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Human Interface Criteria for Terrain Separation Assurance Display Technology

RATIONALE

This document has been reaffirmed to comply with the SAE 5-year Review policy.

1. SCOPE:

This document sets forth design and operational recommendations concerning the human factors issues and criteria for airborne terrain separation assurance systems. The visual and aural characteristics are covered for both the alerting components and terrain depiction/situation components. The display system may contain any one or a combination of these components. Although the system functionality assumed for this document exemplifies commercial aircraft implementation, the recommendations do not exclude other fixed wing aircraft types. Because of their unique operations with respect to terrain, rotorcraft will be addressed in a separate document.

The assumptions about the system that guided and bounded the recommendations included: the system will have a human centered design based on the "lessons learned" from past systems; the system is not intended to replace the Ground Proximity Warning System (GPWS) function; the system is an on-board system that is not dependent on ground systems (except possibly navigation sensors) for operation; the system is intended to be used for terrain separation rather than navigation; there will be pilot in the loop/manual involvement in any flight path changes; information will be accessible by all flight crew members; the system will be based on the English language, but other languages may have to be considered; the system will address all fixed wing airplane types; the system will be operational full time in all flight phases; and the system will meet harmonized certification requirements.

2. REFERENCES:

The documents listed in 2.1 are referenced for guidance in this document. The documents listed in 2.2 are provided for information purposes only and do not form a part of the recommendations of this document. A bibliography of literature relevant to this document is presented in 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, 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
AS425	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
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
ARP4107	Aerospace Glossary for Human Factors Engineers
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, etc. al., 1981)
DOT/FAA/PS-89/1	Flight Status Monitor Design Guidelines (Anderson et al., 1989)
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

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

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

AIRPLANE STATE: Conditions of the airplane that include speed, flight path vector, attitude (pitch and roll), and horizontal track.

AIRSPACE: The atmosphere in which aircraft operate, extending upwards from the surface of the earth.

AIRWORTHY: In a condition suitable for safe flight

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

AURAL ALERT: Discrete tone/sound used for attention getting.

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

CFIT: 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.

3. (Continued):

CFTT: Incidents in which an aircraft under control of a flight crew is unintentionally flown toward terrain, obstacles, or water with awareness on the part of the flight crew coming in sufficient time to prevent an accident.

CULTURAL FEATURES: Man made features of the terrain.

ESCAPE MANEUVER: Aircraft maneuver performed to resolve a time critical conflict with the terrain and to ensure safe separation.

FALSE ALARM: An alert that occurs in a situation for which the system design should not have presented an alert.

LATE ALERT: An alert that does not provide the crew with sufficient time to respond successfully.

MISSED ALERT: The absence of an alert in a situation for which the system was designed to provide an alert.

PICTORIAL INFORMATION: Presentation of information in a form other than alphanumerically.

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., switching a shared display to terrain information when there is a caution level terrain conflict alert).

PRIMARY FLIGHT DISPLAY (PFD): An electronic display which provides the basic "T" including information and warnings pertinent to navigation and fundamental control of flight.

NUISANCE ALERT: An alert that, while occurring as intended in the system design, was not appropriate in the specific situation for which it occurred.

TERRAIN: Stationary obstacles including both ground and cultural features.

TERRAIN DATABASE: Computer storage of a representation of terrain.

TIME-CRITICAL WARNING: Non-normal operational or aircraft system conditions that require unconditionally immediate corrective or compensatory crew action usually involving the flight path of the airplane.

VISUAL ALERT: Discrete alphanumeric/light used for attention getting.

VOICE ALERT: Auditory property of voice messages that get the attention of the flight crew.

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

WARNING: Non-normal operational or aircraft system condition that requires immediate corrective or compensatory crew action after considering ensuring the required flight path.

4. SYSTEM FUNCTIONALITY - POTENTIAL FUNCTIONS:

The system's operation can be segmented into five functional areas: Sensing and Estimation, Conflict Detection, Crew Alerting, Information Transmission, Self-Diagnostics and Conflict Analysis.

4.1 Sensing and Estimation:

In order to determine whether a terrain alert is necessary, the system should have access to information related to the state of the aircraft and its proximity to 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 is an outline of the types of information that could be used.

4.1.1 3D Position of Aircraft Relative to Terrain: An estimate of the spatial proximity of the aircraft to the terrain is necessary. This estimate may be obtained from an onboard sensor directly providing relative range to terrain and/or from a correlation between aircraft position and a terrain database. The accuracy of the position estimate should be high enough relative to the terrain database resolution that the uncertainty in terrain proximity does not result in an unacceptable rate of nuisance alerts or late alerts.

4.1.2 Aircraft State: In addition to proximity information, additional state information is required to determine whether the projected flight path may impact terrain. This state information includes aircraft speed, attitude, horizontal track, and vertical flight path. The uncertainty of these state estimates should be controlled to prevent an unacceptable rate of nuisance alerts or late alerts.

4.1.3 Aircraft Capability/Performance: Information about aircraft performance should be available to the system in order to determine when an alert or escape maneuver should be issued based on the airplane performance capability and current state data.

4.1.4 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.

4.1.5 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 with which the alerting system operates. The definitions of the phases of flight, relationship to the runway and the permitted separation criteria (e.g., arrival segment - 1000 ft, intermediate segment - 500 ft, and final approach segment - 250 ft) should be specified.

4.1.6 Intended Flight Path: The ability to have access to a Flight Management System (FMS) flight plan or other intended flight path information may be very useful. 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 entire intended flight path for terrain obstacles before the plan is executed. In a second mode, knowledge that the aircraft will be turning, climbing, and descending at a given waypoint can be used to reduce the probability of nuisance alerts that would have been produced without the intent information. Overreliance on intent information may result in nuisance alerts or late alerts if the aircraft deviates from the intended flight path.

4.1.7 Runway Location: Each flight must end with controlled flight onto terrain as the plane lands on a runway. The ability should be provided by the system to alert in cases of descent short of the intended landing runway without producing nuisance alerts when performing normal landings. Runway information may be obtained through position information and a runway data base or by using an active sensor on the aircraft that identifies the runway.

4.2 Conflict Detection:

The system should be able to detect a potential conflict with terrain. This decision is based on the information obtained through the Sensing and Estimation Function: proximity and trends toward terrain, aircraft performance, and estimates of the aircraft's intentions. The decision that a situation is a conflict should carefully balance safety against nuisance alerts. The system should not issue an alert when published procedures are being followed. This can be accomplished by examining a wide variety of terrain encounters. Both flight toward rugged terrain and descent into flat terrain (land or water) should be considered.

4.3 Crew Alerting:

Once a conflict has been detected, the system should alert the flight crew to that fact. Alerting should include aural and visual components. The system should be able to determine the urgency of a terrain situation and alerts should be designed to allow the crew to understand this urgency in an unambiguous manner. Typically, this involves a succession of alerts from the initial caution information through warning and time critical alerts.

4.4 Information Transmission:

In addition to an alerting function, the system may have a function that allows the flight crew to obtain more detailed information. This information can be separated into Terrain Awareness and Terrain Avoidance categories.

4.4.1 Terrain Awareness: The system could enhance the crew's situation awareness by allowing them to view relevant terrain features. In order to accomplish this, the aircraft's location (in all dimensions) relative to terrain should be able to be displayed. Terrain altitudes should be able to be determined through altitude coding of terrain information. Altitude coding may use a scale that is relative to the aircraft's altitude or that is referenced to mean sea level. The crew should be provided sufficient information to accurately anticipate conflict situations.

4.4.2 Terrain Avoidance: When a conflict is detected and an alert is used, additional resolution information may be needed. This may be in the form of a caution (e.g., 'Terrain'), an open-loop command (e.g., 'Pull-Up'), or closed-loop command guidance (e.g., flight director bars). Conflicts may be resolved through a vertical or lateral (or combination) maneuver. The Terrain Awareness System should provide clear information to the crew of what type of maneuver to perform (either through training or via information provided from the terrain system). The system should provide a means to indicate when the alerting situation no longer exists.

4.5 Self-Diagnostics:

The system should detect and communicate failures in its operation. The system can be designed without redundant components or to be fail-operational. In either case, any failure should be detected and communicated to the flight crew. Means should be provided to detect database errors in order to update terrain databases as required to improve system performance.

4.6 Conflict Analysis:

The system should provide a means for post flight analysis of terrain conflict situations.

5. DESIGN OBJECTIVES:

The control and display equipment for the terrain separation assurance 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:

a. Simplify operations;
b. Facilitate error-free operation;
c. Maximize crew situation awareness;
d. Minimize head down operation;
e. Provide consistency of operation for common functions;
f. Promote timely and accurate operation;
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 the operational capability of other systems with which they interact;
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 the crew in verification and error detection;
k. Minimize nuisance alerts;
l. Permit conflict analysis.

These 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 Generating Appropriate Response:

Since one of the system requirements is full time operation during all flight phases and in all visibility conditions, in the worst case, the crew may be required to respond to a terrain conflict situation without seeing the threat terrain or other terrain in the area. 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 either when the terrain is not physically visible or when it is visible.

6.2 Response Urgency:

The urgency of a terrain conflict situation is usually determined by the amount of time that the crew has to respond to the situation. The less time the crew has to respond, the more the system should help in determining what response should be made. These time constraints have an influence on how the system is used, especially at the most urgent levels. The overall time budget for the crew/aircraft system to respond to a terrain conflict situation is of critical importance. The system should provide enough information to ensure position awareness by the crew in time for them to respond by maneuvering the airplane to achieve the necessary terrain clearance. Because of the wide range of potential airplane/terrain geometries, the system should be able to accommodate situations with both long and very short response time requirements. The assumption that should be made when designing a system around a very short pilot response time is that a portion of the system will have to be executive in nature (tell the pilots what response to make and expect them to make it). The system should be designed to minimize the occurrence of situations requiring very short response times.

6.3 Nuisance Alerts and False Alarms:

The number of nuisance and/or false alerts have a direct influence on the usefulness of the system because they affect the crew'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. Nuisance alerts (that is, conflicts caused by or resolved by normal operations such as leveling at assigned altitudes or circling approaches) that generate time critical terrain warnings should be minimized. The design criteria to minimize nuisance alerts should be based on the number of nuisance alerts per flight hours as well as the ratio of nuisance to real alerts.

A key parameter is defining the result of not alerting a real threat. The tension in designing the system is produced when trying to eliminate the nuisance alerts while alerting all the threat situations. This is made even more difficult because the system should account for pilot response time and the time that the maneuver will take, without having any knowledge of the crew's intensions.

6.3.3 The system should use the permitted terrain separation criteria to determine the protection that the system will provide. The navigation and other airplane systems may be used to provide positional information to identify the appropriate criteria (e.g., arrival segment 1000 ft, intermediate segment 500 ft, and final approach segment 250 ft).

6.3.4 Information provided by nuisance alerts is at times considered useful by the crew, and a way should be identified to provide the same information without using the alert. This is especially true of caution level alerts since the time to respond is much longer than that of the time-critical situations and, therefore, the number of nuisance alerts will be much higher. The information provided by the caution alert, however, is that there is potential terrain conflict if the crew intends to continue on the current flight path. Even though this information generates situation awareness and the crew is 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. CANDIDATE GRAPHIC DISPLAY CONCEPTS:

The following graphic display concepts may be used separately or in combination to provide spatial situation awareness. Each display type or combination of types has advantages and disadvantages that should be considered in the system design.

7.1 Plan View:

In a plan view display, the terrain information is presented in a planform track-up, heading-up, or north-up format. The terrain information should be coded (through alphanumerics, patterns, or color) to allow the flight crew to determine terrain separation. The terrain information should be distinguishable from other display symbology including weather radar information. The range setting of the display should be shown and some method of viewing close terrain hazards is necessary even if the display is set to a large range scale. The presentation of aircraft position on the display aids the pilot in determining proximity to terrain and in enhancing situation awareness.

7.2 Profile View:

In a profile view display, the aircraft's position and vertical flight path of the aircraft are shown relative to terrain. This path is a straight-line projection, a curved path following a projected turn, or an FMS flight plan. Issues remain regarding how the path may change as the aircraft changes autopilot modes (e.g., from Lateral Navigation (LNAV) to heading-select). The aircraft's projected trajectory should be distinguishable from terrain and vertical and horizontal scales should be used to allow the flight crew to monitor altitude relative to terrain. If the profile display has an expanded vertical scale, the display should not be used for attitude control.

7.3 Perspective View:

Terrain information on a perspective view provides an accurate representation of the outside view. The heading and pitch scales should be consistent with the scene depiction. Depth cueing should be used (e.g., reference grid or texture) to resolve the ambiguity between size and distance. Symbology should be used to aid the pilot in determining if the flight path will clear terrain with adequate margins.

8. FLIGHT DECK INTEGRATION:

Integration of the control and display components of a terrain separation assurance 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 aircraft alerting system standardization guidelines (Berson et al. 1981 and Anderson et al. 1989) should be applied to the terrain separation assurance displays and controls to promote a consistent implementation philosophy on the flight deck thus maintaining high levels of pilot performance. For those flight decks that employ an integrated alerting system, the terrain separation assurance information should be integrated into that system. For retrofit application, the principles set forth in the above document should be used wherever possible to design the displays and controls.

9. FLIGHT CREW INTERFACE CHARACTERISTICS:

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 compliment 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 appropriate visual angles and reach envelopes and so that there is no sight line interference from the design eye reference point.

In general, terrain separation system information can take a variety of forms from situation information to time-critical alerts (or combinations of information). The urgency of the information to the crew should dictate how the information is presented. Normal situation information should not use the alerting system as an attention getter. Alert urgency should be part of the information contained in the alert information. The recommendations for interface characteristics provided below were generated in FAA sponsored alerting system design guidelines development efforts (Berson et al. 1981 and Anderson et al. 1989).

9.1 Visual Alerts:

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

9.1.2 Two visual alerts should be provided for each pilot, one for warnings and one for cautions.

9.1.3 Visual alerts should be located within 15° of the pilot's centerline of vision (both head up and head down).

9.1.4 The onset of the visual alert should occur simultaneously with the aural alert and no more than 0.5 s after the system sensors/algorithms detect the alerting situation. The visual alert should remain on until it is canceled by the pilot or until the problem has been corrected. Upon cancellation, the alert should reset and be capable of announcing a new situation or a change in the urgency of the current situation.

9.1.5 The 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 be capable of dimming to a level that is consistent with other displays on the flight deck.

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

9.2 Aural Alerts:

9.2.1 An aural alert should be used to attract the crew's attention and give initial information about the urgency of the situation. Voice may be used for attracting attention in warning situations.

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

9.2.3 For optimal attention getting quality, 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 to 3000 Hz. High urgency signals should be composed of at least two widely spaced frequencies and the frequencies should be chosen to differ from those that dominate the ambient noise.

9.2.4 The first presentation of voice alerts should exceed the masking threshold of the ambient noise by at least 8 dB ± 3 dB with an automatic gain control to maintain this approximate signal-to-noise ratio.

9.2.5 If an aural sound is used with the voice message, the duration of the sound should vary depending on the urgency of the situation. For time-critical situations, the alerting sound should occur for a maximum of 0.75 s and be followed by the appropriate voice message. The off time between the sound and the voice message should be no less than 0.15 s and no more than 0.7 s. For caution level alerts, the sound should last 1.2 to 2.0 s and be repeated every 8 to 10 s until the pilot cancels the alert or the terrain conflict no longer exists. Research indicates (Berson et al. 1981 and Anderson et al. 1989) that voice messages should not be used for caution level alerts.

9.2.6 If possible, the sound source for the system should be perceptually separated in space by at least 90° from competing sound sources.

9.3 Escape Maneuver Display:

9.3.1 Any visual depiction of the terrain escape maneuver should be visible to both pilots and within 15° of their centerline of vision when head down.

9.3.2 The display should present the information pictorially if possible to minimize confusion.

9.3.3 The display should clear automatically when the alerting situation (threat) no longer exists.

9.3.4 Command Guidance: If command guidance is provided it can take one or more of the following forms:

a. Flight director bars on Primary Flight Display (PFD), Electronic Attitude Director Indicator (EADI), or Attitude Director Indicator (ADI)
b. Fly to/away from symbology on the vertical speed indicator
c. Turn director or commanded path on Electronic Horizontal Situation Indicator (EHSI)
d. Vertical flight path director on profile view

Some of these concepts are innovative and should be thoroughly studied prior to implementation. It should be obvious to the flight crews that the Command guidance is associated with the terrain alert. The Command guidance should be removed as soon as the alert condition no longer exists.

9.4 Voice Messages:

9.4.1 Automatic voice messages should be used for all time-critical threat situations.

9.4.2 Empirical testing should be performed to select the appropriate voice (male/female/computer, pitch, speed, emphasis, etc.) and to assess the intelligibility of the voice messages in the ambient speech and noise environment in which the system will be implemented.

9.4.3 Research indicates (Berson et al. 1981 and Anderson et al. 1989) that voice messages should be presented with a distinctive somewhat mechanical sounding voice quality. If a mechanical sounding voice is used, an aural alert is not recommended except where it is needed to be consistent within existing alerting systems.

9.4.4 For the time-critical escape maneuver, the essential information elements of the first repetition of the alert message should be conveyed within 2.5 s. If during the course of the escape maneuver a change (e.g., an increase in the severity of the maneuver or going from a vertical to a horizontal maneuver) becomes necessary, the essential elements of the voice message should be conveyed within 1.5 s.

9.4.5 The number of repetitions of the voice message should be kept to a minimum to reduce the potential of auditory overload. However, this recommendation should be tempered by the requirement that the crew hears and understands the message.

9.4.6 Each voice message should be unambiguous, distinctive, and unique to the specific alert and should not contain similar phraseology, which may be misinterpreted if one or more words are not heard.

9.4.7 The voice message for any specific situation should be standardized across manufacturers.

9.5 Graphic Displays:

Potential terrain displays have been categorized into two types: stand alone and shared. A stand alone display is defined as a dedicated terrain display that is not used to depict other types of information. A shared display is one in which terrain information is one of several types of information that can be depicted. Many of the recommendations are common to both types of displays (e.g., size, brightness), however, if a guideline is specific to a display type, it will be so stated.

9.5.1 Stand Alone Displays (dedicated terrain display):

9.5.1.1 Size: The display should be of sufficient size to allow unambiguous discrimination of the information presented on its surface.

9.5.1.2 Location: The display, if a single installation, should be clearly visible to both pilots when viewed from the design eye positions of both pilots. In dual installations, it is not required to have an individual display be visible to both pilots. But it should be clearly visible to the pilot for which the display is intended when viewed from the design eye position.

9.5.1.3 Brightness: The display brightness should be sufficient to provide a usable display under the maximum ambient illumination level appropriate for the location of the display. The brightness control can be automatic or manual. If a manual control is provided, it should allow the pilot to adjust the brightness to obtain usable display conditions under all illumination levels appropriate for the location of the display. If automatic brightness control is provided, it should maintain display brightness at a level to allow useful display brightness under all illumination levels appropriate for the display location.

9.5.1.4 Color: The use of color should not result in the erroneous or ambiguous interpretation of the terrain information. If colors specified in ARP4102/4 are used, color assignments to the terrain characteristics should follow ARP4102/4 requirements for the relative criticality of the terrain being displayed.

9.5.1.5 Content: The display should show only information relevant to terrain clearance for the flight path of the aircraft.

9.5.1.6 Update Rate: The display screen should refresh at a rate that is free from flicker or other objectionable visual conditions. The displayed terrain data update rate should be at least one update per 5 s.

9.5.1.7 Transport Delay: The terrain information and aircraft position should update at a rate not less than once per second.

9.5.1.8 Terrain Depiction: Several modes of terrain presentation are possible, summarized in Section 7.

9.5.1.9 Terrain Data Resolution: Horizontal and vertical data resolution should be sufficiently high that terrain conflicts are not observed during normal operations. A research study (Kuchar, 1993) suggests that horizontal resolution need not be higher than 12 arc seconds on a 10 nmi range display. Vertical terrain data for contour-map-type displays should be depicted in multiples of 500 or 1000 ft intervals for ease of interpretation.

9.5.1.10 Altitude Coding: Terrain altitudes can be coded using alphanumeric tags or color. Alphanumerics should be legible and overlap should be minimized. Color codes should be easily distinguishable from one another. Terrain altitudes may be coded in terms of MSL altitude or in altitudes relative to the aircraft or both. An issue remains regarding whether terrain data should be stored and presented in a contour format or in a grid format. For emergency descent and engine out drift down situations, a depiction of MSL terrain should be available.

9.5.1.11 Trend Information Based on Intended Flight Path: Short-term (e.g., 30 to 90 s) path predictions and/or long-term FMS-based flight plan information should be clearly distinguishable from terrain data on the display.

9.5.1.12 Alert Depiction: A clear method of depicting the alert is required. This includes an unambiguous aural alert and/or a rapidly understood textual or graphical display.

9.5.1.13 Alert Persistence: An alert should persist until corrective action is no longer needed. However, additional latency may be required to prevent spurious or intermittent alerts. Alerts should persist for at least 10 s.

9.5.1.14 Mode Annunciation: The operating mode of the terrain display should be clearly displayed. Changes in modes should be highlighted to aid the pilot in determining that a mode change has occurred.

9.5.1.15 Failure Annunciation: A failure of the display or other component of the system should be clearly indicated.

9.5.2 Shared Displays:

9.5.2.1 Information Integration:

9.5.2.1.1 Priority: A hierarchical organization of information priority is required. The importance of background terrain, altitude coding, and terrain alerting information should be specified relative to other information on the display such as FMS flight path, weather radar returns, and traffic.

9.5.2.1.2 Pop-Up Display Mode: A means may be implemented to automatically display the terrain information if it is not being displayed when a terrain conflict situation is detected (caution or warning levels).

9.5.2.1.3 Discrimination of Terrain Information: Terrain information should be clearly discriminated from other types of information such as weather radar returns.

9.5.2.1.4 Consistency of Coding and Symbology: The coding for the terrain display should be consistent with the coding of other data on the same display.

9.5.2.1.5 Declutter: A means of decluttering the terrain information may be provided. This may include selective display of terrain data, cultural features, and altitude coding. The pilot should be able to determine (either through displayed information or switch position) what information has been deselected.

9.5.2.1.6 Incompatible Mode/Range Annunciation: When display re-scaling is required for a terrain alert, appropriate annunciation should be displayed to inform the crew of the need to re-scale.

9.5.2.2 Information Distribution:

9.5.2.2.1 Conflict Resolution: Conflict resolution information should be presented on the displays that are used to perform the escape maneuver. This may include the depiction of flight director bars on the Primary Flight Display or target vertical rates on the vertical speed indicator or profile terrain display.

9.5.2.2.2 Sequential Presentation: If sequential presentation is implemented such as displaying either terrain or weather, the type of data being displayed should be clearly annunciated to the flight crew. Selection means for data to be displayed should be provided.

9.5.2.2.3 Parallel Presentation: If terrain data is displayed simultaneously with other data such as weather, map, or TCAS, there should be no possibility of confusion between the different data being displayed. This will be very difficult with terrain and weather information presented simultaneously.

9.6 Controls:

9.6.1 Flight deck control panel(s) primary to the captain and/or the first officer should be located so that no portion of the panel is less than 18 in from the design flight eye position. The panels should also be located so that the angular measurements from each normal eye position reference point should not be more than 45° above or 75° below the horizon, and no portion of the panel should be aft of 115° to the left or right from straight ahead on the captain's/first officer's centerline.

9.6.2 Functionally related controls should be grouped together.