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Volume I

IMPROVEMENT OF HEAD-UP DISPLAY STANDARDS

Volume I: Head-Up Display Design Guide (Appendix)

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This report has been reviewed by the Office of Public Affairs (ASD/PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

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

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A design guide for Head-Up Displays (HUDs) has been prepared to assist the HUD engineer by providing in one source a list of design criteria for HUDs. The criteria are based on a review of existing HUD specifications and HUD research.

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Summary

A design guide for head-up displays (HUDs) has been prepared to assist the HUD engineer by providing in one source a list of design criteria for HUDs. The criteria are based on a review of existing HUD specifications and HUD research.

Acknowledgement

This design guide was prepared as part of a program to develop new criteria for HUDs. This program had five tasks. Task A was a flight test effort to develop dynamic response criteria for HUD control laws using a variable stability NT-33 aircraft. Task B was a flight test program to determine the accuracy requirements for HUD gyro platforms. Task B was carried out simultaneously with task A. Task C was a simulation study designed to improve symbology for unusual attitude recognition and recovery. Task D was the preparation of this design guide. Task E was a review of HUD safety.

This work was performed under contract F33615-85-C-3602 and sponsored by the Flight Dynamics Laboratory, Aeronautical Systems Division (AFSC), United States Air Force, Wright-Patterson AFB. Mr. William Augustine served as Government Project Engineer.

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DESIGN GUIDE FOR HEAD-UP DISPLAYS (HUDs)

FOR FIXED-WING AIRCRAFT

I. PURPOSE AND SCOPE

A. PURPOSE

This document presents recommendations for the general design and performance for fixed-wing aircraft head-up displays (HUDs).

B. SCOPE

These recommendations are applicable to HUD systems which display flight information in virtual images in the pilot's forward field of view. They do not address devices for peripheral vision or helmet mounted displays worn by the pilot.

HUD systems considered will include those displays used for routine flying maneuvers, for all-weather instrument landing, for weapons delivery, and for other specialized uses. This HUD design guide is intended for all fixed-wing aircraft, tactical, transport, and specialized mission aircraft. Where appropriate, recommended values will be shown for each type of aircraft.

C. GENERAL

HUD systems are intended to provide the pilot with a display to enable him to view real world cues in conjunction with on board flight information. This combination of real world cues and artificial cues requires displays which are collimated at infinity and have an adequate field-of-view (FOV) for the intended operation. These displays will be used for aircraft control, hence it is essential that the symbols shown on the HUD be appropriate for flying the aircraft and be compatible with the real world cues. While the discussions refer to pilots and imply the use of HUDs for flight guidance and control, most of the recommendations apply to HUDs used by other crew members.

D. SOURCES OF RECOMMENDATIONS

These recommendations are based on characteristics of HUDs found in the past to have desirable characteristics based on pilot opinion. They are also based on HUD research where germane to the issues.

II. DEFINITIONS

A. GENERAL DEFINITIONS

1. HEAD-UP DISPLAY (HUD): The HUD is a display which projects collimated symbol imagery into the pilot's forward field of view. The technique results in the combination of flight control information possibly combined with weapon delivery cues and external visual cues from the scene normally viewed through the windshield. Several modes may be available. Video formats may also be displayed, such as low level light television, forward looking infrared (FLIR), or radar signals along with the symbology.

2. QUANTITATIVE INFORMATION: Quantitative information is information presented by a display in a manner which permits the display user to observe or extract a numerical value associated with the information.

3. QUALITATIVE INFORMATION: Qualitative information is information presented by a display in a manner which permits the display user to assess the status of the information or to control some parameter without requiring attention to a numerical value.

4. ANALOG INFORMATION: Analog information is information presented by a display in a manner which shows the value as a continuous movement of a symbol.

5. ALPHANUMERIC INFORMATION: Alphanumeric information is information presented by a display as letters and numbers.

   a. DIGITAL INFORMATION: Digital information is quantitative information presented by a display as numerical digits.

6. COMMAND INFORMATION: Command information is information presented by a display in a manner which directs a control action.

7. ERROR INFORMATION: Error information is information presented by a display in a manner which permits the display user to assess the deviation of some parameter from its desired value without requiring attention to a numerical value.

8. DISCRETE INFORMATION: Discrete information is information presented by a display which can only have a small number of possible values.

9. PREDICTIVE INFORMATION: Predictive information is information presented by a display which predicts future status, condition or position of the aircraft, an aircraft system, or a subsystem.

10. STATUS INFORMATION: Status information is information dealing with the current condition of the aircraft, an aircraft system, subsystem, or the aircraft surroundings.

11. WARNING INFORMATION: Warning information is information presented by a display which is intended to call the pilot's attention to abnormal or emergency conditions.

12. CONFORMAL DISPLAY: A conformal display is one in which the symbols, when viewed through the HUD, appear to overlie the objects they represent.

13. CONTACT ANALOG: A contact analog display is a conformal display which is a presentation of the real world.

14. SCALE COMPRESSION: Scale compression refers to a display where an angle within the display corresponds to a greater angle in the real world.

    a. PITCH SCALE COMPRESSION: Pitch scale compression refers to a display in which the pitch and heading angles are compressed, but roll angles are not. Such a display can not be conformal.

15. DIRECTED DECISION CUE: A directed decision cue is a specific annunciation directing the pilot to a specific action, such as "SHOOT," "GO-AROUND," or "BREAKAWAY."

16. MODE: A mode is the operational state of the display: A selected group of display formats, input selections, and processing algorithms.

17. SYMBOL: A symbol is a representation of information.

18. CODING CHARACTERISTICS: Coding characteristics are readily identifiable attributes associated with a symbol by means of which symbols can be differentiated; i. e. size, shape, color, etc.

19. PRIMARY VISUAL SIGNAL AREA (PVSA): The primary visual signal area (PVSA) is the area of the instrument panel enclosed by 12 inch arc centered on the intersection of the crewmember's vertical centerline plane and the top of the instrument panel (AFSC-DH-2-2).

20. MUST, SHOULD, ETC.: "Must" implies an absolute necessity for compliance. "Should" implies a necessity for compliance unless an operational need for non-compliance can be shown. "Recommended" and "Highly Recommended" imply differing degrees of desirability to comply with requirements which are not mandatory.

B. FLIGHT INFORMATION DEFINITIONS

1. PITCH REFERENCE FRAME: One or more symbols which represent fixed angles in space. These symbols are used as references for aircraft pitch and velocity vector symbols.

   a. HORIZON LINE: A reference symbol shown on the HUD which represents zero pitch (the local horizontal) or the location of the real world horizon.

   b. PITCH LADDER: A set of pitch reference symbols showing increments of angles to the horizon.

   c. PITCH INDEX: A symbol on the HUD positioned at a predetermined pitch angle used to represent a desired velocity vector, flight path angle, or a desired pitch attitude.

2. FIXED AIRCRAFT REFERENCE (THETA): The fixed aircraft reference symbol which represents an extension of the fuselage reference line (FRL) or other longitudinal aircraft reference line (ACRL). The symbol indicates relative pitch and roll angles of the aircraft when compared to the horizon (either artificial or real world) or to a displayed pitch ladder. It is sometimes called the waterline.

3. VELOCITY VECTOR (GAMMA): The velocity vector is the linear projection of the aircraft velocity originating at the aircraft center-of-gravity or some other well-defined location on the aircraft. (The use of a location forward of the aircraft center-of-gravity is often used to provide pitch rate quickening to the velocity vector symbol.) Some HUD systems refer to the velocity vector as the flight path marker.

   a. AIR MASS VELOCITY VECTOR: The air velocity vector is the linear projection of the aircraft velocity through the air mass. The inverse of this vector is the relative wind.

   b. INERTIAL VELOCITY VECTOR: The inertial velocity vector is the linear projection of the aircraft velocity relative to the ground. It is sometimes called the ground-referenced velocity vector.

   c. FLIGHT PATH ANGLE: The velocity vector component projected on the plane defined by the aircraft FRL (or ACRL) and the aircraft vertical axis. It is the velocity vector constrained laterally.

      i AIR MASS FLIGHT PATH ANGLE: The flight path angle defined using the air mass velocity vector.

      ii INERTIAL FLIGHT PATH ANGLE: The flight path angle defined using the inertial velocity vector.

iii GHOST VELOCITY VECTOR: For those HUDs which allow the pilot to select either velocity vector or flight path angle (i. e. to "cage" the velocity vector), the ghost velocity vector shows the location of the velocity vector when flight path angle is selected.

4. POTENTIAL FLIGHT PATH (PFP): A cue, normally calculated from longitudinal aircraft acceleration which shows the velocity vector achievable for the aircraft by balancing existing thrust and drag.

5. ANGLE OF ATTACK (ALPHA): The angle of attack is the angle between an aircraft longitudinal reference (FRL or ACRL) and the air velocity vector projected on the plane defined by the aircraft longitudinal reference (FRL or ACRL) and the aircraft vertical axis.

6. AIRSPEED: The magnitude of the speed with which the aircraft moves through the air.

   a. INDICATED AIRSPEED (IAS): Indicated airspeed is the speed calculated from the dynamic pressure of the impact air pressure from the pitot-static system. IAS is uncorrected for position error.

   b. CALIBRATED AIRSPEED (CAS): Calibrated airspeed is IAS corrected for pitot-static system position error.

   c. TRUE AIRSPEED (TAS): True airspeed is the actual aircraft speed through the air mass.

   d. MACH NUMBER: The Mach number is the ratio of the TAS to the ambient speed of sound.

7. ALTITUDE: Altitude is the height of the aircraft above sea level or some other reference.

   a. BAROMETRIC ALTITUDE: Barometric altitude is the altitude calculated from measuring the ambient static pressure through the pitot-static system.

   b. RADAR ALTITUDE: Radar altitude is the altitude above the terrain measured from the time for a radar signal to return. It is sometimes called radio altitude.

8. VERTICAL VELOCITY: Vertical velocity is the rate of ascent or descent, usually calculated from the rate of change of barometric altitude. It is sometimes called vertical speed in civilian operations.

9. HEADING: The horizontal angle made by the longitudinal reference (FRL or ACRL) with a reference direction.

a. MAGNETIC HEADING: The horizontal angle made with magnetic north.

b. TRUE HEADING: The horizontal angle made with true north.

c. GRID HEADING: The horizontal angle made with grid north.

10. BANK: The angle between local vertical and the plane defined by the aircraft's vertical and longitudinal axes.

11. ANGLE OF SIDESLIP (BETA): The angle of sideslip is the angle between the aircraft longitudinal reference (FRL or ACRL) and the air velocity vector projected on the plane defined by the aircraft longitudinal reference and the aircraft lateral axis. BETA is the left-right equivalent of ALPHA.

12. NORMAL LOAD FACTOR: Normal load factor is the ratio of the lift to the aircraft weight.

C. NAVIGATION INFORMATION DEFINITIONS

1. DEVIATION: An indication of aircraft displacement (left-right, up-down) from a desired track.

a. COURSE DEVIATION: An indication of aircraft displacement (left-right) from a desired track (VOR or TACAN radial, ILS or MLS localizer, INS track, etc.).

i ROLLOUT GUIDANCE: An indication of aircraft displacement (left-right) from the runway centerline used for instrument takeoffs and low visibility landings.

b. VERTICAL DEVIATION: An indication of aircraft displacement (up-down) from a desired track (ILS or MLS glideslope, target altitude. etc.).

c. STEERING BOX: An indication of aircraft displacement (left-right, up-down, or both) from a desired track. Normally shown as a box or circle, the steering box shows the displacement compared to a maximum or nominal displacement (such as the ILS Category II limits).

2. FLIGHT DIRECTOR: Flight director information is single, dual, or multiple axis steering command information which, when followed, will place the aircraft on a trajectory to intercept and maintain a preselected computed path through space.

a. LATERAL STEERING COMMAND: A single axis steering command which, when followed, will place the aircraft on a trajectory to intercept and maintain a preselected computed ground track.

i ROLLOUT STEERING COMMAND: A lateral steering command which, when followed during the take-off or landing ground roll, will place the aircraft on a trajectory to intercept and maintain the runway centerline.

b. VERTICAL STEERING COMMAND: A single axis steering command which, when followed, will place the aircraft on a trajectory to intercept and maintain a preselected vertical flight path (ILS or MLS glideslope, target altitude, etc.).

c. COMBINED STEERING COMMAND: A multiple axis steering command which, when followed, will place the aircraft on a trajectory to intercept and maintain a preselected computed path through space.

d. SPEED COMMAND: A steering command which, when followed, will cause the aircraft to maintain a desired airspeed.

3. WAYPOINT: A symbol depicting the location of a particular ground point.

a. RUNWAY SYMBOL: A symbol depicting the location of the runway.

4. DIRECTION CUE: A symbol depicting the location of a particular line of position (LOP). LOPs include VOR or TACAN radials, runway centerline extensions, INS track, etc.

5. RANGE: A symbol showing the distance (usually in nautical miles) to a specified waypoint, ground location. or target.

a. DME: A symbol showing the distance in nautical miles to a TACAN or DME navigation station.

b. RUNWAY DISTANCE REMAINING: A symbol showing the distance in feet (or meters) to the end of the runway.

6. TIME TO GO: A symbol showing the time to a preselected waypoint. ground location, or target.

7. FLARE CUE: A symbol indicating the desired vertical flight path during the landing flare. The flare cue is usually a vertical steering command.

D. WEAPONS INFORMATION DEFINITIONS

1. AIMING RETICLE: A symbol used as a weapon aiming cue.

a. STANDBY RETICLE: A symbol used as a manual weapon aiming cue. The standby reticle is a backup display intended for use in the event of HUD or other system failure.

2. BOMBFALL LINE: A symbol indicating the approximate trajectory of a weapon following release.

3. BREAKAWAY SYMBOL: A symbol displayed at minimum weapon release range and/or reaching the minimum safe pullout altitude during air-to-ground weapon delivery. It indicates the need for an immediate pullup of the aircraft.

4. CONTINUOUSLY COMPUTED IMPACT LINE (CCIL): A symbol used to display the locus of bullet impact points, usually with bullet time-of-flight points indicated.

5. CONTINUOUSLY COMPUTED IMPACT POINT (CCIP): A symbol indicating the predicted impact point of a weapon.

6. PULLUP CUE: A symbol used to indicate an approaching pullup requirement during air-to-ground weapon delivery.

7. SENSOR SEARCH AREA: A symbol showing the areas of weapon sensor (radar, FLIR, etc.) coverage.

8. SOLUTION CUE: A symbol indicating a release solution for a computed weapon delivery.

9. TARGET INFORMATION:

   a. TARGET DESIGNATOR: A symbol showing the location of the target.

   b. TARGET RANGE: A symbol showing the range to the target.

   c. TARGET RANGE RATE: A symbol showing the rate of change of the target range.

   d. TARGET ASPECT: A symbol indicating the orientation of the target vehicle (aircraft, ship, or ground vehicle).

10. WEAPON BORESIGHT: A symbol indicating the weapon boresight axis.

E: HEAD-UP DISPLAY DEFINITIONS

1. PILOT DISPLAY UNIT (PDU): The assembly which consists of the image source, the collimator, and the combiner.

   a. IMAGE SOURCE: The component which provides the optical origin of the symbology, such as a cathode ray tube (CRT) screen, laser source, etc.

   b. COMBINER: A component located in the pilot's forward field of view which provides superposition of the symbology on the external field of view.

i FIXED COMBINER: A combiner fixed in the pilot's view.

ii STOWABLE COMBINER: A combiner that can be deployed for use or retracted out of view.

iii WINDSHIELD COMBINER: An area of the windshield which functions as the combiner.

iv MONOCULAR COMBINER: A combiner intended to be viewed with one eye.

c. COLLIMATOR: The optical components used to collimate the display image. (Note: The combiner often contributes to the collimation.)

i REFRACTIVE COLLIMATOR: A collimator using only lenses for collimation, i. e. using the principle of refraction. These are sometimes referred to as "conventional" collimators.

ii REFLECTIVE COLLIMATOR: A collimator using mirrors (perhaps in conjunction with lenses) for collimation (and often for superposition as well), i. e. using the principle of reflection. These are sometimes referred to as "conventional" collimators.

iii DIFFRACTION COLLIMATOR: A collimator using one or more diffraction gratings for collimation (and often for superposition as well). Since the diffraction gratings are usually produced using holograms, these are sometimes referred to as "holographic" collimators.

2. ELECTRONIC UNIT (EU): The assembly which consists of the signal processor, the symbol generator, and the display electronics. These may be combined into fewer physical units or they may be merged with other systems.

a. SIGNAL PROCESSOR: The electronic unit which performs any calculations, filtering, etc. of the raw data to generate parameters to be displayed. An example, would be the calculation of inertial velocity vector from the raw data of three velocities from the inertial platform.

b. SYMBOL GENERATOR: The electronic unit which generates the actual symbols to be displayed on the HUD.

c. DISPLAY ELECTRONICS: The electronic unit which produces the visible image of the symbols and which monitors the symbols.

3. DISPLAY CONTROL PANEL (DCP): The assembly which houses the HUD controls, such as brightness, mode selection, etc.

F. OPTICAL DEFINITIONS

1. CONTRAST RATIO: The ratio of display symbology brightness to the external visual cue brightness. Contrast ratio must specify the ambient brightness level.

2. DISPLACEMENT ERROR: The difference in apparent position of a real world visual cue caused by optical effects (such as refraction) when viewed through the combiner.

3. DISTORTION: Variation in apparent geometry of real world objects when viewed through the combiner.

4. EXIT APERTURE: The area of the optical display at the exit of the collimator.

5. EYEBOX: A three dimensional envelope from which the HUD symbology may be viewed.

6. EYE REFERENCE POSITION (ERP): The location of the pilot's eye used to calculate fields of view and to make other comparisons between HUDs.

   a. DESIGN EYE REFERENCE POSITION (DERP): The location of the pilot's eye used in the design of the HUD.

   b. ALERT EYE POSITION (AERP): The location of the pilot's eye when he is looking for critical external visual cues. It is usually assumed to be somewhat forward of the DERP.

7. FIELD-OF-VIEW (FOV): The spatial angle in which the symbology can be displayed measured laterally and vertically.

   a. INSTANTANEOUS FIELD-OF-VIEW (IFOV): The spatial angle in which the symbology is visible from a single eye position. It is the spatial angle of the collimator exit aperture as seen from the eye.

      i MONOCULAR IFOV: The spatial angle in which the symbology is visible viewed from a single eye (left eye, right eye, or single ERP) position.

      ii OVERLAPPING BINOCULAR (AMBINOCULAR) IFOV: The envelope of both left and right eye monocular IFOVs. This is the field-of-view visible to either eye. Called ambinocular IFOV by some authorities and binocular IFOV by others. The use of the adjective "overlapping" is recommended.

iii SIMULTANEOUS BINOCULAR IFOV: The envelope within the overlapping binocular IFOV which is common to both left and right eye monocular IFOVs. The FOV in which the symbology is visible to both eyes simultaneously. Called binocular IFOV by some authorities. The use of the adjective "simultaneous" is recommended.

b. TOTAL FIELD-OF-VIEW (TFOV): The spatial angle in which the symbology can be viewed from within the total viewing cone or wedge. The area covered by the IFOV may not be the entire display. By moving his head, the pilot may be able to see more symbology. The TFOV represents the total symbology available by moving the ERP.

c. KNOTHOLE EFFECT: The apparent limitation of the TFOV by the exit aperture sometimes leads to the expression "knothole effect." This is an analogy of the TFOV which is the world beyond the "knothole" and the IFOV is the "knothole." By shifting one's eye, the view of the real world beyond the "knothole" can be viewed, even though not all at once.

8. LINE WIDTH: The width at 50 percent of peak luminance of the line luminance distribution

9. TRANSMITTANCE OF COMBINER: The percent of ambient light from an external source passing through the combiner. The wavelength spectrum of the light from the external source must be specified. Normally, the spectrum of sunlight is assumed.

10. VISUAL DISPARITY: The difference in apparent position of an image as presented to each eye. Sometimes referred to as "binocular" disparity. Disparity can be divided into vertical and horizontal components. The horizontal component can be described as convergent or divergent. These terms describe the view from the eye, i. e. convergent disparity means the optical rays appear to the pilot to emanate from a point nearer than optical infinity. Divergent disparity means that the rays appear to emanate from a point further than optical infinity.

G. SYSTEMS DEFINITIONS

1. CERTIFICATION AUTHORITY (CA): The agency (or its delegate) with the authority to determine airworthiness of the system. In the case of civil aircraft, this agency is the Federal Aviation Administration (FAA) or its foreign equivalent. In the case of public or military aircraft, this agency is the appropriate government or military organization. The CA will be responsible for minimum or maximum acceptable values for many of the HUD system specifications.

2. USER ORGANIZATION (UO): The organization responsible for issuing the final HUD system specification and which will be the ultimate user of the equipment. For civil aircraft, this will normally be the operator of the aircraft. In the case of military or public aircraft. it is the appropriate organization which will fly the aircraft. The UO will have the final decision on specifications based on the recommendations contained in this document, subject to the airworthiness requirements set by the CA. Note: For military and public aircraft, the CA and the UO may be the same organization.

3. PRIMARY FLIGHT REFERENCE (PFR): A display which displays information sufficient to maneuver the aircraft about all three axes and accomplish a mission segment (such as takeoff or instrument approach). The amount of data displayed obviously depends on the mission segment to be performed. As a guide, the data displayed in the basic "T," i. e. airspeed, pitch attitude, altitude, heading, and lateral deviation (or their substitutes) should be displayed in a primary flight reference. Other data which is critical for immediate use, such as glideslope deviation during a precision instrument approach, should be included for those mission segments where it is required. A PFR must have at least the reliability specified by the CA.

4. RELIABILITY TERMS: The definitions of some reliability terms, such as "extremely improbable," etc., will be specified by the certification authority.

   a. EXTREMELY IMPROBABLE: For civil aircraft, extremely improbable means less than once per billion hours (FAA-AC 25.1309-1). For military aircraft, extremely improbable means that the probability of occurrence cannot be distinguished from zero and that it is so unlikely that it can be assumed that this hazard will not be experienced in the entire fleet (MIL-STD-882C).

   b. FAIL-PASSIVE: A flight control system is "fail-passive" if a single failure will cause a system disconnect leaving the airplane in trim with no control hardover (FAA-AC-120-28A).

   c. FAIL-OPERATIONAL: A flight control system is "fail-operational if a single failure will allow the system to continue operation with no loss in performance (FAA-AC-120-28A).

5. TYPES OF AIRCRAFT

   a. CIVIL AIRCRAFT: An aircraft not operated by a governmental body.

   b. PUBLIC AIRCRAFT: An aircraft operated by a governmental body including a military organization.

c. TACTICAL AIRCRAFT: An aircraft defined as Class IV in MIL-F-8785C. Tactical aircraft will also include primary and basic training aircraft for the purposes of this document.

d. TRANSPORT AIRCRAFT: An aircraft defined as Class III in MIL-F-8785C.

III. SYSTEM CHARACTERISTICS

A. PARTS AND MATERIALS

The materials and processes used in the construction of the HUD system should conform to accepted aeronautical practices. Limited life parts, except for CRTs. should be avoided.

B. DESIGN AND CONSTRUCTION

1. WEIGHT: The weight of HUD components should be kept to the minimum commensurate with design objectives. Handles or grasp surfaces should be provided on all line replaceable units (LRUs) that are heavy or that are difficult to grasp, remove, or carry.

2. CABLING AND CONNECTIONS: The wiring connections of the HUD system should conform to MIL-W-5088H or other appropriate civil cabling standards. Connectors should be provided with a positive index to prevent misconnection.

   All HUD systems must be provided with a wiring interface diagram defining the system inputs, outputs, and power supply requirements.

3. INTERCHANGEABILITY: All HUD parts having the same part number should be interchangeable with each other with respect to installation and performance. Software interchangeability should conform to the requirements of DOD-STD-2167 or RTCA-DO-178.

4. ELECTROMAGNETIC INTERFERENCE (EMI): The HUD system is essentially no different with respect to EMI than any other electronic system. The HUD should not be susceptible to interference from other aircraft systems, considering both interference of signal sources to the HUD and disturbances to the aircraft power system. The HUD in turn must not be a source of EMI to other critical aircraft systems.

   Since the HUD will interface with many other aircraft systems as signal sources, it should be demonstrated that these interfaces have no deleterious effects on those systems or their outputs.

5. MAINTAINABILITY: The HUD system should be designed for maintainability. The design of the equipment should provide for easy access to internal parts, terminals, and wiring. All modules, connectors, adjustment or alignment controls, and test points should be marked or identified. The design should be such that it is impossible to incorrectly install a module in the unit. All alignment or adjustment controls should be accessible with a minimum of need to remove the system or assembly from the aircraft. Scheduled maintenance should be limited to periodic cleaning of exposed optical surfaces, replacement of a CRT, or servicing of optical desiccant material.

6. NOMENCLATURE, NAMEPLATES, AND IDENTIFICATION MARKINGS: Nomenclature. serial number assignment. and identification marking should conform to MIL-N-7513, MIL-P-15024, FAA-AC-21.303-1A, or other appropriate military or civil standard.

7. ENVIRONMENTAL CONDITIONS: The HUD system should be designed to the environmental conditions specified in RTCA-DO-160A or MIL-E-5400. Relaxation of performance standards is often allowed during initial warm-up at very cold temperatures or during the firing of aircraft guns.

8. INPUT ELECTRICAL POWER: HUD systems must normally operate on 400 Hz, 115 V AC and 28 V DC power or as specified by the UO. The power supplied should conform to MIL-STD-704D. The power required should not exceed the amount specified by the UO. The standby reticle, if installed, should have a power supply independent from the other HUD power supply.

9. HUMAN ENGINEERING: The HUD system should be designed and developed with the objectives of enhancing the man-machine interface. MIL-STD-1472 provides criteria for the application of human engineering principles and procedures.

10. SOFTWARE ENGINEERING: The HUD system software should be developed in accordance with the criteria of DOD-STD-2167 or RTCA-DO-178.

11. COOLING REQUIREMENTS: The HUD cooling requirements must be specified for each aircraft installation. Cooling failure should not cause HUD loss. Overheating of the HUD system should be annunciated to the crew.

12. WARM-UP TIME: The HUD equipment should be functionally operational and conform to all accuracy and performance requirements within two minutes of being switched on at any condition within the environmental envelope specified. Power transients of up to ten seconds should not require re-warm-up for periods longer than the power loss.

C. INSTALLATION CRITERIA

1. PDU MOUNTING: Mounting of the PDU or PDU components must be such that the display accuracy and readability is not degraded by the environmental conditions normally expected in flight.

   a. MOUNTING: The mounting of the PDU or PDU components should be designed to withstand the vibration, turbulence, maneuvering, and pressurization loads expected in service. The PDU mounting should provide for both lateral optical and vertical optical adjustments.

      The PDU should make the least practicable interference with mounting the primary head-down flight instrument in the PVSA. As a design goal, the PDU should not interfere with mounting the primary head-down flight instrument in the PVSA.

   b. REPLACEMENT: Replacement of the PDU should not require optical adjustment.

   c. STOWABILITY: If a stowable combiner is used, it should be easily stowed by the pilot with his restraint system fastened (shoulder harness locked). There must be a positive means to ensure that the combiner is fully deployed before symbols are displayed.

   d. HAZARDS: The PDU must not introduce hazards of high voltage, radiation, or blinding during use.

   e. EGRESS: The PDU must not interfere with crew escape, including bailout or ejection seat use, if appropriate. Minor infringement on the ejection plane (defined in MIL-STD-1333A) may be tolerated if this infringement is confined to the central portion of the panel and does not create an unacceptable risk to pilots during ejection.

   f. CRASHWORTHINESS: Protruding parts of the PDU should incorporate impact protection for the crew, such as the use of fold-away or break-away structures or padded structures.

   g. EXTERNAL LIGHT: HUDs designed for use in combat aircraft (including transports) should not be visible from outside the aircraft during night operations.

   h. COMBINER WINDLOADS: For aircraft in which the front part of the canopy is removed prior to ejection, the combining glass and its mounting structure must withstand without breakage the wind loading and temperature differential associated with the sudden removal of the canopy in flight. This requirement is imposed to avoid injuries to the pilot from combiner debris during an ejection.

i. BIRD STRIKE: The design of the combiner should consider canopy or windshield deflection during a birdstrike. If the canopy or windshield could contact the combiner during a birdstrike, the combiner and its mounting should be designed to prevent large, sharp, or high velocity fragments from injuring the pilot when the combiner is struck along its upper edge.

j. RECORDING CAPABILITY: The PDU should be designed with the ability to install a camera to record the visual scene through the combiner and the HUD symbology.

2. HUD CONTROLS

a. SPECIFIC CONTROLS

i HUD ON/OFF SWITCH: The HUD must incorporate an on/off switch to completely remove power from the unit (except power to the standby reticle, if installed). This switch can be included with the brightness control provided a suitable detent is used. If a stowable combiner is used, the on/off switch may be incorporated with the stowing/unstowing of the combiner.

ii BRIGHTNESS: The HUD must have a manual brightness control, an automatic brightness control (if specified by the user), and a manual standby reticle brightness control (if a standby reticle is installed).

(a) MANUAL BRIGHTNESS: The manual brightness control should continuously vary the intensity of all symbols from zero to full intensity.

(b) AUTOMATIC BRIGHTNESS: With automatic brightness on, the brightness control should track the ambient light level to maintain a constant contrast ratio. For an increase in ambient brightness as detected by the light sensor, there will be an associated increase in display intensity to maintain a constant contrast ratio.

(c) STANDBY RETICLE BRIGHTNESS: The standby reticle brightness control should continuously vary the standby reticle intensity from zero to full intensity. It should incorporate a detent to remove power from the standby reticle. A separate power supply should be used for the standby reticle.

iii DECLUTTER SWITCH: A means of selectively removing symbols from the display should be provided.

iv MODE SELECTION: If automatic mode switching is incorporated, it is highly recommended that a manual mode selection switch be available to allow the pilot to over-ride the automatic selection.

v TEST SWITCH: A test switch should be provided to allow the crew to initiate self-testing of the HUD. This may be omitted if an automatic test function is applied with initial power-up.

b. RELATION TO HEAD DOWN INSTRUMENTS: Controls related to display parameters should, whenever possible, be combined with those of the head-down instruments.

3. ELECTRICAL TRANSIENTS

a. ELECTRICAL OVERLOAD: The HUD system must contain overload protection devices for all internal power supplies. These devices should automatically reset when the overload condition no longer exists.

b. POWER INTERRUPTIONS: The HUD should be designed to provide for monitoring of and proper response to interruptions of the primary electrical power. For isolated short term power interrupts, the HUD should go blank for the duration of the interrupt and restore the display following reapplication of power.

c. UNDERVOLTAGE PROTECTION: The HUD system should not be damaged by voltages below those specified in Section III B 8 and should automatically resume normal operation when the undervoltage condition no longer exists.

D. RELIABILITY

The HUD system should be designed to achieve the highest practical level of reliability. Design reliability should be determined using the methods and data of MIL-HDBK-217D.

1. PRIMARY FLIGHT REFERENCE: The system reliability for HUDs intended to be used as primary flight references during flight in instrument meteorological conditions (IMC) must be at least that of the head down instruments. The system must be designed such that the displaying of incorrect attitude information is extremely improbable.

2. INSTRUMENT LANDING: The system reliability for HUDs intended to be used as primary flight references during instrument approaches and landing will generally be much higher than for

other HUDs. The overall system reliability will be specified by the UO or CA. Considerations should be given to incorporating fail-passive or fail-operational designs. The system must be designed so that the displaying of incorrect attitude or guidance data is extremely improbable.

3. NON-PRIMARY FLIGHT REFERENCE: The system MTBFs for HUDs not intended to be used as primary flight references in IMC should be specified by the UO.

E. DOCUMENTATION

The HUD system design should be documented by:

1. Design drawings, schematics, wiring diagrams (including interfaces. see III. B. 2.), and parts lists;

2. Detail specifications;

3. Test procedures defining methods of verifying and evaluating characteristics and performance;

4. Environmental test reports documenting design performance over the full range of applicable environments;

5. Analyses verifying reliability, maintainability, and safety; and

6. Software documentation described in DOD-STD-2167 or in RTCA-DO-178.

IV. OPERATIONAL SYSTEM CRITERIA

A. FIELD-OF-VIEW

The HUD should be designed and installed to meet all operational requirements for the specific application. In particular, the system should be designed to permit the pilot to look in normally expected directions with minimal loss of symbology. The FOV should be centered on the centerline of the pilot.

The pilot should not have to move his head to view the symbology. In other words, the IFOV should include the major flight data symbols in the HUD under normal viewing conditions. Head motion has a tendency to cause or exacerbate spatial disorientation or vertigo and the HUD must be designed to minimize this.

If the displayed flight information includes conformal ground reference symbols, such as a runway or target symbol, the lateral FOV should be sufficient to permit conformal viewing of the symbols during all anticipated crosswinds. Runway symbols should be conformal during crosswind approaches at the maximum approved landing crosswind. The lack of adequate lateral FOV has been identified as a major limitation during crosswind landings.

The FOV should be specified for each installation. Suggested minimum values of overlapping binocular IFOV are

Tactical aircraft:	17 deg vertical 20 deg lateral
Transport aircraft:	12 deg vertical 22 deg lateral

Suggested minimum values for TFOV are

Tactical aircraft	25 deg vertical 25 deg lateral
Transport aircraft	12 deg vertical 22 deg lateral

B. OPTICAL QUALITY

1. BRIGHTNESS: The brightness control should provide a suitable contrast between symbols and external visual cues over the range of ambient lighting conditions expected in service. In the past, problems have been encountered during night operations where the HUD intensity could not be set low enough to provide a comfortable display against a dark background. At the same time, HUDs intended to be used to track aerial targets (such as air-to-air weapons targeting) should ensure that the symbols can be easily seen against bright clouds.

Unless specially enhanced, all symbols should be equally bright. This does not preclude allowing different symbols' brightness to be controlled independently. Aircraft master warning or other critical warning messages should appear fully bright when they first are shown in the HUD FOV, regardless of the brightness setting. Dimming or canceling these messages in the HUD FOV should require some pilot action.

When set for manual operation, the HUD brightness should be adjustable from zero to full intensity. In automatic, the HUD brightness should track the ambient light level to maintain a constant (pilot selectable) contrast ratio. When in automatic brightness, the HUD brightness should track the background brightness with sufficient speed to avoid large variations in contrast ratio. The pilot should have the capability to select manual brightness (i. e., A manual brightness control is required; an automatic brightness control is optional.)

a. DAYTIME BRIGHTNESS: A recommended daytime background brightness is 10,000 FL (sunlit snow).

b. NIGHTTIME BRIGHTNESS: The minimum controllable brightness should provide smooth control of HUD intensity at very low ambient light levels (less than 15 FL). Some HUDs have used a two position manual brightness control with both a day and a night range of settings. This was identified as a problem area in early CRT HUDs.

c. BRIGHTNESS VARIATIONS: The brightness of a uniform display should not vary significantly over the FOV.

2. COLOR: Colors should only be used where an improvement over monochrome can be shown. Colors used should be consistent with head-down instruments. Each color used must be assessed for acceptable contrast against all likely background conditions. (These two requirements may conflict, such as the need to use blue to show pitch up which may not be visible against the sky.) Color must not be the only discriminant. In a degraded or monochromatic mode, a color display must remain legible and unambiguous. Color displays should have a means for the pilot to select a monochromatic display.

Colors used in monochromatic HUDs must be specified for each installation. Any color used should be assessed for acceptable contrast against all likely background conditions. The use of a P-43 phosphor has been found in the past to provide acceptable contrast.

A night filter may be used to provide adequate control or acceptable contrast during night operations. Such a filter should only be incorporated if an improvement over an unfiltered display can be demonstrated. Any night filter color specification should be matched with the color specification for the HUD itself. If night vision goggles (NVGs) are likely to be worn in conjunction with HUD use, then the colors used should also be compatible with the NVGs. Normally, a P-43 phosphor and a narrow bandpass green filter will ensure compliance with this paragraph.

3. COMBINER TRANSMITTANCE: The average transmittance of the combiner to external light should be as high as practical. Minimum values of combiner transmittance should be specified for each installation. A suggested minimum value for combiner transmittance is

Combiner Transmittance: (based on ambient sunlight, averaged over all wavelengths)	70%

No credit for part-time use of the HUD should be allowed in specifying combiner transmittance.

The combiner must not color the ambient light to produce misleading color cues of real world objects.

4. COMBINER WORKMANSHIP AND CONSTRUCTION: The combiner shall be free from defects which will affect the appearance of the glass or which may affect its serviceability.

The entire periphery of the edges and the surface should be gray-ground to reduce objectionable highlights (MIL-R-6771B). The combiner edges and mounting can produce "accommodation traps" which may defeat the purpose of collimating the HUD image. For this reason, the combiner mounting should be as unobtrusive as practicable.

5. DISPLACEMENT ERROR: When objects are viewed through the combiner, the combining glass should not cause real world objects to appear to be displaced significantly. Recommended maximum displacement errors are

Within central 12 deg of FOV	0.6 mr
Within 12 to 24 annular FOV	1.2 mr
Beyond 24 deg annular FOV	2.0 mr

6. DISTORTION: The combiner should not discernibly distort real world objects when they are viewed through it.

If the windshield or canopy is a major source of distortion, the the symbol placement may be modified to allow conformal symbols to overlie their real world equivalents when viewed through the canopy.

7. EYEBOX: The eyebox must contain the HUD DERP. Within the eyebox, the optical specifications should be met. The minimum size of the eyebox should be such to allow for reasonable pilot head motion. Recommended minimum dimensions are

Tactical Aircraft:	
Longitudinal:	4 in
Lateral:	4 in
Vertical:	from 1 in below DERP to highest practical seating height.
Transport Aircraft:	
Longitudinal:	4 in
Lateral:	4 in
Vertical:	2 in

If an AERP is specified, the eyebox must contain the AERP.

There should be a means provided to indicate the proper DERP to the pilot while sitting in his seat. This may be accomplished on the ground prior to flight (i. e., it is not necessary to provide this indication in flight).

Specific consideration should be paid to the typical practice of sitting as high as possible in tactical aircraft to maximize the external view. In these aircraft, the HUD DERP may not be the aircraft DERP used to design the flight instruments (MIL-STD-1333A). The HUD DERP will be specified by the UO.

The HUD DERP for transport aircraft should be the DERP used in the design of the flight instruments (MIL-STD-1333A or SAE-ARP-268F).

8. FATIGUE: The HUD should be designed to minimize personnel fatigue caused by viewing. The pilot should be able to view the HUD while sitting comfortably in his normal sitting position.

9. GLARE: Glare and other unwanted visual signals should be minimized. Stray reflections from cockpit lights, from the sun, moon, or external lights should not interfere with the use of the HUD, with the view of real world objects, or interfere with other crewmembers not using the HUD. (For HUDs intended for use as PFRs, replace "should not" with "must not.")

Multiple reflection combiners should only be installed if necessary since they can be a source of stray reflections. There should be no secondary real world images visible over the entire FOV when viewed from within the eyebox. Solar images should be held to a maximum intensity of 2.5 percent with 0.5 percent as a design goal.

10. MULTIPLE IMAGES: There should be no secondary symbology images visible over the entire FOV when viewed from within the eyebox. (For HUDs intended for use as PFRs, replace "should" with "must.") Care must be taken to avoid unwanted images from the aircraft windshield if the windshield and combiner are in close proximity. An anti-reflective coating should be used on all optical surfaces.

11. VISUAL DISPARITY: Binocular disparity has been shown to be a limiting factor in the pilot's adaptation to a HUD. Any disparity should be minimized. If a choice must be made for slight horizontal disparity, a slight convergent disparity (i. e. the symbols appear closer than optical infinity) is preferred over a divergent disparity. The binocular disparity of the displayed symbols must be specified over the TFOV. Normally the binocular disparity is quoted on a 3 sigma basis.

    Recommended maximum values are

Horizontal	divergence:	0.0 mr
	convergence:	2.5 mr
Vertical:		1.0 mr

    If the real world cues appear to be closer than optical infinity, because of windshield distortion or because the HUD is intended to be used while viewing nearby cues (such as during refueling operations), the convergence and divergence limits should be adjusted so the virtual image does not appear to be further away than the external cues.

    (Note: At this time, there is a minority opinion which disagrees with these maximum values. This opinion suggests that the these limits should be increased in the direction of horizontal divergence, i. e. the HUD imagery should appear to be beyond optical infinity.)

C. SENSOR REQUIREMENTS

1. ACCURACY: The accuracy of the gyroscopic reference has been a problem with the retrofit of HUDs in the past. Generally, conventional aircraft gyros have not had the required accuracy and have presented problems with mismatch with he HUD symbols and the real world.

The following gyro platform accuracies are recommended:

All aircraft(non-contact analog):	
Heading:	1.0 deg
Pitch:	1.0 deg
Roll:	1.0 deg
Pitch zero:	0.5 deg
Roll zero:	0.5 deg

All aircraft (contact analog):	
Heading:	0.2 deg
Pitch:	0.5 deg
Roll:	0.5 deg
Pitch zero:	0.2 deg
Roll zero:	0.5 deg

The final judge of gyro platform accuracies is the lack of interference with non-contact analog symbols or the absence of a discernible mismatch with external visual cues for contact analog symbols. The preceding gyro accuracies are presented as a guide.

2. SENSOR RESPONSE: The response of sensors input to the HUD can have a significant impact on the HUD characteristics. In general, the two sensors that can cause the most difficulty are the response of the gyro platform and the response of the angle-of-attack (and sideslip) sensors.

   a. GYRO PLATFORM: In general, the gyro platform should provide accurate data at a rate approximately four times the response rate of the aircraft. Recommended minimum platform response rates (providing acceptable accuracies) are

Tactical Aircraft:	
Pitch:	180 deg/sec
Roll:	400 deg/sec
Heading:	90 deg/sec

Transport Aircraft:	
Pitch:	90 deg/sec
Roll:	120 deg/sec
Heading:	30 deg/sec

   b. ANGLE-OF-ATTACK: The angle-of-attack sensor should provide a signal without excessive oscillations or noise, but with sufficient response for the HUD symbols on which it is based. No specific recommendations can be made at this time. It is quite likely that angle-of-attack data requirements will differ for a HUD displaying only ALPHA or ALPHA error and for a HUD using angle-of-attack to generate an air mass velocity vector.

V. DISPLAY CRITERIA

A. GENERAL

The HUD may repeat, augment, or replace head-down displays and information for any and all phases of flight. HUD systems that are designed to replace head-down displays should contain the information required by the pilot for manual control during the selected flight phase. It is understood that this information need not be identical in content or format to the head-down information.

B. COMPATIBILITY WITH HEAD-DOWN DISPLAYS

The HUD must display data which is compatible with the head-down instruments. It is important that the control strategies used head-up by the pilot be compatible with those used head-down. This does not mean that the HUD must be constrained to show only that data that is shown head-down. It might not be feasible to display all HUD parameters on a head-down electromechanical instrument. It would not be wise to limit an electronic HUD to only those parameters available head-down.

It does mean that the same pilot will fly the airplane both head-up and head-down. If only pitch information is available head-down, then pitch information must be displayed on the HUD so that in critical flight situations the pilot can use the same information and control strategies. There is a large interaction with pilot training implied by these arguments.

The HUD must be an integrated display -- that is integrated into the cockpit. This means that the same procedures used to fly by reference to the head-up display and those used to fly by reference to the head-down panel must not lead to problems when the pilot switches from one display to the other. For example, the use of longitudinal controls by reference to GAMMA on the HUD should not lead to problems if the pilot mistakenly uses the techniques for flying by reference to THETA on the head-down panel.

C. AMOUNT OF SYMBOLOGY

A cluttered display is one which has an excessive amount of information contained in the number or variety of symbols and spatial relationships. A large fraction of this information may be pertinent to the task at hand, but if the secondary information detracts from the interpretation of the information necessary for the primary task or increases the primary display interpretation error rate, then irrelevant or low priority information must be removed. The designer must guard against the urge to add more and more data to the display.

The pilot must also have a means to reduce the amount of extra, low priority information if it is not desired. There are two primary means to accomplish this: using few HUD modes with declutter options or using many HUD modes with fewer declutter options.

1. DECLUTTER LOGIC: One method is to allow the pilot to manually select from one or more declutter options. In the extreme, this approach would have the pilot select whatever symbols are wanted from a menu.

   The simplest form of declutter is a "scales" switch. This removes secondary information so the pilot can concentrate on the symbols of greater importance. Typical installations use this approach to delete airspeed, altitude, vertical velocity,, and heading from the HUD. Because this "all or nothing" approach leaves something to be desired, some modern HUDs have two or more declutter options, removing part of the secondary displays at one position and the rest at another.

   It is highly recommended that future HUDs have a minimum of two levels of declutter.

   It is also recommended that, while a basic selection of symbols to be displayed be programmed into the HUD controls, the pilot be given the option to modify the programming and select which symbols be included with each level of declutter. This option could be accomplished on the ground prior to flight.

2. MODE LOGIC: The second approach to declutter is to use a large number of modes with symbols chosen for each mode. When this option is used, there is less need for multiple declutter choices. Nevertheless, some declutter choice is desirable.

   It is recommended that future HUDs have a minimum of two levels of declutter even if there are large numbers of modes available.

   It is also recommended that, while a basic selection of symbols to be displayed for each mode be programmed into the HUD controls, the pilot be given the option to modify the programming and select which symbols be included with each level of declutter.

3. AUTOMATIC DECLUTTER: Under some limited circumstances, it may be desirable to automatically declutter the HUD without pilot intervention. This option must be used sparingly and w'th a great deal of caution. Instances where this might be desirable include large pitch or roll excursions typical of unusual attitudes, windshear encounters in transport aircraft, or excessively low altitude during air-to-aground weapons delivery (A/G) where a mandatory breakaway is commanded. During such cases, all non-essential data must be eliminated.

   Extreme care should be used when incorporating these automatic declutter modes. For example, during air combat maneuvers (ACM) in tactical aircraft, pitch or roll attitudes might trigger such declutter. Such automatic action should not detract from the use of the HUD or from the mission.

D. BASIC HUD INFORMATION

The HUD should provide a clear, self-explanatory, and unmistakable display of aircraft attitude, flight path, and altitude. One symbol, normally aircraft pitch (THETA) or velocity vector (GAMMA) should be chosen as the aircraft symbol. The choice of primary aircraft symbol may vary from mode to mode. (Note, the symbols chosen for GAMMA and THETA should not change to reflect this. That is, it is not necessary to have a specific symbol for the aircraft symbol.)

The following parameters are recommended for a basic instrument HUD mode:

1. AIRSPEED OR ANGLE-OF-ATTACK: The airspeed, airspeed error, angle-of-attack, or angle-of-attack error should be shown on the left side of the display or on the left side of the aircraft symbol. The choice of airspeed or angle-of-attack may be at the pilot's option or it may be automatic. Airspeed or angle-of-attack may be de-selected by means of a declutter switch.

2. ALTITUDE: Altitude, radio or barometric, should be displayed to the right of the FOV or on the right side of the aircraft symbol. The choice of radio or barometric altitude may be at the pilot's option or it may be selected automatically. Altitude may be de-selected by means of a declutter switch.

3. ATTITUDE: As a minimum, the horizon line should be displayed. If velocity vector is not displayed, a pitch symbol must be displayed. It is highly recommended that a pitch symbol be displayed in addition to the velocity vector. The pitch symbol must be displayed in an Unusual Attitude Mode.

4. HEADING: The aircraft heading should be displayed as a scale on the horizon line, at the top of the FOV, or at the bottom

of the FOV. The heading may be de-selected by means of a declutter switch.

5. VELOCITY VECTOR: The velocity vector or flight path angle should be shown, if available. The velocity vector may be de-selected, if desirable, in an Unusual Attitude Mode or during ACM.

6. OTHER SYMBOLS: Other symbols should be shown depending on the operational needs of the pilot.

E. FAULT ALERTS

1. HUD DATA: The HUD should not display false or misleading information. If invalid data is received from HUD input sources, then the HUD should indicate the loss in validity by deleting the symbol(s) in question.

Symbols that are calculated using backup or reversionary sources (such as calculating velocity vector based on air data vice inertial data) should be clearly indicated to the pilot.

Symbols that are incorrectly positioned because of FOV limitations should clearly indicate this to the pilot. In the past, this has been successfully accomplished by placing an "X" over the symbol, by truncating the symbol at the FOV limit, or by adding a "LIM" near the symbol.

Particular care should be taken so that two symbols which are positioned relative to each other do not change this relationship when placed at or near the limit of the FOV. An example would be the flight director and the velocity vector (if the flight director is shown relative to the velocity vector as is common practice). When the velocity vector is limited by the FOV limit, this should not affect the relative location of the director steering symbol relative to the velocity vector. This might be accomplished by limiting the velocity vector slightly inside the FOV limit so the director steering symbol can still move around it.

The use of flashing symbols to indicate degraded or FOV limited data is not acceptable by itself.

Symbols that can be deleted by declutter should have a secondary warning when they are deleted because of faulty data. An example might be the annunciation "DELETED" in place of airspeed digits if airspeed is deleted because of invalid data. In this case, if airspeed data was invalid, but the airspeed deleted by a declutter option, the "DELETED" message would not be shown.

2. AIRCRAFT MASTER WARNING/MASTER CAUTION: The HUD should repeat the aircraft master warning and master caution annunciation. Specific annunciations should be included only if necessary for safe flight. If specific indications are used, they should conform to MIL-STD-411D or SAE-AS-425C.

F. SCALING

Generally one-to-one pitch scaling of HUD data has been preferred,, although other scalings have been shown to be advantageous under some circumstances. A slight compression (of the order of 1.5:1 or 2:1) may help tracking performance and may be useful if a conformal display is not needed (such as during high altitude cruise).

This pitch compression or more can be of assistance to the pilot during large amplitude maneuvers (such as ACM, acrobatics, or unusual attitude (UA) recoveries). An Unusual Attitude Mode has been suggested with pitch compression and limited data to assist the pilot during spatial disorientation. Such a mode is recommended for all aircraft, transport as well as tactical.

One-to-one scaling is indicated during ground reference maneuvers (such as landing).

G. REFERENCE

Traditionally, the location of the reference for error displays (course deviation information, airspeed error, angle-of-attack error, etc.) has been the primary aircraft symbol. Normally this location would be recommended, however some recent successful HUDs have used the intersection of the horizon line and the selected course as the reference for ILS deviation error. Further, recent studies indicate that increased use of the pitch symbol as a reference may enhance resistance to spatial disorientation. It is premature to insist that deviations and error symbols be referenced to the primary flight symbol.

Flight director information should have zero reference located at the primary airplane symbol unless enhanced performance can be demonstrated.

The special relationship between ALPHA, GAMMA, and THETA must be considered when selecting a reference for angle-of-attack error. (See Section VI. D. below.)

H. SYMBOL PRIORITY

A table of symbol priority must be established for those symbols that can move within the FOV. If any symbols can over-write one another, the symbol generator must use this symbol priority table to blank the symbol of lower priority to prevent interference with the legibility of the higher priority symbol.

The lower priority symbols should be partially or completely blanked as it approaches the lesser priority symbol. This symbol priority table is not the same as the order of decluttering. For example, in most display formats, the pitch ladder is never decluttered, yet it has the lowest rank on the symbol priority table for most formats. (That is, when the a portion of the pitch ladder approaches another symbol, a mask around the other symbol blanks the pitch ladder in the neighborhood of the other symbol.)

Recommended symbol priorities are shown in Appendix B.

VI. SYMBOLOGY CRITERIA

A. GENERAL

Symbols should appear clean-shaped, clear, and explicit. Lines should be narrow, sharp-edged, and without halo.

The meaning and behavior of symbols must be consistent for all modes of a given display.

B. ACCURACY

The accuracies of symbol placement should be commensurate with the intended use of the parameter and the operational requirements. All accuracies, except boresight accuracy, should be considered system accuracies, not just HUD accuracies.

1. BORESIGHT: The recommended boresighting accuracy specifications are

Tactical aircraft:	1.0 mr
Transport aircraft:	3.0 mr

2. CONTACT ANALOG SYMBOLS: Positioning of contact analog symbols should produce no discernible mismatch with the real world cues. If a mismatch is unavoidable, symbolic rather than realistic symbols should be used (see runway symbols in Appendix A for example.)

3. OTHER SYMBOLS: Recommended positioning tolerances of other symbols are

Conformal symbols:	1 mr
Non-conformal symbols:	3 mr

4. STANDBY RETICLE: Positioning of the standby reticle should be commensurate with the intended use of the HUD.

5. PLATFORM ACCURACIES: Recommended platform accuracies are shown in Paragraph IV. C. 1.

C. DYNAMIC RESPONSE

The motion of all analog symbols on the HUD should be smooth, with no objectionable overshoot, and should generally track the short period of the airplane. Symbols should be stable with no discernible flicker or jitter.

1. FLICKER: Symbols should show no discernible flicker. A minimum symbol refresh rate of 50 Hz is recommended. Note: The use of 60 Hz may enhance recordability with video recording equipment.

The HUD should be synchronized with other CRT displays visible to the pilot. This is particularly important when basic refresh rates less than 60 Hz are used.

2. JITTER: Symbols should be stable with no discernible jitter, i. e. less than the minimum linewidth (3 sigma). Motion at frequencies above 0.25 Hz is considered jitter.

3. NOISE: Display noise should not cause symbol forms or accuracies to exceed recommended or specified limits. Display noise should not interfere with the intended use of the HUD.

4. FRAME TIMES: Recommended minimum sampling rates for aircraft attitude, inertial velocities, and accelerations are

Tactical aircraft:	25 Hz (up-and-away)
	12.5 Hz (landing config.)
Transport aircraft:	10 Hz

These rates correspond to frame times of 40 msec for tactical aircraft (up-and-away), 80 msec for tactical aircraft in the landing configuration, and 100 msec for transports. Slower sampling rates (3-4 Hz) may be used for other quantities, such as airspeed and altitude. Airspeed data for air mass velocity vector calculations should be sampled at the rates shown unless no degradation in performance can be shown.

5. QUICKENING: Symbol quickening may be required to yield a "flyable" symbol. Symbol quickening should not change automatically (within a given mode) in a non-failure state. Symbol quickening should be kept to the minimum necessary to provide a flyable symbol.

6. DAMPING: Symbol damping may be required to yield a "flyable" symbol. Symbol damping should not change automatically (within a given mode) in a non-failure state.

7. PLATFORM RESPONSES: Recommended platform response requirements are shown in Paragraph IV. C. 2.

8. DIGITAL DISPLAYS: Digital displays, such as airspeed, altitude, etc., should not be refreshed on the display faster than 3-4 Hz. The data can be updated at a faster rate and used in the other flight control computations at faster rates, but the data displayed on the HUD should change at this rate.

D. FLY-TO-SENSE

All error symbols should be "fly-to" symbols. The only exception has historically been the angle-of-attack error which, in some airplanes, has had a "fly-from" sense.

The choice for the angle-of-attack sense is based on two conflicting criteria. The conventional criteria of always "flying-to" an error and the geometrical criteria of attempting to show the relationship between ALPHA, GAMMA, and THETA which leads to a "fly-from" sense. Selection on one choice would be premature at this time.

Both criteria could yield a "fly-to" sense if the angle-of-attack error used the aircraft pitch symbol as its reference. Requiring this option would be premature at this time.

E. PITCH SCALING CONSIDERATIONS

If compressed pitch scaling is used to assist in unusual attitude recognition or for use in acrobatic flight, it will not be possible for the various HUD symbols to all be conformal. The common choices in compressed pitch scale use are to have the aircraft pitch symbol (waterline) remain fixed in the HUD FOV, to have the horizon symbol remain conformal with the real world horizon (zero pitch angle), or have the velocity vector symbol remain conformal with the true velocity vector. For most applications, it is recommended that the HUD horizon remain conformal with the real world horizon.

For ground referenced maneuvers (A/G weapons delivery, landing approach, or terrain following) with inertial velocity vectors, then the HUD velocity vector should remain conformal with the true velocity vector.

In either case, the angular relationships between ALPHA, GAMMA, and THETA should be retained (although compressed).

Target symbols should overlie the actual target and not be shown at the correct angles on the pitch scale.

F. CODING

Each symbol should be unique by virtue of at least two coding characteristics. Color coding is acceptable, however colors should be consistent with head-down displays. Flashing of symbols should be minimized. Flashing may be used to attract attention to a symbol, but should not be used by itself to denote data error, FOV limits, decision height, etc.

G. DIRECTED DECISION CUES

The use of a directed decision cue must be held to an absolute minimum and confined to those situations where loss of the aircraft is imminent if the trajectory is continued (i. e. a breakaway commanded because of impending ground impact). Landing minimums, if annunciated, should use "MINIMUMS" not "GO-AROUND."

The use of directed decision cues during combat, such as "SHOOT" should be avoided since this requires the pilot to follow specific tactics which may not be desired in all situations. An "IN RANGE" annunciation is preferred to "SHOOT."

H. SIZE AND SHAPE OF SYMBOLS

Generally, the symbols in MIL-STD-1787 are recommended. Where other symbols are recommended, these are shown in Appendix A.

I. SIZE AND SHAPE OF CHARACTERS

1. SIZE OF CHARACTERS: The size of alphanumeric characters will depend on the degree of importance attached to the particular character. Recommended size guidelines are

Basic size:	4 X 8 mr
Maximum size:	8 X12 mr

2. SHAPE OF CHARACTERS: The shape of alphanumeric characters has not been specified in the past. Two recommended fonts are the MIL-M-18012 and the Leroy fonts.

J. LINE WIDTH

The recommended line width is:

Unenhanced:	1.0 mr
Enhanced:	3.0 mr

K. MINIMUM MOVEMENT

The minimum movement of symbols should be

Minimum movement:	0.135 mr

L. VIDEO DISPLAY CRITERIA

Video display criteria should be developed. In the interim, the criteria of MIL-D-87213 should be followed.

VII. PRIMARY FLIGHT REFERENCE CRITERIA

A. GENERAL

HUDs intended for use as primary flight references are clearly critical to flight safety. Many of the specific requirements have been discussed in the appropriate sections of the Head-Up Display Design Guide. Because of the interest in HUDs as primary flight references and because of the critical nature of such displays, this section discusses some issues of primary flight references (PFRs).

PFRs are defined in Section II as providing sufficient information for the pilot to fly the airplane in IMC during a particular mission segment. As guidance to the designer, "sufficient information" can be defined as the information contained in the traditional basic T, i. e. airspeed, altitude, attitude (pitch and roll), heading, and (usually) course guidance information. Obviously, the specific data may vary, ALPHA (angle of attack) may be substituted for airspeed, radar altitude for barometric altitude, etc.

The PFR provides data for the pilot to control the airplane, i. e. climb/descend, bank left/right, etc. It will not include navigation data nor will it include systems data unless critical to the mission segment.

Normally, a HUD should be treated as a PFR since the pilot will likely use it as such as if it were the primary flight reference regardless of the words in the flight manual.

B. DATA REQUIREMENTS

The need for course deviation, navigation, or systems data during a specific mission segment will depend on how critical constant reference to a specific parameter is. As an example, consider course deviation. During normal cruise at high altitude, it could be considered that course deviation data would not be required for a PFR, while during an ILS final approach, both course and glideslope deviation data would be. Both the UO and CA will have to determine if a specific data parameter (i. e. course deviation) is required depending on the complexity of the tracking task. Overwater, high-altitude cruise will not normally require course deviation; terminal tracking certainly will.

Table I lists typical data requirements for a PFR in terms of traditional data likely to be on a HUD. The table shows these requirements for various mission segments.

Table I

Typical Data Requirements
for a Primary Flight Reference HUD

PARAMETER	MISSION SEGMENT TOGA	CRUISE	TERM-INAL	FINAL (N/P)	FINAL (PRE)	AIR-TO-AIR
PITCH	X	X	X	X	X	X
ROLL	X	X	X	X	X	X
VEL VECTOR	X		?	?	X	?
HEADING	X	X	X	X	X	X
LAT DEV	X	?	X	X	X	?
VERT DEV			?		X	?
ALTITUDE	X	X	X	X	X	X
AIRSPEED	X	X	X	X	X	X
ALPHA	?			?	?	X
BETA	?			?	?	

Note: Instrument meteorological conditions are assumed.

These data may be replaced by other data which will allow the pilot to accomplish the mission segment. For example, ALPHA would be an acceptable substitute for airspeed on final approach, but not during an air-to-ground delivery.

Declutter of data required to be on a HUD primary flight reference should be permitted provided the pilot can regain the decluttered data without removing his/her hands from the aircraft controls (stick and throttle).

C. EQUIVALENCE WITH HEAD-DOWN DISPLAYS

If the HUD is to be the primary flight reference, it must be possible to view substantially the same data on the head-down panel. This is required for several reasons: as a backup to the HUD symbol generator, to allow the pilot to view the display without the view of the external real world cues, and to allow the pilot to have a close focus when cross-checking instrument panel data.

Substantially the same data means the data must be in the same format as the HUD, although the scale may be compressed and declutter options may be omitted. Additional data, not present on the HUD may be present if there is no interference with the use of the the display to fly the airplane. The display may be a color display even if a monochromatic HUD is used. The two displays, HUD and head-down should use the same mode switch to ensure that they are operating in the same mode.

The head-down display should be visible in the PVSA at all times, unless mission requirements require all usable panel space. In this event, the display must be available when called for by the pilot (without the need to remove his or her hands from the aircraft controls). This requirement applies to the pilot flying in two pilot airplanes.

In two pilot airplanes, the pilot not flying must have this head-down display visible in the PVSA at all times (assuming no failures). The pilot flying (on two pilot airplanes) must be able to regain the head-down display at any time (again keeping his/her hands on the controls). This means that the pilot flying may be flying by reference to the HUD and must have substantially the same display shown on his primary panel unless mission requirements dictate the use of this panel space. The pilot not flying must have the equivalent display shown head-down on his primary panel at all times whether or not he uses the HUD.

D. HUD SYMBOLOGY FOR A PRIMARY FLIGHT REFERENCE

A primary concern for HUDs intended for use as PFRs is the need to prevent occurrence of and to aid in the recovery from unusual attitudes (UAs). To this end, any such HUD must be designed with UA recovery and spatial disorientation in mind.

Aircraft pitch attitude, not velocity vector, is of primary importance during UA recovery. At large angle-of-attack, the velocity vector will not be responsive to control inputs. In particular, a large ALPHA indicated by a large negative GAMMA and a nose high THETA must not cause the pilot to attempt recovery by raising the velocity vector by pulling on the control column. With present HUD formats and existing pilot backgrounds, two symbologies are essential: (1) the pitch reference frame (pitch ladder) must clearly indicate aircraft pitch during extreme pitch excursions, and (2) the velocity vector must not attract the pilot's attention from the pitch attitude.

The pitch ladder format must clearly indicate nose high angles from nose low. A format which accomplishes this is the modified F-18 format in which negative angles (i. e. below the horizon) are slanted to indicate the direction to the horizon. As additional discriminants, the negative "rungs" of the pitch ladder are dashed, have the vertical ticks in the center and have the numerical angles on the left side only. The dashing of the "rungs" should be at three to five dashes per degree. Positive angles should use solid horizontal lines with tick marks at the outside edge and numerical indices on both sides. Five degree spacing is recommended for 1:1 scaling.

The pitch reference for a HUD intended for a PFR should use a complete pitch ladder, not just a horizon line or a horizon line and a pitch mark. While the use of a horizon lines alone has been suggested in the past for transports, the possibility of an

UA in a transport can not be ignored. A horizon line only (or a horizon line plus a pitch mark) would be acceptable only if a clear improvement in performance can be shown and if reversion to a conventional pitch ladder is automatic during UAs before the horizon leaves the instantaneous field of view from any point within the eyebox.

De-emphasizing the velocity vector at large ALPHAs has been accomplished by deleting the velocity vector when ALPHA becomes excessive. It is also possible to use the pitch reference symbol (waterline) as the basis for angle-of-attack error or for the ALPHA scale. The velocity vector can also incorporate a fly-from ALPHA error symbol (as on the A-7C/D/E HUD). Preliminary simulator experiments indicate that deletion of the velocity vector symbol at high ALPHA is preferred.

Other data shown on the HUD will depend on the specific requirements of the mission segment. The aircraft master warning and master caution annunciation must be repeated on the HUD.

E. PRIMARY FLIGHT DISPLAY RELIABILITY

The reliability of a HUD primary flight display, in general, should match or exceed that of the head-down instruments it is replacing. The system must be designed such that the displaying of incorrect attitude information is extremely improbable. HUDs intended for precision instrument approach primary flight references should be designed such that the displaying of incorrect attitude or course guidance information is extremely improbable.

When incoming data or processing that affects primary symbology is identified as invalid, the affected symbology should automatically be deleted or should revert to a backup mode. The processor should check the incoming data needed to generate the primary symbology for reasonableness with respect to physical aircraft parameters. It should also cross-check related data for predetermined differences if more than one source of data is available.

At a minimum, there should be two symbol generators available to provide symbology to the HUD (one of which can drive the symbology for the head-down display discussed previously).

There is no particular reason why an electronic display can not serve as a stand-by attitude indicator provided it has sufficient reliability. A general rule is that the standby indicator must be more reliable than the primary indicator. The standby attitude indicator in a single pilot airplane must be clearly visible at all times without pilot selection.

F. HUD MODE SWITCHING FOR A PRIMARY FLIGHT REFERENCE

Automatic HUD mode switching is not desirable for a display intended as a primary flight reference. While some modes of flight do use automatic switching (such as the breakaway X in ground attack), these HUDs have implicitly assumed VMC. While automatic switching may be acceptable in IMC (The use of a PFR assumes IMC.), care must be taken not to delete the pitch reference needed by the pilot to recover from UAs and to fly the airplane.

It is highly recommended that any HUD intended as a PFR incorporate a basic instrument mode which can always be selected by the pilot regardless of the other modes being used. The pilot should be able to select this mode without removing his or her hands from the flight controls. This could be accomplished by a dedicated switch on the stick or throttle. This will always provide basic attitude reference as well as airspeed, altitude, and heading.

G. INERTIAL VS. AIR MASS DATA

There are valid reasons to choose either air mass or inertial velocity vector data. The use of air mass data allows direct integration of ALPHA and BETA (sideslip). Where ALPHA information is critical (such as high ALPHA near stall), or BETA information is critical (such as or engine-out situations), the use of air mass data is recommended to show ALPHA and BETA directly (Figure 1). If inertial data is used, non-conformal ALPHA and BETA cues must be introduced (Figure 2).

Historically, the choice of whether to use inertial or air mass velocity vector data has depended on whether or not an inertial navigation system (INS) was installed in the airplane. This is not a valid reason for this decision. Just because we can display something doesn't mean we should. While an INS is required to show inertial velocity vector, the needs of the pilot may dictate a need for air mass data. Further, it is not necessary to use ALPHA and THETA data to calculate GAMMA. GAMMA can be found using the relationship of vertical velocity and horizontal velocity. The same computation which produces an inertial GAMMA = arcsin(vertical velocity/inertial velocity) can substitute true airspeed for inertial velocity and calculate air mass GAMMA. If an air mass velocity vector is needed, it would be desirable to use a filtered GAMMA derived from both ALPHA and THETA data and from inertial vertical velocity and air data computer true airspeed.

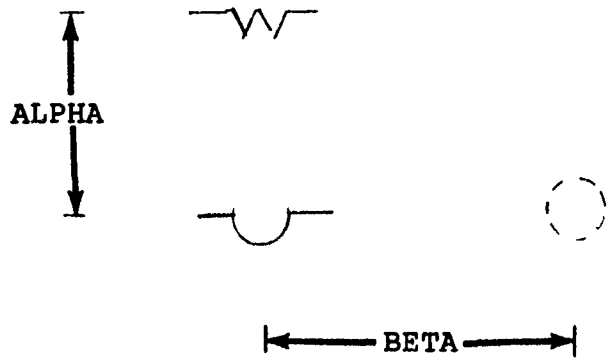

Figure 1

ALPHA and BETA Using Air Mass Velocity Vector

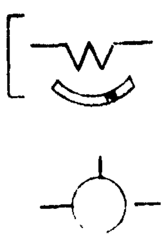

Figure 2

ALPHA and BETA Using Inertial Velocity Vector
(Reference to waterline shown, reference to velocity vector is optional)

EVALUATION OF HEAD-UP DISPLAYS

TO ENHANCE UNUSUAL ATTITUDE RECOVERY

APPENDIX I

Subject Pilot Comments

APPENDIX A: RECOMMENDED SYMBOLS

The following symbols are recommended for use in HUDs and other electronic attitude indicators. Where no symbols are listed in this appendix, the symbols in MIL-STD-1787 are recommended.

A. FLIGHT SYMBOLS

1. AIRSPEED:

The recommended format is a digital display. The digits should be fixed in the FOV near the left side of the Fixed Aircraft Symbol (waterline). The top of the box should be level with the wings on the waterline symbol. The airspeed digits should be 150% of the dimensions of the basic HUD digits. The preferred format is plain digits surrounded by a box. Alternative formats delete the box around the digits or surround the digits with a circle with a "minute hand" display in which the index makes one revolution for every 100 knots.

The use of analog tapes has been thought to detract from spatial orientation by providing a false horizon ninety degrees to the real one. For this reason, vertical tapes should be avoided in future HUDs unless enhanced mission effectiveness can be demonstrated.

The normal airspeed (indicated or calibrated airspeed) should not be denoted. Failure states or alternative speeds should be denoted with a letter or a word:

a. INDICATED AIRSPEED: I or IAS
b. TRUE AIRSPEED: T or TAS
c. MACH NUMBER: M or MACH

Figure A-1

Alternate Airspeed Symbol
(Showing "minute hand")

2. ALTITUDE:

The recommended format is a digital display. The digits should be fixed in the FOV near the right side of the Fixed Aircraft Symbol (waterline). The top of the box should be level with the wings on the waterline symbol. The preferred format is plain digits surrounded by a box. The ten thousand, thousand, and hundred feet digits should be 150% the dimensions of the basic HUD digits. The tens and units digits should be the size of the basic HUD digits. Alternative formats delete the box around the digits or surround the digits with a circle with a "minute hand" display in which the index makes one revolution for every 1000 feet. The format is similar to the airspeed display shown in Figure A-1.

The barometric altitude should not be denoted. Radio or radar altitude should be denoted with an R or with the word RADIO, RADAR, or RAD.

3. ANGLE OF ATTACK (ALPHA):

The symbol shown in MIL-STD-1787 has been successful. The fly-to or fly-from sense is not specified. At this writing, alternative presentations should be developed to exploit the unique relationship between ALPHA, GAMMA, and THETA.

4. ANGLE OF SIDESLIP (BETA):

The choice of display has not been resolved at this writing. As is the case with angle of attack, the relationship between the velocity vector and the fixed aircraft reference could be used. As an interim recommendation, the symbol shown should be used when BETA is critical.

Alternatively, the angular difference between the air mass velocity vector and the ghost velocity vector can be used. (See Figure 1 in the main text.)

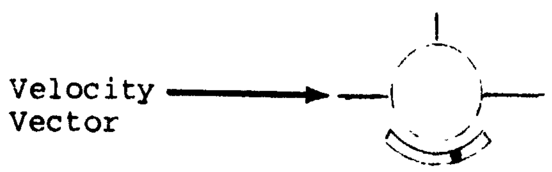

Figure A-4

Interim Angle-of-Sideslip (BETA) Symbol
(Symbol proposed for Inertial Velocity Vector)

5. BANK:

The bank index should only be used for precision instrument flight if procedures require. The index is shown in MIL-STD-1787. The choice of top or bottom (sky pointer or earth pointer) should agree with the head-down instruments.

For orientation, the arrow symbol on the velocity vector has been shown to be effective during simulations.

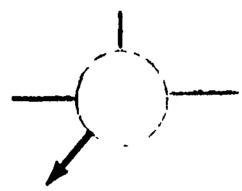

Figure A-5

Arrow on Velocity
Vector(Augie Arrow)

6. FIXED AIRCRAFT REFERENCE (THETA):

This symbol is shown in MIL-STD-1787 and is referenced to the ACRL and represents an extension of (or the direction of) the ACRL. For HUDs with 1:1 pitch scaling, it is in a fixed location on the display. For HUDs with other scalings, it should be placed at the appropriate location to show aircraft pitch.

7. FLIGHT PATH ANGLE: (see velocity vector or ghost velocity vector)

The use of the velocity vector and a ghost velocity vector is recommended rather than the horizontal line.

Figure A-3

Flight Path Angle Symbol

8. GHOST VELOCITY VECTOR: (see flight path angle or velocity vector)

The ghost velocity vector should be displayed at the true location of the velocity vector position if the velocity vector differs by more than a specified angle from the caged position (recommended as two degrees).

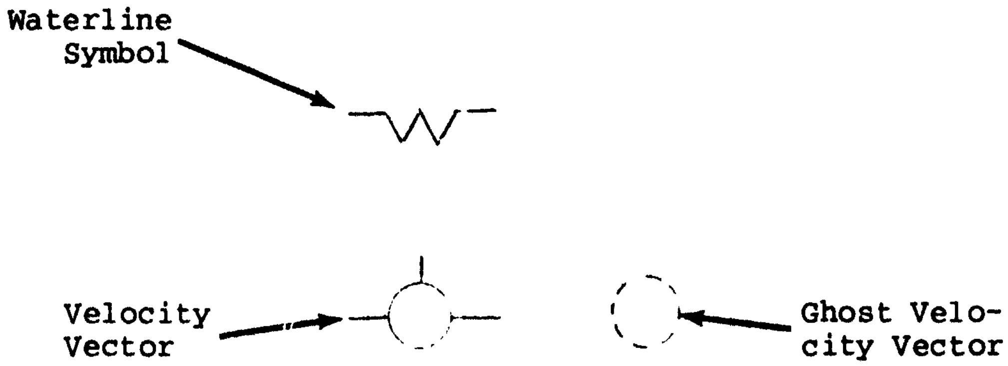

Figure A-8

Ghost Velocity Vector Symbol
(Shown to right of velocity vector)

9. HEADING:

The format is given in MIL-STD-1787. The preferred location is to place the heading marks on the horizon line. This has the advantage of maintaining spatial awareness of heading during steep turns, but the disadvantage of losing heading information during extreme pitch attitudes. If this method is used, the heading information must remain in view -- usually with a digital heading directly above the waterline symbol. Alternatively, the heading could be placed on a pitch ladder rung near the waterline. Similar approaches have been found to be successful on three-axis attitude indicators.

An alternative location is to place the scale should be fixed at the top or bottom of the FOV. Using a boxed digital heading in the center of the symbol has also been used successfully (F-18). If digital heading is used, the heading digits should be 150% of the dimensions of the basic HUD digits. (Heading digits on the horizon or heading scale should be the size of the basic HUD digits.)

Magnetic heading should be the default indication and should not be denoted. Other heading references should be denoted with a letter or a word:

a. TRUE HEADING: T or TRUE
b. GRID HEADING: G or GRID

10. HORIZON LINE:

The horizon line is shown in MIL-STD-1787. The 30 mr gap in the center is optional. The use of a horizon line alone is not recommended since during unusual attitudes it may not be visible within the IFOV. If a horizon line alone is to be used, provision to replace it with a pitch ladder before the horizon line leaves the IFOV must be incorporated.

11. NORMAL LOAD FACTOR:

A digital readout is recommended. The location is unspecified.

12. PITCH LADDER:

The pitch ladder above the horizon is shown in MIL-STD-1787. The pitch ladder below the horizon should be slanted up in the middle when the depression angle exceeds minus ten degrees or when the horizon is no longer visible in the IFOV (similar to the F-18). The vertical ticks for negative angles should be in the center of the FOV. The negative angles should be shown on the left side only with no minus sign. Negative angles should use dashed lines (dashed at 3 dashes per degree).

As an alternative, the F-18 pitch ladder can be used. That is, the above-horizon rungs should also be slanted. A second alternative is the conventional pitch ladder from MIL-STD-1787. That is the below-horizon rungs need not be slanted

Regardless of the pitch ladder style, at the zenith or nadir, the 90 degree mark should be indicated by a "DIVE" or "CLIMB" legend. The pitch ladder should <u>not</u> rotate as the airplane passes through the 90 degree pitch up or down point.

The pitch ladder should be centered on and rotate around the fixed aircraft reference.

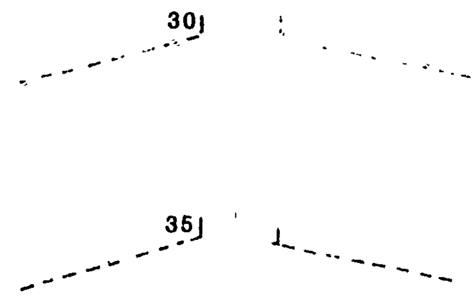

Figure A-12A

Pitch Ladder Below Horizon
(Slanted at twice angle below horizon)

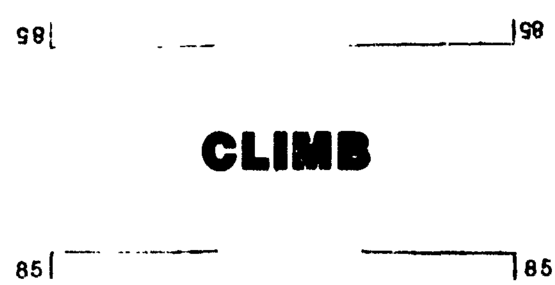

Figure A-12B

Pitch Ladder Indication at Zenith

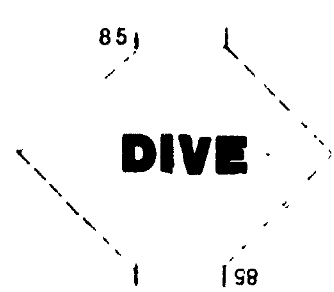

Figure A-12C

Pitch Ladder Indication at Nadir

13. POTENTIAL FLIGHT PATH (PFP):

Reference is the velocity vector. The right symbol is optional.

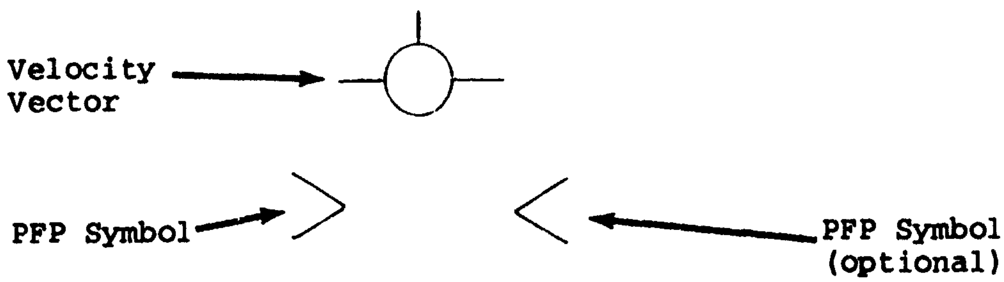

Figure A-13

Potential Flight Path (PFP) Symbol
(Shown with velocity vector)

14. VELOCITY VECTOR (INERTIAL):

The symbol is shown in MIL-STD-1787. It may be caged at the center of the pitch ladder at pilot option.

15. VELOCITY VECTOR (AIR MASS):

This symbol differs from the inertial velocity vector and is always caged. (See flight path angle or ghost velocity vector.)

Figure A-15

Velocity Vector (Air Mass) Symbol

16. VERTICAL VELOCITY:

The recommended symbol is digital. It should be located below the altitude presentation. Vertical velocity is not normally necessary if velocity vector is available.

B. NAVIGATION SYMBOLS

17. DME:

This symbol should be a digital indication. The location is not specified.

18. RUNWAY SYMBOL:

Figure A-18A

Runway Symbol
(Inertial Navigation System)

Figure A-18B

Runway Symbol
(No Inertial Navigation System)

19. STEERING BOX: (see deviation)

Reference is the velocity vector. Other references have been successful, such as desired heading and desired glideslope. The dimensions of the steering box change with the allowable error. (See deviation cue.)

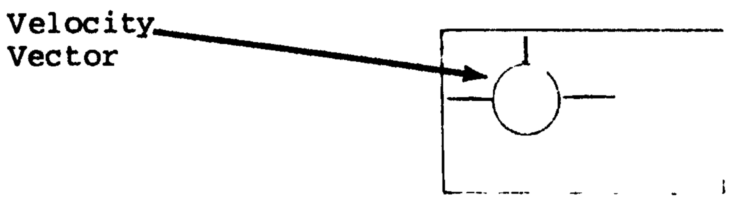

Figure A-19

Steering Box (Deviation) Symbol
(Fly down and right)

20. TIME TO GO:

This symbol should be a digital indication. The location is not specified.

APPENDIX B: RECOMMENDED DATA FOR DIFFERENT HUD MODES

Within each mission segment, a set of recommended data symbols are listed. A letter "D" denotes symbols that can be allowed to be decluttered by the pilot. Underlining indicates symbols recommended which should be present if the display is to be considered a PFR. Note: the use of a PFR assumes flight in IMC.

Symbols are ordered showing priority of display. If two symbols would interfere, the symbol shown first should cause subsequent symbols to be blanked.

The priorities and choice of required symbols for PFRs are recommendations.

A. BASIC MODE -- UNUSUAL ATTITUDE RECOVERY

<u>WATERLINE AIRCRAFT REFERENCE</u>
AIR MASS VELOCITY VECTOR (delete at high ALPHA)
<u>AIRSPEED</u>
<u>ALTITUDE</u>
<u>HEADING</u>
<u>BANK</u> (Augie arrow recommended for UA)
<u>PITCH LADDER</u> (compressed scaling optional. 2:1 scaling recommended for UA. If compressed scaling used, horizon should remain conformal.)

B. TAKEOFF/GO-AROUND

	<u>WATERLINE AIRCRAFT REFERENCE</u>
D	<u>ANGLE-OF-ATTACK</u> (desired)
	VELOCITY VECTOR (air mass recommended)
D	<u>AIRSPEED</u>
D	<u>ALTITUDE</u>
D	<u>ANGLE-OF-SIDESLIP</u> (multi-engine or VTOL)
D	<u>HEADING</u>
D	POTENTIAL FLIGHT PATH (desired)
D	COURSE DEVIATION (optional)
D	FLIGHT DIRECTOR (optional)
D	SPEED COMMAND (optional)
D	RUNWAY REMAINING (on runway, optional)
	<u>PITCH LADDER</u>

C. CRUISE

	WATERLINE AIRCRAFT REFERENCE
D	VELOCITY VECTOR
D	COURSE DEVIATION
D	VERTICAL DEVIATION (optional)
D	FLIGHT DIRECTOR (optional)
D	WAYPOINT (optional)
D	DIRECTION CUE (optional)
D	AIRSPEED
D	ALTITUDE
D	HEADING
D	RANGE (optional)
D	DME (optional)
D	TIME-TO-GO (optional)
	PITCH LADDER

D. APPROACH/LANDING

	WATERLINE AIRCRAFT REFERENCE
	VELOCITY VECTOR
D	FLARE CUE (optional)
D	COURSE DEVIATION (optional for VMC)
D	GLIDESLOPE DEVIATION (for ILS approach)
D	FLIGHT DIRECTOR (optional)
D	POTENTIAL FLIGHT PATH (desired)
	ANGLE-OF-ATTACK (desired)
D	ANGLE-OF-SIDESLIP (multi-engine or VTOL)
D	RUNWAY REMAINING (on runway, optional)
D	AIRSPEED (may be replaced by ANGLE-OF-ATTACK)
D	ALTITUDE
D	HEADING
D	SPEED COMMAND (optional)
	PITCH LADDER

E. TERRAIN FOLLOWING

	BREAKAWAY
	WATERLINE AIRCRAFT REFERENCE
	VELOCITY VECTOR (inertial recommended)
D	VERTICAL DEVIATION
D	POTENTIAL FLIGHT PATH (optional)
D	COURSE DEVIATION
D	FLIGHT DIRECTOR (optional)
D	DIRECTION CUE (optional)
D	AIRSPEED
D	ALTITUDE
D	HEADING
D	RANGE (optional)
D	TIME-TO-GO (optional)
D	WAYPOINT (optional)
	PITCH LADDER

F. AIR TO GROUND

BREAKAWAY
WATERLINE AIRCRAFT REFERENCE
VELOCITY VECTOR (inertial recommended)
D ANGLE-OF-SIDESLIP (if needed)
D BANK INDEX (if needed)
BOMBFALL LINE (if needed)
CCIP (if needed)
TARGET SYMBOLS (if needed)
SOLUTION CUE (if needed)
D AIRSPEED
D ALTITUDE
D VERTICAL VELOCITY (if needed)
D NORMAL LOAD FACTOR (if needed)
AIMING RETICLE (if needed)
WEAPON BORESIGHT (if needed)
PITCH LADDER

G. AIR TO AIR

WATERLINE AIRCRAFT REFERENCE
D VELOCITY VECTOR
D AIMING RETICLE (if needed)
CCIL (if needed)
TARGET SYMBOLS (if needed)
SOLUTION CUE (if needed)
SENSOR SEARCH AREA (if needed)
D AIRSPEED
D ALTITUDE
D HEADING
D VERTICAL VELOCITY (if needed)
D ANGLE-OF-ATTACK (if needed)
D NORMAL LOAD FACTOR (if needed)
D WEAPON BORESIGHT (if needed)
D PITCH LADDER

H. TRAINING (BASIC HUD FLYING)

D WATERLINE AIRCRAFT REFERENCE
D VELOCITY VECTOR
D ANGLE-OF-SIDESLIP (multi-engine or VTOL)
D COURSE DEVIATION (optional)
D AIRSPEED
D ALTITUDE
D HEADING
D ANGLE-OF-ATTACK (if not clear from GAMMA and THETA relationship)
D PITCH LADDER

I. SYMBOL REPLACEMENT OPTIONS

PITCH LADDER ------ Replace by Horizon with automatic replacement by pitch ladder when horizon leaves IFOV. (Note: This substitution is not recommended for the Basic Mode)

AIRSPEED ---------- Replace CAS/IAS by TAS or MACH (label as TAS or MACH.) Note: Primary airspeed (either IAS or CAS) should have no label.

ALTITUDE ---------- Replace Barometric Altitude by Radar (label as Radar) Note: Barometric altitude will have no label.

ILS DEVIATION ----- Replace Course and Glideslope Deviation by Runway Symbol.

DECLUTTER --------- Declutter recommendations are shown by a D.

VELOCITY VECTOR --- Delete at large angle of attack.

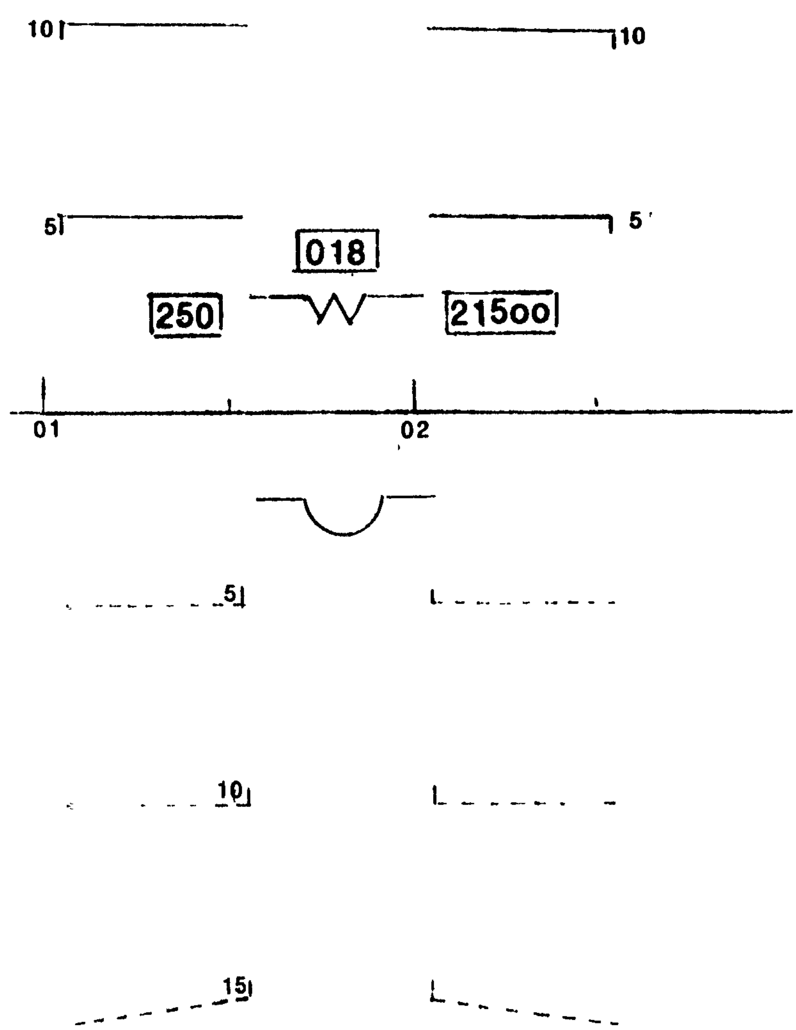

Figure B-1

BASIC MODE

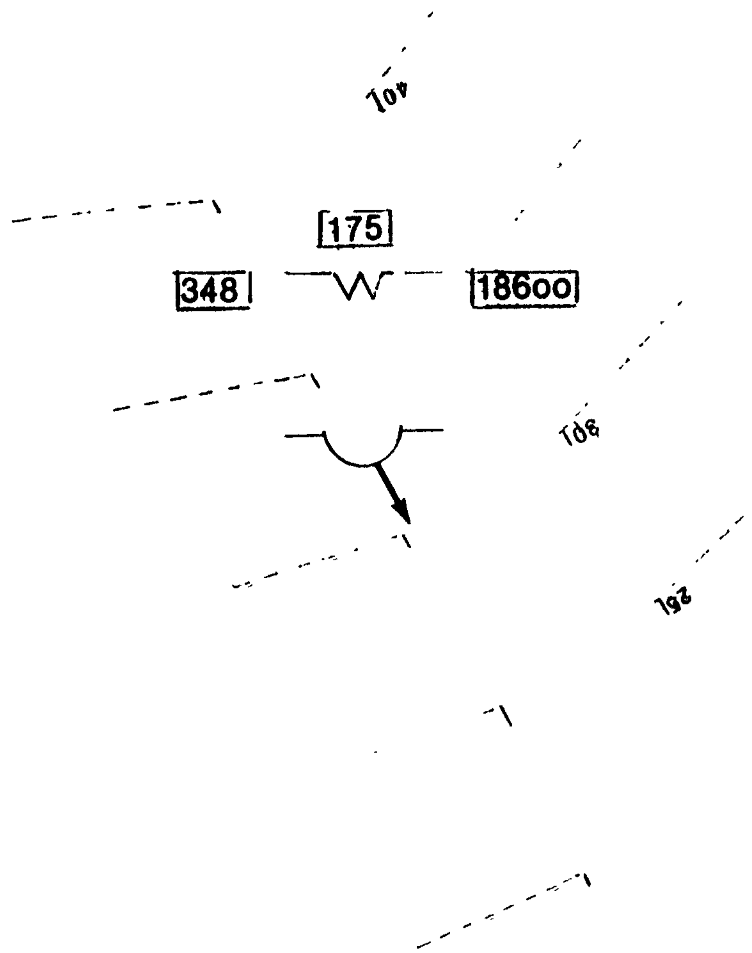

Figure B-2

BASIC MODE -- UNUSUAL ATTITUDE RECOVERY

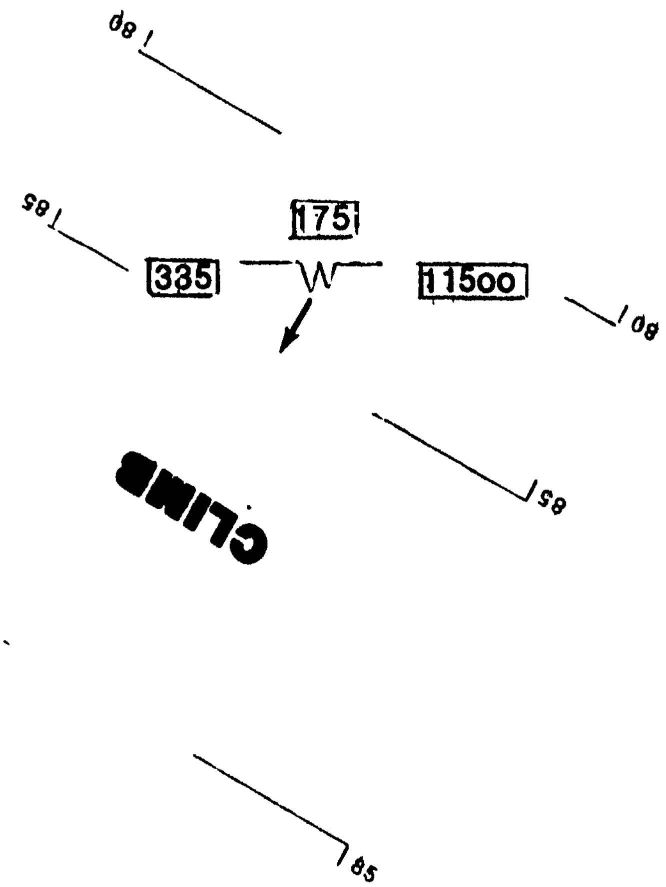

Figure B-3

BASIC MODE -- UNUSUAL ATTITUDE RECOVERY
(Velocity vector deleted at large ALPHA)

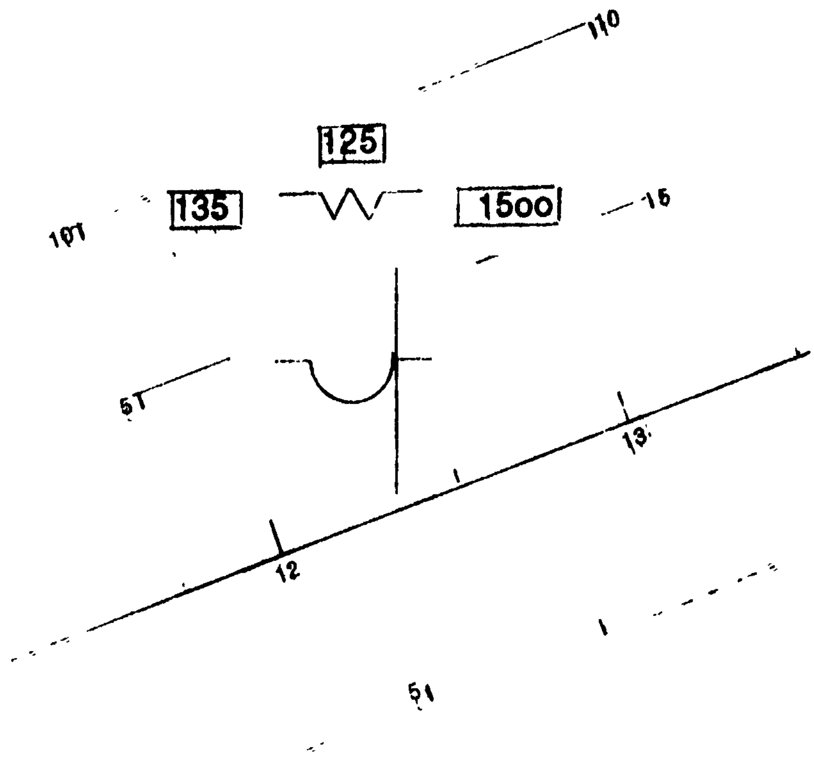

Figure B-4

TAKEOFF/GO-AROUND MODE

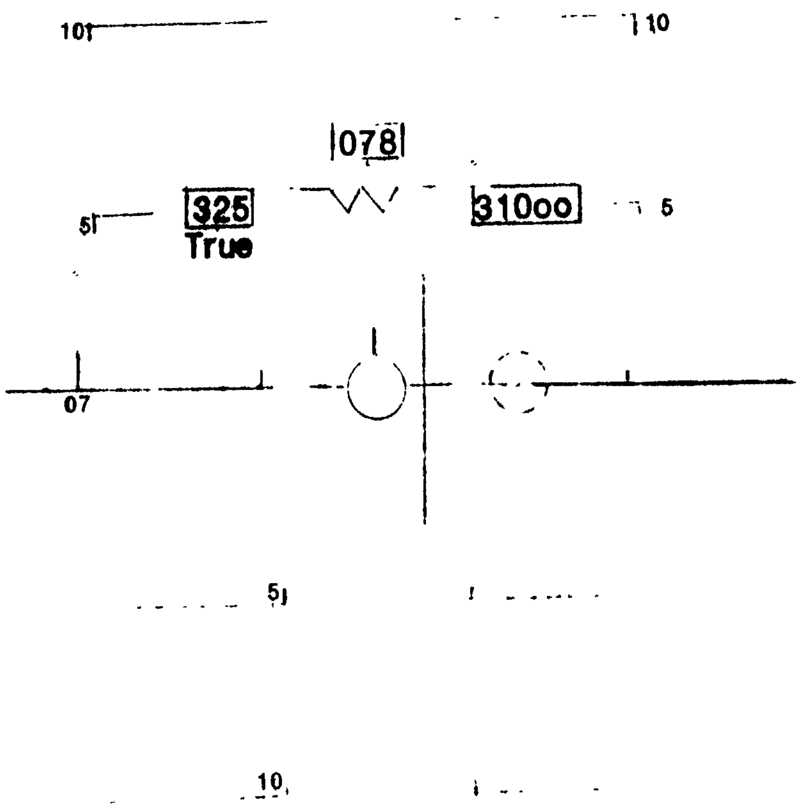

Figure B-5

CRUISE MODE

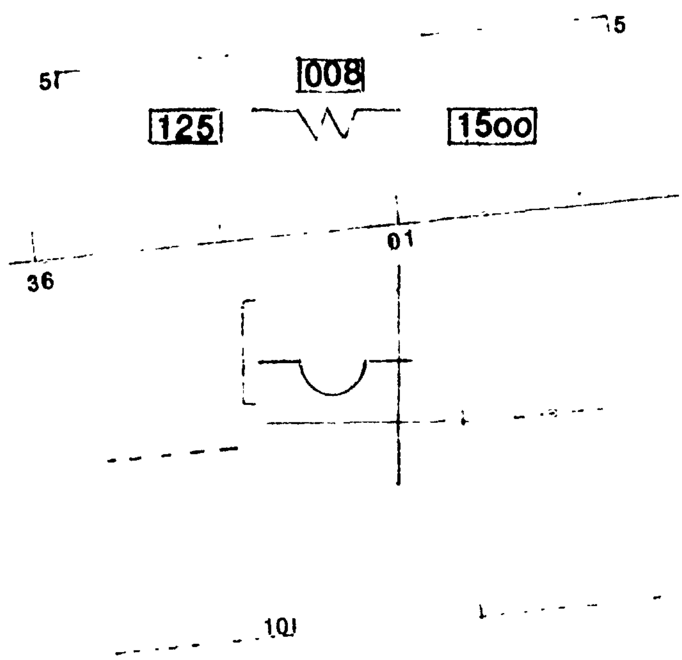

Figure B-6

APPROACH/LANDING MODE
(ILS deviation and air mass velocity vector)

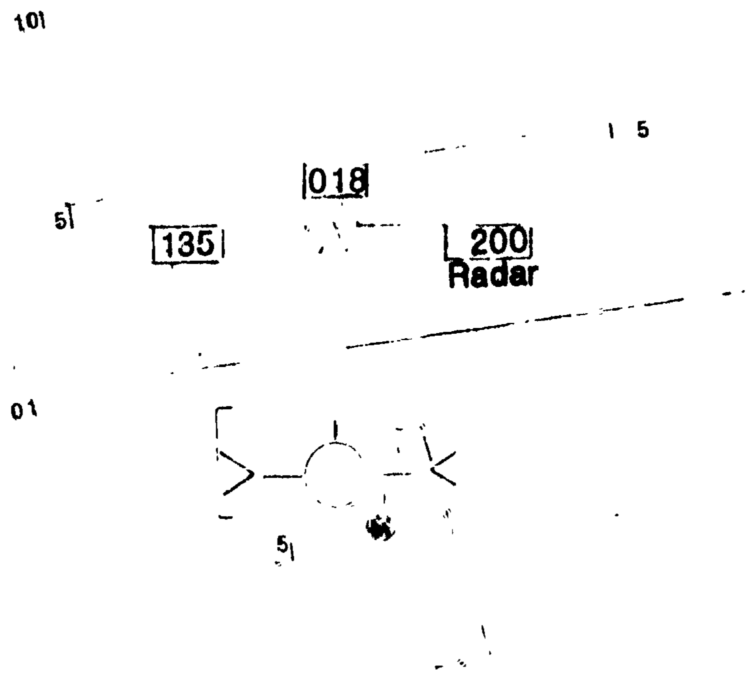

Figure B-7

APPROACH/LANDING MODE WITH RUNWAY SYMBOL
(INS data and inertial velocity vector)

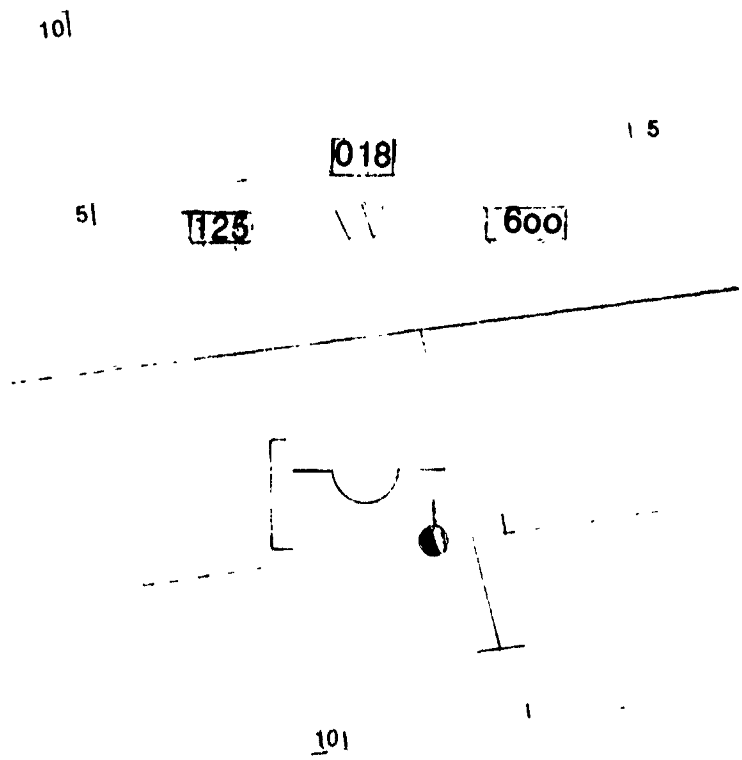

Figure B-8

APPROACH/LANDING MODE WITH RUNWAY SYMBOL
(No INS data available)

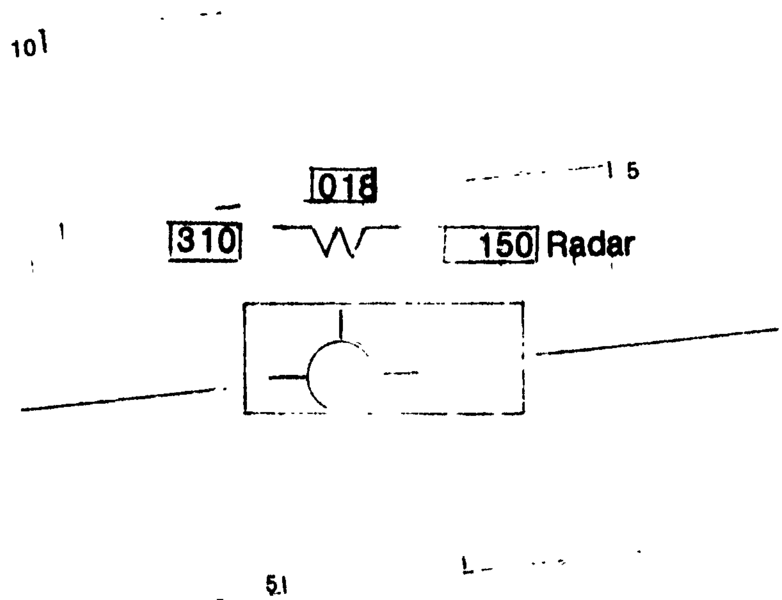

Figure B-9

TERRAIN FOLLOWING MODE

APPENDIX C: ABBREVIATIONS

A/A	Air-to-air
A/G	Air-to-ground
AC	(1) Advisory circular
	(2) Alternating current
ACM	Air combat maneuver
ACRL	Aircraft reference line
AERP	Alert eye reference position
AFSC	Air Force Systems Command
ALPHA	Angle-of-attack
ARP	Aerospace recommended practice
AS	Aerospace standard
ASL	Azimuth steering line
BETA	Angle-of-sideslip
BFL	Bombfall line
CA	Certification authority
CAS	Calibrated airspeed
CCIL	Continuously computed impact line
CCIP	Continuously computed impact point
CRT	Cathode ray tube
DC	Direct current
DCP	Display control panel
DERP	Design eye reference position
DH	Design handbook
DME	Distance measuring equipment
DOD	Department of Defence
EMI	Electromagnetic interference
ERP	Eye reference position
EU	Electronic unit
FAA	Federal Aviation Administration
FLIR	Forward looking infrared
FOV	Field-of-view
FRL	Fuselage reference line
GAMMA	Flight path angle
HDBK	Handbook
HUD	Head-up display
IAS	Indicated airspeed
IFOV	Instantaneous field of view
ILS	Instrument landing system
IMC	Instrument meteorological conditions
INS	Inertial navigation system
LOP	Line of position
LRU	Line replaceable unit
MACH	Mach number
MIL	Military specification/standard
MLS	Microwave landing system
MTBF	Mean time between failures
N/P	Non-precision
NVG	Night vision goggles
PDU	Pilot display unit
PFP	Potential flight path

PFR	Primary flight reference
PRE	Precision approach
PVSA	Primary visual signal area
RTCA	Radio Technical Commitee for Aeronautics
SAE	Society of Automotive Engineers
STD	Standard
TACAN	Tactical air navigation (system)
TAS	True airspeed
TFOV	Total field of view
THETA	Aircraft pitch attitude
TOF	Time of flight
TOGA	Takeoff/go around
UA	Unusual attitude
UO	User organization
VFOV	Vertical field of view
VHF	Very high frequency
VMC	Visual meteorological conditions
VOR	VHF omnirange (navigation system)
VTOL	Vertical takeoff and landing

APPENDIX D: REFERENCES

A. Specifications/standards cited as references:

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FAA-AC-25.1309-1	SYSTEM DESIGN ANALYSIS
FAA-AC-21.303-1A	CRITERIA FOR APPROVAL OF CATEGORY III LANDING WEATHER MINIMA
MIL-E-5400	MILITARY SPECIFICATION: ELECTRONIC EQUIPMENT, GENERAL SPECIFICATION FOR
MIL-W-5088H	MILITARY SPECIFICATION: WIRING, AEROSPACE
MIL-R-6771	MILITARY SPECIFICATION: REFLECTOR, GUNSIGHT GLASS
MIL-F-7513	MILITARY SPECIFICATION: NOMENCLATURE ASSIGNMENT, CONTRACTORS METHOD FOR OBTAINING
MIL-F-8785C	MILITARY SPECIFICATION: FLYING QUALITIES OF PILOTED AIRPLANES
MIL-P-15024	MILITARY SPECIFICATION: PLATE, IDENTIFICATION
MIL-M-18012	MILITARY SPECIFICATION: MARKING FOR AIRCREW STATION DISPLAYS, DESIGN CONFIGURATION OF
MIL-D-87213	MILITARY SPECIFICATION: DISPLAYS, AIRBORNE, ELECTRONICALLY/OPTICALLY GENERATED
MIL-HDBK-217D	MILITARY HANDBOOK: RELIABILITY STRESS AND FAILURE RATE DATA FOR ELECTRONIC EQUIPMENT
MIL-STD-411D	MILITARY STANDARD: AIRCREW STATION SIGNALS
MIL-STD-704	MILITARY STANDARD: AIRCRAFT ELECTRICAL POWER CHARACTERISTICS
MIL-STD-882C	MILITARY STANDARD: SYSTEM SAFETY PROGRAM REQUIREMENTS

MIL-STD-1333A MILITARY STANDARD: AIRCREW STATION GEOMETRY FOR MILITARY AIRCRAFT

MIL-STD-1472 MILITARY STANDARD: HUMAN ENGINEERING DESIGN CRITERIA FOR MILITARY SYSTEMS, EQUIPMENT, AND FACILITIES

MIL-STD-1787 MILITARY STANDARD: AIRCRAFT DISPLAY SYMBOLOGY

RTCA/DO-160A ENVIRONMENTAL AND TEST PROCEDURES FOR AIRBORNE EQUIPMENT

RTCA/DO-178 SOFTWARE CONSIDERATIONS IN AIRBORNE SYSTEMS AND EQUIPMENT CERTIFICATION

SAE-ARP-268F AEROSPACE RECOMMENDED PRACTICE: LOCATION AND ACTUATION OF FLIGHT DECK CONTROLS FOR COMMERCIAL TRANSPORT TYPE AIRCRAFT

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MIL-D-87213 MILITARY SPECIFICATION: DISPLAYS, AIRBORNE, ELECTRONICALLY/OPTICALLY GENERATED

MIL-STD-203F MILITARY STANDARD: AIRCREW STATION CONTROLS AND DISPLAYS FOR FIXED WING AIRCRAFT

MIL-STD-884C MILITARY STANDARD: ELECTRONICALLY OR OPTICALLY GENERATED DISPLAYS FOR AIRCRAFT CONTROL OR COMBAT CUE INFORMATION

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APPENDIX E: HUD BIBLIOGRAPHY

The bibliography is intended to assist the HUD engineer in reviewing the state-of-the-art as well as in obtaining some historical perspective of HUDs. The references are listed on a year-by-year basis and are ordered alphabetically by author within each each year. References with no personal author follow on a year-by-year basis. References for which no publication date are available are grouped at the end.

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