

Human Engineering Considerations for Airborne Implementation of Enhanced Synthetic Vision Systems

RATIONALE

The use of enhanced visual scene content as both a tool to increase situation awareness and as a sole flight guidance display has increased and will continue to increase. Correct implementation of these types of displays is essential and critical to safe operation.

SAE G-10 Aerospace Behavior Engineering Technology (ABET) Committee, specifically the Enhanced Vision/Synthetic Vision (EV/SV) Subcommittee, has been tasked to provide implementation document guidance associated with the human interface considerations in the design, development and implementation of enhanced synthetic vision systems.

FOREWORD

This document identifies the recommended human engineering best practices in the design and implementation of Enhanced Synthetic Vision Systems (ESVS). It draws from ARD50019A, Human Engineering Issues for Enhanced Vision Systems and other applicable ESVS data including developmental flight evaluations and fielded data. This document is intended to provide a central source for recommending human engineering applications concerning ESVS and as an aid for development, design and implementation.

DEFINITION

An enhanced synthetic vision system (ESVS) generates and displays visual imagery based upon real-time sensor data, fused (integrated into), not "overlayed on" as in a Combined Vision System (CVS) implementation, with a data-based computer-generated image representing the out-of-the-cockpit view of terrain and selected scene data. The sensor(s) is/are designed to provide useable imagery in degraded environmental visual conditions that enhances the capability of unaided human vision, while the computer generated scene is unaffected by environmental conditions.

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1. SCOPE

1.1 SCOPE

The scope of this document is limited to Enhanced Synthetic Vision Systems ESVS human factors considerations and requirements in comprehension, interpretation and application of imagery and integrated symbology in Enhanced (sensor) and Synthetic (database) Vision Systems in aircraft. Any overlap into logic problems or hardware/software design should be considered to be incidental to the human factors issues. Where the performance characteristics of specific technologies are relevant they will be identified, and where performance criteria are relevant to specific intended functions/use they will be identified. From a regulatory view, intended function (Guidance or Information/Situation Awareness support) has a tremendous effect upon the design of an ESV System. However from a Human Engineering standpoint, the information on a display must be discernible and comprehensible to the human operator in both cases and differences may be primarily in information content (required to support a specific task).

This document attempts to be independent of candidate technologies and concentrate on human interface criteria.

Consideration of NVG use in a cockpit equipped with ESVS is beyond the scope of this document, but it should be noted that there will be significant integration/interaction issues such as black level limits and use of DTED data simultaneous with NVS. This document does not include consideration of detection and/or display of air targets or integration of systems such as TCAS.

1.2 Purpose

This document is a compilation of human factors recommended practices in the design of ESVS. It may be updated to reflect research and development results and as the technology improves and applications expand, the coverage of the document will be expanded.

2. REFERENCES

A full bibliography has been compiled and is attached as Appendix A.

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 International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

ARP571	Flight Deck Controls and Displays for Communication and Navigation Equipment for Transport Aircraft
AS580	Pilot Visibility from the Flight Deck: Design Objectives for Commercial Transport Aircraft
ARP1068	Flight Deck Instrumentation, Display Criteria and Associated Controls for Transport Aircraft
AIR1093	Numerical, Letter and Symbol Dimensions for Aircraft Instrument Displays
ARP1782	Photometric and Colorimetric Measurement Procedures for Airborne 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
ARP4102	Flight Deck Panels, Controls, and Displays
ARP4107	Aerospace Glossary for Human Factors Engineers
ARP4155	Human Interface Design Methodology for Integrated Display Symbolology
ARP4256	Design Objectives for Liquid Crystal Displays for Part 25 (Transport) Aircraft
ARP4761	Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment
ARP5056	Flight Crew Interface Considerations in the Flight Deck Design Process for Part 25 Aircraft
ARP5288	Transport Category Airplane Head Up Display (HUD) Systems
AS8034	Minimum Performance Standard for Airborne Multipurpose Electronic Displays
AS8055	Minimum Performance Standard for Airborne Head Up Display (HUD)
ARD50019	Human Engineering Issues for Enhanced Vision Systems

2.2 Other Applicable References

ADS-33, Handling Quality Ratings

AFRL Report WL-TR-95-3074, Subjective Image Quality Comparisons of AMLCD and CRT Implementations of Electronic Flight Formats, United States Air Force Research Laboratory, Wright-Patterson AFB, Ohio, Sept 1995

EASAOEB ADMINISTRATIVE AND GUIDANCE PROCEDURES,
http://www.easa.eu.int/ws_prod/c/doc/EASA%20OEB%20Admin%20%20Guidance%20Procedures.pdf

FAA AC-20-167 Airworthiness Approval of Enhanced Vision System, Synthetic Vision System, Combined Vision System, and Enhanced Flight Vision System Equipment

FAA AC-25-11A, of 06-21-2007, Transport Category Airplane Electronic Display Systems

FAA AC-90-106, of 06-2-2010, Enhanced Flight Vision Systems

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

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

FAA AC-25.1309-1A, System Design Analysis

FAA AC-25.1322-1, Flight Crew Alerting

FAA TSO C-151b, Terrain Awareness and Warning System, December 17, 2002

ISO FDIS 9241-8, Requirement for Display Colors

MIL-STD -1797, Department of Defense Handbook Flying Qualities of Piloted Aircraft

RTCA/DO-200a/EUROCAE ED-76, "Standards for Processing Aeronautical Data"

RTCA/DO-276, User Requirements for Terrain and Obstacle Data

RTCA/DO-315B, Minimum Aviation System Performance Standards (MASPS) for Enhanced Vision Systems, Synthetic Vision Systems, Combined Vision Systems and Enhanced Flight Vision Systems, SC-213, Washington, D.C., June 2011

RTCA SC-213 (Joint with EUROCAE WG-79), Enhanced Flight Vision Systems/Synthetic Vision Systems, (EFVS/SVS)

MIL-STD-1472F, Human Engineering Design Criteria for Military Systems, Equipment and Facilities

NATO RTO Technical Report HFM-091/RTG-027, Common Methodological Basis for Evaluation and Testing of Visionic Devices; Chapter 3 - Sensor Technologies for Enhanced and Synthetic Vision Systems

NASA Report ARL-02-6/NASA-02-4, 2002, Spatial Awareness Biases (Wickens)

RTCA/DO-309, Minimum Aviation System Performance Standards (MASPS) for Helicopter Terrain Awareness and Warning System (HTAWS) Airborne Equipment, March 13, 2008, RTCA SC-212

RTCA/DO-315:2010, Minimum Aviation System Performance Standards (MASPS) for Enhanced Vision Systems, Synthetic Vision Systems, Combined Vision Systems and Enhanced Flight Vision Systems, September 15, 2010, RTCA SC-213, Washington, DC

2.3 Regulatory Publications

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

14 CFR Part 25 Airworthiness Standards: Transport Category Airplanes (EASA CS Part 25)

14 CFR Part 27 Airworthiness Standards: Normal Category Rotorcraft

14 CFR Part 29 Airworthiness Standards: Transport Category Rotorcraft

EASA CS Part 23 Certification Specifications for Normal, Utility, Aerobatic and Commuter Aeroplanes

EASA CS Part 25 Certification Specifications for Large Aeroplanes

EASA CS Part 27 Certification Specifications for Small Rotorcraft

EASA CS Part 29 Certification Specifications for Large Rotorcraft

TSO-C113 Airborne Multipurpose Electronic Displays

2.4 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]).

ALLOCENTRIC: Scene-based frame of reference particularly with respect to the object's spatial location; an observer-independent (possibly earth-fixed) frame of reference.

AVIONICS ARCHITECTURE: A total set of design choices which make up the avionics system and result in it performing as a recognizable whole. Federated avionics architecture consists of "stand alone" sub-systems and their integration into an overall system is carried out by the crew. Integrated modular avionics architecture relies on the use of a limited range of standard modules which are packaged in a standardized modular format and installed in a small number of common racks.

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.

COMBINED VISION SYSTEM (CVS): A displayed image combining a selected database image (e.g., airport approach data, synthetic image data) overlaid with active sensor image data.

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 and scalar 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.

DEGRADED VISUAL ENVIRONMENT: Atmospheric conditions where the visibility is restricted by obscurants to less than VMC conditions as defined by CFRJAR.

DTED: Digital Terrain Elevation Data - a standard of digital datasets which consists of a matrix of terrain elevation values; standards for Level 1 (3 arc second approximately 90 m) and Level 2 (1 arc second approximately 30 m) DTED.

EGOCENTRIC: A presentation referenced to the aircraft/pilot, rather than the outside world.

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

ENHANCED FLIGHT VISION SYSTEM (EFVS): An electronic means to provide a display of the forward external scene topography (the natural or manmade features of a place or region especially in a way to show their relative positions and elevation) through the use of imaging sensors, such as a forward looking infrared, millimeter wave radiometry, millimeter wave radar, low light level image intensifying. (14 CFR part 1.1 Definitions)

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

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.

ESTIMATED POSITION UNCERTAINTY (EPU): The measurement of the horizontal figure of merit of the actual aircraft position related to predicted position. HFOM is a measure of the accuracy of an aircraft's reported position. It is the radius of a circle, centered on an aircraft's reported position, such that the probability of the true position lying outside that circle is 5% or less. (Revised DO-242A ADS-B MASPS)

EPU: A measure based on a defined scale, in nautical miles, which conveys the current position estimation performance (circular error of probability - CEP); represents the 95% accuracy performance of the navigation solution, computed based on the error characteristics of the particular sensors being used and the variance of the individual sensors position with respect to other sensors.

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.

FEDERATION: Federated avionics architecture consists of "stand alone" sub-systems and their integration into an overall system is carried out by the crew.

FIELD OF REGARD: All of the points of the physical environment that can be perceived by a stable eye.

FIELD OF VIEW:

- **Head Down Display** - The angular extent of the physical display surface referenced to the pilot eye position, often called geometric field of view (characterized as degrees/minutes of visual angle) from the eye.
- **Head Up Display (including Head Mounted Display)** - The (angular or linear or areal from the sensor) extent of the observable world that is seen at any given moment.

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.

FLIGHT PATH VECTOR: The vertical and lateral trajectory (i.e., flight path) of the aircraft, indicating the measured aircraft flight path (i.e., Flight Path Vector, FPV), actual (immediate) or predicted or quickened.

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

HRTI: High Resolution Terrain Information; higher resolution terrain data, resolution for Level 3 DTED is a 1/3rd arc second (approximately 10 m), Level 4 is 1/9th arc second (approximately 3 m) and Level 5 DTED is 1/27th arc second (approximately 1 m) http://www.mission-planning.com/DTED_Part5.htm

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 wherein 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 useable. NOTE: integration can also be applied when discussing combining data and information.

INTUITIVE: Exhibiting the capability of immediate comprehension or cognition.

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

MINIMUM RESOLVABLE TEMPERATURE DIFFERENCE (MRTD): A measure for assessing the performance of infrared cameras.

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 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.

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 should provide full time attitude, altitude and airspeed information; an immediately discernible attitude recognition capability; unusual attitude recovery capability; and complete fault indications.

REGISTERED: In the case of imagery, multiple images or sources aligned to one another within specified bounds with respect to angle (e.g., ± 10 min of arc) and scale (e.g., $\pm 2\%$). With respect to navigation, the image would be registered to a position in space and point of regard; with position/location based on common reference system.

REQUIRED NAVIGATION PERFORMANCE (RNP): A statement of the navigation performance necessary for operation within a defined airspace (Adapted from ICAO - IS&RP 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 ± 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)

- a. 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.
- b. 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.
- c. 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, and spatial orientation.

SUBJECTIVE WORKLOAD ASSESSMENT TECHNIQUE (SWAT): Postulates a multidimensional model of workload comprising three, three-point dimensions or factors: (1) time load, (2) mental effort load and (3) psychological stress load.

SYNTHETIC VISION: A computer-generated image of the external scene topography from the perspective of the flight deck that is derived from aircraft attitude, high-precision navigation solution, and database of terrain, obstacles and relevant cultural features.

SYNTHETIC VISION SYSTEM: An electronic means to display a synthetic vision image of the external scene topography to the flight crew. (14 CFR part 1.1 Definitions)

TLOF: Vertical flight capable platform (rotorcraft/powered lift vehicle) Touchdown and Liftoff Area.

TLX: NASA Task Loading Index; subjective workload assessment tool, using subscales including Mental Demands, Physical Demands, Temporal Demands, Own Performance, Effort and Frustration.

TOTAL SYSTEM LATENCY: Elapsed time from the start of collection and / or processing of frame relevant information to final rendering of the respective frame on the display. No value added to define unit of time.

UNUSUAL ATTITUDE/UPSET: Any unintentional, unanticipated or extreme aircraft attitude.

2.5 Acronyms and Abbreviations

ADI	Attitude Director Indicator
AGL	Above Ground Level
ANP	Actual Navigation Performance
AMS	Air Medical Services
ARP	Aerospace Recommended Practice
CDI	Course Deviation Indicator
CFR	Code of Federal Regulations
CRM	Crew Resource Management
CVS	Combined Vision System
DGPS	Differential Global Positioning System
DMS	Digital Map System
DVE	Degraded Visual Environment
EFB	Electronic Flight Bag
EFIS	Electronic Flight Information System
EFVS	Enhanced Flight Vision System
ESVS	Enhanced/Synthetic Vision System
EVS	Enhanced Vision System
FAA	Federal Aviation Administration
FTE	Flight Technical Error
FOV	Field of View
FOR	Field of Regard
FPV	Flight Path Vector
FPM	Flight Path Marker
HDD	Head Down Display