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Human Interface Criteria for Vertical Situation Awareness Displays

RATIONALE

The G-10 committee has agreed to stabilize this document as the content has been determined to be basic and stable information not dynamic in nature.

STABILIZED NOTICE

This document has been declared "Stabilized" by the SAE G-10, Aerospace Behavioral Engineering Technology Committee and will no longer be subjected to periodic reviews for currency. Users are responsible for verifying references and continued suitability of technical requirements. Newer technology may exist.

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1. SCOPE:

This SAE Aerospace Recommended Practice (ARP) sets forth design and operational recommendations concerning the human factors/crew interface considerations and criteria for vertical situation awareness displays. This is the first of two recommended practice documents that will address vertical situation awareness displays (VSAD). This document will focus on the performance/ planning types of display (e.g., the map display) and will be limited to providing recommendations concerning human factored crew interfaces and will not address architecture issues. This document focuses on two types of VSAD displays: a coplanar implementation of a profile display (side projection) and a conventional horizontal map display; and a 3D map display (geometric projection). It is intended for head down display applications. However, other formats or presentation methods, such as HUDs, HMDs and 3D audio presentations may become more feasible in the future. Even though the relationship of the vertical information and the horizontal map display will be addressed, it is not within the scope of this document to cover Raster Aeronautical Charting displays, or the presentation of vertical status information in horizontal map displays (e.g., altitude errors; altitude range arcs). A second ARP document will be developed to provide recommended practices for the control types of display (e.g., primary flight display) one of which will be a perspective primary flight display.

In this document, the display and control characteristics are covered for displays that contain vertical situation components as well as the alerting depiction associated with the VSAD. It is assumed that the vertical situation awareness may be provided by one or more crew interface component(s). 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 vertical situation awareness display, namely: stabilization of flight path; aircraft energy management; vertical navigation, as well as external hazards such as weather, traffic, and terrain. 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).

The assumptions about the system that guided and bounded the recommendations contained in this document include:

- the system is an on-board (flight deck based) system displaying vertical situation information to the flight crew; multiple sources of vertical position data will be used and some of the data may be transmitted to the airplane from the ground or satellite
- no changes to the existing airspace infrastructure should be required
- there will be pilot-in-the-loop/manual or automatic involvement in all flight path adjustments
- information provided should be accessible by all pilots
- the system will address fixed wing airplane types
- the system will be based on the English language, but other languages may have to be considered
- the system may be operated during all phases of flight
- the system may be operated under different metric conventions (e.g., QFE/QNH or feet/meters)

1. (Continued):

- the VSAD is not intended to replace any of the alerting system components (EICAS, TAWS, TCAS, GPWS, Altitude Alert, etc.). There will, however, be a close relationship between the VSAD and TAWS since both use some of the same sensors, data bases, and address some of the same issues
- human centered design principles will be applied to the system design
- "lessons learned" from past implementations will be applied to the design
- the display function may be stand-alone or part of a multi-function display
- the display will meet harmonized certification requirements and it will be designed with the understanding that if it is in the flight deck the flight crew will use it.

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.

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
ARP1068	Flight Deck Instrumentation, Display Criteria and Associated Controls for Transport Aircraft
ARP1093	Numeral, 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

2.1.1 (Continued):

ARP4102/7	Electronic Displays
ARP4102/7	Appendix A - Electronic Display Symbology for EADI/PFD
ARP4102/7	Appendix B - Electronic Display Symbology for EHSI/ND
ARP4102/7	Appendix C - Electronic Display Symbology for Engine Displays
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)
AS8034	Minimum Performance Standards for Airborne Multipurpose Electronic Displays

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: Available from EUROCAE, 17 Rue Hamelin, 75783 Paris Cedex 16, France.

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

2.2 Related Publications:

The following publications are provided for information purposes only and are not a required part of this SAE Aerospace Technical Report.

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
FAR Part 23	Airworthiness Standards: Normal, Utility, Acrobatic, and Commuter Category Airplanes
FAR Part 25/ JAR Part 25	Airworthiness Standards: Transport Category Airplanes
FAR Part 27	Airworthiness Standards: Transport Category Rotorcraft
TSO-C113	Airborne Multipurpose Electronic Displays

3. GLOSSARY:

3.1 Acronyms and Abbreviations:

3D	Three Dimensional
AC	Advisory Circular
ADS-B	Automatic Dependent Surveillance-Broadcast
ARP	Aerospace Recommended Practice (SAE)
ATC	Air Traffic Control
A/V	Aircraft/Vehicle
CDU	Control Display Unit
CFIT	Controlled Flight into Terrain
EADI	Electronic Attitude Direction Indicator
EHSI	Electronic Horizontal Situation Indicator
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
FMS	Flight Management System
FSF	Flight Safety Foundation
GPS	Global Positioning System
HUD	Head Up Display
ILS	Instrument Landing System
JAR	Joint Aviation Requirements
LNAV	Lateral Navigation
LOS	Line of Sight
MCP	Mode Control Panel
ND	Navigation Display
PFD	Primary Flight Display
POG	Point of Gaze
POI	Point of Interest
PPOS	Present Position
QFE	Field Elevation Pressure
QNE	Standard Altimeter Setting
QNH	Sea Level Pressure
RNAV	Area Navigation
SAE	Society of Automotive Engineers, Inc
TA	Traffic Advisory
TAWS	Terrain Awareness Warning System
TCAS	Traffic Alert and Collision Avoidance System
TIS	Traffic Information Service
VNAV	Vertical Navigation
VSAD	Vertical Situation Awareness Display
VPD	Vertical Profile Display
WXR	Weather Radar (Airborne)

3.2 Definition of Terms:

3D NAVIGATION DISPLAY: An electronic map display format that graphically shows both horizontal and vertical information within the same image using a three-dimensional perspective or orthogonal projection on a two-dimensional display medium.

ABSOLUTE ALTITUDE: Height of the aircraft above the terrain

ACCURACY: A measure of the difference between the reported position as compared to the true position. Accuracy is usually defined in statistical terms of either: (1) a mean (bias) and a variation about the mean as defined by the standard deviation (sigma) or (2) a root mean square (rms) value from the mean. The values given in this document are in terms of the two sigma variation from an assumed zero mean error.

AIRCRAFT/VEHICLE (A/V): Either (1) a machine or service capable of atmospheric flight, or (2) a vehicle on the airport surface movement area.

AIRPLANE STATE: The variables required to fully describe the dynamic behavior of an airplane and to predict this behavior into the future. These variables include speed, flight path vector, attitude (pitch and roll), and horizontal track. Aircraft state is often represented as a state vector, which comprises the minimum number of values required to fully specify the state; from the state vector, related values such as angle of attack, flight path angle and sideslip can be derived.

AIR MASS DATA: Air mass data includes all aircraft sensor information which measures or is derived from the aircraft-local properties of the atmosphere. Direct measurements include air temperature, pressure, humidity and density; derived measurements include barometric corrected altitude (QNH), vertical speed and computed airspeed.

AIRSPACE: In the most general sense, airspace refers to the atmosphere in which aircraft operate, extending upwards from the surface of the earth. However, the term airspace also commonly denotes the spatial boundaries used to define areas restricted to civilian flight and to subdivide the airspace into areas controllable by individual air traffic controllers. These airspace boundaries add a constraint to aircraft operations by limiting acceptable aircraft flight paths.

ALERT: A visual, auditory or tactile stimulus presented to attract the flight crew’s attention and convey some information concerning an event/situation.

AVAILABILITY: Is the probability that a function is up and able to perform were it called on.

BAROMETRIC ALTITUDE: Geopotential altitude in the earth’s atmosphere above mean standard sea level pressure datum plane, measured by a pressure (barometric) altimeter.

CAUTION: Non-normal operational or aircraft system conditions that require immediate flight crew awareness and subsequent corrective or compensatory flight crew action.

3.2 (Continued):

CLUTTER: Clutter is an attribute of poorly organized and crowded displays. It generally results in reduced display legibility, and/or in increases in the time needed to locate information on the display.

CONTROLLED FLIGHT INTO TERRAIN: Accidents in which an aircraft, under control of a flight crew, is flown into terrain, obstacles, or water without prior awareness on the part of the flight crew in sufficient time to prevent the accident.

COPLANAR DISPLAYS: Devices whose display surfaces lie in the same two dimensional plane

CRITICALITY: Indication of the hazard safety level associated with a function, hardware, software, etc., considering abnormal behavior (of this function, hardware, software, etc.) alone, in combination or in combination with external events.

DEDICATED DISPLAY: A display that has only a single intended function in the flight deck.

EGOCENTRIC: A presentation referenced to the aircraft/pilot, rather than the outside world. The point of view is “Inside-out”, so for example when the aircraft rolls to the left the display rolls to the right.

ERROR: (1) An occurrence arising as a result of an incorrect action or decision by personnel operating or maintaining a system. (2) A mistake in specification, design, or implementation. (3) A discrepancy between a measured and a true value.

ESCAPE MANEUVER: Aircraft maneuver performed to resolve a time critical conflict with an external hazard.

EVENT: An occurrence which has its origin distinct from the aircraft, such as atmospheric conditions (e.g., wind gusts, icing, lightning strikes), runway conditions, cabin and cargo fires.

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). An “outside-in” display.

FAILURE: A loss of function or a malfunction of a system or part thereof.

FAULT: An undesired anomaly in a function or system

GUIDELINES: Recommended procedures for complying with regulations

HUE: The dominant wavelength category which is described by a color term such as red or green (white, gray and black are considered achromatic colors, being differentiable but without perceptible hue).

3.2 (Continued):

INDEPENDENCE: (1) A design concept which ensures that a failure of one item does not cause a failure of another item. (2) Separation of responsibilities that assures the accomplishment of objective evaluation.

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.

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

LATENCY: The total system time from the time of applicability of the aircraft/vehicle position report until the information is presented to the flight crew.

LATENCY COMPENSATION: High accuracy applications may correct for system latency introduced position errors using time synchronized position and velocity information.

LINE OF SIGHT: The vector or line that joins the point of gaze to the point of interest in a 3D display.

LUMINANCE: An objective measure of the effective intensity of light emitted from (or reflected by) a surface. Perceived luminance can also be affected by contrast from adjacent or surrounding colors.

MODE: The current selected state of a system that determines which of many possible functions the system will perform at that specific time. For example, VSAD may present different information or use different display formats depending on the particular application (mode).

MODE CONTROL PANEL: Input device that permits the crew to select the state of a system

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 and about which the vertical situation mental model is being built.

PERSPECTIVE VIEW/DISPLAY: A display in which projection lines extend from a single point in order to present objects on a 2D 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.

PICTORIAL INFORMATION: Visual presentation of information in a form other than alpha-numerically.

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

3.2 (Continued):

POINT OF GAZE: The position of the eye relative to the point of interest in a 3D display. This term is often referred to as Camera Position.

POINT OF INTEREST: The center of rotation for the map in a 3D display.

POP-UP MODE: The mode of a shared display that automatically changes the information that is being displayed in response to a specified set of conditions (e.g., automatically switching when there is an alert).

PRIMARY FLIGHT DISPLAY (PFD): An electronic display which provides the basic “T” including information (attitude, airspeed, altitude, and heading) and other information pertinent to guidance and fundamental control of flight.

PROFILE VIEW/DISPLAY: A sideways-looking display which depicts elevation or altitude versus range or speed.

QFE: Field Elevation Pressure above sea level - Altimeter is set to indicate zero when the aircraft is on the ground.

QNE: Standard Altimeter Setting - Altimeter is referenced to 29.92 inches of mercury or 1013 millibars.

QNH: Altimeter is set to indicate the field elevation when the aircraft is on the ground.

REFLECTANCE: The proportion of incident light reflected by a surface.

RELIABILITY: A number associated with (the probability) that a function will perform as required under specified conditions, without failure, for a specified period of time.

REQUIREMENT: An identifiable element of a specification that can be validated and against which an implementation can be verified.

RISK: The frequency (probability) of occurrence and the associated level of hazard.

SATURATION: The perception associated with the purity of a color in terms of the wavelengths represented in that color. Saturated colors consist of a narrow band of wavelengths and appear vivid; desaturated colors contain many other wavelengths as well as the dominant wavelength and appear muted.

SEAMLESS: A continuous and common view of the situation from the perspective of all users.

SHARED DISPLAY: A shared display is multi-function and integrates multiple video/sensor inputs onto a single display.

3.2 (Continued):

SITUATIONAL AWARENESS: (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. For either definition, the following applies: Major components of situational awareness include: operational environment, navigation, weather, communications, aircraft capability, and spatial orientation.

STABILIZED APPROACH: Appropriately configured and on path and on speed. According to the Flight Safety Foundation Approach and Landing Accident Task Force Final Report, the elements of a stabilized approach include: (1) The aircraft is on the correct flight path; (2) Only small changes in heading and pitch are required to maintain the path; (3) The aircraft speed is not more than VREF + 20 knots indicated airspeed (KIAS) and not less than VREF; (4) The aircraft is in the proper landing configuration (approach configuration for small twins); (5) Sink rate is a maximum 1000 feet per minute; if an approach requires a sink rate greater than 1000 feet per minute, a special briefing should be performed; (6) Power setting appropriate for configuration and not below the minimum power for approach as defined by the aircraft operations manual; (7) All briefings and checklists have been performed; (8) Specific types of approaches are considered stabilized if they also fulfill the following: instrument landing system (ILS) approaches - must be flown within one dot of the glideslope or localizer; a Category II or III approach must be flown within the expanded localizer band. Visual approaches - wings must be level on final when the aircraft reaches 500 feet HAT. Circling approaches - wings must be level on final when aircraft reaches 300 feet HAT; and (9) Unique approaches such as the “old” Hong Kong Airport and the DCA (Washington, DC) river visual approach to Runway 18 require a special briefing.

SWATH: Width of the horizontal cross-section that is being depicted by the profile VSAD.

TERRAIN/OBSTACLES: Hard stuff that the aircraft may run into.

TRAFFIC SITUATION DISPLAY (TSD): A flight deck display that provides graphical information that permits the identification of potential conflicts with other aircraft.

TRUE ALTITUDE: Height of the aircraft above mean sea level, corrected for errors such as experienced during non-standard ISA conditions.

VERTICAL PROFILE DISPLAY: A sideways-looking display which depicts elevation or altitude versus range or speed.

VALIDATION: The determination that the requirements for a function or system are sufficiently correct and complete.

VERIFICATION: The evaluation of an implementation to determine that all applicable requirements are met.

VOICE MESSAGE: The information content of a voice presentation in traffic conflict situation.

4. DESIGN OBJECTIVES:

4.1 Background:

Clearly the primary goal of the Vertical Situation Awareness Display (VSAD) is to enhance flight crew awareness of the vertical situation. The VSAD is essentially the vertical plane counterpart to the horizontal map display, improving the crew's overall spatial awareness and consequently enhancing flight safety. The VSAD is not intended to be used for attitude control. The display informational elements should support one or more of the following operational/functional objectives (that are not necessarily mutually exclusive):

- enhanced spatial awareness of the aircraft relative to the current and predicted vertical flight paths;
- better flight path stability awareness - aircraft configuration, intended flight path, airspeed, power setting, altitude and sink rate are implied;
- improved airplane energy awareness - to reduce the occurrence of loss-of-control, landing overruns, and non-stabilized approaches;
- superior vertical navigation capability - basic planning and awareness are both implied;
- enhanced external hazard awareness - primarily terrain and man-made obstacles, but weather and traffic may be included;
- enhanced mode awareness for auto-flight - specifically those modes that are related to vertical path.

4.2 Design Objectives:

The control and display equipment for the vertical situational awareness system should apply the basic design objectives called out in ARP571, taking into consideration the functions, their frequency of use and all aircraft operational and environmental conditions so as to:

- simplify operations;
- facilitate error-free operation;
- maximize crew situation awareness;
- minimize head-down operation;
- provide consistency of operation for common functions;
- promote timely and accurate operation;
- ensure legibility of legends and displays throughout the wide range of flight deck ambient lighting conditions;
- ensure that system failures do not degrade the operational capability of other systems with which they interact;
- ensure intelligibility of computer generated voice messages, if utilized, throughout the wide range of flight deck ambient noise conditions, concurrent speech messages and other aural signals;
- provide for information redundancy to assist the crew in verification and error detection;
- permit conflict analysis.

4.2 (Continued):

The objectives, though not necessarily presented in order of importance, should aim at keeping associated flight crew workload at a level compatible with efficient flight crew operation.

Training: The human interface characteristics of the VSAD should be friendly enough to require minimal training on the display.

5. CANDIDATE GRAPHIC DISPLAY CONCEPTS:

5.1 Profile Display:

In a profile display, the aircraft's position and vertical flight path is shown using a side projection. The vertical dimension of the display corresponds to the local vertical direction, and the horizontal dimension of the display corresponds to either the current track of the aircraft or the planned flight path.

Advantages:

1. Retrofit capability
2. Commonality with existing paper navigation charts
3. Easy to determine absolute distance between aircraft and other features accurately
4. Compatible with LNAV and VNAV partitioning in the FMS, autoflight and ATC
5. The horizontal and vertical plane presentation are unambiguous, i.e., it is easy to determine lateral versus vertical deviations
6. Minimal additional control knob/switch input required

Disadvantages:

1. Profile display has a finite swath that may be at best a compromise
2. Requires mental integration of two displays
3. Curved paths and approaches may be difficult to depict or interpret
4. The VSAD can only depict one slice at a time in the horizontal dimension and needs to be designed so that the selected view is unambiguous
5. Being co-located with the horizontal display may reduce space available for each

5.2 Three-Dimensional Navigation Display:

The three-dimensional navigation display provides a depiction of the aircraft and its flight path using a perspective or orthogonal projection. The center of projection may be variable, both in terms of azimuth and elevation relative to the aircraft and in terms of field-of-view and distance from the aircraft. This may allow the display to be configured to provide a conventional plan-view or profile depiction in addition to a perspective view as seen from the aircraft's position or from a location relative to the aircraft.

Advantages:

1. Fewer scale changes may be required
2. Vertical and horizontal planes are integrated
3. Curved paths and approaches are more easily depicted and potentially easier to interpret
4. Vertical and horizontal dimensions are not limited by an artificial swath size and hence off-path and off-track features are easier to depict
5. The integration of vertical and horizontal planes may allow more information to be presented in a smaller display area
6. The 3D depiction allows for multiple views and perspectives of the same information for optimizing between different tasks
7. In a perspective view, resolution of information increases as that information moves closer to the viewpoint. This allows for a natural progression of detail that will generally correspond to the relevance of information to the current situation

Disadvantages:

1. Perspective depictions are prone to ambiguities in the location of objects in the scene since it is harder to judge distances parallel to the viewing direction
2. Overlap of objects in the scene may also be an issue
3. Higher potential for display clutter
4. Information may not be depicted because of: inherent resolution limits of the display, occlusions and clipping planes that are not shown to the pilot
5. There are a significant number of design parameters that need to be optimized. No one solution may be appropriate across different tasks. May require the pilot to make additional inputs to adjust the display
6. The 3D display is more difficult to retrofit
7. Has high potential to increase initial training

6. SYSTEM FUNCTIONALITY - POTENTIAL FUNCTIONS:

6.1 Data Acquisition:

In order to provide information about the vertical situation, the system should have access to information related to the state of the aircraft and its proximity to hazards such as terrain and the intended landing runway. Generally, as more information is available, the system can be designed to operate in more complex situations. The following sub-sections describe the types of information that could be used.

Position of Aircraft Relative to External Hazards - An estimate of the spatial proximity of the aircraft to the terrain and other hazards may be necessary. For example, this estimate may be obtained from onboard sensors directly providing relative range to terrain, weather, traffic and/or from a correlation between aircraft position and relevant databases. The accuracy and integrity of this information should be high enough to enable the performance of the applications that have been implemented.

Aircraft State - In addition to proximity information, additional state information may be required to determine whether the projected flight path may impact terrain or other hazard. This state information includes aircraft speed, attitude, horizontal track, and vertical flight path.

Aircraft Capability/Performance - Information about aircraft performance should be based on the airplane performance capability and current state data.

Aircraft Configuration - The ability to sense flap and gear status should be provided both to aid in estimating aircraft performance and as a means by which phase of flight and intended flight path may be inferred.

Flight Parameters - The phase of flight (e.g., takeoff, cruise, approach, landing), relationship to the intended landing runway and permitted separation criteria will affect the protection thresholds. The definitions of the phases of flight, relationships to the runway and the permitted separation criteria (e.g., arrival segment - 1000 feet, intermediate segment - 500 feet, and final approach segment - 250 feet) should be specified.

Intended Flight Path - The intended flight path may be derived from the Flight Management System (FMS) flight plan and predicted vertical trajectory.

Runway Location - Each flight must end with controlled flight onto terrain as the airplane lands on the runway. Runway information may be obtained through position information and a runway database or by using an active sensor onboard the aircraft that identifies the runway.

6.2 Information Transmission:

Two main functions for the VSAD are depicting conflicts and assessing flight path monitoring. Where the conflict depiction function is intended, the system should be able to depict a potential conflict with terrain and other external hazards. This depiction is based on the information obtained through the onboard conflict detection systems (e.g., TAWS, TCAS, predictive windshear, etc.). The capability to present stationary obstructions (e.g., towers, cranes, new construction, etc.) is included within the scope of the recommendations provided herein.

Where the flight path monitoring function is intended, the airplanes current path and the intended flight path need to be depicted. The VSAD should provide display cues that enhance the flight crew's ability to attain and maintain an adequate flight path to the runway.

The system may also include additional functions that allow the flight crew to obtain more detailed information.

Spatial Awareness - Information about the position of the aircraft relative to current and predicted vertical flight paths may be presented on the VSAD. Proximity to external hazards, landing runway, FMS VNAV and aircraft trend vector should be considered for display.

Flight Path Stability Awareness - One of the cornerstones of approach and landing safety involves the ability to conduct stabilized approaches. Cues that provided an integrated depiction of approach path stability that enable the flight crew to recognize an unstabilized condition and take corrective action (based on PFD cues) should be displayed on the VSAD. Elements that are used to create an integrated depiction include a consideration of aircraft configuration, vertical position relative to the correct flight path, airspeed and sink rate.

Existing Energy Information - A desirable feature for the VSAD would be to have energy information incorporated through appropriate symbols to permit a quick assessment of the ability to arrive at a certain point with a suitable amount of energy. In addition, information that allows the flight crew to recognize, in a timely manner, the development of a potentially critical energy state (e.g., low-and-slow on final) could be presented. That information should not conflict with other sources of similar information currently available in the flight deck (e.g., low speed cueing on the PFD airspeed tape) or compromise normal instrument scanning.

Vertical Navigation Capability - In one mode, the system could be used for flight planning/re-planning to examine the crew's inputs for accuracy and reasonableness by checking the intended flight path for conflicts (e.g., with flight plan altitude constraints) before the plan is executed. In a second mode, knowledge that the aircraft will be turning, climbing or descending at a given waypoint can be used.

Hazard Awareness - The system should enhance the flight crew's hazard awareness by allowing the crew to view relevant features such as terrain, traffic or weather. In order to accomplish this, the aircraft's location relative to the hazard should be displayed. The flight crew should be provided sufficient information to accurately anticipate conflict situations.

6.2 (Continued):

Weather - Presenting vertical weather information may be another valuable tool for avoiding inadvertent encounters with thunderstorms and towering cumulus clouds. The ability to better assess the choice of diversions around thunderstorms could be achieved through such an improved display.

Terrain - A valuable feature of a VSAD is the ability to depict terrain during all phases of flight. By having a depiction of terrain all the way to the runway threshold, one purpose this display serves is to enhance situational awareness of the terrain to help prevent CFIT during all phases of the approach. Good quality terrain data is required for this segment of the flight. The resolution requirements of that data may be more demanding than currently used with TAWS. Altitude coding of terrain information should be considered. Altitude coding may use a scale that is relative to the aircraft's altitude or that is referenced to mean sea level.

Enhanced Vertical Mode Awareness for Autoflight - A VSAD can be an effective means to improve the pilots' awareness of the current autoflight system mode and/or changes in mode that will occur automatically. Predicted change in flight path angle that will occur based on the current or future mode could be represented in a way that would improve the crew's ability to detect incorrect settings or hazardous situation (e.g., wrong selected altitude, open descent with no limits).

Limits/Constraints - Consideration should be given to integrating the presentation of limits that are associated with Minimum Sector Altitude (MSA), Minimum Descent Altitude (MDA), altitude constraints associated with specific waypoints, and crossing restrictions, etc. Consideration may also be given to depicting aircraft performance constraints/limits. This information should be consistent with other sources of similar information currently available in the flight deck (e.g., altitude tape).

6.3 Self-Diagnosis:

The system should detect and communicate failures in its operation. Failures that may lead to hazardously misleading conditions should be detected and communicated to the flight crew.

7. FLIGHT DECK INTEGRATION:

The VSAD should be designed so as to be consistent with the flight deck design philosophy used throughout the rest of the flight deck. It should also be compatible with the information and features of the flight deck in which it is installed, as well as the crew procedures.

7.1 Integration With the Total Flight Deck:

The VSAD should be compatible with the following features as applicable to its installation:

Navigation Information - The VSAD should supplement the ND and add the vertical situational awareness element. The VSAD should not conflict with information on the ND.

FMS/CDU Information - The VSAD should provide a graphical picture that is consistent with the information available via the various pages of the FMS/CDU. For example, an FMS stored route containing various step down points should be reflected in the VSAD as that route is planned or flown.

Autoflight Systems and Mode Annunciation Information - The addition of the VSAD to the flight deck is not expected to have any major effects on autoflight systems and mode annunciation. If any VSAD mode annunciation is presented, it should be consistent with the Primary Flight Display mode annunciation. Since additional awareness of the vertical situation is available, a “Direct To” VNAV mode may be supported with a VSAD.

System Failure Information - Any display of system failure information should be integrated with other display of system failures.

Existing Vertical Information - The VSAD should be consistent with existing vertical information. Examples include but not limited to: altitude scale, MCP selected altitude, radio altitude, and height above terrain.

Altitude Data Source - The depiction of own ships’ altitude on the VSAD should be consistent with the Primary Altimeter. However, if other sources of altitude data, such as GPS, are available then it would be desirable to have the VSAD display significant differences between the data sources.

7.1 (Continued):

Weather Information - If vertical weather information is presented on the VSAD, it should be consistent with weather information presented on other displays. Weather information may include digital weather, WXR, and windshear.

Traffic Information - If traffic information is presented on the VSAD, it should be consistent with other displays of traffic. In addition the Vertical Profile Display should be considered a supplementary source of traffic information and hence should not distract from the function of the primary traffic alerting displays.

Terrain Information - In general, if terrain is presented on the VSAD, it should be consistent with other displays of terrain. The VSAD may present terrain information that is not available or is different from other displays, such as terrain display on a TAWS system close to an airport. In this case consideration should be given to pilot training of this feature.

Alerting System Information (e. g., TCAS, GPWS, TAWS, etc.) - The VSAD is not a primary alerting device but may contain supplementary or supporting information to existing alerting functions. If presented, this supplementary or supporting information should be consistent with the primary alerting functions.

Database Information - To be effective, several different types of databases should be available for use with a VSAD. Any discrepancies, among databases used on the VSAD versus other displays, can not lead to the presentation of hazardously misleading information. Examples of databases include:

- FMS Navigation which includes ground based navigation aides, intersections, airways, departures, arrivals, etc.
- Runway Ends which includes location of the runway ends and their corresponding elevation.
- Obstacles, specifically man-made obstacles.
- Notices to Airman - It is desirable for the VSAD to have the capability to account for NOTAMs that would affect the correctness of the display, such as displaced thresholds, construction cranes, new buildings, closed runways, runway construction, etc. This type of information may not now be computerized in data base form suitable for such a display, but could be in the future.
- Charts - When a particular approach is selected from the CDU of the FMS, the VSAD should reflect this approach and it should be the same as is shown on the instrument approach chart. The same should hold true for departure and arrival procedures.

7.2 Integration Considerations:

Flight Deck Location - The VSAD should be located in an area most appropriate for its intended use.

Symbols - Symbols should be consistent with use elsewhere in the flight deck.

Color - Colors should adhere to the existing flight deck philosophy. Industry standards and guidelines describing requirements and conventions in the use of color on flight deck displays are available for reference. These include: 14 CFR23.1309, 14 CFR 23.1322, 14 CFR 25.1309, and 14 CFR 25.1322, DOT/FAA/RD-95.1, AC 25-11, AC 23.1311a, SAE ARP4032, and SAE ARP4102.

Scaling - For the Vertical Profile Display the horizontal scaling should be consistent with the distance scaling used on the Navigation Map Display.

8. FLIGHT CREW INTERFACE CHARACTERISTICS:

8.1 Basic Information Content:

This document currently focuses on two types of VSADs: Vertical Profile Displays and 3D Navigation displays, which have many of the same basic information content features. Information content which may be implemented on either type of VSAD includes the following:

- Present position
- Trend information
- VNAV path
- Escape maneuvers
- Terrain, WXR, Traffic
- Flight path angle and limits
- Deviation indication
- Navaids and altitude constraints
- Autopilot mode control panel selections

The specific information elements chosen for presentation on the VSAD should reflect the intended functions of the display. For example, information elements can be chosen to support any or all of the following uses:

- Increased situation awareness about the current state of the aircraft, including its velocity and position as well as its relationship to other factors including terrain, weather and traffic.
- Increased situation awareness about planned or intended vertical flight path.

8.1 (Continued):

As such, it should be recognized that the choice of information to be shown on the display should reflect the desired functionality of the display. These graphical displays tend to look realistic and could lead the flight crew to believe that they are more accurate then they actually are and consequently they may inappropriately use these data over raw data instruments. Because these are very compelling displays, the integrity, accuracy and availability of the databases, such as the FMC and terrain must be carefully considered. (EUROCAE ED76/RTCA DO200A "Standards for Processing Aeronautical Data" EUROCAE ED77/RTCA DO201A "Industry Requirements for Aeronautical Information") Testing should be conducted to affirm the display enables its intended use, as well as to test for the potential for unintended uses.

The following sub-sections (8.2 and 8.3) provide specific guidance and recommended practices on implementing each of the different types of basic information listed above, as appropriate for profile/ Coplanar displays versus “3D” VSADs.

8.2 Vertical Profile Display/Coplanar:

8.2.1 Intended Flight Crew Usage: The Vertical Profile Display (VPD) is intended to give the pilot the same type of information in the vertical dimension as the current navigational maps give in the horizontal or lateral dimension. As such, the two views, vertical and horizontal are complementary to each other and both views should be available to the pilot when the vertical view is selected.

The VPD is intended to give the pilot performance/planning information concerning the airplane's vertical relationship to the ground along a given horizontal path. It is intended to augment any Terrain Avoidance Warning Systems (TAWS) on the airplane, such as the Enhanced Ground Proximity Warning System. The VPD achieves this by giving the pilot enough vertical situation information, through the use of a graphical depiction, to avoid those situations that would lead to a TAWS caution or warning. In addition the VPD may include traffic and weather depiction to facilitate avoidance of hazards other than terrain. As with the horizontal view, another intended function of the VPD may be flight path navigation in both normal and non-normal conditions. Consequently, the VPD may also depict navigation information such as waypoints, with altitude constraints, airport runways, relative vertical deviation from a navigation path and general vertical navigation information along a planned route. It may also be used in non-normal situations to overcome the coarseness of minimum altitude constraints in situations like drift-down. The VPD may also include information that depicts the energy state of the airplane to aid the pilot in energy management.

8.2.2 Basic Characteristics of the Vertical Profile Display: The VPD is a side-looking, cross-cut view of the vertical dimension. As such, the side profile depicts some swath or slice of the airplane’s horizontal path or track. The horizontal swath or slice requires some finite width and characteristic. The VPD may depict a projection along the airplane’s current track, the airplane’s predicted path or along its intended flight path. It shall be made clear to the pilot which projection technique(s) are being depicted. The projection technique used may vary as a function of intended usage but the technique used should not cause misleading information or negatively impact the detection and time to respond to a potential conflict.

8.2.2 (Continued):

The VPD may present various types of information including but not limited to the following: terrain, navigation symbology such as waypoints or runway symbols, traffic symbols, weather depiction, intended flight plan, altitude constraints, mode control panel settings, vertical flight path and airplane altitude.

In general, navigational data and external hazard depiction should be correlated. There may, however, be instances where they are not correlated and this fact should be made obvious to the pilot.

Since both vertical and horizontal displays are two views of the same information, the VPD and lateral or horizontal view map should be positioned to facilitate visual scanning between the two views.

8.2.3 Display Characteristics:

8.2.3.1 Symbology Compatibility: Symbology presented on the VPD shall be compatible with that presented on the horizontal map, including shape, size, color and where applicable, logic. Any symbol motion should also be compatible with motion depicted on the horizontal map and not be distracting.

8.2.3.2 Reference Scale Orientation: The VPD consists of both a horizontal distance scale along the x-axis and an altitude scale along the y-axis. The placement of the altitude scale shall be compatible with the rest of the display format. The sense of direction and motion given by the airplane symbol and scale placement should be immediately interpretable by the pilot.

8.2.3.3 Horizontal Scale: A horizontal distance scale calibrated in the same units (nautical miles or kilometers) that are used for the map display, should be provided on the VPD. The distance scale shall be compatible with the scale used on the horizontal map display, and the same control should be used to select range on both the map display and the VPD.

Horizontal scale numbering and markers on the VPD should be compatible with the equivalent range symbology on the map display.

8.2.3.4 Vertical Scale: A vertical altitude scale, calibrated in the same units (feet or meters) that are used for the primary flight display altitude scale, shall be provided on the VSAD. The altitude reference used for the vertical scale should be consistent with that used on the Primary Altimeters. For any presentation mode the datum of the altitude scale, i.e., its reference such as QFE, QNE (standard) or QNH, should be clearly depicted. For flight plan path only presentations, a relative altitude reference scale, that depicts deviation relative to a vertical flight path without depicting absolute altitude, has been shown to be acceptable.

8.2.3.4 (Continued):

For absolute altitude scales, the altitude scale should move in the same direction and manner as the barometric altitude scale on the primary flight display. As far as possible, the numbering interval on the altitude scale should be the same as that for the barometric altitude scale on the primary flight display. It is recognized that, for long display range settings, the extent of the altitude scale may become large. In this case the numbering interval on the scale may differ from that on the primary flight display, but shall in any case be easily interpreted in terms of thousands of feet (meters) or Flight Levels. For display range settings typical of terminal area operations, the total extent of the altitude scale shall vary to maintain a constant display aspect ratio. The total extent of the altitude scale should be chosen to include a useful portion of the vertical flight plan. For example, for range settings of 20 nm , the entire vertical extent of an instrument approach procedure should be visible on the display.

8.2.3.5 Horizontal to Vertical Scaling and Resolution: The horizontal and vertical scaling and resolution of the display shall be such that the following criteria are met:

- Vertical flight plan information, including path symbology, waypoint symbology and identifying text, and planned crossing altitude text shall be readily distinguishable.
- Significant terrain features shall be readily distinguishable.
- For display distance range settings typically used in the terminal area, the aspect ratio between the vertical and horizontal scales should remain constant. This ensures that a constant angle approach path (e.g., 3 degrees) will be depicted on the VSAD as a line with a constant slope, independent of range setting within the terminal area during approach. The line on the VSAD will in general be drawn at an exaggerated slope with respect to the slope of the path being represented. One should consider the horizontal to vertical scaling ratio such that the predicted vertical trend vector appears compatible with any vertical speed needle being presented on the primary flight display.
- For display ranges greater than those typically used in the terminal area, the aspect ratio may be allowed to vary such that the vertical scaling is adequate to depict vertical flight plan information and relevant external hazards.

NOTE: It is expected that in many implementations the vertical area of display available to the VSAD will be quite small. In these cases, the display design should be such as to minimize clutter.

8.2.3.6 Airplane Symbol: If the current airplane altitude is being depicted on the VPD then a reference airplane symbol shall be provided on the VPD for indicating the current altitude of the airplane. The airplane symbol shall be depicted in such a manner to give immediate awareness of the direction of motion of the airplane with respect to the other information depicted on the VPD.

8.2.3.6 (Continued):

The reference airplane symbol should be a stylized airplane symbol, and should be compatible in shape and color with equivalent reference airplane symbols on the Primary Flight Display and Navigation Display. The size of the reference airplane symbol shall be sufficient for unambiguous viewing, and should be of constant size, independent of the selected range of the display. The reference airplane symbol may be stationary, or may move on the display surface. Either the symbol itself or a reference line coming from it should be used to indicate the current altitude of the aircraft relative to an altitude scale on the display. The exact location of the aircraft should be represented unambiguously and consistent with the navigation display. The airplane symbol could but does not have to be rotated to match the current vertical flight path of the aircraft.

The location of the reference airplane symbol on the altitude scale should be subject to the following criteria:

- The location of the reference airplane symbol should be such that sufficient display area to provide situational awareness and look ahead is visible to the pilot. The objective is to provide the pilot with awareness of aircraft vertical position and trend with respect to the desired flight profile and with respect to significant terrain.
- If the reference airplane symbol moves on the display, the display scaling and the motion of the marker should be controlled to avoid abrupt jumps in the position of the symbol. Pilot-initiated changes of display range may be allowed to cause jumps. If the reference airplane symbol moves, the location of the symbol and its direction of movement should not be misleading.
- If both airplane symbol and altitude reference scale move, the airplane's altitude and its trend should be unambiguous to the pilot.

8.2.3.7 Vertical Profile Swath:

Swath Width - A good rule of thumb for deriving lateral swath width of the vertical presentation is to use the Required Navigation Performance (RNP) for each phase of flight however the resolution of the terrain database must also be considered. The width of the swath should be sufficient to ensure that the information depicted on the VPD, such as external hazards or navigation data, is useful during appropriate phases of flight and should not in any way be hazardously misleading. The characteristics of the swath should either be easily understood by the pilot or intuitively depicted on the display. Where multiple characteristics of the swath are utilized, such as during different range settings, phase of flight or airplane flight conditions, those characteristics should be easily understood or graphically depicted to the pilot. During turning maneuvers, it may be beneficial to modify the horizontal swath to give additional look-ahead into the direction of the turn. If the horizontal swath is modified in this manner, the effects on performance should be evaluated.

8.2.3.7 (Continued):

Multiple Lateral Width Modes - If multiple swath widths or characteristics are utilized either simultaneously or successively, the information depicted should be unambiguous and not misleading to the pilot. For example, where more than an airplane track-up mode for VPD depiction is utilized, ie., planned flight path versus current airplane track, the distinction among the modes should be intuitively obvious to the pilot.

8.2.3.8 External Hazard Symbology: Significant man-made obstacles, terrain, traffic or other external hazards that lie on or near the projected flight path, may be depicted by suitable symbols or icons. This symbology should be consistent with any symbology used for depiction of these hazards on the map display. The symbology should also be consistent with the altitude and/or vertical height and uncertainty of the horizontal location of the hazard. The full picture of weather information may only be available with, of course, a WXR/VSAD interface and perhaps some modifications in the way the weather radar antenna scans. It may have to vary the antenna tilt to get the full weather picture. It may be desirable to display the current antenna tilt on the VSAD graphically. This might prove useful to the flight crew when manually adjusting the radar tilt angle.

The external hazards depicted on the VPD should be derived from a section of the external hazard database. The horizontal orientation of this section may be along the aircraft track, predicted track or planned horizontal flight path. Special consideration needs to be given to depiction of the swath on a VPD when the horizontal map is in a heading-up mode. In each case, the width of the section of the external hazard data that is depicted should be sufficiently large to contain the external hazards which are relevant to the current phase of flight. Consideration should be given to modifying the width of the swath with distance along the expected path as well as for different external hazards. In general, the Required Navigational Performance is a good factor for determining the width of the swath.

8.2.3.9 Flight Plan Vertical Profile: The planned vertical path of the airplane may be shown on the VPD. The profile should be visible only when the aircraft position and track are within pre-determined alignment criteria. If the planned vertical path is associated with a planned horizontal path which includes course changes, then the path should be projected laterally onto a linear horizontal distance scale as discussed in 8.2.3.5. In this case the terrain profile should be along the planned horizontal path, and this should be indicated to the pilot (e.g., by color coding or shading the terrain profile

8.2.3.10 Path Projection Methods: There are two elements which must be defined in order to depict information in the profile view. First, the projection method for the horizontal dimension on the display must be defined: distances measured along the horizontal dimension in the profile view should correspond to either the range from the aircraft or to distance as measured along the planned flight path. Second, a swath must be defined to filter out information from the environment to exclude from the profile display. The design of the projection method and the swath are interconnected as described below.

8.2.3.10 (Continued):

Figure 1 shows an example situation in which the aircraft is currently turning to the right on a track to intercept a programmed flight path. The profile display is configured to project information onto the current, instantaneous track of the aircraft. Thus, a given distance measured along the horizontal dimension in the profile display corresponds directly to the same distance along the aircraft's instantaneous track. Use of the current track has the benefit of depicting terrain or other hazard information which lies directly in front of the aircraft. This may be of interest to the pilot especially when the aircraft is flown manually or on heading vectors. A swath is also shown in Figure 1 which extends a certain distance to either side of the current track. Only information within this swath is depicted on the profile display. Thus, the pilot does not see the programmed waypoints or hazard Y in the profile display. Depicting information far off the current track of the aircraft could be misleading, since it would not be clear on the VPD whether this information is truly in front of the aircraft. Similarly, projecting the planned flight path onto the current track would distort the distances between waypoints.

The size and shape of the swath should be carefully considered. There may also be benefit to adjusting the swath to look into a turn, as shown in Figure 2, so as to provide some look-ahead to the pilot of potential hazards that are likely to be encountered.

If the swath becomes relatively wide, there is an additional issue to be resolved having to do with the method by which the information is projected onto the track. In Figure 2, assume that hazard Z is projected perpendicularly onto the track. As the aircraft turns toward hazard Z, it would actually appear to move a small distance away from the aircraft on the VPD even though the true range to the hazard was decreasing. Alternatively, if information is projected according to its range from the aircraft, then this distortion would not occur. The swath that is used should be examined to determine if this form of distortion can occur, and if so, information should be projected according to its range from the aircraft rather than by projecting information onto the aircraft track.

A second option for the horizontal projection method is to use the planned flight path, as shown in Figure 3. This would facilitate verifying that the programmed vertical flight profile is correct, ensuring that the planned path does not conflict with hazards, and for comparing the aircraft's current position against the plan. Again, a swath should be defined to filter out information that is not relevant to the planned path.

As shown in Figure 3, it may be the case that the aircraft is actually outside the swath. In general, it would still be desirable to depict the flight plan information within the swath, e.g., for flight planning. However, it may be necessary to cue the pilot that the information that is depicted is not necessarily in front of the aircraft. In addition, information that is in front of the aircraft may not be depicted on the VPD. For example, note that hazard X is not depicted and since the hazard Z was slightly outside of the swath, it would also not be depicted on the VPD.

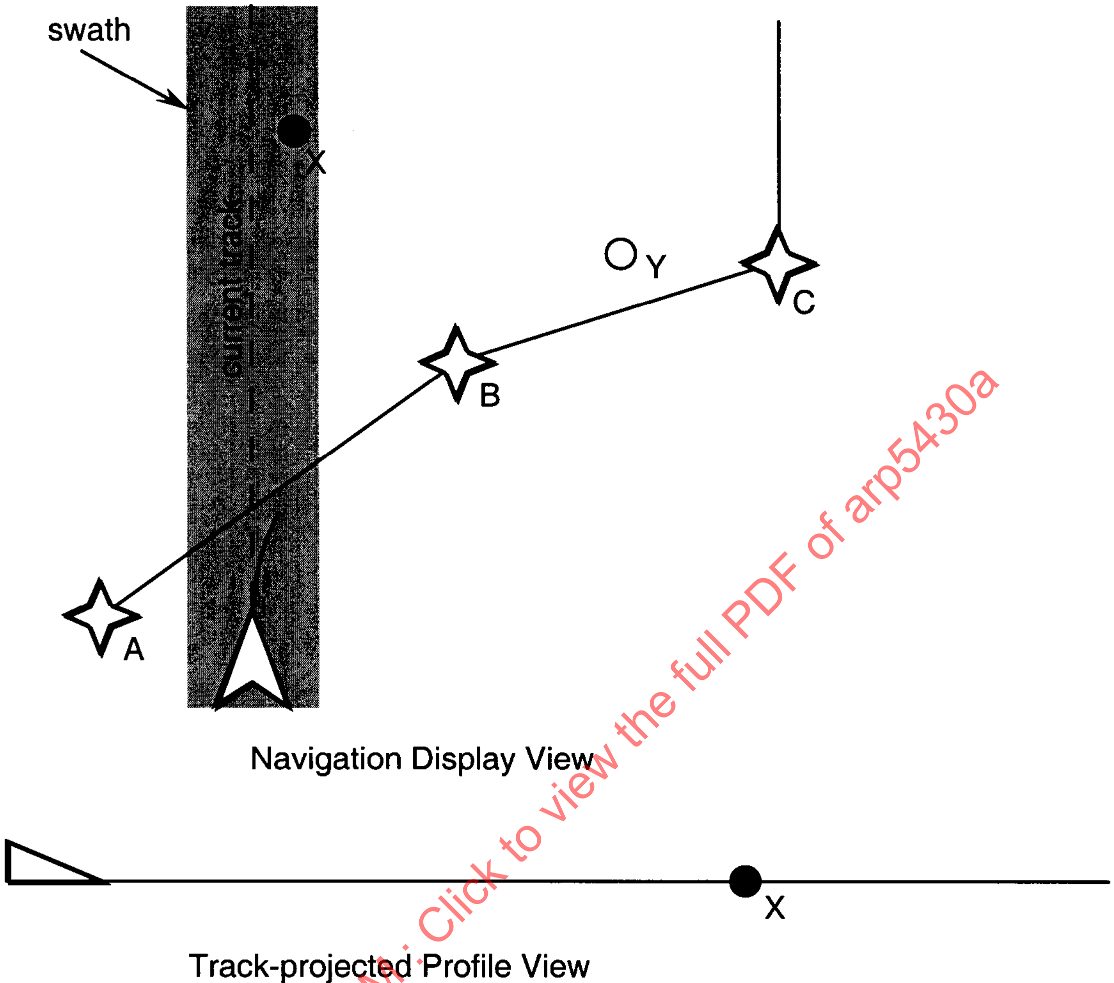

FIGURE 1 - Current Track Projection

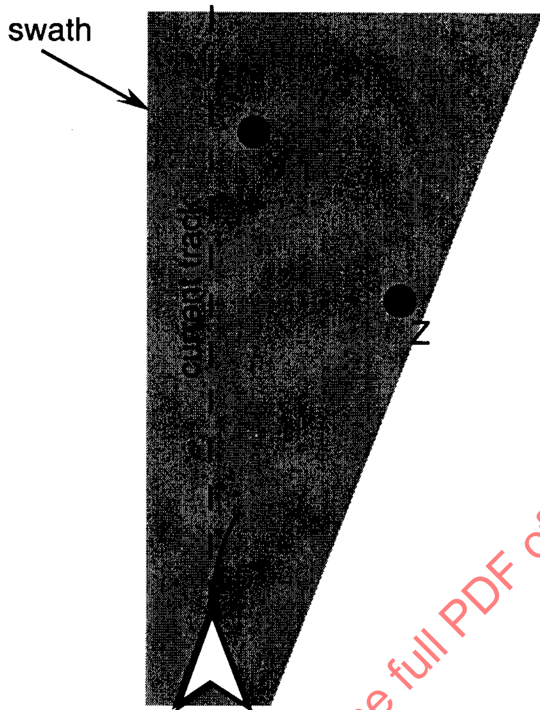

FIGURE 2 - Swath Adjustment to Look Into Turn

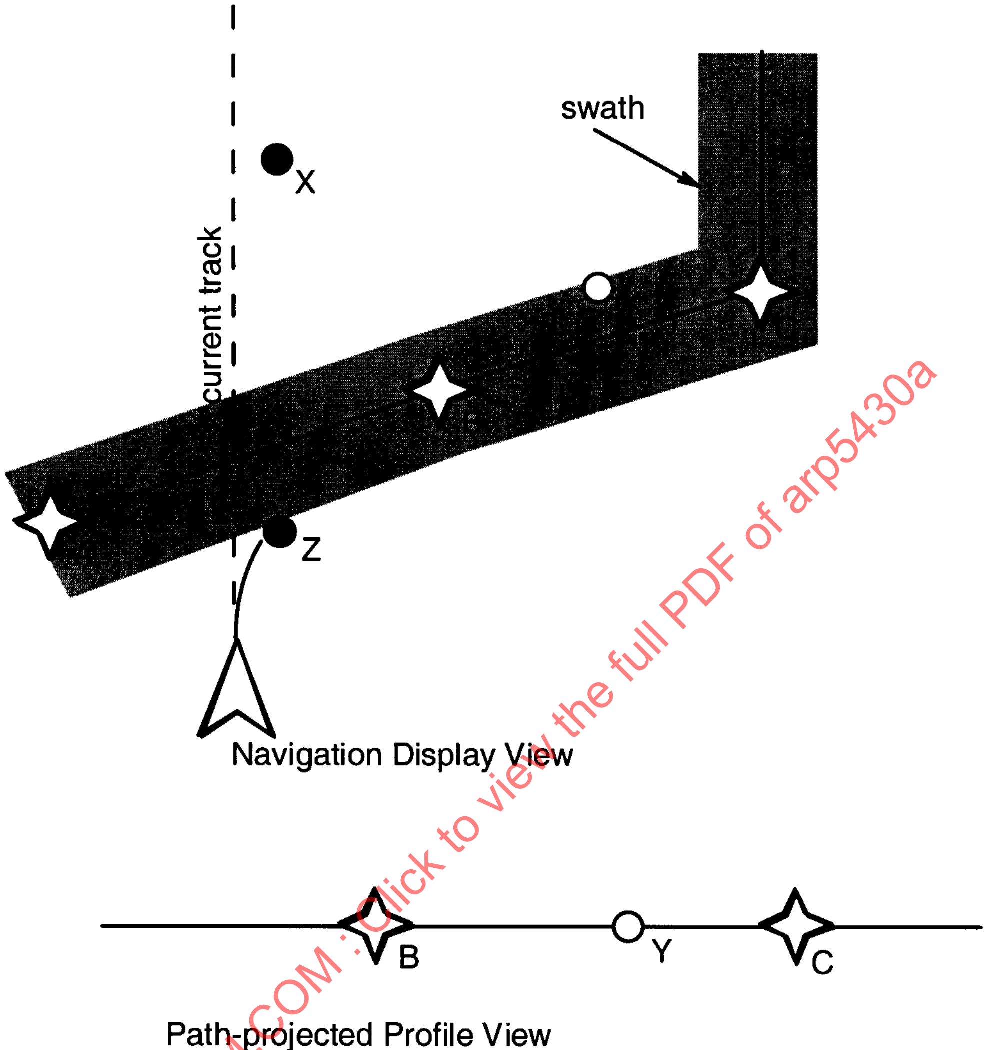

FIGURE 3 - Planned Flight Path Projection

8.2.3.10 (Continued):

One additional issue for the planned path projection is whether horizontal distance in the profile display corresponds to horizontal distance as measured along the programmed path, or to the horizontal distance as measured by the actual path the aircraft will fly. For example, hazard Z in Figure 2 is shown a distance in front of the aircraft in the profile display that corresponds to its actual distance along the curved turning flight path of the aircraft. Alternatively, hazard Z could be shown in its projected position on the line connecting waypoints A and B, in which case it might appear to be farther ahead in the profile view.

8.2.3.11 Declutter Philosophy: Design of the Vertical Profile Display (VPD) should avoid the inclusion of extraneous information, in order to prevent an overly cluttered display. The VPD should also include a means for pilot manipulation of the information displayed in the VPD in order to make the information currently necessary most salient. This task is not unlike situations that exist on the ND. It is possible, through optional pilot selections, to get the ND so cluttered that it is useless. This is not generally a problem on the ND, since the optional display selections and the range combinations are naturally avoided by the flight crew. The philosophy of use of the VSAD should be the same as has been successfully employed on the ND. The flight crew should be given a number of display tools which are useful under various situations and then let them prioritize how they are used and when, as circumstances dictate. This may be accomplished either by temporarily deleting unnecessary information from the display, by making the necessary information more salient, or the unnecessary information less so. Saliency may be adjusted using visual display techniques such as color, brightness, contrast, and so forth.

Regardless of the means by which a display will be decluttered, the guidelines listed below should be followed:

1. Information critical to the safety of flight must not be available for declutter manipulation. The criticality of information may be a function of the flight phase.
2. Information should be removed or made less salient in logical layers. The organization of the information layers should be compatible with that of the horizontal situation display.
3. Decluttering should be controlled manually, unless it can be shown that the automatic removal of information layers will have no impact on crew situational awareness or the safety of flight.
4. The means by which declutter is controlled should be compatible with that of the horizontal situation display.
5. An indication of information layers shown should be provided.
6. Any “pop-up” alert implementation (of any level) should be consistent with the implementation utilized on the horizontal navigation map. However, it may not always be necessary to remove information on the VPD per the ND algorithm. For example, it may be acceptable to leave terrain data available on the VPD even though a weather-related alert has removed terrain from the navigation display. The driving factor should be conflict resolution. Consideration should be given such that the return of layers does not create an overly cluttered or unreadable display.
7. The information layers available for decluttering may be a function of the VPD mode.

8.2.3.12 Resolution: The design of the VPD should provide sufficient resolution capability to serve its intended function. One means to achieve this is to use digital display of flight path angle in degrees.

8.2.4 Procedural Considerations: The VPD should be evaluated to determine the procedures for use of the system and how they will affect aircraft operations. Procedures for use must clearly indicate the types of vertical situation information (terrain, man-made obstacles, traffic, etc) included in the VPD. These procedures may be included in the airplane flight manual in the relevant section.

The following procedural limitations may be relevant:

1. The VPD is intended to serve as a situational tool only. It should not be used for altitude control since existing altitude indicators on the PFD must remain the primary source of altitude information values. It should also not be used for navigation since the VPD may not provide the necessary accuracy on which to base navigation decisions.
2. When an alert is issued, corresponding information may also be provided on the VPD. The VPD is not intended as the sole display on which to base hazard avoidance maneuvering decisions.

Of course the specific procedural limitations are going to be a function of the accuracy and fidelity of the data driving the VPD, and the types of information included in the display.

8.3 Three Dimensional Navigation Display:

The 3D VSAD employs geometric projection techniques to present an “outside world view” on a two dimensional cockpit display for purposes such as flight path stabilization, situation awareness relative to the planned route, terrain, obstacles, weather, and other aircraft, and for route planning. Principal design issues involve the choice of appropriate reference frame and viewing position/ direction. The 3D display is not intended to be a conformal display and unlike conformal HUD displays, a moderately wide-angle view is often used. The virtual viewpoint is normally located outside the cockpit, and an earth-horizontal reference frame is used. The viewpoint can be tethered so it follows along the flight-planned route, or follows the aircraft itself producing a “wingman” view. The tether length and direction may be under automatic and/or user control. Alternatively, the display view direction may be slaved to follow a specific point on the ground. As with map displays, the VSAD reference frame and viewpoint control scheme must be appropriate for the task and phase of flight. It is helpful to graphically depict the 3D display view in concurrent map and profile displays.

8.3.1 Projection Parameters and Types: The depiction of a 3D scene on a 2D display can be accomplished using various projection methods. However, the type of projection that is used, determines the location on the display for each object of the scene. To illustrate the concepts involved imagine an eye viewing a scene through a glass window. Now a marker is used to print on the glass window the objects of the scene where they appear. When the window is taken and put on a display, one can see the 2D projection of the 3D scene.

Whatever projection type is used for a 3D VSAD, several parameters must be taken into account. For this document, the 3D projection parameters are defined as follows and illustrated in Figure 4.

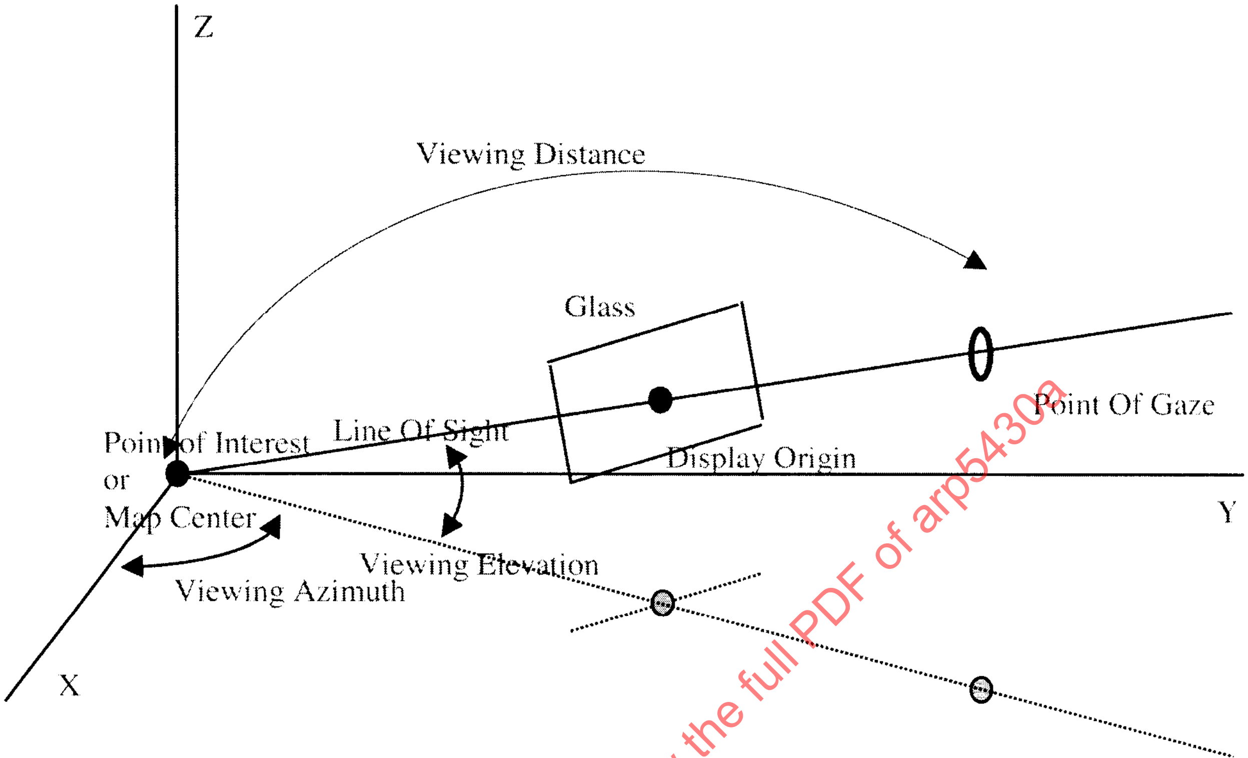

FIGURE 4 - 3D Projection Parameters

8.3.1 (Continued):

- The position of the eye is defined as the Point Of Gaze (POG).
- A specific point on the glass window is defined as the Display Origin.
- The point in the scene that is aligned with the POG and Display Origin is defined as the Point Of Interest (POI). Alternatively, the POI can be described as the Map Center.

  NOTE: The Display Origin is therefore the point on the display where the Map Center is desired to appear.

- The line joining the POI (or Map Center) and the POG is defined as the Line Of Sight (LOS).
- The lateral angle-of-view of the LOS referenced to the horizontal plane at the Map Center of the 3D scene is defined as the viewing azimuth.
- The vertical angle-of-view of the LOS referenced to the horizontal plane at the Map Center of the 3D scene is defined as the viewing elevation.

8.3.1 (Continued):

- The distance along the LOS that is between the POI and POG is defined as the viewing distance.

  NOTE: The notion of eye rotation around the line of sight (i.e., twist) is omitted from the discussion on purpose as it is not considered to have any merits for a 3D VSAD application. For example a non null twist will produce an apparent horizon that is not horizontal.

The following discussion will be limited to an exocentric referenced display format (i.e., the POG is located outside of the own ship). The 3D VSAD format displays both horizontal and vertical information within the same graphical image. The LOS is described as off-axis as it does not correspond to the same view as found in a top-down plan view (i.e., Horizontal Map Display) and side view (i.e., Vertical Profile Display). Instead, the 3D view is a combination of the plan view and side view such that both sets of information are simultaneously shown together.

The LOS may be fixed or variable depending on the application and intended usage. A fixed LOS has a constant viewing azimuth and viewing elevation whereas a variable LOS has a viewing azimuth and/or viewing elevation that can be adjusted. Both the fixed and variable types of LOS have their unique advantages and therefore should be considered. Fixed LOS applications have the following advantages.

- Require fewer display controls.
- Ensure both pilot and co-pilot displays provide the same graphical depictions.

Conversely, variable LOS applications have the following advantages.

- Viewing azimuth and elevation can be adjusted to minimize occlusions and display clutter.
- Optimal viewing perspectives can be achieved for all flight phases, flight plan routes and all hazards that are displayed.

For a 3D VSAD exocentric display, three projection types will be addressed. These are:

- Perspective Projection
- Orthogonal Projection
- Window Projection

Perspective Projection:

In a perspective projection, it can be shown that 2 parallel lines (L1 and L2) of the scene will not appear parallel on the display unless they are parallel to the glass window. If not, lines L1 and L2 will appear converging toward a specific point. This point is situated at the intersection of the plane P0 containing the glass window and the line L0 parallel to L1 and L2 going through the POG as shown in Figure 5. The following describes some of the relationships between the projection parameters.

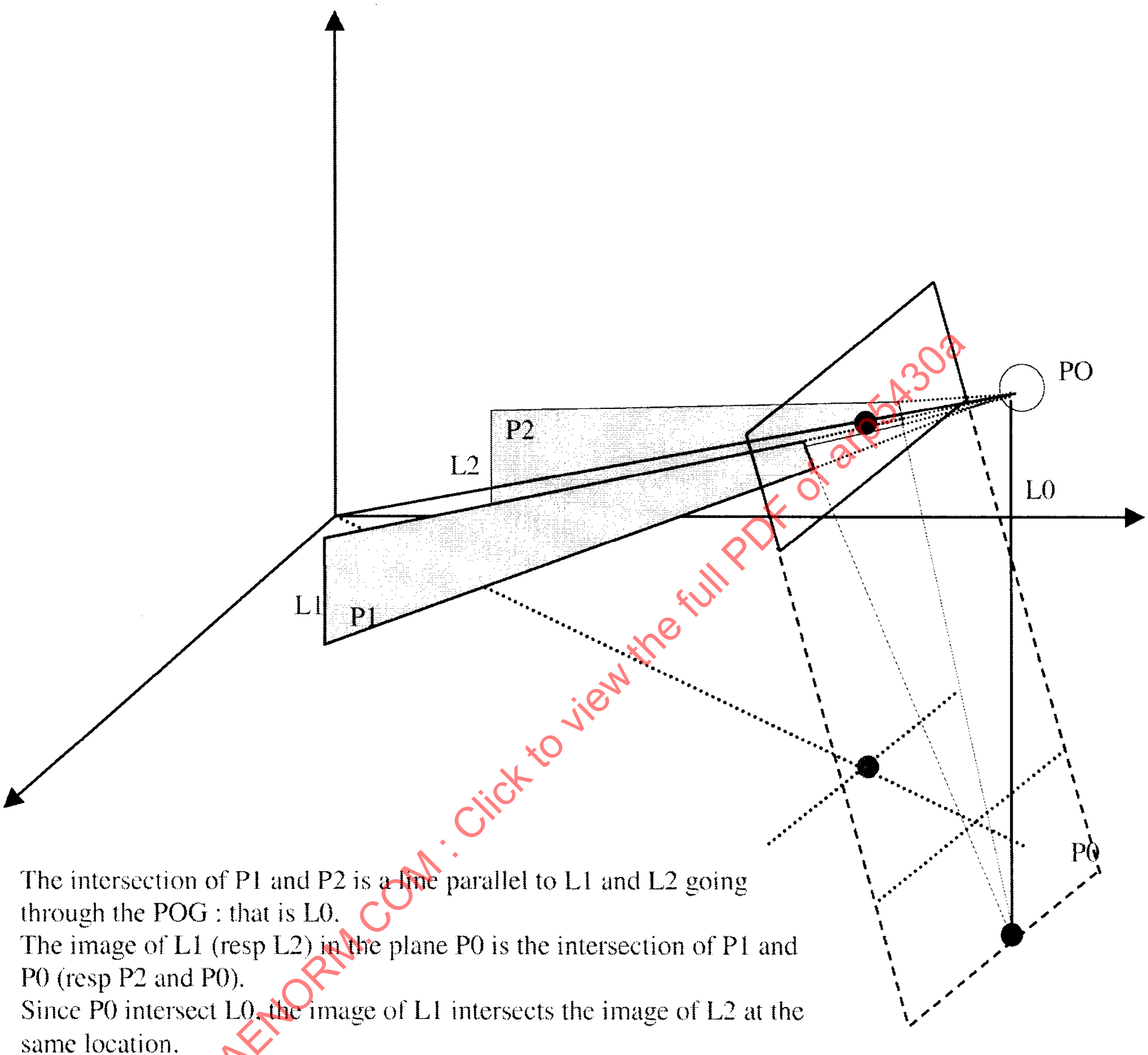

FIGURE 5 - Perspective Projection

8.3.1 (Continued):

With a constant distance between the POI and POG (i.e., a constant viewing distance), moving the glass window toward the POG increases the Field Of View (FOV). At the same time the portion of the 3D scene viewed in the display, which is referred as Depicted Range, increases. An example of Depicted Range is shown in Figure 6.

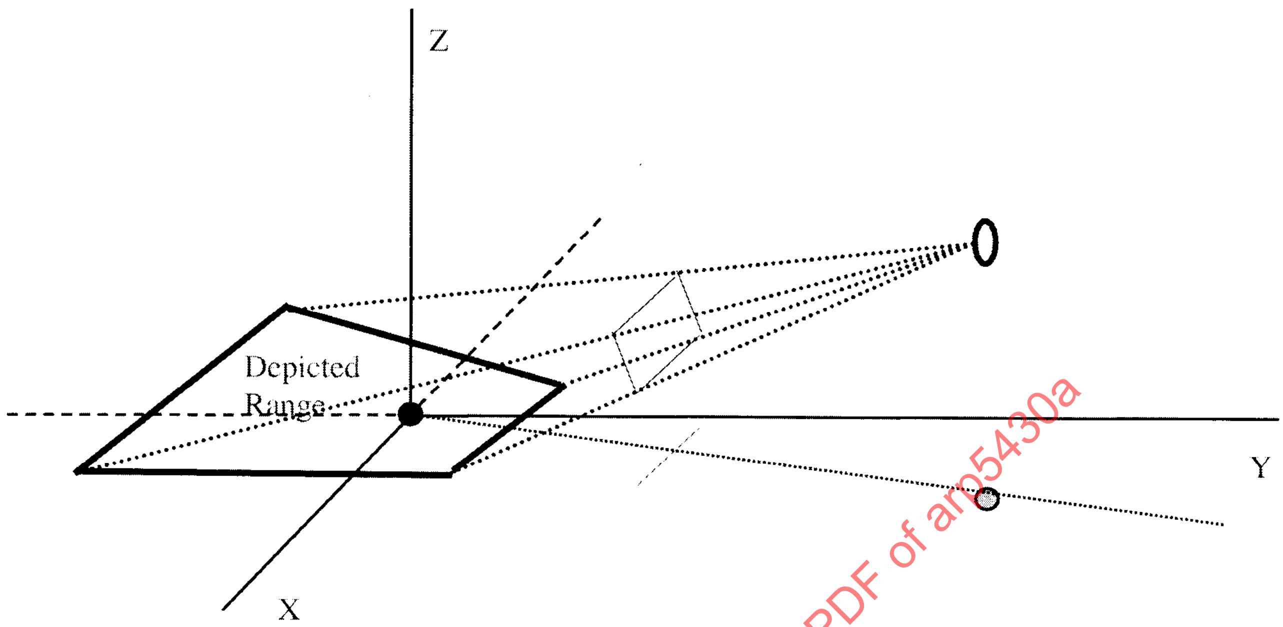

FIGURE 6 - Depicted Range

8.3.1 (Continued):

The effect of changing the FOV is equivalent to a simple two-dimensional scaling of the 3D scene, it does not affect the perspective geometry. Hence, the setting of FOV may be used to enlarge the 3D scene to fill the available display area, providing more space for labels; but it does not serve to declutter the image, or remove overlap or occlusions.

Alternatively, moving the POG while maintaining a constant ratio between POI, glass window and POG (i.e., an increase in viewing distance) will reduce the Depicted Range without changing the FOV. Moving the POG away from (or towards) the POI is better suited for "focusing" on certain regions of the scene, as it changes the perspective geometry and thus provides more depth information to the viewer.

NOTE: This notion of FOV and the way to manage the Depicted Range is valid only when the POG is not at infinity.

The main advantage of the perspective projection is that depth information is provided. To some extent this projection type presents a 3D "picture" that looks similar to the real scene viewed by the pilot (i.e., it provides pictorial realism). The apparent size of display objects varies as a function of distance along the LOS. Near objects are displayed larger than far objects (which are displayed smaller). This makes display object distance relationships unambiguous in the 3D scene.

8.3.1 (Continued):

Orthogonal Projection:

The orthogonal projection is equivalent to a perspective projection using a zero FOV (i.e., it corresponds to a POG at infinity or an infinite viewing distance). In this kind of projection, it is not possible to define the LOS by the line joining POI and POG (since POG is at infinity). Therefore one has to use the viewing azimuth and the viewing elevation. Together with the POI they define the LOS. One of the advantages using this kind of projection is that two parallel lines of the scene will always appear parallel whatever their direction is.

One of the characteristics of orthogonal projection is that the apparent size of objects does not depend on their distance along the LOS. Figure 7 shows the difference between a perspective and an orthogonal projection. For the orthogonal projection, objects A and B have the same apparent size; this is not the case for perspective projection. This attribute of an orthogonal projection may be considered an advantage depending on the intended use.

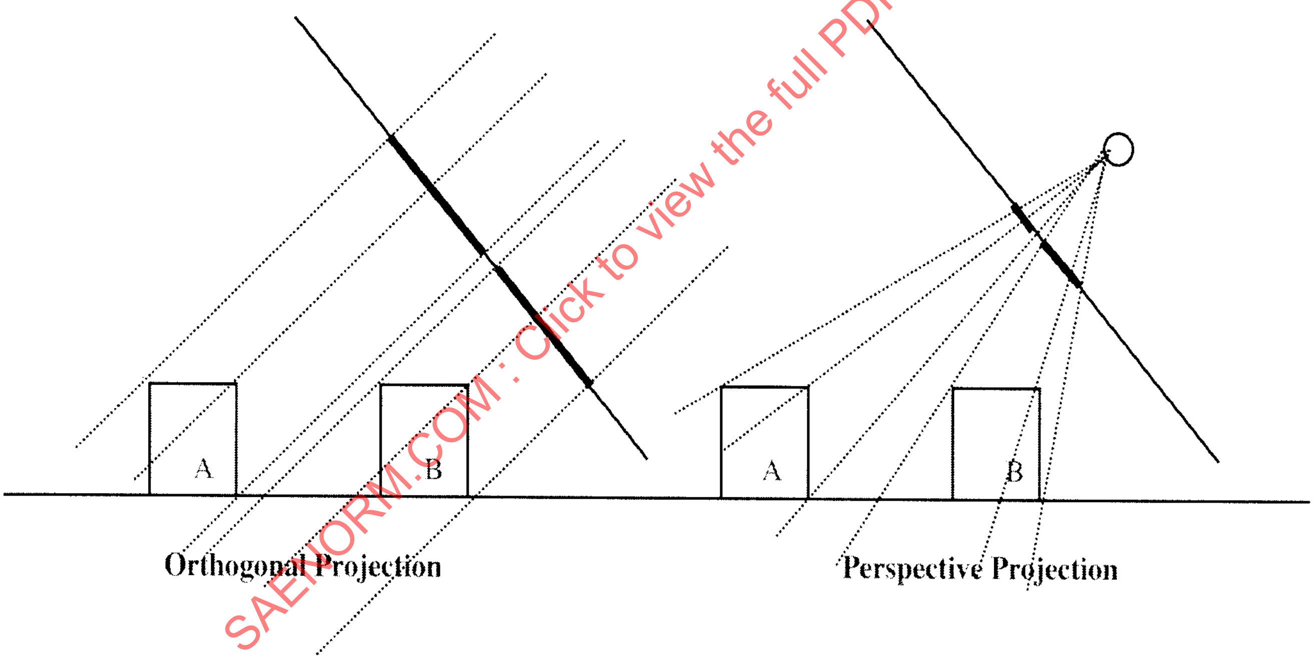

FIGURE 7 - Difference Between Orthogonal and Perspective Projections

8.3.1 (Continued):

The main advantage is that equal display resolution exists at all positions on the display. This is consistent with traditional horizontal map displays. Equal display resolution is especially important when displaying vertical information in that equal height objects are scaled the same regardless of their respective positions on the display. This effect is most apparent for viewing elevation settings that approach a sideways view of the 3D scene.

A disadvantage of the orthogonal projection type is that it may suffer from a telephoto effect where the relative size and distance of objects are being misrepresented and consideration must be given that perception of depth is very limited or missing.(Ellis et al. 1991). A direct consequence of this characteristic is that a grid viewed under orthogonal projection may be ambiguous. It can be considered as a "floor" or as a "ceiling". In Figure 8 the grid represented on the left could be seen from the top or the bottom; the lower square of the grid could be the closest or the furthest. There is no such ambiguity with the grid depicted on the right as the lower square is bigger than the others and is therefore closer. The view is therefore from the top.

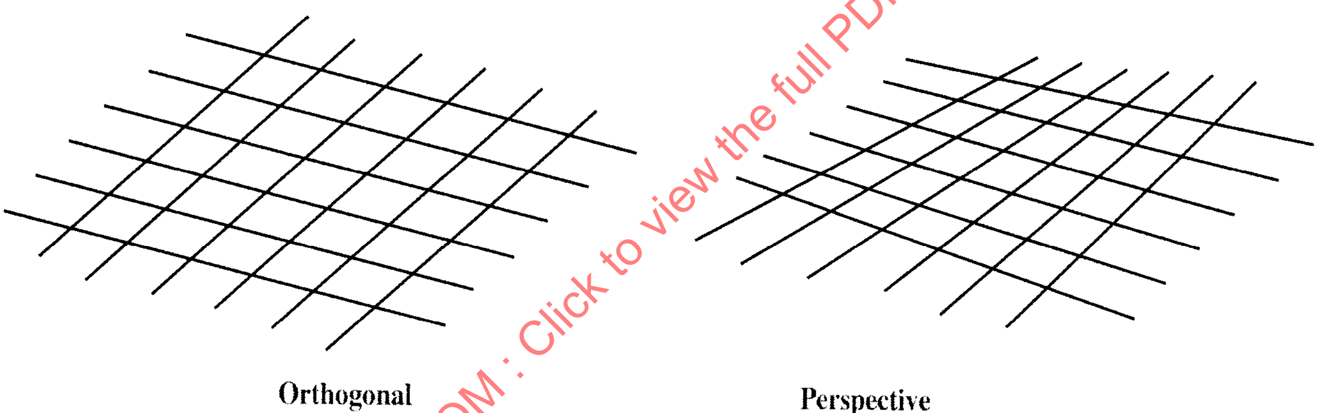

FIGURE 8 - Ambiguity Caused by Orthogonal Projection

Window Projection:

The third type of projection is the window projection. It is a perspective projection as described above with the difference that the glass window can be oriented in a different direction from the line between the POG and POI. This leads to an image distortion that can be beneficial.

Figure 9 shows a minor difference from Figure 4. The window is now vertical. The advantage of a window projection type with such a feature is that the horizontal plane yields a perspective effect (i.e., provides depth information) while maintaining all vertical lines of the scene vertical in the display (since vertical lines of the scene are parallel to the glass window).

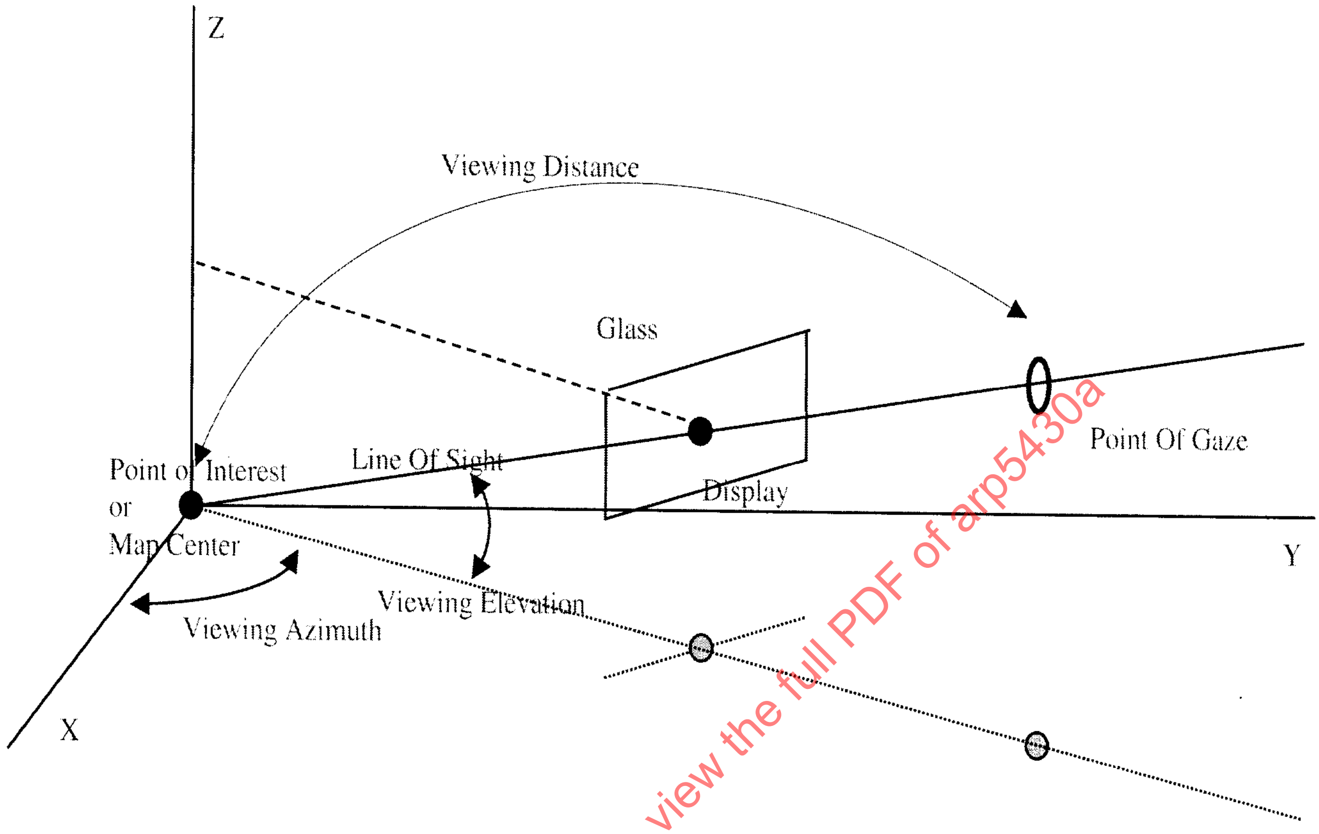

FIGURE 9 - Window Projection

8.3.2 Ground/3D Reference Symbology: Since the perspective image displays three-dimensional information in a two-dimensional display, depth information is lost and the vertical and horizontal position of objects is often ambiguous. It is the role of the reference symbology to restore this lost information by providing the observer visual cues which resolve some of the positional ambiguities in the image. This philosophy should serve as the guideline in designing reference symbology (Barfield, Lim and Rosenberg 1990).

The ground symbology serves as a reference when resolving the three dimensional position of symbols, hence as a minimum ground representation, a grid should be provided. When display of terrain is not included, a flat, equally spaced, grid provides the necessary horizontal spatial orientation (Owen and Suiter 1997) but by itself is insufficient for terrain avoidance. Where depiction of terrain is provided, the grid should overlay the terrain features. In cases where areas of the terrain data base may be missing, that area should be clearly and unambiguosly depicted on the display.

8.3.2 (Continued):

Considerations, when establishing the grid size, should include some relationship to the scaling of the map display range(s) and other displays with grids. The grid spacing should give an unambiguous perception of distance. A fixed ratio of grid size to map range has been shown to be acceptable. Acceptable ratios include 1:2, 1:1 or 2:1. Figures 10, 11 and 12 are examples of a 40 nm map range, that is depicted by a range ring, with grid size to map range ratios of 1:2, 1:1 and 2:1, respectively.

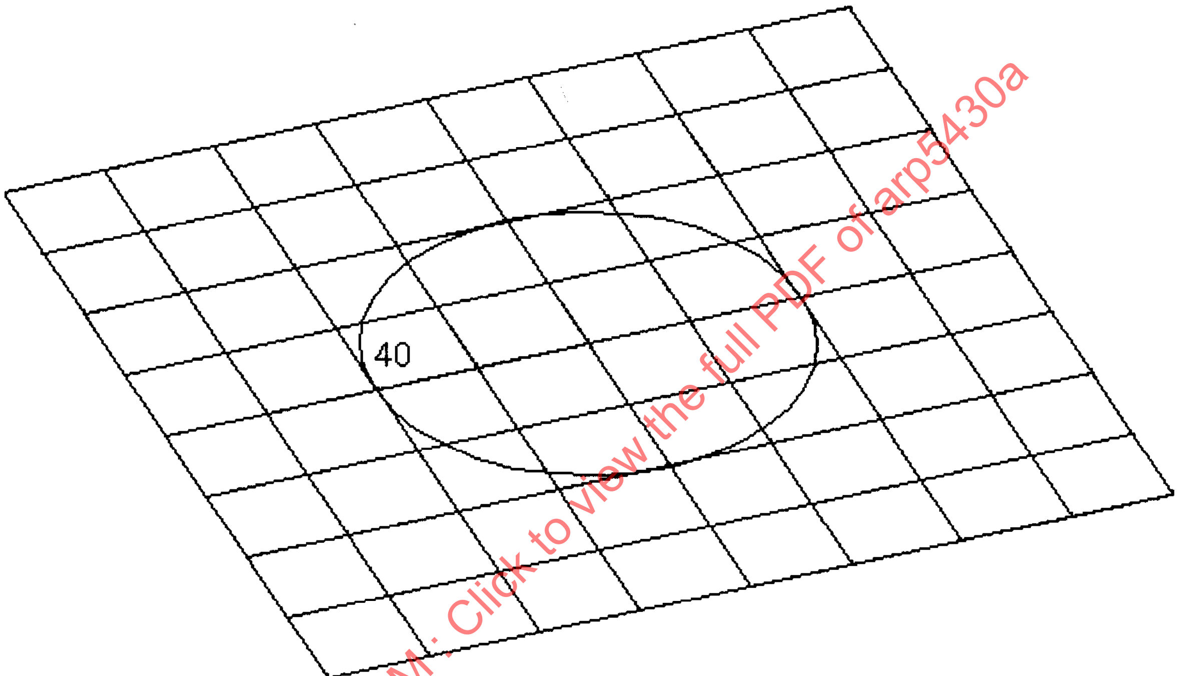

FIGURE 10 - 1:2 Grid Size to Map Range Ratio

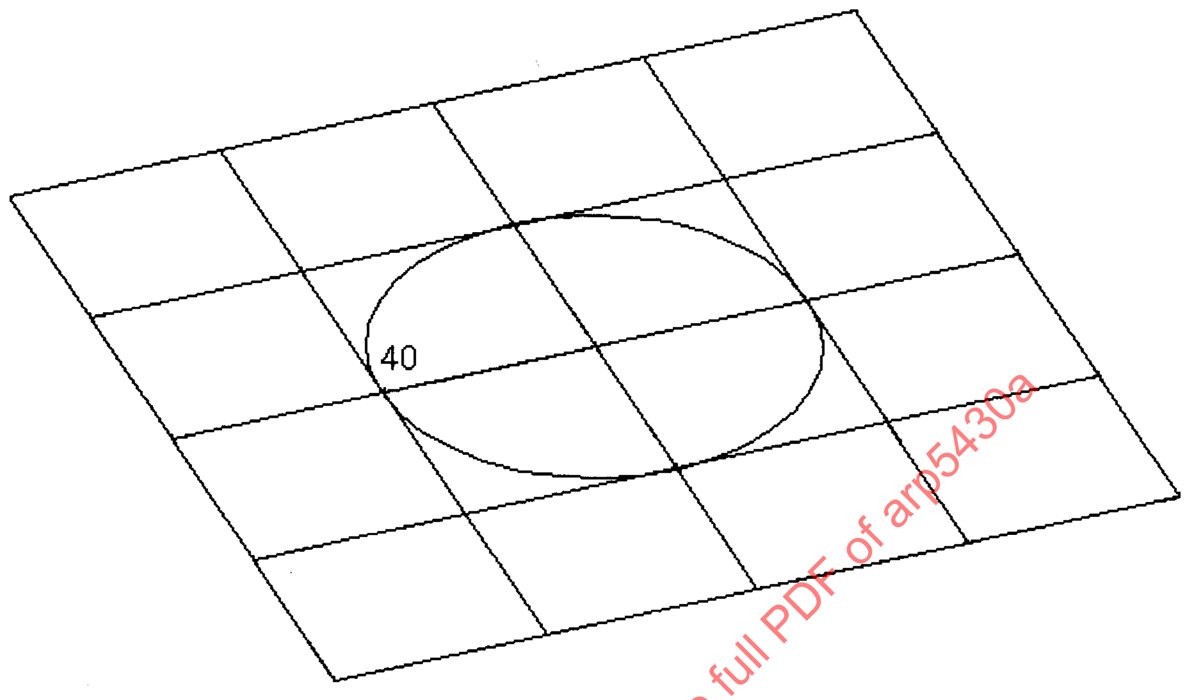

FIGURE 11 - 1:1 Grid Size to Map Range Ratio