

**(R) Human Engineering Considerations in the
Application of Color to Electronic Aircraft Displays**

RATIONALE

The use color content as both a tool to increase situation awareness and as a sole information discriminator display has increased and will continue to increase. Correct implementation of these applications of displays is essential and critical to safe flight display applications.

SAE G-10 Aerospace Behavioral Engineering Technology Committee, specifically the G-10D Color Subcommittee, has been tasked to update this Aerospace Recommended Practice to provide current document color use guidance to implement increased use of color when used in and on flight decks and cockpits.

FOREWORD

While old generations of civil or military aircraft only had a limited number of colors, the newer glass cockpit generations started to use color in a far more extensive way than simply providing alerting information. The initial goal of ARP4032 was to issue recommendations on the use of colors for flight deck displays that, at the time, were mainly related to symbology color coding issues.

Currently the role of color in the flight deck/cockpit is expanding again far beyond coding symbolic information (alphanumeric, scale, graduations) or even larger areas, as display background or sky and ground in the primary flight display (PFD) or terrain and flight path data on navigation display (ND) including other multifunction displays such as electronic flight bags (EFB), EICAS and CDU data entry (see Acronyms List).

New features of modern cockpit are now including the need to displaying large color fields for a number of applications such as charting, terrain awareness and weather information products including own-ship weather radar, satellite weather data, etc. In turn, new considerations have to be taken into account as the use and the number of colors for coding large fields, cultural aspects of color and color "affordance" for representing information and environment with large fields; non coding use of color for large fields, color contrast for symbology overlaid on large field, etc. Additionally, attributes such as the level of transparency of the color used to code information in large fields needs to be considered. It is also necessary to review the integration of multiple color display features and intermixability, understood as resolution of the differences in the characteristics of the display hardware, or compatibility of displays from different manufacturers.

The goal of this document is not only to update the recommendations of the Initial ARP4032, but intends to address new considerations about the use of colors in modern flight deck design and practice.

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ACKNOWLEDGEMENT

The following document was a collaborative effort of many dedicated and experienced individuals who provided the perspective from a representative cross section of the international aerospace industry. Their efforts and contributions have resulted in a document that considers flight crew performance issues and implementation, certification and operational limitations and constraints. The following individuals and organizations have contributed directly to the development of this document.

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

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1. SCOPE

This document is intended for the application of color to cathode-ray-tube (CRT) displays, liquid crystal displays (LCD) and other types of display technologies such as projection displays. Emerging color display technologies other than those noted above, may not be adequately covered by these recommendations.

Color recommendations will not address Night Vision Devices (NVD), Head-Up Displays (HUD) or Head or Helmet Mounted Displays (HMD).

This document is applicable to aircraft as understood in 14 CFR Parts 23, Part 25, Part 27 and Part 29, and EASA CS-23, CS-25, CS-27 and CS-29 certification standards.

1.1 Purpose

This document makes recommendations concerning human factors issues in the application of color to flight deck display systems.

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 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.

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
ARP4033	Pilot-System Integration
ARP4102	Flight Deck Panels, Controls, and Displays
ARP4102/4	Flight Deck Alerting System (FAS)
ARP4102/7	Electronic Displays
ARP4102/7	Appendix A – Electronic Display Symbolology for EADI/PFD
ARP4102/7	Appendix B – Electronic Display Symbolology for EHSI/ND
ARP4102/7	Appendix C – Electronic Display Symbolology for Engine Displays

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 Electronic Flat Panel Displays
ARP5119	Location of and Display Symbology Requirements for Head-Down Electronic Flight Displays for Steep IMC Approaches
ARP5289	Electronic Aeronautical Symbols
ARP5364	Human Factor Considerations in the Design of Multifunction Display Systems for Civil Aircraft
AS8034B	Minimum Performance Standard for Airborne Multipurpose Electronic Displays

2.1.2 FAA Publications

Available from Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC 20591, Tel: 866-835-5322, www.faa.gov.

14 CFR 23	Airworthiness Standards: Normal, Utility, Acrobatic and Commuter Category Airplanes
14 CFR 25	Airworthiness Standards: Transport Category Airplanes
14 CFR 27	Airworthiness Standards: Normal Category Rotorcraft
14 CFR 29	Airworthiness Standards: Transport Category Rotorcraft
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 25-11A	Transport Category Airplane Electronic Display Systems
AC-25-11A	Electronic Flight Deck Displays, June 21, 2007
AC-25.773-1	Pilot Compartment View Design Considerations, January 8, 1993
AC-25.1309-1A	System Design and Analysis, June 21, 1988
AC-27-1B	Certification of Normal Category Rotorcraft
AC-29-2C	Certification of Transport Category Rotorcraft, FAA AC-29-2C

2.1.3 EASA Publications

Available from European Aviation Safety Agency, Postfach 10 12 53, D-50452 Koeln, Germany, Tel: +49-221-8999-000, www.easa.eu.int.

AMC 23	"Acceptable Means of Compliance," Certification Specifications for Normal Category Aeroplanes
AMC 25	"Acceptable Means of Compliance," Certification Specifications for Large [Turbine Powered] Aeroplanes
AMC 27	"Acceptable Means of Compliance," Certification Specifications for Small Rotorcraft

AMC 29	"Acceptable Means of Compliance," Certification Specifications for Large Rotorcraft
CS 23	Certification Specifications for Normal, Utility, Acrobatic and Commuter Category Aeroplanes
CS 25	Certification Specifications for Large [Turbine Powered] Aeroplanes
CS 27	Certification of Small Rotorcraft
CS-29	Certification of Large Rotorcraft

2.1.4 Other

Engineering Data Compendium, Human Perception and Performance, Edited by Kenneth R. Boff and Janet E. Lincoln, 1988.

CIE 2001 report, Commission Internationale de L'Eclairage (CIE), 2001, Improvement to Industrial Colour-Difference Evaluation, Technical Report CIE 142-2001, Vienna, Austria.

CIE 2001, Commission Internationale de L'Eclairage (CIE), 2001, International Recommendations for Colour Vision Requirements for Transport, Technical Report CIE 143-2001, Vienna, Austria.

CIE Publication No. 15.2 (1986), Colorimetry, 2nd Edition.

Farrell, R.J. and Booth J.M., 1984, Design Handbook for Imagery Interpretation Equipment, Boeing Aerospace Company, Seattle, Washington 98124.

Gannon, A., 2010, Flightdeck Aesthetics and Pilot Performance: New Uncharted Seas. In *Handbook of Aviation Human Factors 2nd Edition*.

Widdel, H. and Post, D., 1992, Color in Electronic Displays, Defense Research Series, Plenum Press, New York.

ISO/FDIS 9241-8.2, Ergonomic requirements for office work with visual display units (VDTs) – Part 8: Requirements for displayed colors.

NATO RTO TR-016 / HFM-012, Operational Color Vision in the Modern Aviation Environment 2001.

Stokes, Kite and Wickens, 1990, Display Technology Human Factors Concepts, SAE International, Warrendale, PA.

Wise, J.A., Hopkin, V.D., and Garland, D.J. (Eds.), 2010, *Handbook of Aviation Human Factors 2nd Edition*, Boca Raton, FL, CRC Press LLC.

2.2 Definition of Terms

Definitions used in this document shall be as noted in the Glossary of Terms defined in Appendix E.

The word "shall" is used to express an essential requirement where compliance is mandatory.

The word "should" is used to express a recommendation. Deviation from the specified recommendation shall require justification.

The word "must" is used to express an essential (mandatory) requirement that is required by a specific regulation.

2.3 Acronyms and Abbreviations

AC	Advisory Circular (FAA)
ADI	Attitude Director Indicator
AMC	Acceptable Means of Compliance (EASA)
ANP	Actual Navigation Performance
CDI	Course Deviation Indicator
CDU	Control Display Unit
CS	Certification Standards (EASA)
DEP	Design Eye Position
DERP	Recommend not using – Design Eye Reference Position
DGPS	Differential Global Positioning System
DMS	Digital Map System
EICAS	Engine Instrument Crew Alerting System
EFB	Electronic Flight Bag
EFIS	Electronic Flight Information System
ERP	Eye Reference Position
ESVS	Enhanced/Synthetic Vision System
EVS	Enhanced Vision System
FAR	Federal Aviation Regulations
FTE	Flight Technical Error
FOV	Field of View
FPV	Flight Path Vector
FPM	Flight Path Marker
HDD	Head Down Display
HMD	Head Mounted Display/Helmet Mounted Display
HUD	Head Up Display
JAR	Joint Airworthiness Regulations (JAA)
PFG	Perspective Flight Guidance

PFGD	Perspective Flight Guidance Display
PFD	Primary Flight Display
PF	Pilot Flying
PNF	Pilot Not Flying
QFPV	Quickened Flight Path vector
SVS	Synthetic Vision System
TCAS	Traffic Alerting and Collision Avoidance System

3. ASSUMPTIONS

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

- 3.1 Color will be used increasingly on all applicable displays and used for all phases of flight and lighting conditions throughout the day and night spectrum.
- 3.2 The pilot population does not exhibit uniformity of color vision. All types of color deficiencies are taken into account.

4. USES FOR COLOR

While most pilot certification standards include a requirement for some level of color vision in the applicant, color deficient users still need to be considered in the selection and use of color in aviation displays. First, there is no inherent need for color vision in the act of flying. Color requirements for all medical certification classes are based on the need to distinguish aviation light gun signals not a basic task need. The preamble to CAR 29, amendment 29-2¹, states that “a pilot who is unable to meet the color vision requirements in any way may be authorized to fly only with two-way radio communications available or under conditions where aviation lights would not be used for communication.”

Because color, perhaps more than any other coding technique, enjoys such an undeserved reputation for ease of interpretation, the designer needs to understand the difference between absolute versus relative discrimination of colors and what it means to the application of color as a code.

Relative discrimination indicates that if two colors are placed next to each other it is possible to tell that they are different. Absolute discrimination means that every time a particular color is presented the person observing it gives it exactly the same name or meaning, e.g., danger. The number of colors that are relatively discriminable is extremely high. The number of colors that are absolutely discriminable is in the order of eight to twelve colors.

The automotive industry has defined areas on the CIE Chromaticity chart where, for example, a certain proportion of observers call a color “red” These are elliptical contours on the chart showing 90%, 95%, etc. This research needs to be replicated for the flight crew population. The conclusion in RTO-TR-016 that all color specifications be stated in terms of the CIE coordinate system should be considered. It can be observed that the FARs do this for wingtip navigation lights, but for no other color use.

¹ “Color Vision, Near Vision, and Blood Pressure Requirements for Airmen,” Civil Air Regulations Amendment 29-2 to C.A.R. 29, “Physical Standards for Airmen; Medical Certificates,” adopted February 13, 1951.

4.1 Attention-Getting and Alerting

4.1.1 Considerations

Color has been shown to be a practical means of alerting or drawing attention to specific information when applied within appropriate constraints (e.g., the color is in the observer's color sensitive field-of-view). Use of color alone as an alerting device is also affected by the associated background of similar color or contrast or separate displayed information of the same color and must be differentiated. A specific color maintains its attention-getting value only if it is used sparingly and consistently within cultural paradigms.

It may be difficult to discriminate between two similar-appearing colors such as yellow and amber. This is especially true when displayed on a multi-color displays under variant shifting ambient light conditions (see Farrell & Booth, 1984, and Boff & Lincoln, Engineering Data Compendium, 1988) and different viewing angles, e.g., cross cockpit.

The use of similar-appearing colors (proximate to each other in color space) either successively or simultaneously, on the same display may lead to a loss of attention-getting value as well as color confusions. These problems are more apt to occur when high ambient illumination falls on the display. This causes displayed color to become less saturated thereby reducing color differences. This effect of ambient illumination may become less serious for some color display technologies (e.g., LCDs) that may have a larger color gamut and be less susceptible to color shifts under ambient illumination. See the graphics of color confusion lines in Appendix C.

Forward field illumination levels need to be considered as they influence the perception of color. At the lower levels of forward field illumination the pilots will dim the displays to match. Crews will transition from daylight adapted, rods, color perception capabilities to dark adapted, cones, color perception capabilities. At the higher end of forward field illumination reflections off the display will de-saturate the colors. Also because of these reflections the luminance contrast of the displays is also decreased making the display less readable.

It should be noted that the attention-getting value of color is apt to be reduced for pilots with color vision deficiencies (see 3.4 and Section 9).

4.1.2 Recommendations

4.1.2.1 Small Field (such as symbology, alpha-numerics) traditional warning and cautionary colors (red and amber or yellow) should be reserved solely for this purpose, as the use of these colors for other functions will degrade their alerting value.

4.1.2.2 Large Field colors normally used for small field alerting (red and amber or yellow) may be used and should be addressed based on purpose. See Section 7.

4.1.2.3 A single display device should not employ colors that are closely spaced on a chromaticity diagram as these will appear similar and be difficult to discriminate (see Appendix C for example of a chromaticity diagram).

If closely spaced colors such as yellow and amber are employed, the ability to discriminate among the colors under all ambient conditions and viewing angles, as well as the maintenance of attention-getting value, should be demonstrated empirically.

4.1.2.4 For critical displays and alerting functions, color coding shall be redundant and supported by other visual or auditory information coding methods.

4.2 De-Cluttering

4.2.1 Considerations

Color can serve to group or organize information. This allows information to be transmitted more efficiently as long as the number of colors used for this purpose is limited. A large number of colors may actually be counter-productive to organizing information.