

AEROSPACE RECOMMENDED PRACTICE

SAE ARP5589

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Human Engineering Considerations for Design and Implementation of Perspective Flight Guidance Displays

FOREWORD

Flight guidance for manually flown tasks is essential for precision navigation. Current generations of flight director guidance symbology function well in this role, but are limited in their ability to display future flight path information and may not be optimal for situation awareness or workload.

This SAE Aerospace Recommended Practice (ARP) sets forth design and operational recommendations concerning the human factors/crew interface considerations and criteria for perspective flight guidance displays which offer potential for increased situation awareness and precision flight path control. This document is the first of two recommended practice documents that will address perspective flight guidance displays (PFGD). This document will focus on human factors issues associated with perspective head-down displays, and not address architecture issues. A second ARP document will be developed to provide recommended practices for the design and implementation of perspective displays applied as head-up (HUD) and helmet- or head-mounted (HMD) displays.

In this document, the display and control characteristics are covered for displays that contain perspective flight guidance components. This document addresses design and implementation without regard to the display background even though synthetic vision, terrain depictions, or enhanced vision sensor imagery, for example, are typically used. A separate ARP will address design guidance of EVS and SVS. Design considerations for the integration of perspective flight guidance and EVS/SVS and other attributes are addressed herein. Although the system functionality assumed for this document exemplifies fixed-wing aircraft implementation, the recommendations do not preclude other aircraft types. The recommendations contained in this document address currently envisioned functionality for a perspective flight guidance display, namely: stabilization of flight path; aircraft energy management; vertical and lateral navigation, as well as external hazards such as weather, traffic, and terrain.

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We also wish to thank all the many individuals who contributed to the depth and quality of this document through their constructive reviews and comments.

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1. SCOPE:

The document focuses on perspective flight displays with or without guidance and is intended for flight deck display applications. Further, this document does not directly address the presence or absence of background information, e.g., synthetic and/or enhanced imagery. Such issues are addressed in a separate E/SVS document.

Since this document provides recommendations, the guidance is provided in the form of “should” statements as opposed to the “shall” statements that appear in standards and regulations. When “shall” statements are used, the regulation or standard is referenced (where applicable).

1.1 Purpose:

The purpose of this document is to set forth the recommendations of SAE Committee G-10 Perspective Flight Display Subcommittee relative to the requirements for design and implementation of electronic perspective predictive flight display information systems for use as a primary flight display, which may or may not also use synthetic or enhanced imagery in its background. These recommendations are intended to be intuitive and easily interpretable to minimize confusion, distraction and fatigue, thereby reducing crew workload and increasing crew performance, efficiency, safety and reducing factors detrimental to flight safety. In arriving at these recommendations the committee carefully reviewed the layouts of modern commercial and military aircraft, developmental tiltrotor flight deck/cockpit layouts, the recommendations and requirements of the Federal Aviation Administration Aircraft and Rotorcraft Certification Branches, the Avionics Branch, and the requirements of commercial operators and aircraft/avionics original equipment manufacturers (OEMs). In cases where conflicting opinions existed, suitable compromises were made.

2. REFERENCES:

2.1 Applicable Documents:

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

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2.1.1 SAE Publications: Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

AS264	Instrument and Cockpit lighting for Commercial Transport Aircraft
ARP268	Location and Actuation of Flight Deck Controls for Transport Aircraft
AS425C	Nomenclature and Abbreviations for Use on the Flight Deck
ARP571	Flight Deck Controls and Displays for Communication and Navigation Equipment for Transport Aircraft
ARP1068B	Flight Deck Instrumentation, Display Criteria and Associated Controls for Transport Aircraft
ARP1093	Numerical, Letter, and Symbol Dimensions for Aircraft Instrument Displays
ARP1161	Crew Station Lighting - Commercial Aircraft
ARP1782	Photometric and Colorimetric Measurement Procedures for Direct View CRT Displays
ARP1874	Design Objectives for CRT Displays for Part 25 (Transport) Aircraft
ARP4032	Human Engineering Considerations in the Application of Color to Electronic Aircraft Displays
ARP4033	Pilot-System Integration
ARP4101	Core Document, Flight Deck Layout and Facilities
ARP4101/2	Pilot Visibility from the Flight Deck
ARP4102	Core Document, Flight Deck Panels, Controls and Displays
ARP4102/4	Flight Deck Alerting Systems
ARP4102/7	Electronic Displays
ARP4102/7	Appendix A - Electronic Display Symbolology for EADI/PFD
ARP4102/7	Appendix B - Electronic Display Symbolology for EHSI/ND
ARP4102/7	Appendix C - Electronic Display Symbolology for Engine Displays

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2.1.1 (Continued):

ARP4105	Abbreviations and Acronyms for Use on the Flight Deck
ARP4107	Aerospace Glossary for Human Factors Engineers
ARP4153	Human Interface Criteria for Collision Avoidance Systems in Transport Aircraft
ARP4256	Design Objectives for Liquid Crystal Displays for Part 25 (Transport) Aircraft
ARP4260	Photometric and Colorimetric Measurement Procedures for Airborne Direct View Flat Panel Displays (when approved)
ARP5119	Location of and Display Symbology Requirements for Head-down Electronic Flight Displays for Steep Instrument Approaches
ARP5289	Standardized Color and Symbology for Displays
AS8034	Minimum Performance Standards for Airborne Multipurpose Electronic Displays
ARD50018	The Integration of Vertical Flight Aircraft Into The National Airspace System

2.1.2 FAA Publications: Available from Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC 20591.

FAA-RD-81-38II	Aircraft Alerting System Standardization Study: Volume II Aircraft Alerting System Design Guidelines (Berson, et. al., 1981)
DOT/FAA/PS-89/1	Flight Status Monitor Design Guidelines (Anderson, et. al. 1989)

2.1.3 EUROCAE Publications:

EUROCAE ED76/RTCA DO200A	Standards for Processing Aeronautical Data
EUROCAE ED77/RTCA DO201A	Industry Requirements for Aeronautical Information

2.2 Other Applicable References:

FAA Advisory Circular AC 25-11, of 07-16-87, Transport Category Airplane Electronic Display Systems

FAA Advisory Circular AC 120-29a, of 12 August 2002, Criteria for Approval of Category I and Category II Weather Minima for Approach

FAA AC-23.1309-1A Equipment, Systems, and Installations in Part 23 Airplane

FAA AC-23.1311-1 Installation of Electronic Display Instrument Systems in Part 23 Airplanes

FAA AC 25-11 Transport Category Airplane Electronic Display Systems

FAA AC 25.1309-1A System Design Analysis

Aeronautical Design Standard-33 (ADS-33) Handling Qualities Requirements for Military Rotorcraft, (US Army Aviation document)

MIL-STD-1472_ Design Criteria Standard for Human Engineering, Revision F (www.mil-std-1472.com)

2.3 Regulatory Publications:

FAR Part 23 Airworthiness Standards: Normal, Utility, Acrobatic, and Commuter Category Airplanes

FAR Part 25 Airworthiness Standards: Transport Category Airplanes

JAR Part 25 Joint Aerospace Regulations Airworthiness Standards for Aeroplanes in Transport Category

FAR Part 27 Airworthiness Standards: Transport Category Rotorcraft

ICAO Standards and Recommended Practices (SARP) Annex 6 - Operation of Aircraft

TSO-C113 Airborne Multipurpose Electronic Displays

2.4 Related Publications:

Anderson, Berson, Boucek, LaLumiere-Grubbs, and Williams; Flight Status Monitor Design Guidelines, Boeing Commercial Airplane Group, unpublished, 1989

Kelley, Greaber and Fadden, Applying Crew Centered Concepts to Flight Deck Technology; The Boeing 777, Flight Safety Foundation 45th International Air Safety Seminar, Long Beach, CA November, 1992

Civil Tiltrotor Missions and Applications: A Research Study; NASA Contractor Report 177451, Boeing Commercial Airplane Company, Bell Textron, Boeing Vertol, NASA ARC., November 1987

Garland, Wise and Hopkin, Handbook of Aviation Human Factors, Lawrence Erlbaum Associates, Mahwah, NJ, 1999

Grunwald, A.J., J.B. Robertson and J.J. Hatfield. (1980). 'Evaluation of a Computer-Generated Perspective Tunnel Display for Flight-Path Following', NASA TP1736, Langley, VA.

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Integrated Cockpit Assessment; NASA Contract NAS2-13625 Phase 2 Task 15, Draft Report, June 1995

Managing The Modern Cockpit: Third Human Error Avoidance Techniques Conference Proceedings; SAE P-239, Society of Automotive Engineers, Inc. Warrendale, PA 1990

Newman, Richard L., Head-Up Displays: Designing the Way Ahead, Ashgate Publishing Company, Brookfield, VT, 1995

Reising, J.M., Liggett, K.K., Kustra, T.W. and Snow, M.P. (1998). Evaluation of pathway symbology used to land from curved approaches with varying visibility conditions. Proceedings of the Human Factors and Ergonomics Society 42nd Annual Meeting, Chicago, IL, pp. 1-5

Stokes, Kite and Wickens; Display Technology Human Factors Concepts, Society of Automotive Engineers, Warrendale, Pa, 1990

Theunissen, E., Integrated Design of a Man-Machine Interface for 4-D Navigation, Delft University Press, Delft, Netherlands, 1997

2.4 (Continued):

Theunissen, E. and Rademaker, R.M. (2001). 'Spatially Integrated Depiction of Dynamic Trajectories', SAE 2001-01-2960. Proceedings of the World Aviation Conference, September 10-14, Seattle, WA

Theunissen, E., R.M. Rademaker and T.J. Etherington (2002). Path Intercept Functionality for Perspective Flight Path Displays, Proceedings of the AIAA 2001 MST Conference, paper no. AIAA 2002-4788 (11 pages), Monterey, CA

Theunissen, E., F.D. Roefs, G.J.M. Koeners, Delft, R.M. Rademaker and T.J. Etherington (2004). Integration of Imaging Sensor Data into a Synthetic Vision Display, to be published in the proceedings of the 23rd Digital Avionics Systems Conference, October 24-28, Salt Lake City, UT

V-22 Side-Stick Controller Study, Bell*Boeing FSD V-22 Contract, Boeing Helicopters, Philadelphia, PA, 1990

Wickens, C.D., Todd, S., and Seidler, K. (1989). Three-dimensional displays: Perception, implementation, applications. Crew System Ergonomics Information Analysis Center, #CSERIAC SOAR-89-01, University of Illinois

Wilkins, R., Harris, K. and Walz, C., Precision Pathway Terminal Guidance (PPTG) Perspective Flight Guidance (PFG) Display Study, Advanced Rotorcraft Technology Multi-Year Project Final Report, NASA Cooperative Agreement # NCCW-0076 Entitled Advanced Rotorcraft Technology, Rotorcraft Industry Technology Association (RITA), Inc., March 2002

Wilkins, R., Use of Predictive Perspective Guidance Displays for Increased Situation Awareness, American Helicopter Society, 57th Annual Forum, Washington, DC, May 2001

Wilkins, R., FTE and Pilot Workload Comparison of Perspective Flight Guidance Displays to Conventional Flight Director Symbolology in Instrument Approach Applications, Society of Automotive Engineers Aerospace, World Aeronautical Congress, Seattle, WA September, 2001

Williams, K.W. (2002). Impact of aviation highway-in-the-sky displays on pilot situation awareness. Human Factors, 44(1), 18-27

Woods, David D. and Elias, Glenn, Significant Messages: An Integrated Display Concept; Ohio State University, Columbus, OH

2.5 Definition of Terms:

ACTUAL NAVIGATION PERFORMANCE (ANP): A measure of the current estimated navigation performance, excluding Flight Technical Error (FTE). Actual Navigation Performance is measured in terms of accuracy and integrity, and may be affected by the type and availability of navigation signals and equipment.

NOTE: Also see Estimated Position Uncertainty ([EPU]).

CLUTTER: Clutter is an attribute of poorly organized and crowded displays. A cluttered display is one which uses an excessive number and/or variety of symbols, colors, or small spatial relationships. This causes increased processing time for display interpretation. It generally results in reduced display legibility, and/or in increases in the time needed to locate and interpret information on the display.

COMMAND INFORMATION: Information that directs the pilot to follow a course of action in a specific situation (e.g., Flight Director or TCAS RA - resolution advisory).

COMMAND REFERENCE FRAME: A symbol, appropriately colored, indicating the position within which the pilot should place the flight path marker to affect the desired flight performance response.

CONFORMAL INFORMATION: Information which correctly overlays the image of the real world, irrespective of the pilot's viewing position.; Conformal means having a 1:1 angular relationship. For displays the field of regard is the same as the field of view.

COPLANAR DISPLAYS: Devices whose display surfaces lie in the same two dimensional plane Also use this to describe views like the plan view and VPD.

DATA FUSION: Combining or consolidation and integration of separate data sources into a single entity where each data source is indistinguishable.

EGOCENTRIC: A presentation referenced to the aircraft/pilot, rather than the outside world. Both an inside-out and outside-in display are usually egocentric, however, the inside-out display usually shows the outside world moving relative to a stationary ownship, while the outside-in shows a stationary outside world and a moving ownship symbol. The attitude indicator is an inside-out display, so for example when the aircraft rolls to the left the display rolls to the right.

EMERGENT FEATURE: Features that are immediately perceived such as symmetry, horizontalness and verticalness.

ENHANCED VISION SYSTEM: An electronic means to provide the flight crew with a sensor derived or enhanced image of the external scene (e.g., Millimeter wave radar, Forward Looking InfraRed).

2.5 (Continued):

ENHANCED/SYNTHETIC VISION SYSTEM: An integrated or fused display system which combines sensor-/enhanced and synthetic vision elements to provide the pilot with an optimally-resolved valid, and accurate representation of the real-world for external visual reference.

EXOCENTRIC: A presentation referenced to a stationary point in the outside world, or to a fixed position relative to the aircraft (e.g., a tethered “wingman” view), a view from a position away from the pilot position.

FIELD OF REGARD: The angular extent of the external world that is represented on a display.

FIELD OF VIEW: The angular extent of the physical display surface referenced to the pilot eye position, often called geometric field of view.

FLIGHT TECHNICAL ERROR: The accuracy with which the aircraft is controlled as measured by the indicated aircraft position with respect to the indicated command or defined flight path position.

FLIGHT PATH MARKER: The display symbol used to indicate the vertical and lateral trajectory (i.e., flight path) of the aircraft. This symbol may indicate the measured aircraft flight path (i.e., Flight Path Vector, FPV) or it may indicate a predicted or quickened aircraft flight path.

GUIDANCE: Information used during manual or automatic control, or monitoring of automatic control of an aircraft that is of sufficient quality to be used by itself for the intended purpose of achieving a particular flight path.

GHOSTED: Symbology that is grayed out, lower contrast/brightness or dashed to indicate changed/altered parameter.

IMAGE FUSION: Combining or consolidation and integration of separate image sources into a single entity where each image source is indistinguishable.

INTEGRATION: (1) The act of causing elements of an item to function together. (2) The act of gathering a number of separate functions within a single implementation. (3) The process where information from different sources is placed on a single display in such a manner that it is graphically compatible with other data and does not degrade, mask, corrupt, or otherwise render other information unusable. NOTE: Integration can also be applied when discussing combining data and information.

INTUITIVE: Exhibiting the capability of immediate comprehension or cognition.

2.5 (Continued):

ISOMETRIC VIEW: A method of drawing so that three dimensions are shown not in perspective but in their actual measurements.

MINIFICATION: Reduction in size (of symbology).

ORTHOGRAPHIC VIEW: Drawing in which the lines of projection are perpendicular to the display plane.

OWN SHIP: The aircraft in which the display is installed.

PERSPECTIVE VIEW/DISPLAY: A display in which projection lines extend from a single point in order to present objects on a 2-D surface as they would normally appear to the eye. The projection is defined by the viewpoint location (or equivalently the point of interest and viewing distance), direction of view and field of view.

PLAN VIEW: A drawing which shows a horizontal section using an orthographic projection.

PRIMARY FLIGHT DISPLAY (PFD): A display that provides all required information for instrument flight. The display must provide full time attitude, altitude and airspeed information; an immediately discernible attitude recognition capability; unusual attitude recovery capability; and complete fault indications.

REQUIRED NAVIGATION PERFORMANCE (RNP): Required Navigation Performance is a statement of the navigation performance necessary for operation within a defined airspace (Adapted from ICAO - ISARP Annex 6). Required Navigation Performance is specified in terms of accuracy, integrity, and availability of navigation signals and equipment for a particular airspace, route, procedure, or operation.

Example - RNP 4 represents a navigation lateral accuracy of plus or minus 4 nm (7.4 km) on a 95% basis. RNP is typically defined in terms of its lateral accuracy, and has an associated lateral containment boundary

SITUATION AWARENESS (SA): (1) The perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future. (2) A pilot's continuous perception of self and aircraft in relation to the dynamic environment of flight, and the ability to forecast, then execute tasks based on that perception. (3) Having information to allow for appropriate decisions. For either definition, the following applies: Major components of situation awareness include: operational environment, navigation, weather, communications, aircraft capability, traffic, terrain, and spatial orientation.

2.5 (Continued):

SYNTHETIC VISION SYSTEM: A system used to create a synthetic image (e.g., typically a computer-generated picture) representing the environment external to the airplane.

2.6 Acronyms and Abbreviations:

ADI	Attitude Director Indicator
ANP	Actual Navigation Performance
CDI	Course Deviation Indicator
DGPS	Differential Global Positioning System
DMS	Digital Map System
EFB	Electronic Flight Bag
EFIS	Electronic Flight Information System
EPU	Estimated Position Uncertainty (also Circular Error of Probability - CEP)
ESVS	Enhanced/Synthetic Vision System
EVS	Enhanced Vision System
FAR	Federal Aviation Regulations
FTE	Flight Technical Error
FOV	Field of View
FOR	Field of Regard
FPV	Flight Path Vector
FPM	Flight Path Marker
HDD	Head Down Display
HMD	Head Mounted Display/Helmet Mounted Display
HUD	Head Up Display

2.6 (Continued):

JAR	Joint Aviation Regulations
PFG	Perspective Flight Guidance
PFGD	Perspective Flight Guidance Display
PFD	Primary Flight Display
PF	Pilot Flying
PNF	Pilot Not Flying
QFPV	Quickened Flight Path vector
SVS	Synthetic Vision System
TCAS	Traffic Alerting and Collision Avoidance System
VPD	Vertical Profile Display (also Vertical Situation Display - VSD)

3. ASSUMPTIONS:

The assumptions about the system that guide and bound the recommendations contained in this document include:

- the displays considered in this document are all ego-centric, primary flight displays
- information provided should be accessible to pilot flying and pilot not flying (if applicable)
- the system may be operated during all phases of flight

4. DESIGN REQUIREMENTS AND OBJECTIVES:

Perspective displays, used as flight guidance, can be classified as those displays using perspective (3-dimensional) symbology designs to impart intuitive depictions of the upcoming flight path. They may be displayed in three dimensions or as three-dimensional systems on a two dimensional format. Perspective flight guidance displays may or may not include explicit flight director or guidance command information. For examples, see Appendix A.

4.1 Design Requirements:

The Perspective Flight Guidance Display (PFGD) should enhance flight crew awareness of aircraft position relative to future commanded position. The display informational elements should be:

The PFGD should display all required primary flight information.

The PFGD should display, in an integrated fashion, the programmed/commanded flight path in a three dimensional (3-D) depiction.

4.2 Design Objectives:

The Design objectives for the PFGD should:

1. Simplify operations
2. Reduce crew workload
3. Facilitate automation monitoring
4. Maximize crew situation awareness
5. Provide for information redundancy to assist the crew in verification and error detection
6. Improve airplane energy awareness
7. Provide superior vertical and lateral navigation capability resulting in reduced flight technical error (FTE) - basic planning and awareness are both implied
8. Provide enhanced auto-flight mode awareness
9. Reduce training relative to traditional PFDs

5. CONCEPT OF PERSPECTIVE DISPLAYS:

5.1 Basic Philosophy - Why Perspective Guidance? (See Appendix B):

The philosophy of perspective display symbology uses intuitive symbology and processing to provide foreknowledge of the future flight path. The use of a perspective flight guidance displays with a predictive flight path/performance symbology set provides that increased situation awareness and foreknowledge. Three key concepts provide the basic philosophy: 1 - Preview of the desired trajectory, 2 - ability to predict future aircraft states and, 3 - the ability to apply different control strategies.

Raw data and non-integrated displays are non-optimum. As stated in O'Hare, & Roscoe, 1990, increasingly such displays cause much "mental gymnastics" cognitive processing and pilot mental workload, often leading to additional error and total loss of situation control, resulting in full scale deflection, that is, maximum deviation mandating a missed approach.

In order to reduce tracking errors and pilot workload, the pilot should be provided with a display of the current flight path and aircraft performance as well as the future track and commanded and/or predicted aircraft performance.

5.2 Underlying Rationale:

Flight guidance for manually flown tasks is essential for precision navigation. Current generations of guidance symbology, e.g., "Delta-Veebar" and "Two-Bar", work well, but are limited in their ability to display future flight path information and/or the results of pilot control input. Both display symbology sets are designed to follow command guidance from an off-course situation to return to a nominal (null error) solution, known as compensatory tracking. Such displays require significant attention and force the human operator to be a tracking servo resulting in little additional attention to attend to other cockpit tasks during precision tasks like flying an approach. Further, the algorithms do not support curved or complex maneuvers and the tracking of the commands does not contribute to pilot situation awareness.

Flight path vector (FPV) - based perspective guidance provides pilots with an symbology set which provides preview and information of aircraft state in a frame of reference allowing the pilot to relate the required aircraft control movement to the desired trajectory and gain an understanding of external dynamics. Perspective flight guidance display technology utilizes accurate position information for precision waypoint geolocation, combined with a FPV symbol and "tunnel-in-the-sky" pathway guidance. With a properly designed prediction algorithm implemented with the FPV, accurate understanding (SA) of future aircraft states is possible. Effectively designed and implemented, perspective flight guidance display technology is capable of replacing traditional, two-bar and Delta-Veebar flight director guidance while providing reduced flight technical error (FTE) and reduced pilot workload. (Wilkins, 2002) A properly designed PFGD may enable the execution of steep, precision, instrument approaches in near zero visibility.

5.3 Advantages:

Preview - The ability to determine future changes in the desired trajectory. May also help eliminate automation surprise.

Tracking Strategies - Determining aircraft dynamics and the relationships to control along the desired trajectory. An error neglecting strategy may be employed if the aircraft is slightly off path and is already in a position to correct the error without pilot input. The pilot can attend to other tasks while flying a straight segment and the control task may need more attention during maneuvering.

Reduced Flight Technical Error - With a properly designed PFGD, the pilot contribution to flight technical error is so small that it can be neglected.

Ability to fly curved, steep and other complex approach and departure procedures
Complex procedures can be flown that were difficult or impossible with conventional displays and they can be flown with no increase in workload over normal flight director approach tasks.

Reduced Cognitive Workload - By providing information in the appropriate reference frame the display reduces informational processing requirements

5.4 Potential Disadvantages:

Clutter - Display of too many symbols or pathway tends to provide information overload and to clutter the display, resulting in loss of situation awareness and an inability to select required data from displayed symbology.

Cognitive capture or attentional tunneling - A tendency to narrow down the pilot's focus to the tunnel to the exclusion of other task-relevant data, e.g., out the window traffic.

Unintended increased difficulty in manual flying task - by demanding more precision than the task requires.

5.5 Issues:

Off path guidance - or loss of pathway and return to path guidance.

Pathway concepts may be difficult to interpret while maneuvering off path or while intercepting from outside. This problem needs to be weighed against the clutter issues.

Inappropriate application of potential non-attainable pathway-required performance, e.g. unattainable climb. This is applicable to all guidance displays, even current flight director displays.

5.6 Data Integration versus Workload Reduction:

If a task requires the integration of information, workload should be reduced by presenting the information in an integrated form.

5.7 Minimize Mental Rotations:

The need to mentally rotate spatial information that is not in a useable frame of reference will tend to increase workload and probability of error. The perspective flight guidance display provides a spatially integrated presentation of data in a suitable frame of reference that can be used to minimize required mental integrations and rotations.

5.8 Preview:

With a control task the user benefits from a preview of the upcoming forcing function and its constraints since this allows a certain amount of anticipatory control to be applied. As a result, the gain for closed loop compensatory control can be reduced. This translates to lower workload, less overshoots at transitions and smoother control. Preview facilitates task division and scheduling of attention.

6. PFGD DESIGN RECOMMENDATIONS:

6.1 Display Characteristics:

General display requirements are the same as those specified in AC 25-11 and TSO-C113 for a Primary Flight Display with the exception of these following requirements.

- 6.1.1 Field of Regard: The FOR should be determined based on the task to be performed. Field of regard settings, if available, should be pilot selectable. Changes to fields of regard should be pilot selectable.

Field of regard settings should be available for values from unity to 90 degrees. Options should be limited. Experience indicates that not more than 4 settings are preferred.

Consider that the field of regard affects the control task and that the field of regard can be affected by conformality with sensor display requirements. Minified fields of view distort depth perception to objects in the image and tend to minimize threatening features, but provide increased viewing area (nominally situation awareness), while non-minified or unity views remove this distortion but decrease the amount of information presentable and usually result in increased pilot performance. Minification affects handling qualities. Minification of background information like terrain reduces the overall visual effect. By making the features look smaller than they are, they will be less threatening. This needs to be balanced with the need for increased SA of a wider field of view.

6.1.1 (Continued):

NOTE: Field of regard is a training issue. One to one non-minified, i.e., conformal, displays are helpful in understanding geometric field of view issues relative to the real world.

Displays where symbology is overlaid on the outside world should be conformal

- 6.1.2 Frame of Reference: The recommended mode is attitude aligned displays because attitude aligned displays are more compatible with head up displays, enhanced and synthetic vision displays, and the outside visual scene. In an attitude-aligned display, the aircraft attitude (butt line and pitch ladder) is laterally referenced to the center of the display. In a pathway/flight path vector-centered display, the flight path marker is laterally centered.

In some attitude aligned displays, based on the display field of regard, data may become masked and ghosting may be required at some extreme angles of attack. For discussion and rationale of attitude-based versus flight path marker-based see Appendix B.

Should the design use a velocity vector aligned display system, that mode should be clearly annunciated. It should be noted that the display reference will be different from that of the outside world. Flight path vector centered displays may not be conformal. Accommodation for aircraft handling requirements and training will become an issue.

6.2 Elements of 3-D Data Presentation:

- 6.2.1 Spatial Orientation: The PFGD uses 3-dimensional drawing techniques and symbology derived from an ego-centric frame of reference. It should provide the pilot with an unambiguous depiction of the ownship relationship to the desired flight path or trajectory.
- 6.2.2 Pathway Depiction: Any pathway should be displayed in such a manner as to be readily and intuitively understood by the pilot. It should show the required trajectory to be flown; both on course and off course conditions; deviations from planned/required altitude; and lateral track.

- 6.2.3 Control Task: The display should be designed to depict the aspect of the desired pathway, own orientation with respect to the pathway, and velocity along or through the pathway: so as to support manual acquisition/maintenance of the flight path with satisfactory handling characteristics.

When intercepting the pathway the pilot should be able to derive pathway closure rate and the amount of control input required to enter and remain within the confines of the pathway.

The display should be tuned to the performance characteristics of the specific platform.

- 6.2.4 Trajectory Guidance: The pathway should indicate current position, heading and velocity relative to the current flight path trajectory; guidance towards that flight path; and prediction (foreknowledge) of the desired (future) flight path.

6.3 Flight Crew Interface Requirements:

- 6.3.1 Mode Change: Any change in the flight director/pathway mode should be immediately annunciated to the crew. Any change in the commanded flight path caused by a mode change should be immediately shown in the PFGD.

- 6.3.2 PFGD Differentiation: The design should differentiate the PFGD from the background imagery via color, luminance, or contrast, etc. When presented with background imagery, the pilot should be provided with independent control of PFGD brightness and contrast in reference to the background imagery

Strong preference should be given to an overall brightness control with automatic control during changing ambient light conditions with an independent control of relative brightness of the background imagery. If required, a separate contrast control should be provided for the background imagery.

- 6.3.3 Declutter Mode(s): PFGD declutter modes are desirable; however, all declutter modes should retain all required primary flight information.

The pilot should be able to remove the pathway from the display. When the pathway is removed, the flight path marker and any associated cues should remain.

A minimum declutter mode containing essential flight control cues should be considered.