer/radial readout. A space and a five letter/digit identifier are displayed to the right of the value to indicate to which navaid the distance is referenced, i.e., TACAN/VORTAC/DME channel, INS steerpoint number, GPS/MLS waypoint number.

12.4 CH115 or 12.4 INS12 or 12.4 GPS16 or 12.4 MLS03

11.0 **Flight Director.** One of the two symbols described below will be selected after further research is completed. The dual cue flight director has led to increased performance over the single cue, but clutter issues remain to be resolved.

11.1 Dual Cue Flight Director. The dual cue flight director consists of two solid lines which move in reference to the CDM to give steering guidance to course and glide path. The vertical line commands turns toward the course while the horizontal line commands climbs/descents toward the glidepath. If the guidance of either line is unavailable, the respective line is removed.



Turn right and climb
Vertical & horizontal steering

Proper corrections
Vertical & horizontal steering

Turn right
Vertical steering unavailable

11.2 Single Cue Flight Director. The single cue flight director is an open circle. It moves laterally about the CDM to give steering guidance to the course and glidepath. When vertical steering to the glidepath is available a short fin will appear in the top of the circle. If vertical steering is unavailable the circle will rise to/remain on the horizon line and show an x where the fin would appear. Loss of horizontal guidance will result in loss of the flight director and an "FD OUT" annunciator.

Turn right and climb
Vertical & horizontal steering

Proper corrections
Vertical & horizontal steering

Turn right
Vertical steering unavailable

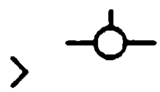
1.2.0 **Flight Path Marker (FPM).** The flight path marker is a small diamond which can fit entirely within the CDM and represents the vertical and horizontal component of the aircraft's flight path. The FPM diamond is always displayed at the true flight path position. The FPM is unlimited to the edge of the HUD FOV and is dampened in the same manner as the CDM. When the FPM diamond is limited at the edge of the FOV, a horizontal or vertical arrow, as appropriate, is drawn through it to indicate the direction in which the true flight path lies.

No crosswind or yaw   Left crosswind/yaw   Limited to the right

13.0 **Heading Suite.** The heading suite incorporates a 5:1 compressed, moving scale displaying aircraft magnetic heading from 0 to 360 degrees when read against the fixed heading index. The scale is located slightly above the center of the FOV in the instrument mode. Its location in employment modes will be determined by operational requirements. A minimum of 30 degrees is represented by tick marks at 5 degree intervals. Numerics are displayed above the scale, along with longer tick marks, every 10 degrees. A caret positioned below, and pointing toward, the scale identifies the command heading. Ground track can be added to the suite by placing an inverted "T" below the scale.

14.0 **Horizon line.** This symbol is used with the C/D ladder at the zero angle position to provide a true horizon reference. The line extends the entire width of the HUD FOV, but does not blank out any other symbol. It is twice as thick as the C/D lines, and has a gap in the middle the same width as do the C/D lines.

15.0 **Longitudinal Acceleration Cue**. A caret located to the left of the CDM indicates the acceleration or deceleration of the aircraft along its longitudinal axis. When the cue is above the wing of the CDM, the aircraft is accelerating. When the cue is below the CDM's wing, the aircraft is decelerating. When the CDM wing and acceleration cue are aligned horizontally, the aircraft is in an unaccelerated state. When read against the C/D ladder, the cue indicates the climb or dive angle at which the aircraft can climb or dive and remain in a longitudinally unaccelerated state (potential vertical flight path indication).



16.0 **Nadir Circle**. The nadir symbol is a circle with a double-written line extending from the circumference in the direction of the nearest horizon and is positioned at the -90° angle on the C/D ladder in place of a -90° dive line. The circle has five solid lines inside it which are always parallel to the C/D ladder lines. The center of the circle is considered the center of the symbol for placement on the C/D ladder.

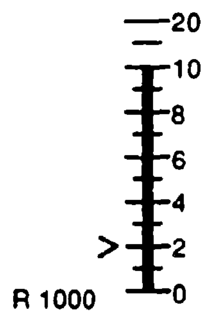
17.0 **Pitch Reference Symbol**. This symbol is in a fixed location on the display. It is referenced to the aircraft fuselage datum (or waterline) and represents an extension (or the direction) of the fuselage reference line. It is displayed only when the aircraft has entered (or is about to enter) a high angle of attack, sinking condition as denoted in the aircraft flight manual.

17.1 Alternate Pitch Reference Symbol. A gun cross symbol may be substituted for the above symbol on aircraft that employ guns boresighted to the aircraft fuselage datum.

18.0 **Radar (Absolute) Altitude.** Radar or absolute altitude is presented in a digital format and located below the barometric altitude display. It is preceded by the letter "R" and a space. Selected minimum radar altitude will be placed below the radar altitude and will also be a digital display preceded by the letters "AL" and a space. Aircraft that use a "thermometer" scale to present radar altitude during the employment phase may also use that scale for instrument flying in lieu of the digital display. However, the scale will be located in the lower right of the HUD IFOV and will include the digital presentation at the bottom of the scale. A caret will be placed on the left side of the scale to reference the selected minimum radar altitude in place of the digital "AL". For both presentations when descent is made below the selected minimum altitude, the "AL" and digital value, or the caret, as applicable, will flash to alert the pilot.

R 1000

AL 200



19.0 **Speed/AOA Deviation Tape.** The speed/AOA deviation tape appears on the left wing of the CDM and shows the difference between the current speed and the commanded speed. If current speed is faster than commanded speed, the speed tape rises from the left wing of the CDM. If the speed is slower, the tape extends below the wing of the CDM. An on-speed condition is indicated by the tape's disappearance into the wing. The length of the tape is proportional to the amount of speed error. Tick marks along the tape indicate increment deviations from commanded speed as applicable to the specific aircraft. AOA may be used to generate the error signal in lieu of airspeed.

20.0 **Timing Device.** A timing device is located in the lower right corner of the HUD FOV. It can show real time, time-to-go, or elapsed time. If all three categories can be presented, a space and a three letter identifier will be added to the right of the last digit, i.e., HRS, TTG, ELP, respectively. Time-to-go or elapsed time is required in the approach mode.

01:43:25 HRS or 01:43 TTG or 01:43 ELP

21.0 **Vertical Deviation Indicator (VDI).** This display is located to the right of the CDM and presents the aircraft's vertical position relative to the glideslope. The scale is composed of a center rectangle and four open dots. Each dot represents vertical angular deviation from the desired glideslope. An open triangle to the left of the display indicates deviation from on-glidepath. The center rectangle remains centered vertically on the CDM so that the VDI moves with the CDM.

22.0 **Vertical Velocity Indicator (VVI).** This numeric display, which is preceded by the letters "vv", indicates the vertical velocity of the aircraft rounded to the nearest ten feet per second. The display is positioned below the barometric altitude display. Descending vertical velocity is preceded by a minus sign.

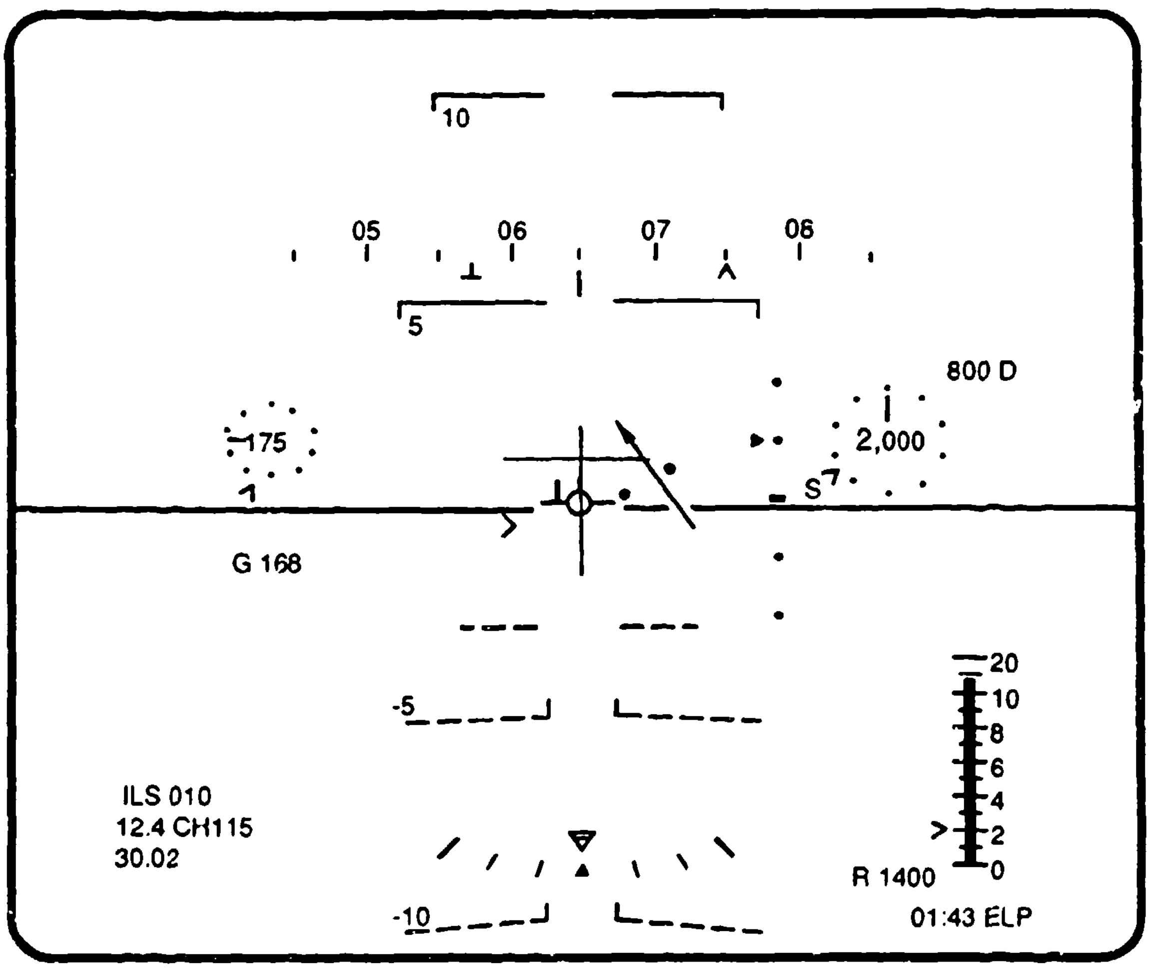
VV -780

23.0 **Yaw.** This symbol is a triangle located in the center and at the bottom of the FOV and represents the sideslip (beta) of the aircraft. It is part of the bank scale when the bank scale is displayed.

Coordinated flight | Right yaw condition | Yaw indicator as bank pointer

24.0 **Zenith Star**. The zenith symbol is part of the C/D ladder and is written at the + 90° angle in place of a +90° line. It is an eight pointed star with four large points separated by four smaller points. One of the large points is larger than the others and points to the nearest horizon.

Typical Composite Display



EFFECTS OF VARIATIONS IN HEAD-UP DISPLAY AIRSPEED AND ALTITUDE REPRESENTATIONS ON BASIC FLIGHT PERFORMANCE

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ABSTRACT

Five different head-up display (HUD) airspeed and altitude symbol sets were examined for efficacy in a basic instrument crosscheck during visually simulated flight. Twenty-five pilot subjects used each HUD symbol set while tasked to maintain straight and level flight for 200 seconds. Airspeed and altitude were caused to vary during the flight profile, requiring the pilots to recognize deviations and correct back to target conditions. Root mean square (RMS) performance errors (deviations from assigned airspeed and altitude) were measured. The pilots' airspeed and altitude performance was significantly better ($p<0.01$) with two new formats--rotating pointers with dot scales and plain rotating pointers--than with two more common formats--boxed digits and moving vertical tapes. Another novel format, boxed digits with trend bars, provided the best performance with respect to altitude error, but not airspeed error. Measures of subjects' confidence in their ability to use the different displays for basic instrument flight were significantly different ($p<0.001$) and consistent with the performance measures. The results of this study are important because of the need to standardize HUD symbology, and because of the trend to make the HUD, rather than the panel instruments, serve as the single-source primary flight reference in military aircraft.

INTRODUCTION

The most beneficial characteristic of the HUD has been its ability to allow the pilot to spend increasing amounts of visual time outside the cockpit. This benefit is realized at a cost--the amount of information displayed on the HUD has steadily increased. More information displayed on a HUD does not necessarily make a better HUD (Gold, 1968); in some cases a HUD is rendered less effective because of occlusion. The small space available on the HUD, and the continuing effort to reduce aircraft frontal area by forcing more instrument information onto the HUD, as well as inherent HUD design problems (Gibson, 1980) that contribute to the development of spatial disorientation, are reasons that HUD symbology must be examined for ease of use.

Spatial disorientation occurs when a pilot has an erroneous sense of the aircraft control and performance parameters normally displayed by the flight instruments (Gillingham, 1990). As flying operations dictate more dependence on the HUD, the HUD symbology must become more efficient to reduce the potential for spatial disorientation; i.e., it must be based on criteria developed from an understanding of the functioning of the visual system and of the impact various display designs have on perception of spatial orientation (Previc, 1989). To support the objective of an efficient, physiologically based HUD symbology, we examined five HUD altitude and airspeed display formats for relative ability to contribute to pilots' basic instrument flight performance in a visual flight simulator. The work was in conjunction with a larger HUD symbology standardization effort being managed by the USAF Instrument Flight Center (Evans, USAF IFC, personal communication, 1990).

METHOD

Subjects

Twenty-five experienced United States Air Force pilots, with an average age of 39 years and an average flight time of 2800 hours, were asked to fly a basic instrument profile, i.e., to maintain straight and level flight (2,000 feet and 360 knots), for 200 seconds. They were instructed to use the instrument flying technique taught in USAF undergraduate pilot training--that based on the control and performance concept of instrument flight (AFM 51-37, 1986). Since the task required the use of a basic instrument crosscheck, the subjects were required to be instrument rated military pilots with a good knowledge of instrument flight techniques and procedures. Seven subjects had operational HUD experience. Three of these subjects had experience on more than one type of HUD.

Apparatus

Subjects sat in a simulated aircraft seat with a side-stick controller on the right and a throttle on the left. The seat was in an isolated booth with a large projection screen on the front wall. HUD symbology was generated on a Silicon Graphics IRIS 3130 workstation and was rear-projected on the screen with a video projector (Figure 1). Each HUD symbol set consisted of pitch-ladder lines (climb-dive angle markers), a pitch index symbol (miniature aircraft), a ground pointer, a bank scale, a heading scale, and one of five different sets of airspeed and altitude readouts. A digital tachometer located on the lower left side of the traditional instrument panel helped the subjects establish of the beginning thrust needed for target airspeed (approximately 90% rpm for 360 knots). The aircraft dynamics were those of the F-16.

Experimental Design and Procedure

The five HUD altitude and airspeed symbol sets examined were (Figure 2): (A) rotating pointers with dots, (B) rotating pointers, (C) moving vertical tapes, (D) boxed digits, and (E) trend bars. The altitude was displayed on the right-hand side of the HUD, slightly above the mid-position, and the airspeed was displayed in a corresponding position on the left. In format A, pointers analogous to those of a round-dial altimeter or airspeed indicator rotated about the digital display like hands on a clock; ten dots were placed equidistantly around the circles described by the distal ends of the moving pointers. Format B was the same as Format A except that the dots were removed. Format C, vertical tapes (similar to those used in the F-16), consisted of moving altitude and airspeed scales indexed by stationary pointers on the medial sides of boxed digital displays. Plain boxed digits (similar to the symbology used in the F/A-18) constituted Format D. Format E displayed the instantaneous rates of change of the altitude and airspeed as trend bars above or below boxed digital displays; magnitudes and signs of altitude and airspeed changes were represented by the lengths and directions of the trend bars, respectively.

The sum of five sinusoids with different frequencies, amplitudes and phases was used to perturb the altitude represented in the simulated flight. Airspeed changes were the result of the subject's stick and throttle adjustments for altitude control. The changing altitude condition required the subjects repeatedly to recognize altitude and airspeed deviations (crosscheck) and then to adjust the aircraft attitude and power to reestablish target altitude and airspeed. The level of difficulty was similar to that of flight conditions requiring a continuous, concentrated instrument crosscheck. Altitude, airspeed, altitude perturbation, stick response, and throttle response were recorded. Deviations of altitude and airspeed from target values were calculated as root mean square (RMS) errors. All test subjects received the same altitude perturbation.

The experiment followed a within-subjects, repeated-measures design. Subjects practiced ad lib with each symbol set before performance was measured. Performance was first measured with 60 seconds of straight and wings-level flight without any altitude perturbation. The subjects were then given the 200 seconds of perturbed flight. The order of presentation of the five symbol sets was balanced to the extent possible to control for learning and other order effects. Since all order permutations (120) could not be achieved with the limited subject pool, each format was presented the same number of times in each order position. For example, Format A was presented five times each in the first, second, third, fourth, and fifth order position.

The pilots' post-test subjective estimates of confidence in their ability to use the various displays were also collected. We asked the subjects to rate the five displays on a scale from 1 to 5, with 1 representing the best and 5 representing the worst case.

RESULTS

The RMS altitude and airspeed performance errors (Table 1) were each subjected to an analysis of variance with one fixed factor (the five displays) and one random factor (the twenty-five subjects). For both altitude and airspeed measurements, the null hypothesis that the different displays were not associated with different performances was rejected ($p<0.0001$). Duncan's multiple range test revealed that, for altitude control, the trend bars and both rotating pointer formats were associated with performance scores significantly better ($p<0.01$) than those associated with the tapes and plain boxed digits. For airspeed control, the two rotating pointer formats gave better performance scores ($p<0.01$) than did the other three formats.

The results of the post-test subjective evaluations (Table 2) were consistent with the objective findings. A two-way analysis of variance on the ranked ratings (Friedman's Test) resulted in rejection of the null hypothesis: i.e., the subjects' confidence in their ability to use a display for the required task (instrument crosscheck) differred significantly ($p<0.0001$) across the displays. Duncan's multiple range test revealed the rotating pointer formats and the trend bars were preferred ($p<0.001$) over the other two formats.

DISCUSSION

The results suggest that altitude and airspeed information presented in the rotating pointer HUD formats is easier for pilots to assimilate than is such information presented in the vertical tapes and boxed digits formats. Rotating pointers are probably more effective because their position and movement are relatively easy to detect in parafoveal and peripheral vision while foveal vision is occupied with reading the digital representations of altitude/airspeed and with monitoring other parameters (e.g., pitch/bank attitude). These findings are consistent with recommendations for HUD standardization reported by researchers from the United Kingdom (Hall, Stephens, Penwill, 1989).

There were no significant altitude and airspeed performance differences between the rotating pointers with dots and the rotating pointers without dots. The obvious suggestion would be to eliminate the dots, thereby keeping the HUD free of unnecessary clutter. Another idea would be to use the dots to provide additional cues to the pilot. Dot size could be used to indicate blocks of altitude and airspeed; e.g., large dots would indicate low altitude and low airspeed, and no dots would indicate high altitude and high airspeed.

Because the subjects' flight experience was predominantly with the common rotating pointer type of display on the head-down instrument panel, it could be argued that better performance with the rotating pointer formats was merely a result of training and experience with similar presentations, like the round-dial altimeter and airspeed indicator. After examining each pilot's background, we noted that 9 subjects had flown predominantly with vertical tape instruments, while the remaining 16 subjects had flown with only rotating pointer instruments. A follow-up group (9 vs 16) by display by subject analysis of variance was therefore performed on the data. In this case the null hypothesis was accepted: there were no significant differences in performance between the two groups.

Thus, it appears that training or past experience with a particular format type did not necessarily influence instrument flying performance. Performance seems to be best with the rotating pointers because of the symbol design. But because all the subjects (even the tape users) had previous experience with rotating pointer instruments, a study with control over this experience variable would be required to help us understand to what extent a pilot's prior exposure to a particular format determines the relative efficacy of that format.

The fact that our pilot subjects had essentially no prior experience with trend bar displays, and yet exhibited as good altitude control with the trend bars as with the rotating pointers, suggests that the trend bar format may have an inherent advantage. We propose that a horizontally displayed airspeed trend format, as opposed to the vertical trend bar format used for airspeed in this study, be examined for relative efficacy.

CONCLUSION

If the HUD is to be used as a single-source primary flight reference in the types of aircraft and with the types of training programs currently available, a rotating pointer format for display of altitude and airspeed information should be a leading candidate for incorporation in a standard set of HUD symbols. Novel formats, such as trend bars, should also be considered for future standard HUD symbols.

TABLE 1: Pilot Subjects' Instrument Flying Performance (RMS error) while Using Different HUD Symbol Sets

ANOVA $p<0.0001$

	A Pointers with Dots	B Rotating Pointers	C Vertical Tapes	D Boxed Digits	E Trend Bars
N (subjects)	25	25	25	25	25
Altitude (ft)	124.98	130.78	192.91	207.24	117.92
S.E.	8.89	12.99	14.28	18.26	19.03

Duncan's Multiple Range Test:

A, B, E less than C, D ($p<0.01$)

Airspeed (kt)	5.986	6.480	8.646	9.729	8.412
S.E.	0.553	0.594	0.552	0.641	0.779

Duncan's Multiple Range Test Results:

A, B less than C, D, E ($p<0.01$)

TABLE 2: Pilots Subjects' Ratings of Different Symbol Sets

ANOVA $p<0.0001$

	A Pointer with Dots	B Rotating Pointers	C Vertical Tapes	D Boxed Digits	E Trend Bars
N (subjects)	25	25	25	25	25
MEAN	1.66	2.14	3.26	4.02	2.28
S.E.	0.15	0.15	0.22	0.19	0.22

Duncan's Multiple Range Test:

A, B, E less than C, D ($p<0.001$)

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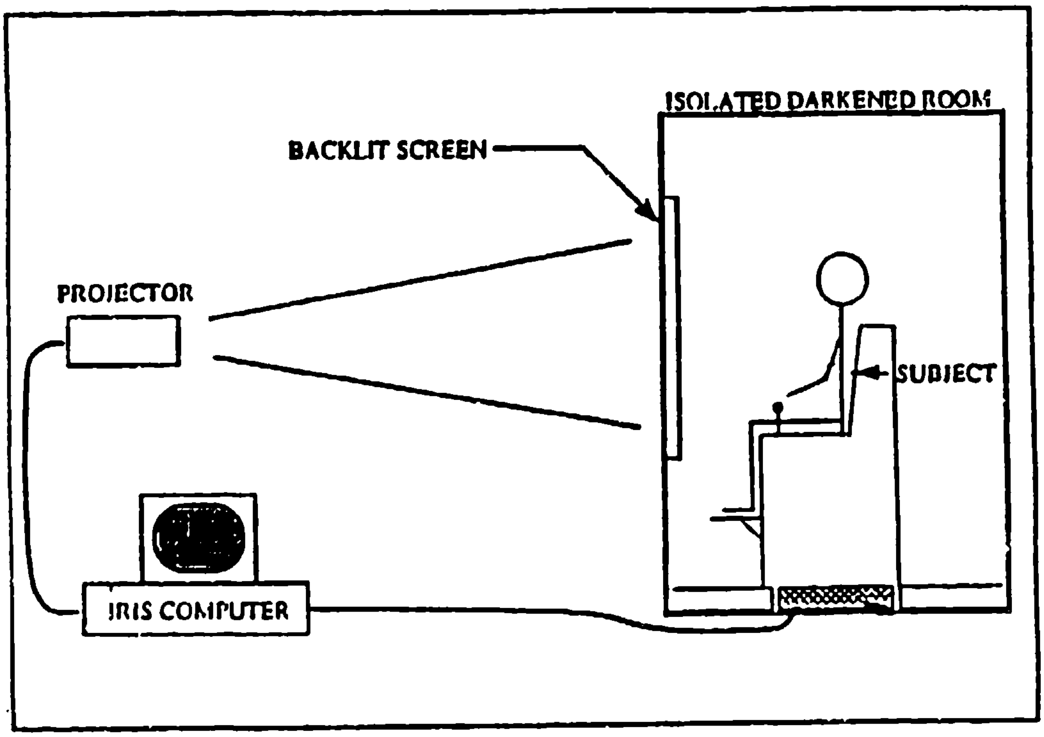
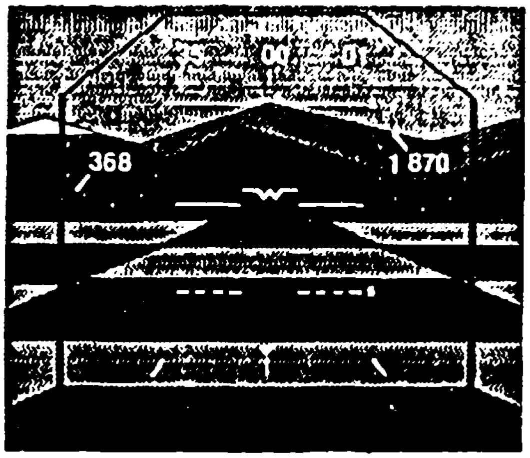
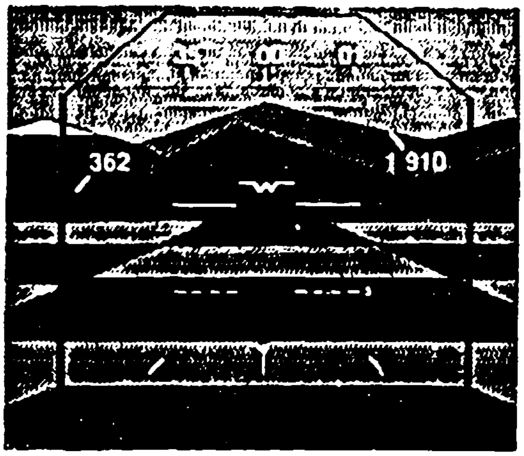


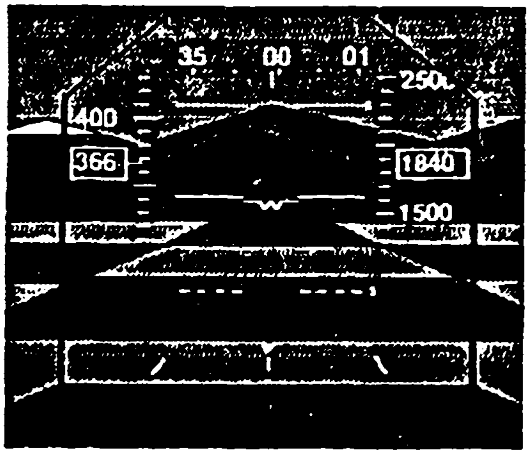
Figure 1. The Visual Orientation Laboratory



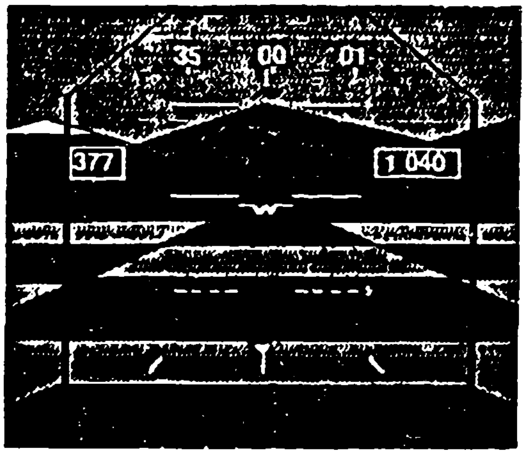
A ROTATING POINTERS WITH DOTS



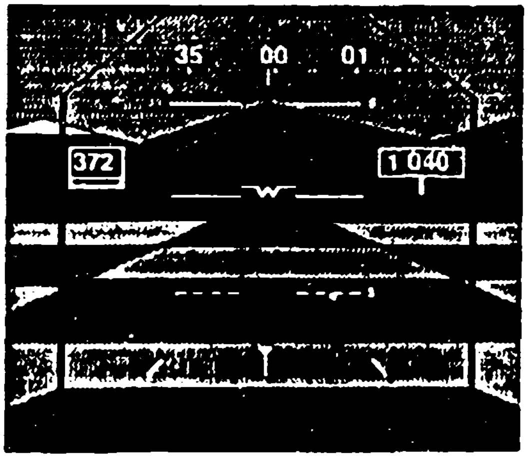
B ROTATING POINTERS



C VERTICAL TAPES



D BOXED DIGITS



E TREND BARS

Figure 2. The five HUD formats compared in this study.

Appendix B

DRAFT

CSEF-TR-90-IFC-001

A COMPARISON OF ALTERNATIVE HEAD-UP DISPLAY SYMBOL SETS DURING APPROACH AND LANDING, NAVIGATION, AND UNUSUAL ATTITUDE RECOVERY TASKS

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DRAFT

INTRODUCTION

In March 1989, HQ USAF released a report on the status of Instrument Flying Standardization. The report was prepared for the Chief of Staff of the United States Air Force and included discussions and specific recommendations for standardization in cockpit development.

The report states "Recent instrument related flight mishaps are causing a growing concern about reduction in Air Force instrument flight capability. Expanding technology and more realistic mission training are enhancing our ability to accomplish the complex employment portion of our flying mission. Unfortunately, this improved 'weapons on target' capability is not accompanied by a specific focus on basic instrument flight skills and overall instrument flight capability. This lack of emphasis, combined with overall lower pilot experience levels, is making our combat crews less capable of performing the instrument portion of their mission. The changes in cockpit design have created new problems as others were solved. A significant effort is needed to improve the current cockpit development process."

The report went on to identify several specific recommendations with regard to instrument flying standardization; the first of which is to "develop a standard for USAF instrument flight symbology, terminology, and mechanization for both head-up (HUD) and head-down displays. The standard should address the use of the HUD as a primary flight reference and the presence of a prominent, centrally located primary attitude display."

In response to this recommendation, the USAF Instrument Flight Center tasked the Crew Station Evaluation Facility (CSEF) to conduct a series of part task simulations to evaluate several alternative symbology sets for use on the HUD during instrument flying.

The aim of the evaluation was to assess alternative flight directors, airspeed/altitude scales and climb/dive angle (CDA) scales under various instrument flight conditions with emphasis on the ability of the pilot to acquire and maintain awareness of critical flight parameters. The specific objectives for this initial study were to evaluate pilot performance during: 1) A precision approach task using either a single cue or dual cue flight director, 2) Navigation and precision/non-precision approach tasks using either vertical tape scales or counter-pointer scales in the HUD to present altitude and airspeed information, 3) Recovery from unusual attitudes using either vertical tape or counter-pointer scales in the HUD to present altitude and airspeed, 4) Recovery from unusual attitudes using a tapered upper hemisphere CDA scale and a non-tapered upper hemisphere CDA scale, and 5) obtain pilot opinions and reaction to several features of the HUD which were not of experimental interest via subjective data from pilots relating to user acceptance, operational utility, workload, and safety of the symbology configurations under evaluation.

METHODS

Apparatus

Experimental Facility

The experiment was conducted at the Crew Station Evaluation Facility , an Air Force flight simulation facility that belongs to the Aeronautical Systems Division of the Air Force Systems Command, at Wright-Patterson AFB, Ohio. The facility is used to conduct human engineering and system design/mechanization studies in support of a variety of Air Force programs.

F-16 Simulator

The F-16 simulator was constructed using a salvaged single-seat F-16 cockpit, truncated in front of the forward portion of the windscreen and behind the canopy hinge. The cockpit controls and displays were configured to the F-16 Multi-Staged Improvement Program (MSIP) Block 40 design. This all digital design included two 4 x 4 inch Multifunction Displays (MFDs), a Wide Field-of-View (WFOV) Head-Up Display (HUD), and Integrated Control Panel (ICP), and Data Entry Display (DED), centralized flight instruments, and the LANTIRN avionics suite (terrain following, radar altimeter, forward looking infrared (FLIR), etc.). The side control stick, throttle, and flight controls were actual F-16 components, all of the other instruments, controls, and displays were simulated using locally available equipment. The aerodynamic model was the same one that is used for aircrew training, and its validity has been demonstrated in prior experiments.

Computer Complex

The computer complex at the CSEF consists of four Gould series 32/7780 mainframe computers, one Gould Concept 32/8730 mainframe computer, PDP 11/34 and 11/35 computers and a Silicon Graphics Iris 2400 graphics station.

Visual System

The out-of-window visual scene was provided using a computer generated Night Vision System (NVS).

Simulator Head-Up Display

The LANTIRN HUD simulation was created by using the model developed to verify the production design. The integrated control panel (ICP) was built and interfaced through software programming to provide full control of the HUD symbology. A Vector General symbol generator displayed the symbology, while a PDP 11/34 computer mapped and controlled the HUD's position. The Gould mainframe computers sent the flight parameters to the PDP computers to enable it to position the stroke symbology within the raster video scene so the pilot can use the ICP and the HUD imbedded symbology to fly the simulator.

Wind Gust Model

The wind gust algorithm output a wind vector for the crosswind conditions. This vector was summed to the aircraft CDAM and its effect depicted by lateral displacement of the ghost CDAM velocity vector. The runway heading was 264 degrees with the winds occurring 45 degrees off of the nose of the aircraft from either side.

Experimeter's Console

The experimeter's console included an intercom system for four experimenter/ observers, together with communication to and from the pilot inside the simulator. Console displays duplicated the pilot's HUD, data entry display (DED), and multifunction displays (MFDs) to enabled the experimenter to observe and monitor the pilot's performance. The console controls enable the experimenter to start, stop and reset the simulation. An attached computer terminal was used to access the mainframe computer to input the HUD format, subject number, set number, run number and to set up for data collection.

Baseline Head-Up Display

As stated earlier, the intent of this evaluation was to further the understanding of flight symbology and how presentation of alternative symbol sets may affect pilot performance during instrument flight. For this evaluation, F-16 HUD symbology was modified to formats created by the Instrument Flight Center and used as a baseline from which all deviations were made. This baseline set, shown in Figure 1, was created in accordance with Mil-Std-1787, primary flight reference display requirements.

The HUD incorporated several features that satisfy several of the requirements for a primary flight reference. The following are detailed descriptions of the make-up and functionality of this symbology.

Climb/Dive Angle Marker (CDAM). The CDAM operated like a Flight Path Marker (FPM) in the vertical axis to show a climb and dive angle referenced to the Climb/Dive Angle scale. Unlike a classical FPM, the CDA scale did not move left and right of center drift/yaw angles. In the current design, travel was limited at the top and bottom of the HUD

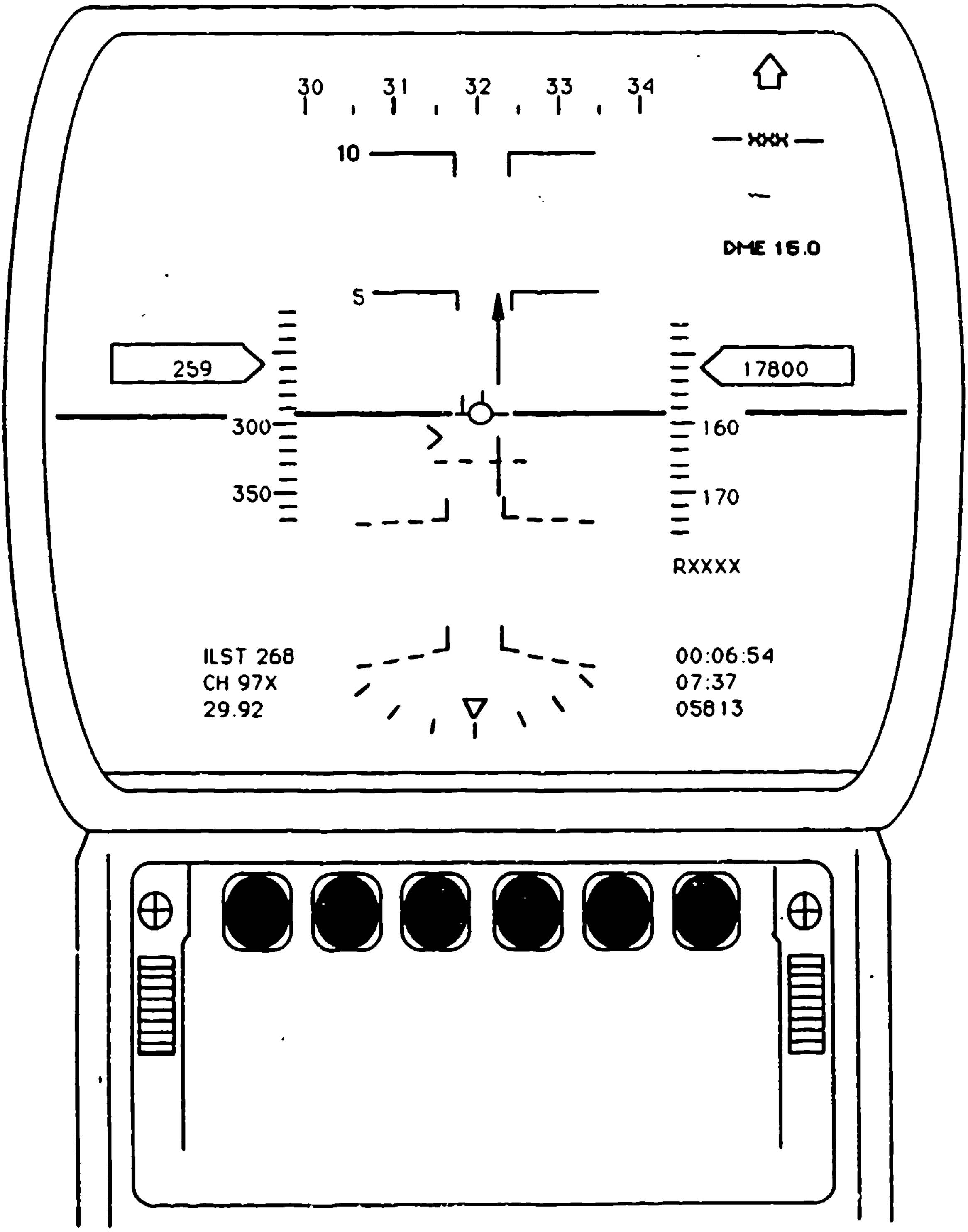


Figure 1. Baseline IFC HUD

field-of-view. When flight path exceeded HUD upper or lower FOV limits, an "X" was placed over the CDAM symbol to indicate that actual flight path was off the scale.

Ghost CDAM. A ghost CDAM appeared left or right of the CDAM when yaw and/or drift angle exceeds 2.5 degrees. This marker was a dashed version of the CDAM and showed actual aircraft flight path with respect to the outside visual scene (Figure 2).

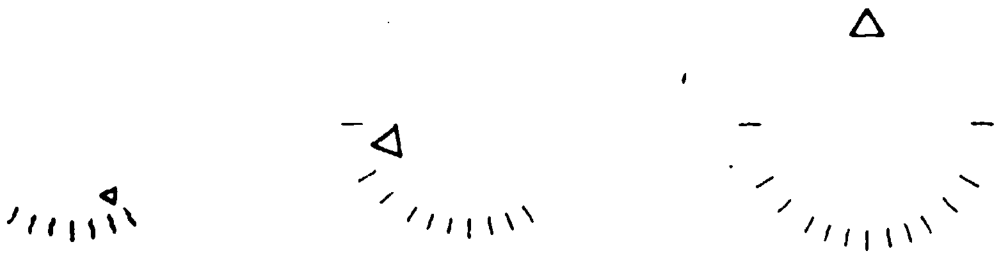
Climb/Dive Angle Marker

Ghost Climb/Dive Angle Marker

Figure 2. CDAM and Ghost CDAM

Bank Scale. A bank scale and a pointer were positioned at the bottom of the display. In near wings level flight, the scale displayed indices every 10 degrees up to 30 degrees left or right bank. As bank angle increased toward 30 degrees and beyond, scaling appeared at 45, 60 and 90 degrees. When bank angle increased beyond 60 , the bank pointer size doubled to make it easier to find. The bank scale was fixed laterally on the HUD centerline.

The bank pointer was displayed conventionally and served as a ground pointer. Unlike the F-16C Block 40 and F/A-18 display, this bank pointer, shown in Figure 3, was allowed to rotate through 360 degrees to aid in unusual attitude recoveries and in over-the-top/inverted maneuvers.



25 Right Bank

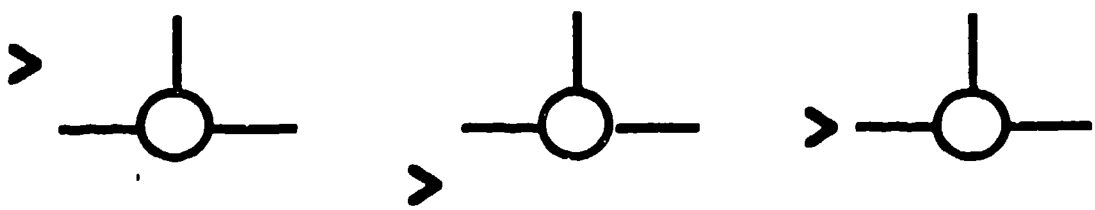
80 Left Bank

180 Inverted

Figure 3. Bank Scale

Longitudinal Acceleration Cue. This cue, shown in Figure 4, was used adjacent to the Climb/Dive Angle Marker (CDAM), or Flight Path Marker to display acceleration. When the cue was above the CDAM, the aircraft was accelerating; when it was below the CDAM, speed was decreasing.

The cue could be used in constant airspeed maneuvers (climb, penetration) as an aid to pitch control. In level flight, or in rate/flight path maneuvers, it should aid in power control to achieve and maintain a desired airspeed or angle-of-attack. For example, on GCA or ILS final approach (front side of power curve), power could be adjusted to accelerate/decelerate toward the desired speed of AOA. When on speed/AOA, the pilot would adjust power so as to position the cue opposite the CDAM "wing tip". (Figure 4)



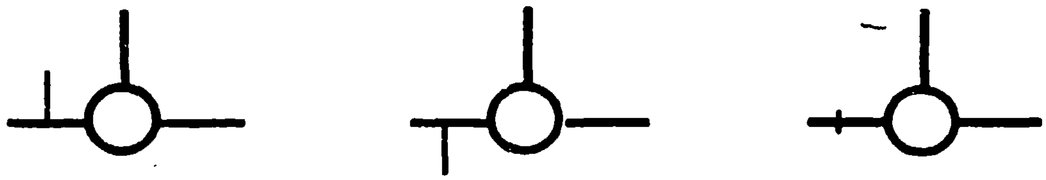
Accelerating

Decelerating

Constant Speed

Figure 4. Longitudinal Acceleration Cue

Angle-of-Attack (AOA) Error Cue "WORM". The AOA cue, shown in Figure 5, was optimized at an 11 degree AOA final approach. The cue appeared when the aircraft was configured for landing (gear down). When the cue extended above the CDAM "wing", AOA was low (airspeed high); below the "wing", AOA was high (airspeed low). When the cue overlayed the "wing", AOA was at 11 degrees.



Speed High/AOA Low Speed Low/AOA High Speed /AOA On

Figure 5. AOA Error Cue

Bearing. A bearing pointer, shown in Figure 6, was placed in the upper right of the display, showing approximate relative bearing to the selected navigation facility or INS steerpoint. Distance to the selected navigation facility/steerpoint was shown below the bearing pointer.

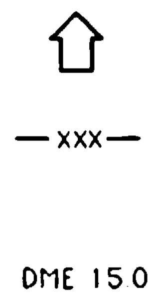


Figure 6. Bearing Pointer

Course Selector Arrow/Course Deviation Indicator (CDI). The course selector arrow was centered vertically on the CDAM and rotated through 360 degrees as a function of a selected course. The arrow was configured to act as both a course selector indication and a Course Deviation Indicator (CDI). A course deviation scale, perpendicular to the course arrow, was scaled conventionally. To reduce clutter in the vicinity of the CDAM, the off course dots appeared only when course deviation was 'significant'. For example, when intercepting a selected course on a 45 degree intercept from the right, the CDI would look as shown in Figure 7.

7.5 degrees off course on 45 degree intercept (VOR/TACAN)

On course

Figure 7. Course Deviation Indicator

Course Selector. The course selector function for TACAN and ILS was performed using the course selector knob on the HSI (the HSI display was covered during data collection). A digital course readout similar to an HSI was provided in a window on the lower left side of the HUD (see Figure 8). Unlike the HSI with a 360 degree compass rose, the selection on the HUD required the pilot to turn the knob in either direction to get the proper reading.

Navigation Data. Information on the navigation facility selected and the current navigation sub-mode was shown in the lower left portion of the HUD. An example of the format used in this design is shown in Figure 8.

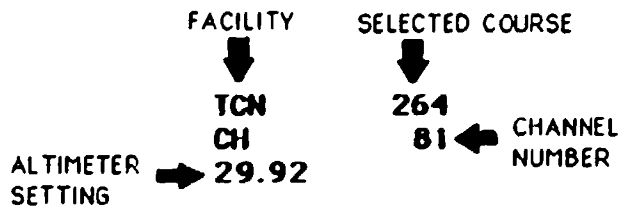
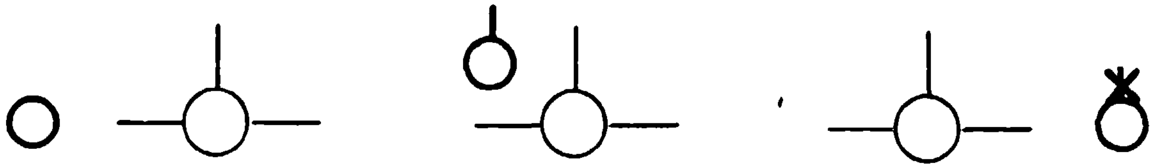


Figure 8. Navigation Data

Experimental Symbology

Flight Director (FD) Steering Cue. Two FD steering displays were used in the evaluation: The F-16 HUD single cue (Figure 9) and the dual steering bar (Fig 10) configuration similar to a standard Air Force ADI. Both steering displays were driven by the F-16 FD algorithm with mechanization changes made to make the dual cue operate conventionally.



Lateral steering prior to glideslope capture

Pitch and bank steering after glideslope capture; commanding nose up and left bank steering

Loss of glideslope steering when more than 8 degrees glideslope deviation after glideslope capture

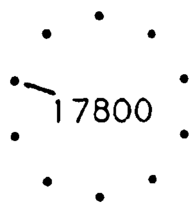
Figure 9. Single Cue Flight Director

Pitch steering command "nose down"
Roll steering command "left"

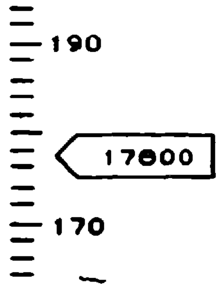
Pitch or bank steering commands satisfied

Figure 10. Dual Cue Flight Director

Airspeed and Altitude Displays. Two display formats were evaluated for speed and altitudepresentation: A tape format with digital readout (F-16) and a round dial format with digital readout, popular in the United Kingdom. For the purpose of this evaluation, only calibrated airspeed and barometric altitude were shown in these formats (Figure 11).



Dial/Digital



Vertical Tape/Digital

Figure 11. Altitude/Airspeed Formats

Climb/Dive Angle Scale. These lines were configured somewhat like the early A-7's, with horizon pointing tic marks at the inside of the line as opposed to locating them at the outer extremities, as they are in F-16/FA-18 aircraft. Scale lines above the horizon line were straight; those below the horizon were articulated toward the horizon at a value, in degrees, equal to one-half of the displayed climb/dive angle. For example, the line at -20 degrees was angled toward the horizon at 10 degrees.

Numerals displaying scale line values were placed only on one side of the scale indicating inverted flight when numerals were inverted and on the wrong side of the HUD. The horizon line was extended almost to the full width of the HUD FOV. To avoid conflict between the horizon line and other displays (altitude and airspeed), the line was always occluded by the scales (Figure 12).

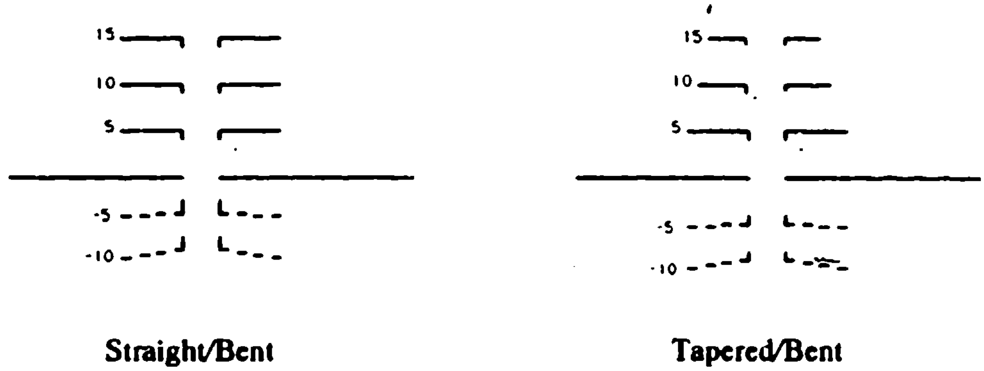


Figure 12. CDA Scales

Subjects

A total of eleven volunteer pilots participated as subjects in the evaluation, with subjects varying considerably in types of aircraft flown (6/F-16, 2/F-15, 1/F-4, 1/A-7, 1/A-10) and flying experience (1250 to 4000 flying hours). A review of pilot background is presented along with the results of the post evaluation survey in Appendix A. All of the pilots had at least some experience with instrument flying using HUD symbology. Seven of the pilots had experience flying the CSEF's F-16 simulator in previous studies.

Flight Tasks

In accomplishing the aforementioned objectives, four flight tasks were developed, each designed to require extensive use of the information presented via the symbology sets under evaluation. The first three tasks, being (1) a non-precision (TACAN) approach, (2) a navigation and (3) a precision (ILS) approach were combined to form a single flight profile. The approach profiles used in flying this portion of the mission are presented in Figures 13 & 14. Task 4 consisted of a series of unusual attitude recoveries.

Non-Precision (TACAN) Approach (Task 1). The aircraft was placed at DONAR

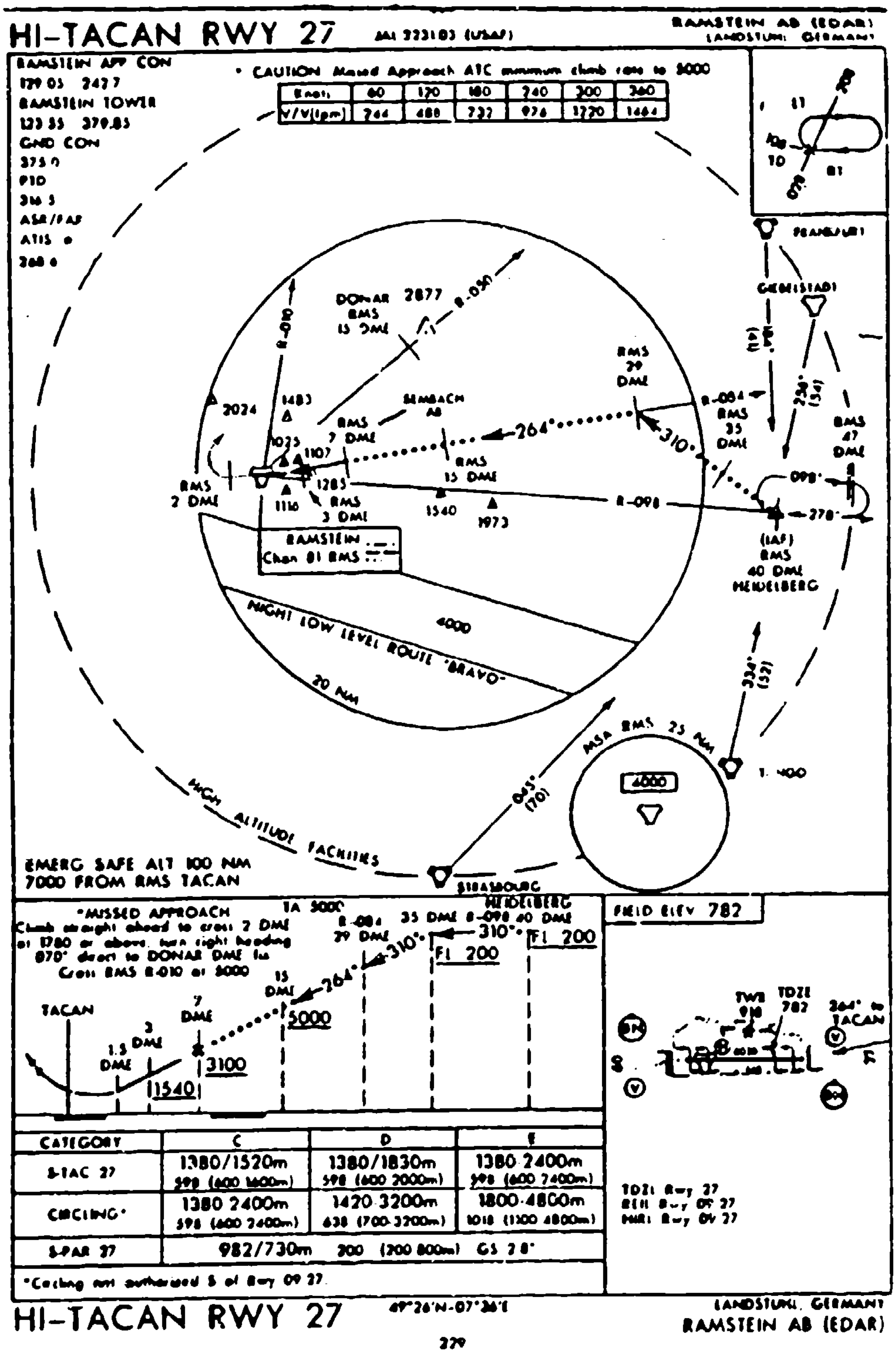
(IAF), 35 miles from the TACAN on a heading of 310. The pilot was briefed to fly on the established heading at FL200 until he was at the 29 DME mark at whioch time he was to turn to the final approach heading of 268, and fly a standard TACAN approach. Simulated weather conditions required the pilot to initiate a missed approach.

Navigation (Task 2). The standard missed approach had the pilot climb straight to cross 2 DME at 1780 or above, then turn right to a heading 070 to intercept the 050 radial. The only deviation to the standard missed approach had the pilot fly on a heading of 080, which enabled him to intercept the 050 radial earlier, so more data could be collected on the straight and level (5000') portion of the navigation segment.

From the 050 radial, the pilot was instructed to intercept the 15 DME arc in order to position the aircraft for the Ramstein ILS approach. Because there were no numerals associated with the HUD bearing pointer, pilots were instructed to select the published final approach course while on the arc. The CDI (in TACAN mode) could then be used to identify a lead radial for starting the turn to final. It should be noted that this procedure worked well for this Ramstien approach; there are many other approach procedures for which this would not be a satisfactory solution.

Precision (ILS) Approach (Task 3). In the turn to final approach from the 5000 ft arc, the aircraft was very close to the glideslope. Rather than descend to the initial approach altitude, pilots were briefed to intercept the glideslope prior to 12 miles. This provided additional time to establish the aircraft on final approach, use the two flight directors option and collect data. Weather conditions were set so that the transition to visual occurred at approximately 1 mile from touchdown for the full stop landing.

Unusual Attitude (UA) Recovery (Task 4). The trial began with a blacked HUD, while the autopilot flew the aircraft into the appropriate unusual attitude. Once the aircraft was properly positioned and trimmed, the experimenter indicated to the pilot that he could



CATEGORY	C	D	E
S-TAC 27	1380/1520m 598 (600 1600m)	1380/1830m 598 (600 2000m)	1380 2400m 598 (600 2400m)
CIRCLING*	1380 2400m 598 (600 2400m)	1420 3200m 638 (700 3200m)	1800 4800m 1018 (1100 4800m)
S-PAR 27	982/730m 200 (200 800m) GS 2.8°		

HI-TACAN RWY 27

LANDSTUHL, GERMANY
RAMSTEIN AB (EDAR)

279

Figure 13. HI-TACAN Approach Profile

DRAFT

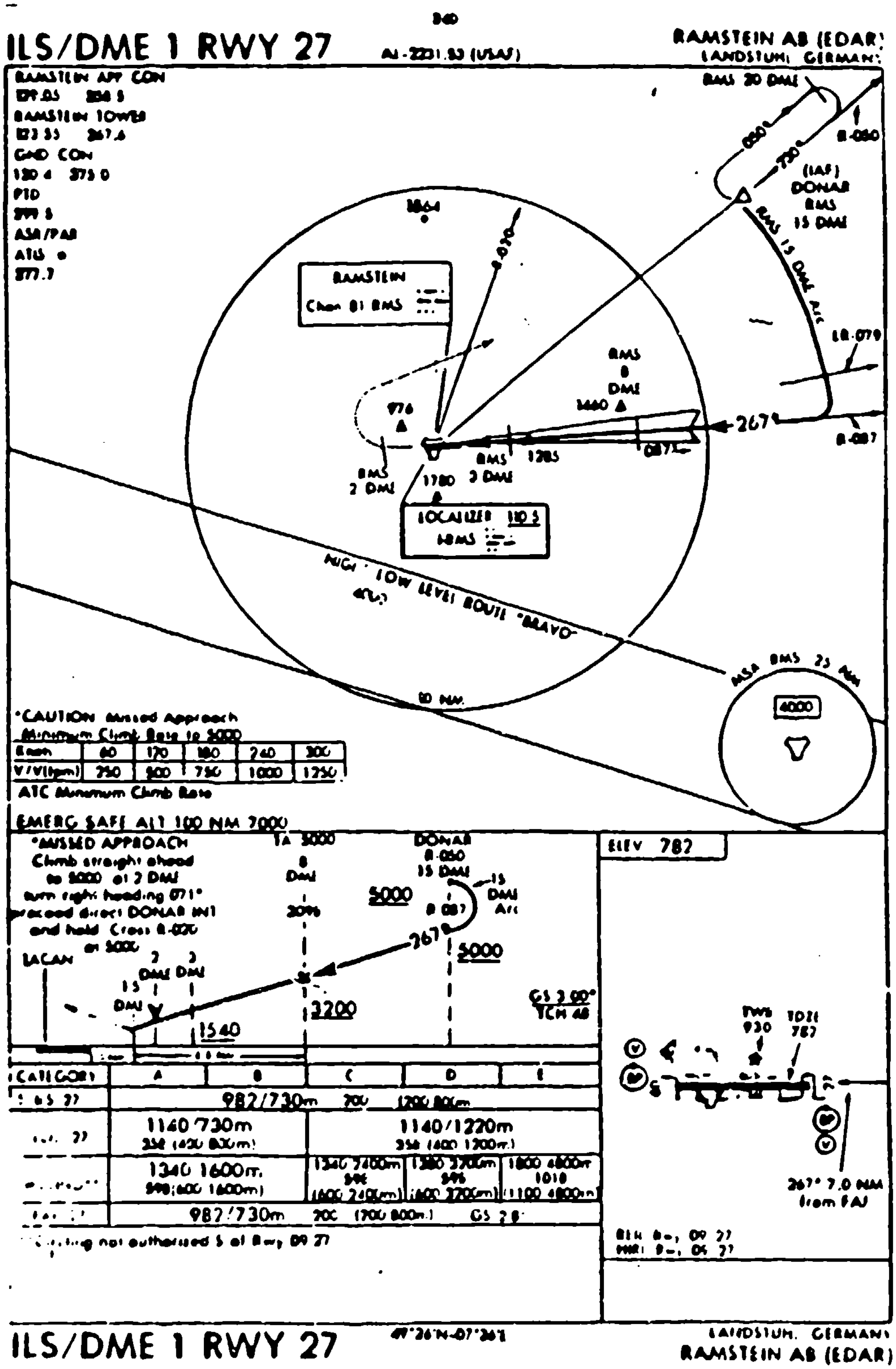


Figure 14. ILS Approach Profile

initiate the trial at any time. The pilot initiated the trial by depressing the radar cursor enable switch which activated the HUD. Half the trials were accompanied by a threat warning presented through a voice waring system to the pilot's headset (e.g., "SA-7") 0.3 seconds after pilot activation of the HUD. The pilot responded to the threat via the UHF/VHF switch (aft/chaff, forward/flare) while flying the aircraft to a straight and level flight attitude. Once the aircraft was held to within 3 degrees of pitch and 5 degrees of roll for a period of 2 seconds the HUD blanked and the trial ended.

Test Procedures

Each pilot was given a briefing on the Crew Station Evaluation Facility, followed by a detailed briefing about the study that included the objectives of the study, a description of the HUD formats being evaluated, and a detailed description of the four mission tasks the pilots would be flying during the course of the evaluation.

Once in the simulator the pilot flew as series of training profiles to become familiar with the HUD configurations and the tasks. The pilots would continue to fly the training profiles until 1) they become comfortable with each of the HUD configurations, and 2) demonstrated an understanding of the HUD by performing training profiles to an acceptable level of performance.

The pilots flew a total of four data collection sessions during the course of the study. Each session consisted of one approach profile, Tasks 1,2 and 3; and 18 unusual attitude recovery profiles. Before each block of UA recoveries, the pilots were presented with the HUD configuration to be flown and was given the opportunity to familiarize themselves with the dynamics of each symbol. After each data collection session the pilot was given a short break to reduce the effects of fatigue. Each session lasted approximately 50 min.

Once the pilots had completed the four data collection session, they were asked to commplete a short questionnaire and workload survey.

RESULTS

The cockpit encironment associated with the present simulation (and the aircraft) is so dieverse and dynamic that attempting to restrict the pilots' focus to one specific instrument or symbol is virtually impossible. Thus, while the objective of this study was to evaluate flight director, altitude/airspeed, and CDA scale symbology, most other instrument flying related symbology was also incorporated, resulting in a more complete mission scenario. This, in turn, decreased to level of experimenter control over the pilot's decisions and actions during task performance. To avoid overlooking any significant effects between the different configurations during the evaluation, it seemed appropriate to assume a liberal stand in rejecting the null hypothesis by selecting a confidence level (ρ value) of less than, or equal to 0.10. A review of the data collected during each task is provided in Table 1. A review of the mean values for each of the measure is provided in Table 2.

Table 1. Objective data parameters

Variable	Units	Explanation
Tasks 1-3		
Airpseed Deviation	knots	Number of kts deviation from briefed airspeed
Altitude Deviation	feet	Number of feet deviation from briefed altitude
Localizer Deviation	degrees	number of degrees horzontal deviation from glidepath
Glideslope Deviation	degrees	Number of degree vertical deviation from glidepath
AOA Deviation	degrees	Number of degrees deviation from approach angle of attack
Pitch Rate	degrees/sec	Rate of change of pitch angle
Roll Rate	degrees/sec	Rate of change of roll angle

Variable	Units	Explanation
Task 4		
Reaction Time	seconds	Number of seconds to first correct stick input
Response Time	seconds	Number of seconds to first stick input
Altitude Gain/Loss	feet	Number of feet lost or gained during course of recovery
Recovery Time	seconds	Number of seconds to recovery aircraft to wings level

Task 1. Non-precision TACAN Approach. The main purpose of Task 1 was to determine if a significant difference in pilot performance existed when flying with dials versus vertical tapes. Performance data were collected in each of four segments during this task. The segments defined by the distance from the TACAN station at which altitude minimums changed, were as follows: Segment 1: 35 - 29 DME; Segment 2: 29 - 15 DME; Segment 3: 15 - 7 DME; and Segment 4: 7 - 4 DME.

For each of the four segments, pitch rate Root Mean Square (RMS) was collected. During segment 1, RMS airspeed deviation was also collected. An analysis of variance showed a statistically significant increase in RMS airspeed deviaton during segment 1 for the vertical tape type airspeed/altitude display, $\underline{F}(1,8)=3.59$, $p<0.10$, indicating a significant performance advantage for the dial scales. All other dependent measures were not significant for this task.

Task 2. Navigation. As in Task 1, the main purpose of Task 2 was to determine if a significant difference in pilot performance existed when flying with dials versus vertical tape altitude and airspeed scales. Perofrmance data were collected in two segments during this task: (1) straight and level on the 050 radial and (2) maintaining level flight on a 15 mile DME arc between the 065 and 075 radials. Performance measures collected during each segment included: RMS pitch rate, RMS airspeed deviation, and RMS altitude deviation. None of these measures showed a statistically significant difference between the dials and vertical tapes during the navigation task.

Task 3. Precision ILS Approach. The main purpose of Task 3 was to determine if a significant difference in pilot performance existed when flying an ILS approach with a dual cue flight director versus a single cue flight director; and whether a performance difference existed when flying the same approach with dial versus tape altitude/airpseed scales. The task itself consisted of a single segment that ran from 12 - 2 DME. Performance measures analyzed indicated a statistically significant performance enhancement when using the dual cue flight director for RMS Airspeed Deviation, $F(1,8)=4.25$, $\rho<0.10$, RMS Glideslope Deviation, $F(1,8)=3.62)$, $\rho<0.10$, RMS Localizer Deviation, $F(1,8)=5.17$, $\rho<0.10$, RMS AOA Deviation, $F(1,8)=3.78$, $\rho<0.10$ aand RMS Roll Rate, $F(1,8)=5.55$, $\rho<0.10$.

Results of the analysis of variance of RMS Pitch Rate indicated a statistically significant interaction between type of flight director and altitude/airpeed scale type suggesting a performance advantage for the dual flight cue and dial altitude/airspeed scales, $F(3,35)=5.33$, $\rho<0.10$.

Task 4. Unusual Attitude Recovery. The purpose of Task 4 was to determine whether tapering of the CDA scale would serve as a significant additional cue to the pilots in recognizing and identifying unusual aircraft attitudes; thus, allowing them to recover more quickly and efficiently. Alternative altitude and airspeed scales were also compared to determine whether use of different presentation styles significantly assisted pilots in recognizing a nose-up versus a nose-down attitude via changes in altitude and airspeed. Data collected during the unusual attitude recovery task included: reaction time to first control input, reaction time to first correct control input, number of incorrect inital contol inputs, reaction time to countermeasure activation, number of correct/incorrect countermeasure activations, and altitude gain and loss. Analysis of these data showed no significant difference between either the two CDA scales or the altitude/airspeed scales for unusual attitude recovery.

Subjective Data

Pilot Questionnaire. Results of the pilot debrief questionnaire indicated a slight preferrnce for the single cue flight director. Six pilots expressed a preference for the single cue, three pilots expressed a preference for the dual cue and two pilots expressed no

Table 2. Mean values of performance measures

Task 1 Non-Precision (TACAN) Approach	**Tapes**	**Dials**
Segment 1 (35 - 29 DME)		
RMS Pitch Rate (deg/sec)	0.7361	0.8700
RMS Airspeed Deviation (kts)	24.259	16.042*
Segment 2 (29 - 15 DME)		
RMS Pitch Rate (deg/sec)	0.6394	0.8367
Segment 3 (15 - 7 DME)		
RMS Pitch Rate (deg/sec)	1.1290	1.1722
Segment 4 (7 - 4 DME)		
RMS Pitch Rate (deg/sec)	1.0456	0.8850
RMS Airspeed Deviation (kts)	13.883	12.074
Task 2 Navigation		
Segment 1 (5 - 12 DME on 050 radial)		
RMS Airspeed Deviation (kts)	19.713	15.986
RMS Altitude Deviation (ft)	316.60	241.28
Segement 2 (15 DME arc/065-075 radial)		
RMS Airspeed Deviation (kts)	9.7567	10.288
RMS Altitude Deviation (ft)	95.067	71.104

Table 2. Mean values of performance measures (cont)

Task 3 Precision (ILS) Approach		
Segment 1 (12 - 2 DME)	Tape	Dial
RMS Airspeed Deviation (kts)	35.822	25.233
RMS Glideslope Deviation (deg)	0.3539	0.2267
RMS Localizer Deviation (deg)	0.6294	0.2978*
RMS AOA Deviation (deg)	4.3122	3.5561*
RMS Pitch Rate (deg/sec)	1.1806	0.9172
RMS Roll Rate (deg/sec)	2.8455	2.7989
	Single Cue	Dual Cue
RMS Airspeed Deviation (kts)	33.485	27.570*
RMS Glideslope Deviation (deg)	0.3428	0.2378*
RMS Localizer Deviation (deg)	0.5411	0.3861*
RMS AOA Deviation (deg)	4.2694	3.5989*
RMS Pitch Rate (deg/sec)	1.1967	0.9172*
RMS Roll Rate (deg/sec)	3.1278	2.6665*

Task 4 Unusual Attitude Recoveries	Non-Tapered	Tapered
Reaction Time (sec)	1.6624	1.8590
Response Time (sec)	1.0867	1.1203
Recovery Time (sec)	10.857	10.045
Altitude Gain/Loss (feet)	1880.62	1866.22

* = Significant difference at the .10 level of confidence

preference.

Nine pilots expressed a preference for the dial type altitude/airspeed displays over the vertical tape type displays for both straight and level flight, and climbs and descents. Two pilots expressed a preference for the tapes. Pilot responses to other questions regarding specific mechanization features of the two flight directors, altitude/airspeed display, CDA scales, and other features of the HUD are presented in Appendix A of this report.

DISCUSSION

The remainder of this report will review the pilot responses during the post-evaluation interest (i.e., flight director, altitude/airpseed scales, and CDA scales), but also any other features of the HUD that the pilots found of value or distracted from their ability to perform the tasks. Because there were many features of this HUD which had, up to this point, never been flown in a dynamic simulator, pilot reactions to these features were of particular interest.

Control Information

Flight Director. Pilots reported a slight preference for the single cue flight director as opposed to the dual cue. This can be attributed, in part, to the fact that a majority of the pilots used in the study flew F-16s and were more accustomed to the single cue. Another reason for this preference may be attributed to the increased perception of clutter using the dual cue flight director. Several pilots reported losing the dual cue flight director or confusing it with other symbols central to the HUD (i.e., AOA/Airspeed Error Cue and CDI) during the turn to final.

Surprisingly, pilots performed at a significantly higher level when using the dual cue flight director across all performance (e.g., Glideslope, Localizer, AOA, Airspeed RMS deviation, pitch and roll rate RMS) measures recorded. These results are consistent with results of a similiar study under similiar conditions (Burns, 1990).

This contradiction may be attributed to the perception by several pilots that the single cue was more sensitive and therefore provided more accurate information. This increase in preceived sensitivity may have created pilot induced occilations which would have increased both glideslope/localizer deviation and pitch/roll rates.

Pitch Attitude/Vertical Path. For this simulation, the CDA scale and CDAM were centered laterally in the HUD as they are in existing Air Force HUDs when operating in a drift cutout mode. This mechanization was implemented as an aid in Instrument Metorological Conditions (IMC), with no outside visual references, because it eliminates one axis of freedom, reducing, to a great extent, the interference of control, performance, and some navigation information at high drift/yaw angles.

The CDA scale used in the evaluation featured dashed articulated lines below the horizon and straight lines above the horizon. This configuration was shown in a previous CSEF study (Ward, 1990) to improve pilot performance in unusual attitude recovery. The rationale behind the design was to provide the pilot with additional cues regarding nose up versus nose down attitude. This configuration increases the amount of asymmetry between the two hemispheres as an attempt to duplicate the effectiveness of the black and white ADI ball.

Although the objective data did not suggest improved performance of tapering, subjectively, tapering was preferred by most of the evaluators. In some cases, pilots doubted the utility of tapering in the beginning, but liked it as they gained experience. In one example, a pilot stated, after the first series of UA recoveries, that he could not detect the existence of tapering in maneuvering flight. In a later series without tapering, he said he "really missed it when it was gone." In discussions with the RAF on their use of tapering, they felt that moving the tic marks to the inside of the scale reduced the saliency of the tapered scale. By placing the tic marks on the outside, they feel that they have created a more pronounced effect.

Tic Marks. The tic marks on the CDA scale lines were moved from the outer ends of the lines. By moving the tic marks, the CDA scales provide an effective horizon pointer for use in UA recoveries. The feature was so effective that many pilots commented that their first cue for recovery was the orientation of the tic marks. In fact, since the pilots' first action was typically based on the orientation of the tic marks, the effectiveness of the tic marks may have occluded any difference we may have otherwise found between the two CDA scale configurations.

There were, however, some reservations with using the tic marks in this location. Although this configuration appears promising for UA recovery, some concern exists regarding the effects of this change in air-to-ground (A-G) applications such as low and high angle dives where the pilot attempts to fly a specific dive/climb angle. This might take away the appearance of precision, and pilots might fly to the tic mark instead of the extended scale line. In addition, some pilots expressed concern over the added cluttered in the central portion of the HUD created by the movement of the tic marks in both air-to-air (A-A) and A-G. There appears to be several advantages and disadvantages to placing the CDA scale tic marks on the inside and will require further evaluations to determine the optimum configuration.

CDA Scale Numbers. Numerals on the CDA scale were located only on the left side. This was done as an additional cue in roll attitude control. If the numbers appear on the right side, the aircraft is upside/down. This again was an attempt to create as much asymmetry as possible providing the pilot clear unambiguous information regarding aircraft attitude.

Numbering only on one side does, however, present two conditions that make scale values impossible to see. In a 90 degree right bank, the left side of the CDA scale starts to move off the HUD FOV at angles of attack over approximately ten degrees. In this condition, tapering and articulating the lines becomes increasingly important if the pilot is to have any indication of pitch/path angle. When a bank pointer is available, it can be used to roll the aircraft toward wings level (upright or inverted) to bring the numerals back into view.

Ghost CDAM. Several pilots commented on the appearance of the ghost marker in crosswind conditions and overwriting the glideslope deviation indicator (left crosswind) and the longitudinal acceleration cue (right crosswind) as an unnecessary distraction under the given task conditions.

Performance Information

Airspeed and Altitude Formats. Analysis of AOA and localizer RMS deviations suggested that pilots performed at a more proficient level when using the dial altitude/airspeed scales during ILS approaches. Although thses two measures are not directly related to altitude and airspeed, the results do indicate that because of the dial scales, the pilots crosscheck may have been more efficient, thus allowing more time for other monitoring/control tasks. The fact that RMS measures for airspeed deviations did not indicate enhanced performance may be attributed to the implementation of the longitudinal acceleration cue which enabled pilots to maintain awareness of changes in airspeed without monitoring airspeed scales.

Most pilots reported they preferred the round dial display as compared to the vertical tape displays for presentation of altitude/airspeed information. This may be attributed to several factors. In altitude control especially, the display looks much like the familiar mini-counter drum pointer similar to those found in head down altimeters. Also, as configured in this simulation, the separation between 100 scale markings was larger for the dial display than the vertical tape display (gear up). Pilots commented that this makes altitude changes/errors easier to see on the dial without reference to the digital readout, and, combined with the angular relationship of the pointers (airspeed and altitude), makes things easier to maintain or correct.

The airspeed and altitude dials are different diameters in the Royal Air Force (RAF) design. No rationale for this difference was given and pilots did not question it in this evaluation. However, a few pilots had problems maintaining a desired heading. This could have been caused by their crosscheck; perhaps, the location of the heading scale (top of HUD) and bank scale (bottom of HUD) caused it. Another possibility is, when the horizon line is close to the top or bottom of the dials, the difference in size causes a loss of symmetry of the appearance of "levelness." If a pilot inadvertently aligns the horizon to the top of the dial, the aircraft will be in a right turn; aligned to the bottom, it will be in a left turn. This design feature should be looked at more carefully.

Several pilots complained about the scales and dials dropping too low and too abruptly when transitioning to the gear down configuration. These were prepositioned to approximately the 11 degree AOA location so that speed and altitude values could be read close to the CDAM on final approach. As the wing flaps extend and AOA decreases for a short period of time, the horizon line and CDAM rise closer to the top of the HUD while the airspeed and altitude displays drop to the bottom. Happening just at the time when pitch/altitude control is difficult, the shift can be quite discomforting. While most pilots liked the location of the scales aligned with the CDAM during final, they also felt that a more gradual transition would be more appropriate.

Longitudinal Acceleration Cue. The subject pilots were nearly unanimous in their agreement that the longitudinal acceleration cue was a useful cue and would be of benefit during instrument flight. Several of the pilots commented that the central location of the cue and its proximity to the CDAM enabled them to maintain constant awareness of airspeed and reduced the time away from the flight director to crosscheck the airspeed indicator. Some pilots also indicated the cue would be of benefit during any navigation task that required the pilot to fly constant speeds.

As mechanized for this simulation, it appeared that the range of movement of the symbol was about right. Since it displayed actual aircraft acceleration, engine spool up/down time made it appear that the symbol followed throttle movement be a discernible time factor depending on how much or how fast the throttle was mved. As pilots gained experience with the display, improvement in the way they used it was noticeable.

There is little doubt that presentation of longitudinal acceleration could be improved upon either by modifying the way it is presented or, perhaps, by adding a lead term that would better predict where it would settle.

Angle-of-Attack/Airspeed Error Cue. This display which appearred on the left wing of the CDAM, indicated difference between the current AOA/Airspeed and the approach AOA/Airspeed. The cue was designed as a simple means to crosscheck airspeed and AOA without requiring the pilot to divert gaze from the CDAM and the flight director. Several pilots expressed a preference for the current F-16 AOA Error bracket for presentation of this information. The most frequent reason given for this preference was that the error cue used in this evaluation was too small and would tend to get lost in the other symbology during final approach, this problem was most evident when using the dual cue flight director because of the number of vertical lines located in close proximity to the CDAM. Some pilots reported difficulty in maintaining approach AOA once aircraft was established at or near approach AOA/airspeed. This may be attributed to the sensitivity of the cue. Several pilots recommended desensitizing the cue when at or near the approach AOA/airspeed.

Navigation Information

Bearing Pointer. The bearing pointer was used to indicated relative bearing to the selected navaid. For the most part, the pilots felt the cue was inadequate for intercepting an inbound or outbound course or doing point-to-point navigation. This could be attributed to the separation between the CDI which was centered on the CDAM and the bearing pointer which was located in the upper right corner of the HUD. Because both of these symbols appear on an HSI with a corresponding scale reference, most pilots expressed the need for a head-down HSI. Pilots did report that the bearing pointer was helpful in intercepting and maintaining an arc but did not provide enough information to make precise corrections using AFM 51-37 techniques. Pilots also expressed the need for precise radial information. As mechanized, the only way to determine, with any precision, what radial you were on was to use the course selector knob on the HSI and dial the course that centered the CDI on the CDAM. Originally, the three X's on the bearing pointer were to display current radial which would have solved this problem; however, it was not implemented during this evaluation.

Course Deviation Indicator (CDI). The CDI was mechanized in the evaluation to display the lateral and angular displacement of the aircraft from the selected course as it does in a conventional HSI. Nearly all the subject pilots found the symbol useful; however, several also found the symbol somewhat confusing under certain circumstances. Much of the confusion may be attributed to the amount of clutter in the center of the display. This problem seemed more prevalent when flying with the dual cue flight director. Before their turn to final, pilots typically configured for final approach (e.g., sellected INS mode and lowered landing gear) upon crossing the lead radial bringing the Bank Steering Bar and AOA error cue into view. Pilots reported difficulty in maintaining contact with the CDI and occasionally confused the bank steering bar with the CDI and vice versa.

CONCLUSIONS

The data collected in this evaluation suggest that a dual cue flight director yield better performance than the single cue flight director presently used in the F-16. However, the subjective data indicated a slight preference for the single cue flight director. In addition, analysis of pilot performance measures suggest that the dial altitude and airspeed scales yeild better performnace then the vertical tape scales; pilots also expressed a preference for the dial scales. Although theobjective data did not identify a difference between tapered and untapered CDA scales, the subjective data suggest a preference tapered CDA scales for UA recoveries.

DRAFT

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ANNEX 1

Pilot Questionnaire Responses

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Question 1

In this evaluation you used two flight director steering configurations, a single cue (tadpole) and dual cue (steering bars). Rate your preference.

Subject 1

Strongly prefer duel cue (5)

Subject 2

Somewhat prefer single cue (2)

Dual cue lines tend to get lost in clutter and lights on approach - otherwise would probably prefer

Subject 3

Somewhat prefer single cue (2)

Once course and glideslope are captured it seemed simpler to follow. There were fewer symbols to look at. The separate (dual) cues did seem to give earlier glideslope info when course was not quite captured.

Subject 4

Neutral (3)

Both were overly sensitive. Both were easy to interpret and make corrections to course/glideslope

Subject 5

Strongly prefer dual cue (5)

The single cue is very erratic because of the time lapse between display updates.

Subject 6

Strongly prefer single cue (1)

The tadpole is the easiest to use, especially coupled with ILS raw data
Dual cue is too sensitive

Subject 7

Strongly prefer single cue (1)

Flight director adds another bar and a bigger presentation than the tadpole which clutters up the HUD

Subject 8

Somewhat prefer single cue (2)

I leaned toward the tadpole because of my more recent F-16 experience. I still liked the 'T-38' bars, however, the sims course bar was too sensitive.

Subject 9

Strongly prefer single cue (1)

Single cue easier to interpret - based on easier recognition of motion. Longer baseline CDI is somewhat distracting

Subject 10

Neutral (3)

Prefer to have one on the HUD (pilot selectable) and the other down on the instrument panel. Needles used outside of 1 mile, tadpole inside of 1 mile.

Subject 11

Somewhat prefer dual cue (4)

1) Tadpole seemed too sensitive and could lead to PIOs

2) The separation of the tadpole and the glideslope indicator made cross check greater than dual cue.

3) I sometimes had to think about what the glideslope was telling me - was I high or low? What kind of correction did I need?

<u>Question 2</u>

When using the single cue flight director, the steering commands tripped to a null position when glideslope or localizer deviation exceeded certain limits. What is you opinion of this mechanization feature?

Subject 1

Neutral (3)

Subject 2

Poor/Dangerous (5)

Should always get valid steering

Subject 3

Neutral (3)

I'm used to it in the F-16 and have no strong feelings about it.

Subject 4

Neutral (3)

I can not recollect experiencing or seeing this mechanization. If it was there I was not using the information presented.

Subject 5

Neutral (3)

Its good to have some kind of safety feature when you're out of limits, I'd think there could be something better through. The null does not look that much different than the tadpole

Subject,6

Neutral (3)

It is OK as long as the steering is still displayed for the LOC. When the GS is lost, the tadpole should continue to show steering to the LOC with an X on top. This allows you to fly to LOC minimums. If LOC is out of limits you must execute missed approach or switch to TACAN

Subject 7

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Somewhat safe (2)

OK provided you can easily tell the cue is out of limits.

Subject 8

Somewhat safe (2)

Subject 9

N/A

Subject 10

Neutral (3)

Subject 11

Poor/Dangerous (5)

I would prefer that they went cross hatched or all the way to the side and that there.

<u>Question 3</u>

When using the dual cue flight director, once operating, the steering bars remained in view commanding a correction toward the localizer and glideslope as long as localizer and glideslope signals were good. Rate your feelings on this mechanization feature.

Subject 1

Excellent/Safe (1)

Subject 2

Excellent/Safe (1)

Subject 3

Somewhat safe (2)

See initial comment previous question

Subject 4

Neutral (3)

Subject 5

Excellent/Safe (1)

Subject 6

Somewhat safe (2)

Subject 7

Somewhat safe (2)

Subject 8

Somewhat safe (2)

Subject 9

Somewhat dangerous (4)

Steering cues should flash outside limits

Subject 10

Neutral (3)

Subject 11

Excellent/Safe (1)
That is what I was initially trained with so it seems more natural

Question 4/5

Did you, on any precision approach, think that pitch steering was available when it was not ? If yes, which display format?

Subject 1

Subject 2

Yes, Single steering cue

Subject 8

No

Subject 9

No

Neither bothered me

Subject 10

No

Subject 11

Don't know - Don't remember ever losing it, so I guess I didn't recognize when I actually did lose it.

Question 6-8

In this evaluation you used two airspeed and altitude formats, one displaying airspeed and altitude in a tape format with digital readouts and one using a round dial format with digital readout. Which do you prefer. Please comment on your rationale for your preference.

(a) Straight and Level flight

Subject 1

(a) Somewhat prefer round dials (4)
(b) Somewhat prefer round dials (4)
(c) Somewhat prefer tapes (2)

Subject 2

(a) Much prefer round dials (5)
(b) Much prefer round dials (5)
(c) Neutral (3)

Dials give better felling for trends/rates. Don't need to start at display to figure if slightly above/below desired altitude

Subject 3

(a) Much prefer round dials (5)
(b) Much prefer round dials (5)

(c) Neutral (3)

Analog view of deviations was much easier for me to recognize. Precise instrument flight seemed much less stressful with round dial presentations. Note: Airspeed scale seemed upside down to me. High numbers up and lower numbers down is the F-16 convention I'm used to. Reason -- in F-16 you don't lower nose to go faster, you just push up the throttle, therefore, this sims convention is not so applicable to and F-16 type flight control system and its associated flight control techniques.

Subject 4

(a) Much prefer round dials (5)
(b) Much prefer round dials (5)
(c) Somewhat prefer round dials (4)

Round dials were easy to detect deviations, to set precise settings, to adjust rate of change, and to generally gather information without looking directly at the readout/display

Subject 5

(a) Much prefer round dials (5)
(b) Much prefer round dials (5)
(c) Much prefer round dials (5)

Subject 6

(a) Much prefer tapes (1)
(b) Much prefer tapes (1)
(c) Much prefer tapes (1)

Tapes should roll the same way. Higher airspeeds and altitudes should be at the top. It is easier to keep track of high (alt or a/s) is up and low is down. Fix it like current F-16 A/S and Alt

Subject 7

(a) Somewhat prefer tapes (2)
(b) Somewhat prefer tapes (2)
(c) Neutral (3)

Subject 8

(a) Somewhat prefer tapes (2)
(b) Strongly prefer tapes (1)
(c) Strongly prefer tapes (1)

Round dials did not give me a 'head-up' of approaching altitudes or airspeeds. With a tape I can see the desired numbers coming up.

Subject 9

(a) Somewhat prefer round dials (4)
(b) Somewhat prefer round dials (4)
(c) Somewhat prefer round dials (4)

Spent a little bit more time interpreting tapes

Subject 10

(a) Somewhat prefer round dials
(b) Neutral (3)
(c) Neutral (3)

Both OK, circular was a little raster to read

Subject 11

(a) Much prefer round dials (4)
(b) Much prefer round dials (4)
(c) Neutral (3)

1) The round dials were easier to read for exact A/S and ALT
2) The round dials were easier to determine when I was off conditions.
3) The round dials have me better feedback for trends away/toward desired conditions.

<u>**Question 9**</u>

In this evaluation you were presented with two different CDA scale configurations, one tapered the scale in the upper hemisphere the other did not. Rate your preference in recovering from unusual attitudes between the two configurations. Please comment on your rationale for preference of one configuration over the other.

Subject 1

Somewhat prefer tapered scale (2)

Subject 2

Neutral (3)

Didn't notice any difference during tests

Subject 3

Neutral (3)

Could not really recognize the taper in "heat of battle"

Subject 4

Neutral (3)

In determining horizon position the taper did not give the first clue by rather the pitch of the sloped lines and the horizon pointer were quickly ciphered.

Subject 5

Somewhat prefer tapered CDA scales (2)

Extra info and does not take away from anything else.

Subject 6

Neutral (3)

Both were equal since each line has a pointer to the horizon (tic marks on the inside of pitch lines pointing to horizon).

Subject 7

Strongly prefer tapered CDA scale (1)

Taper marks really help.

Subject 8

Strongly prefer tapered CDA scale (1)

I would like to have the same habit pattern for recovering in the direction that the CDAs are tapered to.

Subject 9

Neutral (3)

Tapered only slight preferred, very little distinction. Cued primarily off of tic marks on inside of pitch lines. Need bigger pitch ladder numbers.

Subject 10

Strongly prefer tapered CDA scale (1)

Tapered caused less confusion

Subject 11

Strongly prefer tapered CDA scale (1)

Tapered gave me a better clue about the aircraft approaching extreme flight attitudes.

<u>Question 10-11</u>

A bearing pointer has been installed in the HUD to show approximate relative bearing to, in this case, the TACAN. Rate your opinion of this display feature.

(a) For intercepting an inbound/outbound course:

(b) For intercepting and arc:

Subject 1

(a) Useful, about equal to an HSI (2)

(b) Very useful, equal to an HSI (1)

Subject 2

(a) Not very useful, not like an HSI (4)

(b) Very useful, equal to an HSI (1)

Without digital bearing info, would have to refer to HSI anyway (either in HUD or head down)

Don't need digital bearing for intercepting arc

Subject 3

(a) Very useful, equal to an HSI (1)

(b) Very useful, equal to an HSI (1)

Worked well

Subject 4

(a) Not very useful, not like an HSI (4)

(b) Marginally useful (3)

More information was necessary. A magnetic bearing would be useful. With the symbol up and right outside the field of vision, I had to a make a positive effort to look at it to gain

any useful information.
I could not make precise corrections from AFM 51-37 techniques to maintain the arc. I had to use my experience and knowledge of expected performance to maintain the arc.

Subject 5

(a) Marginally useful (3)
(b) Marginally useful (3)

You certainly need it but its too high. Also its very disorienting not being able to tell what radial you are on
If you didn't have it, how else would you intercept an arc? So you need it but it would be nice to have better trend information

Subject 6

(a) Marginally useful (3)
(b) Useful, about equal to an HSI

OK for maintaining an arc but you cannot do a point. The only way you can tell which radial you are on is to turn the CRS knob until it centers

Subject 7

(a) Not very useful, not like an HSI (4)
(b) Useful, about equal to an HSI (2)

Only good for arcing, Can not tell lead points very easily

Subject 8

(a) Marginally useful (3)
(b) Useful, about equal to an HSI (2)

Did not try them but I would think fix-to-fixes would be difficult compared to using HSI
Not as accurate, obviously

Subject 9

(a) Marginally useful (3)
(b) Very useful, equal to an HSI (1)

Needs definition in course/radial
Great for minor changes

Subject 10

(a) Useless, of no value (5)
(b) Useless, of no value (5)

My kingdom for an instrument panel mounted HSI, How do you do point to point NAV on the HUD?
Too many extra steps. To intercept the 050 radial outbound you can look at an HSI and tell if you're there. With the HUD you're forced to dial in the course on the CDI. Not a good extra manual input step when going missed approach.

Subject 11

(a) Not very useful, not like an HSI (4)

(b) Useful, about equal to an HSI (2)
That took awhile to get used to. I would have liked to see a 'tail' for radial information to keep my situational awareness of position in relation to the TACAN (N,E,S,W,etc.) After awhile I got the hang of it for arc intercepts. Still didn't give me as much info as an HSI bearing pointer for staying on or correcting back to an arc.

Question 12

A CDI has been configured on the HUD to show the angular relationship of the aircraft (heading) to the selected course. Its mechanization is similar to an Air Force HSI except that the course selector arrow and CDI have been combined and course deviation dots appear only when they have significance. Rate your feelings on this display feature.

Subject 1

Somewhat useful (2)

Subject 2

Somewhat useful (2)

Would prefer digital bearing data near head of CDI/arrow

Subject 3

Somewhat useful (2)

Once course is close, it is as useful as CDI. When away from course not as much information is available as with CDI, i.e., bearing point and CDI and course selector arrow give some good information on HSI that is not available here.

Subject 4

Somewhat useful (2)

Placing this display in the middle of my primary field of vision I became momentarily disoriented when change course due to the rotation of the symbol set. The was more prevalent in a pitch up turn.

Subject 5

Somewhat useful (2)

Very confusing. There are so many vertical lines all coming in to play at the same time. When the bank steering bars come into view, on some approaches, its also time to lower the gear so everything changes at once. Also, you are changing to ILS around the same time. I had a difficult time figuring if I was left of right of course for about 5-10 sec rolling out on final.

Subject 6

Very useful (1)

Do not break the line when it comes in contact with the FPM. Run the line through the FPM just like the LOC.

Subject 7

Somewhat useful (2)

Useful for HUD only head-up approaches

Subject 8

Somewhat useful (2)

If a lead turn from an arc to a course of greater than 10 degrees is required; you have no way of measuring it until the display for what radial you're on/passing works

Subject 9

Somewhat useful (2)

Like it - results in less clutter on approach

Subject 10

Somewhat useful (2)

I found it confusing at times. Give me an HSI with a TACAN needle.

Subject 11

Somewhat useful (2)

Again, it took awhile before it became user friendly to me, but after the first couple approaches, I got pretty used to it.

<u>Question 13-17</u>

Longitudinal Acceleration Cue

(a) Rate the utility of the longitudinal acceleration cue as a display parameter for speed control

(b) Rate the sensitivity of the cue

(c) Where did you find the cue most useful?

(d) Where did you find the cue least useful?

(e) Would you like to have this cue on your HUD?

Subject 1

(a) Neutral (3)

(b) About right (3)

(c) Level flight (power control) (1)

(d) Penetration (pitch control) (2)

(e) Yes, if optimized (2)

Needs other location

Subject 2

(a) Very helpful (1)

(b) About right (3)

(c) All phases (1-4)

(d) Penetration (pitch control) (2)

(e) Yes (1)

Useful in all modes of flight

Subject 3

(a) Somewhat helpful (2)
(b) About right (3)
(c) Level flight (power control) (1)
(d) Penetration (pitch control) (2)
(e) Yes, if optimized (2)

I did not need it with round dial. Trends could be seen will without. With tapes it gave some good information.

Subject 4

(a) Very helpful (1)
(b) About right (3)
(c) Penetration (pitch control) (2)
(d) Precision final (4)
(e) Yes, if optimized

This made all phases of flight in power/pitch control extremely easy and took a lot of guess work or trial and error out of instrument flight.

Subject 5

(a) Somewhat helpful (2)
(b) About right (3)
(c) Precision final (4)
(d) Non-precision final (3)
(e) Yes

Subject 6

(a) Of little use (4)
(b) About right (3)
(c) Non-precision final (3)
(d) Penetration (pitch control)
(e) No

Subject 7

(a) Very helpful (1)
(b) Somewhat sluggish (4)
(c) Penetration (2)
(d)
(e) Yes, if optimized

Need less lag but could be used better once you got used to it.

Subject 8

(a) Somewhat helpful (2)
(b) About right (3)
(c) Precision final (4)
(d) Penetration (pitch control)

(e) Yes, if optimized

Subject 9

(a) Somewhat helpful (2)

(b) Somewhat sensitive (2)

(c) Precision final (4)

(d) Non-precision final (3)

(e) Yes, if optimized

Would nave felt better about it after some flights using it

Subject 10

(a) Very useful (1)

(b) About right (3)

(c) Level flight (pitch control) (1)

(d) Non-precision final (3)/Precision final (4)

(e) Yes (1)

Subject 11

(a) Somewhat helpful (2)

(b) About right (3)

(c) Level flight (pitch control) (1)

(d) Penetration (but still some use) (2)

(e) Yes (1)

It might have been a sim problem, but I thought I had it centered at times and my airspeed would still be off by 10-20 kts quickly without me knowing it.

<u>Question 18-20</u>

AOA Error

(a) Rate utility of the AOA Error Cue

(b) Rate the sensitivity of the AOA Error Cue

(c) Would you like to have this cue on your HUD?

Subject 1

(a) Somewhat helpful (2)

(b) About right (3)

(c) Yes, if optimized

Needs to go away when within small deviations.

Subject 2

(a) Very helpful (1)

(b) About right (3)

(c) No

About same as AOA bracket except get more info from bracket

Subject 3

(a) Of no use (5)

(b) Somewhat sensitive (2)

(c) No

Too dynamic! In landing phase did not give near the same AOA trend info that F-16 bracket currently gives. Therefore, landings require pure airspeed control vs AOA control to touchdown.

Subject 4

(a) Somewhat helpful (2)

(b) About right (3)

(c) Yes, if optimized

At or near on-speed this cue was too precise or sensitive enough to maintain an exact AOA. I used the horizontal airspeed cue to determine rate and then the AOA cue to approximate magnitude.

Subject 5

(a) Very helpful (1)

(b) About right (3)

(c) Yes (1)

Subject 6

(a) Of no use (5)

(b) About right (3)

(c) No

This cue is confusing. It looks too much lice a CDI with the gear down. Use a bracket with offset from the FPM like currently in the F-16

Subject 7

(a) Of little use (4)

(b) Somewhat sluggish (4)

(c) Yes, if optimized

The current E bracket on the F-16C HUD is fine. It is larger than the AOA error cue on this simulation

Subject 8

(a) Somewhat helpful (2)

(b) About right (3)

(c) Yes, if optimized

I liked it

Subject 9

(a) Of little use (4)

(b) Somewhat sluggish (4)

(c) Yes, if optimized

Basic flight reference

Subject 10

(a) Very helpful (1)
(b) About right (3)
(c) Yes

Subject 11

(a) Of little use (4)
(b) About right (3)
(c) Yes if optimized

1) being right next to the FPM, I was fighting the urge to fly the marker toward it
2) It was difficult to see the base of the 'stick' so slow 'stick' looked just like fast 'stick'

<u>Question 21</u>

Please rate the HUDs used for the approach and landings in terms of display clutter.

Subject 1

Somewhat cluttered (2)

Subject 2

Too cluttered (1)

Particularly 2-bar flight director at night - bars get lost in pitch bars and bank indicator on approach.

Subject 3

Somewhat cluttered (2)

In all displays, I did not like the position of the A/S and Alt scales whet down. In landing (gear down) phase, the info did not seem as readily available. Maybe this was due to clutter, not sure.

Subject 4

Somewhat cluttered (2)

Some displays such as the AOA cue was lost in approach lights or obscured the runway environment. The horizontal airspeed cue was sometimes lost in the same manner or in the ghost FPM. Inside 2-3 miles on final the clutter of symbols where the runway environment should be is disconcerting and distracting.

Subject 5

Too cluttered (1)

Especially if you are VFR at night. The landing lights are so bright you can't see much of anything and tend to fly high or low so you can. Too many vertical lines on the display tends to be confusing.

Subject 6

Neutral (3)

The HUD is good but you could eliminate the acceleration cue

Subject 7

Somewhat cluttered (2)

Subject 8

Somewhat uncluttered (4)

Subject 9

Somewhat cluttered (2)

Subject 10

Relatively Uncluttered (5)

Subject 11

Relatively uncluttered (5)

The HUD had the info I needed, but sometimes the symbols ran into each other. I did not like the Ghost coming in and out of view. When it was visible it didn't really tell me anything and was distractive.

Question 22-23

A bank scale and pointer has bèn placed low in the HUD for use in bank angle control in instrument flight and for use in unusual attitude recoveries. Rate the utility of this display for:

(a) Normal instrument maneuvering

(b) Unusual attitude recoveries

Subject 4

(a) Somewhat helpful (2)

(b) Of little use (4)

For unusual attitudes it was adding to spacial misorientation during the first moments of interpretation. This was because the triangular pointer was opposite the horizon. It might help to have it remain pointed to the horizon.

Subject 5

(a) Somewhat helpful (2)

(b) Somewhat helpful (2)

1) It is too low on the HUD

2) Helpful mostly during inverted recoveries - that was about the only time I used it and that was because of the triangle.

Subject 6

(a) Very helpful (1)

(b) Of no use (5)

Subject 7

(a) Somewhat helpful (2)

(b) Very helpful (1)

Subject 8

(a) Very helpful (1)

(b) Very helpful (1)

Subject 9

(a) Somewhat helpful (2)

(b) Of little use (4)

Numbers/scales/pitch ladder more obvious than bank marker\

90 degrees down needs definition from marker

Subject 10

(a) Very helpful (1)

(b) Of little use (4)

Never used or even noticed it in recoveries.

Subject 11

(a) Somewhat helpful (2)

(b) Neutral (3)

1) They (the scales) were all the same length. Need to have the 30/45/60 degree larger for easy reference.

2) I would lose that bank marker during nose low conditions and had troubles sometimes determining which way to roll. Did it get lost in the vertical indicators?

__Question 24__

A ghost FPM providing 'actual' flight path information appears at drift angles greater than 3 degrees. Rate the utility of this display feature.

Subject 4

Of little use (4)

Prior to inside final approach I could not use it to increase my perception of situation of relation to any navigational requirements. Inside the FAF it was not always reset or flashed in and out of view so much that it was more distracting than useful.

Subject 5

No rating

I never really used it

Subject 6

Of no use (5)

The ghost clutters up the HUD. It is better to display heading with a line and ground track with an arrow. If in normal flight the FPM tells you if the winds are causing you to drift.

Subject 7

Of no use (5)

Clutters the HUD too much. I prefer the current F-16 type FPM with the switch for drift cutout when required.

Subject 8

Somewhat helpful (2)

Subject 9

Of little use (4)

Subject 10

Neutral (3)

Subject 11

Of no use (5)

See other comments. I didn't like the ghost at all!!

Other comments:

Subject 6

Why not incorporate a steering cue for TACAN?

Subject 10

1) When lowering gear, the A/S and Alt display went down too far, too fast. If I followed it, I would end up 10 degrees nose down. I found I had to lock on the flight path marker and the horizon. A/S and Alt dropped completely out of the scan during this time (10-15 sec) GET AN HSI w/ TACAN!!!