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HUMAN INTERFACE CRITERIA FOR COLLISION AVOIDANCE SYSTEMS IN TRANSPORT AIRCRAFT

1. PURPOSE AND SCOPE:

This document sets forth design and operational recommendations concerning the human factors issues and criteria for airborne collision and avoidance systems. The visual and aural characteristics are covered for the display of traffic information as well as the escape maneuver display on conventional and electronic flight decks. System utilization philosophy and flight deck integration considerations are also presented.

2. REFERENCES:

2.1 Applicable Documents:

AS264 - Instrument and Cockpit Lighting for Commercial Transport Aircraft
ARP268 - Location and Actuation of Flight Deck Controls for Transport Aircraft
AS425 - Nomenclature and Abbreviations for Use on the Flight Deck
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
ARP1093 - Numeral, Letter and Symbol Dimensions for Aircraft Instrument Displays
AS8034 - Minimum Performance Standard for Airborne Multipurpose Electronic Displays
FAA-RD-81-38II - Aircraft Alerting System Standardization Study, Volume II Aircraft Alerting System Design Guidelines

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2.2 Proposed Applicable Documents:

ARP1782 - Color and Light Intensity Measurements for Direct View CRT
ARP4032 - Human Integration for Color Criteria and Standards
ARP4102/4 - Flight Deck Alerting Systems
ARP4102/10 - Collision Avoidance System

3. DEFINITIONS:

This section contains definitions of terms used in this document.

Advisory System - A system that supplies the crew with information and guidance that they can follow only if they have other reasons that reinforce such information and guidance.

Alert - Indicator (visual, auditory or tactile) which provides information to the crew in a timely manner about a non-normal situation.

Bearing - The angle, in the horizontal plane, between the longitudinal axis of the own aircraft and the relative location of an intruder aircraft measured in the clockwise direction when viewed from above.

CAS - Collision Avoidance System.

Caution Alert - Abnormal operational or aircraft system condition that requires immediate crew awareness and subsequent corrective or compensatory crew action.

Corrective Alert - Alert which requires a positive corrective action to resolve a conflict situation.

CPA - Closest point of approach of two aircraft in conflict.

Escape Maneuver - A computed maneuver to prevent a potential collision. It can be any single or combination of maneuvers which resolve a conflict.

Executive System - A system that supplies the crew with guidance that they are required to follow unless they have good reason to believe it should be ignored.

False Alert - An alert, caused by a false track or a system malfunction, that is given when no threat exists in the TCAS operational envelope.

Intruder - Any aircraft in the airspace of the own aircraft that is tracked by the collision avoidance system (including all threat aircraft).

Missed Alert - A system alert which is not given even though an aircraft is in the TCAS operational envelope and the threat of collision or potential collision exists.

Negative Alert - A corrective or preventive alert that requires the pilot not to do something to resolve a conflict (for example, "DON'T CLIMB").

3. DEFINITIONS: (Continued)

Nuisance Alert - An alert that is given when an aircraft is in the TCAS operational envelope and a maneuver by the TCAS aircraft is not necessary to achieve satisfactory aircraft separation.

Own Aircraft - The CAS-equipped reference aircraft.

Preventive Alert - An alert which provides the crew an escape maneuver (usually a vertical speed limit or a negative command) for which, because of their current flight path, they do not need to respond, for example, a "LIMIT CLIMB 500 fpm" alert when the aircraft is in level flight.

Resolution Advisory - Term used with the TCAS system for the display indication given to the crew recommending an escape maneuver to increase or maintain separation relative to an intruder aircraft.

TAU - A derived quantity, usually expressed in seconds, which represents the time to the point of closest approach between the own and intruder aircraft. It is defined as the range divided by the range rate.

TCAS - Traffic Alert and Collision Avoidance System

TCAS Invalid - A TCAS system alert that indicates that the Resolution Advisory, to which the crew is currently responding, is no longer a valid advisory.

TCAS Operational Envelope - The geometry of two or more aircraft (that is, altitude, speed, range, range rate, altitude rate, etc.) which is defined as a collision threat by the collision avoidance logic and causes an alert to be issued.

Threat Aircraft - An intruder that has been determined by the CAS threat detection logic to warrant either a caution or a warning alert.

Time Critical Warning - A warning condition in which the time to respond is extremely limited and the response to the alert is the most important action that the crew can take at that specific time (for example, ground proximity, windshear, collision avoidance).

Traffic Advisory - Term used with the TCAS system for the display indication that there is a traffic situation that could subsequently require a resolution advisory. The information contains no suggested maneuver.

Warning Alert - Emergency operational or aircraft system conditions that require immediate corrective or compensatory action by the crew.

4. FUNCTIONAL REQUIREMENTS OF A CAS SYSTEM:

The requirements for a universal collision avoidance system include:

a) The system must be integrated and compatible with the existing ground-based Air Traffic Control (ATC) system;

b) The system must be capable of issuing traffic alerts and escape maneuvers in all weather conditions;

c) Protection must be offered in all airspace, including airspace not covered by ground-based primary or secondary ATC radar systems;

d) The elements comprising the system must interface with each other and where appropriate with other elements on the flight deck and must operate in a compatible and mutually supportive manner;

e) The system should not generate a large number of nuisance alerts (alerts occurring when no unsafe events have occurred or will occur);

f) The system should not miss alerts or fail to provide adequate warnings for potentially dangerous threats;

g) The system must be capable of resolving encounters involving more than two aircraft;

h) Protection must be available to the first user who purchases the equipment;

i) The system must accommodate realistic operator performance (including requiring maneuvers consistent with what a prudent pilot would perform) in terms of response times and potential errors;

j) If system effectiveness changes during operation, the system should be most effective in areas of greatest threat such as the terminal area;

k) The logic should be able to handle conflicts if either aircraft is maneuvering.

The system, if it is stand alone, should also be capable of performing the following functions allocated to alerting systems:

a) Attracting the attention of the crew and directing that attention to the alerting condition so that corrective action can be taken;

b) Informing the crew of the nature of the condition;

c) Providing some guidance for the correct response; and

d) Providing the crew feedback on the adequacy of their corrective action.

5. DESIGN OBJECTIVES:

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

a) Simplify operations;

b) Facilitate error-free operation;

c) Maximize crew situational awareness;

d) Minimize head down operation;

e) Provide consistency of operation for common functions;

f) Promote timely and accurate operations;

g) Ensure legibility of legends and displays throughout the wide range of flight deck ambient lighting conditions;

h) Ensure that system failures do not degrade operational capability of other systems with which it interacts;

i) Ensure intelligibility of computer generated voice messages throughout the wide range of flight deck ambient noise conditions, concurrent speech messages and other aural signals;

j) Provide for information redundancy to assist pilot verification and error detection.

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.

6. UTILIZATION PHILOSOPHY:

In order to define what information the crew needs and the way in which that information should be presented, the overall objective of the system should be identified along with its utilization philosophy (that is, how it will accomplish its objectives).

6.1 Visual Acquisition: Since one of the system requirements is operation in all weather conditions, in worst case, the crew may be required to respond to a collision avoidance situation without visually acquiring the threat aircraft. Therefore, the information provided by the system should enable the crew to respond in the prescribed manner and should not promote incorrect or unproductive response patterns when visual acquisition is not achieved.

6.2 Response Urgency: The urgency of an alerting situation is usually determined by the amount of time the crew has to respond to the situation. The less time that the crew has to respond, the more the system should help in determining what response should be made. These time constraints impact how the system is used, especially at the most urgent levels. The overall time budget for the crew/aircraft system to respond to a collision avoidance alert is of critical importance. The alert should be sufficiently attention-getting to assure situational awareness by the crew in time to develop an appropriate mental set. The alert should be given in sufficient time for the crew to respond by maneuvering the aircraft to achieve the necessary miss distance. The assumption that should be made when designing a system around a very short pilot response time is that it is an executive system requiring immediate crew action rather than an advisory system.

6.3 Nuisance Alerts and False Alarms: The number of unnecessary and/or incorrect alerts have a direct impact on the usefulness of the system because they affect the pilot's perception of and confidence in the information that the system presents.

6.3.1 False alarms and missed alerts should be eliminated.

6.3.2 The effect of nuisance alerts on the crew is dependent on the urgency of the alert and the expected crew response to the alert. Corrective escape maneuvers can be classified as time-critical alerts and, therefore, nuisance alerts (that is, conflicts resolved by normal operations such as leveling at an assigned altitude or turning to a parallel runway) should be minimized.

6.3.3 Research has shown that ideally there should be no more than one nuisance alert for every ten real ones. Previous work with time-critical alerting systems (for example, windshear) has indicated that the minimum acceptable ratio between nuisance and true time-critical warnings is approximately 1:1. This value promotes pilot confidence in the system.

6.3.4 It should be noted that information provided by nuisance alerts is at times considered useful by the pilots and a way should be identified to provide the same information without using the alert. This is also true of nuisances for caution level alerts. Even though pilots are more tolerant of these types of alerts, evidence indicates that using the same alert for normal and non-normal situations increases the probability of error (for example, the altitude alert).

7. FLIGHT DECK INTEGRATION:

Integration of the control and display components of a collision avoidance system into the flight deck should include (but not be limited to) considerations of: system type; flight deck geometry; information requirements; interaction with other aircraft systems; and the technology of the target flight deck. The standardization fundamentals recommended in the FAA alerting system design guidelines and in ARP4102/4 should be applied to the CAS displays and controls in order to promote a consistent implementation philosophy on the flight deck. For those flight decks that employ an integrated alerting system, the collision avoidance information should be operationally integrated into that system. For retrofit application, the principles set forth in the above documents should be used wherever possible to design the displays and controls.

8. PILOT INTERFACE:

8.1 General: Decisions about the type, number and location of the displays for effective information presentation should be based not only on how the system will be used, but also on the geometry of the flight deck and the available technology. Such variables as crew coordination, operational procedures and crew complement will dictate the number of displays and have an effect on the design of the display and control components. Displays and controls should be located within the appropriate visual angles and reach envelopes and so there is no sight line interference from the design eye reference point.

8.2 Alert Urgency: In general, CAS alerts fall into one of two categories: they require immediate action (time-critical warning); or they require immediate attention (caution). All corrective evasive maneuvers should be presented as warning alerts. All preventive and traffic alerts should be presented as caution alerts. Negative alerts should not be used regardless of the urgency category.

8.3 Displays: Potential system display components should include: master visual alerts; master aural alerts; an escape maneuver display; voice alerts; and a traffic information display.

8.3.1 Master Visual Display:

8.3.1.1 A master visual display should be used to attract the attention of the crew and to give them preliminary information about the urgency of the situation.

8.3.1.2 Two master visual alerts should be provided, one for warnings and one for cautions.

8.3.1.3 Master visual alerts should be located within fifteen degrees of each pilot's centerline of vision (both head up and head down).

8.3.1.4 The onset of the master visual alert should occur simultaneously with the onset of the master aural alert and no more than 0.5 seconds after the system sensors detect the alerting situation. The alert should remain on until it is cancelled by the pilot or until the problem has been corrected. Upon cancellation, the master alert should reset and be capable of announcing a new situation.

8.3.1.5 The master visual alert should be bright enough to attract the crew's attention. The range of brightness should provide sufficient contrast in both high and low ambient lighting conditions and should adjust automatically. The display should not be capable of dimming below 15 ± 3 ft-L.

8.3.1.6 The master visual alert should subtend at least one square degree of visual angle.

8.3.2 Master Aural Alert:

8.3.2.1 A master aural or voice alert should be used to attract the crew's attention and give preliminary information about the urgency of the situation.

8.3.2.2 When master aural alerts are used, a unique sound should be used for each level of urgency. If the CAS alerts are being implemented into an integrated alerting system, the warning and caution sounds of that system should be used.

8.3.2.3 The frequency of the alerting sounds should be between 250 and 4000 Hz. However, because of the potential hearing loss due to the age of senior crew members, a more preferable range would be 500 - 3000 Hz. High urgency signals should be composed of at least two widely spaced frequencies. Frequencies should be chosen to differ from those that dominate the ambient noise.

8.3.2.4 The first presentation of master aural and voice alerts should exceed masked threshold by at least 8 ± 3 dB with a dynamic automatic gain control to maintain this approximate signal-to-noise ratio. Subsequent presentations should be 12 ± 3 dB with a maximum of 105 dB SPL.

8.3.2.5 If a master aural is used with the voice alert, the duration of the sound should vary depending on the urgency of the alert. For the corrective alerts, the alerting sound should occur for a maximum of 0.75 seconds and be followed by the appropriate voice message. The off time between the sound and the voice message should be no less than 0.5 seconds and no more than 0.7 seconds. For caution level alerts, the sound should last 1.2 to 2 seconds and be repeated every 8 to 10 seconds until the pilot cancels the alert or the traffic is no longer a threat.

8.3.2.6 The sound source should be perceptually separated in space by at least 90 degrees from competing sound sources.