AEROSPACE RECOMMENDED PRACTICE

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Human Interface Criteria for Cockpit Display of Traffic Information

RATIONALE

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

STABILIZED NOTICE

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

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1. SCOPE:

This SAE Aerospace Recommended Practice (ARP) sets forth design and operational recommendations concerning the human factors issues and criteria for cockpit display of traffic information systems. The visual and aural characteristics are covered for both the alerting components and traffic 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 fixed-wing aircraft implementation, the recommendations do not preclude other aircraft types. The recommendations contained in this document address both near and far term technology directed toward providing in flight traffic awareness, although the present version remains primarily focused on near term applications. Since this document provides recommendations, the guidance is provided in the form of “should” statements as opposed to the “shall” statements that appear in standards and requirements.

The assumptions about the system that guided and bounded the recommendations contained in this document include: the system is an airborne (flight deck based) system displaying traffic surveillance information to the flight crew; multiple sources of surveillance data will be used, when available, to provide the flight crew with the best available information; the system will have a human centered design based on the “lessons learned” from past systems; the system is not intended to replace the current Traffic Alert and Collision Avoidance (TCAS) function, but there will be a close relationship between the CDTI and the alerting system since both use the same sensors, and the display of the generated alerts and command information is generally considered a CDTI function; there will be pilot in the loop/manual involvement in any flight path changes; information will be accessible by appropriate 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 airborne flight phases; the display function may be stand alone or part of a multi-function display; initial design will provide for upgradability and expansion; it will be properly integrated with other display functions and will not interfere with critical functions; the system may be capable of presenting additional traffic outside the range and capability of TCAS; and this document will not deal with the presentation of man made obstructions (e.g., towers or buildings) even though they may be equipped with an ADS-B transmitter.

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 Section 10.

2.1 Applicable Documents:

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications: Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

AS264	Instrument and Cockpit lighting for Commercial Transport Aircraft
ARP268	Location and Actuation of Flight Deck Controls for Transport Aircraft
AS425C	Nomenclature and Abbreviations for Use on the Flight Deck
ARP571	Flight Deck Controls and Displays for Communication and Navigation Equipment for Transport Aircraft
ARP1068	Flight Deck Instrumentation, Display Criteria and Associated Controls for Transport Aircraft
ARP1093	Numeral, Letter, and Symbol Dimensions for Aircraft Instrument Displays
ARP1161	Crew Station Lighting - Commercial Aircraft
ARP1782	Photometric and Colorimetric Measurement Procedures for Direct View CRT Displays
ARP1874	Design Objectives for CRT Displays for Part 25 (Transport) Aircraft
ARP4032	Human Engineering Considerations in the Application of Color to Electronic Aircraft Displays
ARP4033	Pilot-System Integration
ARP4101	Core Document, Flight Deck Layout and Facilities
ARP4101/2	Pilot Visibility from the Flight Deck
ARP4102	Core Document, Flight Deck Panels, Controls and Displays
ARP4102/4	Flight Deck Alerting Systems
ARP4102/7	Electronic Displays
ARP4102/7	Appendix A – Electronic Display Symbology for EADI/PFD
ARP4102/7	Appendix B – Electronic Display Symbology for EHSI/ND
ARP4102/7	Appendix C – Electronic Display Symbology for Engine Displays
ARP4105	Abbreviations and Acronyms for Use on the Flight Deck
ARP4107	Aerospace Glossary for Human Factors Engineers
ARP4153	Human Interface Criteria for Collision Avoidance Systems in Transport Aircraft

2.1.1 (Continued):

ARP4256	Design Objectives for Liquid Crystal Displays for Part 25 (Transport) Aircraft
ARP4260	Photometric and Colorimetric Measurement Procedures for Airborne Direct View Flat Panel Displays (when approved)
AS8034	Minimum Performance Standards for Airborne Multipurpose Electronic Displays

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

FAA-RD-81-38II	Aircraft Alerting System Standardization Study: Volume II Aircraft Alerting System Design Guidelines (Berson, et al.,1981)
DOT/FAA/PS-89/1	Flight Status Monitor Design Guidelines (Anderson, et al. 1989)

2.2 Regulatory Publications:

FAA AC-23.1309-1A	Equipment, Systems, and Installations in Part 23 Airplane
FAA AC-23.1311-1	Installation of Electronic Display Instrument Systems In Part 23 Airplanes
FAA AC 25-11	Transport Category Airplane Electronic Display Systems
FAA Ac-25.1309-1A	System Design Analysis
FAR Part 23	Airworthiness Standards: Normal, Utility, Acrobatic, and Commuter Category Airplanes
FAR Part 25/ JAR Part 25	Airworthiness Standards: Transport Category Airplanes
FAR Part 27	Airworthiness Standards: Transport Category Rotorcraft
TSO-C113	Airborne Multipurpose Electronic Displays

3. GLOSSARY:

3.1 Acronyms and Abbreviations:

AC	Advisory Circular
ACAS	Airborne Collision Avoidance System
ADI	Attitude Direction Indicator
ADS-B	Automatic Dependent Surveillance-Broadcast
AGL	Above Ground Level
ARP	Aerospace Recommended Practice (SAE)
ATC	Air Traffic Control
ATM	Air Traffic Management
A/V	Aircraft/Vehicle
CDTI	Cockpit Display of Traffic Information
CNS	Communications, Navigation and Surveillance
CPA	Closest Point of Approach
EADI	Electronic Attitude Direction Indicator
EHSI	Electronic Horizontal Situation Indicator
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
FMS	Flight Management System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HUD	Head Up Display
Hz	Hertz
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
INS	Inertial Navigation System
ITC	In-Trail Climb
ITD	In-Trail Descent
JAA	Joint Aviation Authority
JAR	Joint Aviation Requirements
MASPS	Minimum Aviation System Performance Standards
MFD	Multi-Functional Display
MHz	Megahertz
MOPS	Minimum Operational Performance Standards
MSL	Mean Sea Level
NAS	National Airspace System
PFD	Primary Flight Display
RA	Resolution Advisory
Rnav	Area Navigation
RTCA	Radio Technical Commission for Aeronautics
RVSM	Reduced Vertical Separation Minimum

3.1 (Continued):

SAE	Society of Automotive Engineers, Inc
TA	Traffic Advisory
TCAS	Traffic Alert and Collision Avoidance System
TIS	Traffic Information Service
UAT	Universal Access Terminal
VDL	VHF Data Link
VHF	Very High Frequency
VFR	Visual Flight Rules
VMC	Visual Meteorological Conditions

3.2 Definition of Terms:

ABSOLUTE ALTITUDE: Aircraft altitude referenced to mean sea level (QNH). Typically referred to as barometric corrected altitude.

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

AIRBORNE COLLISION: This occurs when two aircraft that are in flight come into contact. The word “collision” is not an antonym of the word “separation”, as separation criteria are typically defined to create a significant zone around each aircraft which must not be entered for “separation” to be guaranteed. As such, airborne collisions are subsets of airborne conflicts.

AIRBORNE CONFLICT: This occurs when two aircraft that are in flight come closer together than specified separation criteria. An airborne conflict does not necessarily result in a an airborne collision; however, it does represent a situation considered hazardous, from which a collision may be possible without sufficient warning for a suitable pilot reaction.

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

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

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

3.2 (Continued):

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

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

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

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

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

BAROMETRIC ALTITUDE ERROR: For a given true barometric pressure, P0, the error is the difference between the transmitted pressure altitude and the altitude determined using a standard temperature and pressure model with P0.

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

CLOSEST POINT OF APPROACH (CPA): The minimum horizontal distance between two aircraft during a close proximity encounter, also know as miss distance.

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

COCKPIT DISPLAY OF TRAFFIC INFORMATION (CDTI): A Cockpit Display of Traffic Information (CDTI) is a generic display that provides the flight crew with surveillance information about other aircraft, including their position. Traffic information for a CDTI may be obtained from one or multiple sources (including ADS-B, TCAS, and TIS) and it may be used for a variety of purposes. Any means of communicating the information is acceptable (aural, graphical, head-up, etc.) as long as the information is conveyed effectively. Requirements for CDTI information will vary based on intended use of the data (i.e., application).

COLLISION AVOIDANCE: A maneuver taken to avoid a collision.

COLOR VALUE: The attribute of a color that allows it to be classed on a scale from very dark to very light (brightness is a perception that results from surface luminance and is a property of the object itself and of the light illuminating it).

3.2 (Continued):

CONFLICT: Any situation involving two or more aircraft, or an aircraft and an airspace, or an aircraft and ground terrain, in which the applicable separation minima may be violated.

CONFLICT AVOIDANCE: A maneuver taken to resolve a conflict.

CONFLICT DETECTION: The process of projecting an aircraft's trajectory to determine whether it is probable that the applicable separation minimum will not be maintained between the aircraft and another aircraft or vehicle. The level of uncertainty in the projection is reduced with increased knowledge about the situation, including aircraft capabilities, flight plan, short term intent information, etc.

CONFLICT MANAGEMENT: Process of detecting and resolving conflicts.

CONFLICT PROBE: An airborne or ground based system that performs the process of conflict detection.

CONFLICT RESOLUTION: The process of identifying and/or performing a maneuver or a set of maneuvers that are intended to resolve a conflict or potential conflict between the own ship and either (1) another aircraft or vehicle, (2) a given airspace, or (3) terrain.

COOPERATIVE SURVEILLANCE: (1) Surveillance in which the target assists by cooperatively providing data using on-board equipment. (2) A concept which envisions a transfer of responsibility for aircraft separation from ground based systems to the air-crew of appropriately equipped aircraft, for a specific separation function such as In-trail merging or separation management of close proximity encounters. It is cooperative in the sense that ground-based ATC is involved in the handover process, and in the sense that all involved aircraft must be appropriately equipped, e.g., with RNAV and ADS-B capability, to perform such functions.

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

CROSS-LINK: A cross-link is a special purpose data transmission mechanism for exchanging data between two aircraft—a two-way addressed data link. For example, the TCAS II system uses a cross-link with another TCAS II to coordinate resolution advisories that are generated. A cross-link may also be used to exchange other information that is not of a general broadcast nature, such as intent information.

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

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

3.2 (Continued):

ESCAPE MANEUVER: Aircraft maneuver performed to resolve a time critical conflict with the traffic.

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

EXPOSURE TIME: The period of time between when an item was last known to be operating properly and when it will be known to be operating properly again.

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

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

FAULT: An undesired anomaly in a function or system

GUIDELINES: Recommended procedures for complying with regulations

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

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

INTEGRATION: (1) The act of causing elements of an item to function together. (2) The act of gathering a number of separate functions within a single implementation.

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

IN-TRAIL CLIMB: In-trail climb (ITC) procedures enable trailing aircraft to climb to more fuel-efficient or less turbulent altitude.

IN-TRAIL DESCENT: In-trail descent (ITD) procedures enable trailing aircraft to descend to more fuel-efficient or less turbulent altitude.

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

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

3.2 (Continued):

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

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

MASTER VISUAL ALERT: Discrete annunciator used for attention getting and providing indication of situation urgency.

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

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

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

ORTHOGRAPHIC VIEW: Drawing in which the depicted lines are perpendicular to the plane of projection; a 2-D View.

OWN SHIP: The aircraft in which the CDTI is installed and about which the traffic situation mental model is being built.

PASSING MANEUVERS: Procedures whereby flight crew use: (1) onboard display of traffic to identify an aircraft they wish to pass; (2) traffic display and weather radar to establish a clear path for the maneuver; and (3) communication with controllers to positively identify traffic to be passed, state intentions and report maneuver initiation and completion.

PERSPECTIVE VIEW: A method of drawing used to show the effect of relative distance and position. A perspective view may be either an “inside-out view” (also known as the pilot’s-eye or camera view) or an “outside-in view” (also known as a “God’s-eye view"). Both types of perspective drawings assume a given viewing angle, viewing distance, display field of view and point of convergence. In an outside-in view two additional parameters must be assumed: the elevation-viewing angle and the azimuth viewing angle. Manipulation of any of these parameters changes the viewers perception of the display.

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

PLAN VIEW: A drawing which shows a horizontal section; drawing plane is shown perpendicular to the line of sight between the eye and the object.

3.2 (Continued):

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

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

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

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

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

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

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

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

SEAMLESS: A “chock-to-chock” continuous and common view of the surveillance situation from the perspective of all users.

SEPARATION: (1) Separation exists between two or more aircraft when their positions and velocities are in accordance with standards and procedures that have been determined to be appropriate for the operations in which the aircraft are engaged. (2) The maintenance of independence by means of a physical barrier between two hardware components.

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

STATION-KEEPING: Station-keeping provides the capability for a flight crew to maintain an aircraft’s position relative to the designated aircraft. For example, an aircraft taxiing behind another aircraft can be cleared to follow and maintain separation on a lead aircraft. Station-keeping can be used to maintain a given (or variable) separation.

3.2 (Continued):

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

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

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

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

VISUAL ALERT: Discrete alphanumeric display or light used to get the attention of the flight crew and transfer some information about situation urgency.

VOICE ALERT: Auditory property of voice messages that gets the attention of the flight crew and transfers some information about situation urgency.

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

WARNING: Non-normal operational or aircraft system condition that requires immediate corrective or compensatory flight crew action conditional upon maintaining overall airplane safety.

4. SYSTEM FUNCTIONALITY - POTENTIAL FUNCTIONS:

The system will provide the functionality necessary and sufficient to support the following potential near-term applications. A description of these applications can be found in 7.2. Unnecessary restrictions or constraints should be avoided in order to maintain design flexibility needed for additional functionality that may be implemented to support future applications.

a. Enhanced Visual Acquisition
b. Enhanced Oceanic In-trail Climb/Descent Procedures
c. Facilitate Station Keeping in Oceanic, En Route, and Remote Non-Radar Airspace
d. Enhanced Visual Approach
e. Facilitate Closely Spaced Parallel Approaches in IMC
f. Enhanced Departure Spacing
g. Increased Conflict Awareness

In order to support these operational applications, the system operations can be segmented into six functional areas: Sensing and Estimation, Conflict Detection and Assessment, Crew Alerting, Transmission/Presentation of Traffic Information, Self-Monitoring, and Recordkeeping. These functional characteristics will enhance the flight crew's ability to visually acquire the traffic, to build a mental model of the traffic situation (both spatial and temporal), to perform flight operations that are coordinated with the traffic situation, and to resolve traffic conflicts.

4.1 Sensing and Estimation:

In order to provide information about the traffic situation and to determine if and when a traffic alert is necessary, the system should have access to information related to the state of the own aircraft and its relationship to traffic. Generally, as more information is available, the system can be designed to operate in more complex situations. The following sub-sections describe the types of information that could be used.

4.1.1 3-D/4-D Position of Own Ship Relative to Traffic: An estimate of the spatial and temporal proximity of the own ship to the traffic is necessary. This estimate may be obtained from an onboard sensor directly providing relative range, bearing and track of the traffic. The accuracy and integrity of this information should be high enough to enable the performance of the applications that have been implemented and not result in an unacceptable rate of missed, false, nuisance and late alerts by the alerting function of the system.

4.1.2 Aircraft State: In addition to proximity information, additional state information is required to determine whether the projected flight path of the own ship and that of the traffic are in conflict. 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 maneuvers could be issued based on the airplane performance capability and current state data.

4.1.4 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 and the separation criteria should be specified.

4.1.5 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 intended flight path for traffic conflicts as the plan is being executed. In a second mode, knowledge that the aircraft will be turning, climbing or descending at a given waypoint can be used to reduce the probability of nuisance alerts that would have been produced without the intent information. Over reliance on intent information may result in nuisance alerts or late alerts if the aircraft deviates from the intended flight path.

4.2 Loss of Separation Detection and Assessment:

The system should be able to detect a potential loss of required separation with traffic. This detection is based on the information obtained through the Sensing and Estimation Function: proximity and closure with traffic, aircraft performance, and estimates of the aircraft's intentions. The decision that a situation is a conflict should consider the application and 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 traffic encounters, especially when the own ship, the traffic or both are maneuvering. Although the recommendations contained in this document are base on providing information about traffic/moving obstacles, there may be some benefit defined to provide the capability to present stationary obstructions (e.g., towers, cranes, new construction, etc.) that have been equipped with a position broadcast device.

4.3 Flight Crew Alerting:

Once a loss of separation has been detected, the system should alert the flight crew. Alerting should include aural and visual components. The system should be able to determine the urgency of a traffic situation and alerts should be presented to the flight crew in an unambiguous manner. Alerts should be integrated and consistent with the flight deck alerting system and philosophy. Appropriate response to any level of alert should prevent the conflict from transitioning to a situation of higher urgency.

4.4 Information Transmission:

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

4.4.1 Traffic Awareness: The system could enhance the flight crew's traffic awareness by allowing them to view relevant airspace/traffic geometry information. In order to accomplish this, the aircraft's location (in all dimensions) relative to traffic and it's velocity vectors should be displayed. The flight crew should be provided sufficient information to accurately anticipate conflict situations.

4.4.2 Traffic Avoidance: When a conflict is detected and an alert is issued, additional resolution information may be needed. This may be in the form of a caution (e.g., "Traffic"), an open-loop command (e.g., "Climb"), or closed-loop command guidance (e.g., "Flight Director Bars"). The flight crew should have a clear idea of what action to perform to resolve the conflict. The system should indicate when the potential loss of separation 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/determine information quality in order to permit the assessment of the appropriateness of the information for specific system applications.

4.6 Recordkeeping:

The system should provide a means for post flight analysis of traffic situations and conflicts to support the development of a safer more effective use of the airspace.

5. DESIGN OBJECTIVES:

The control and display equipment for the cockpit display of traffic information 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 flight crew traffic awareness
d. Minimize head down time
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 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 flight crew in verification and error detection
k. Minimize nuisance alerts
l. Permit conflict analysis

The goal of these objectives, though not necessarily presented in order of importance, is to keep associated flight crew workload at a level compatible with efficient flight crew operation.

6. UTILIZATION PHILOSOPHY:

In order to define what information the flight 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). The overall objective of the system is to provide traffic information that will support alerting when required separation is lost or has the potential of being lost, separation monitoring, enhanced visual acquisition, and resolution evaluation. In addition the system is expected to provide the traffic information that supports the operation of TCAS.

6.1 Generating Appropriate Response:

The information provided by the system should enable the flight crew to perform conflict resolutions, or respond to resolution guidance in a timely manner. In support of this, the system should generate a sense of confidence in the flight crew that they are seeing all of the traffic relevant to performing these resolution responses, or that the system is considering in generating resolution guidance. Otherwise, responses may be tentative and delayed, or competing resolutions may appear better suited to the conflict. Similarly, when the system is used for purposes of monitoring separation, or enhanced visual acquisition, the coverage (surveillance) provided by the system should be consistent and compatible with flight crews' mental and visual models. As a general statement, the information provided by the system should enable the flight crew to respond in an appropriate manner and should not promote incorrect or unproductive response patterns.

6.2 Response Urgency:

The urgency of the loss of separation or a traffic conflict situation is usually determined by the amount of time that the flight crew has to respond to the situation. The less time the flight 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 flight crew/aircraft system to respond to a traffic conflict situation is very important. The system should provide enough information to ensure traffic awareness by the flight crew in time for them to respond by maneuvering the airplane to achieve the necessary traffic separation. Because of the wide range of potential traffic conflict 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 flight crew 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 Informational Alerts, Nuisance Alerts, and False Alarms:

The number of nuisance alerts and/or false alerts have a direct influence on the usefulness of the system because they affect the flight crew's perception of and confidence in the information that the system presents. The judicious use of informational alerts can have a direct influence on the usefulness of the system because they can be used to enhance attention to potentially important, but still developing, traffic situations.

6.3.1 False alerts and missed alerts should be eliminated.

6.3.2 The effect of nuisance alerts on the flight crew is dependent on the urgency of the alert and the expected flight 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 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 flight crew's and the traffic's intentions

6.3.3 The system should use the permitted traffic 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

6.3.4 Information provided by nuisance alerts is at times considered useful by the flight crew, and a method should be identified to provide this, and other, event driven information, in the form of an informational alert that is distinct from alerts designed to signal a non-normal situation. For example, the information provided by caution level alerts, even when they are nuisance alerts, may be particularly valuable. This is due to the fact that such alerts often provide useful information, but typically are accompanied by little, or no, response urgency (and its accompanying stress on the flight crew). On the other hand, even though this information generates situation awareness and the flight 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). Therefore, valuable event-driven information that does not signal non-normal operations (such as that which triggers non-urgent nuisance alerts) should be identified and associated with a distinct informational alert.

7. CANDIDATE CONCEPTS:

7.1 Candidate Display Concepts:

The appropriate display format and information content depends on the intended use and operation of the CDTI. Each format has benefits and limitations. Further research and testing is advisable before implementation. For example, the flight crew's assessment of the traffic situation and their required actions has been found to be highly dependent upon the type of display; a display showing a vertical "slice" of the traffic situation typically suggests vertical maneuvers, while a plan view or "birds eye" display typically suggests horizontal maneuvers.

7.1.1 Graphic Displays: Graphic displays may be classified in many ways. Among the common ways to classify graphic displays are: (1) projection technique (i.e., method by which objects in a three dimensional world are mapped onto the two dimensional coordinates of the image); and (2) by point of view presented (the location from which a scene is viewed and direction in which it is viewed). The classification into perspective and isometric projections, and into plan views, profile views, and off-axis views, is especially relevant to CDTIs. However, the appropriate display format depends on the intended use and operation of the CDTI and each view has its own benefits and limitations. For example, a graphic CDTI display could be used to accomplish arrival merging. In this application there is a need to maintain orientation relative to fixed earth coordinates, and this in turn implies the need for a plan view display that depicts the intended horizontal stream geometry. In addition to determining how well a flight crew can fly an intended maneuver, a CDTI can also influence what the intended maneuver is. For example, a flight crew's assessment of the traffic situation and their required actions has been found to be highly dependent upon the type of display; a display showing a vertical "slice" of the traffic situation typically suggests vertical maneuvers, while a plan view or typically suggests horizontal maneuvers. Due to the strong impact of graphic display format, research and testing is advisable before settling on any specific implementation.

7.1.1.1 Graphical Display Formats: Common to all display concepts, the presentation of aircraft position on the display aids the pilot in determining proximity to other traffic and assists in tactical operations and strategic planning. Other information elements may be presented as needed. Table 1 lists potential display viewpoint and projection characteristics. Figures 1, 2, and 3 illustrate some of characteristics of these viewpoints and projection techniques for the depiction of two buildings, where each has a different height and shape. These viewpoints and projections are discussed in more detail below, with the advantages and disadvantages of the respective display types being noted.

Perspective Projection: Perspective projection, or perspective mapping provides an integrated three dimensional representation of the traffic information. This type of projection yields images similar to those in a conventional photograph, and reflects the type of stimuli which natural vision has evolved to process. However, the exact layout within perspective images can also be hard to interpret due to difficulty in assessing object size and or object depth (distance to objects measured normal to the plane of the image). Perspective views require a frame of reference and way to relate the target aircraft to a ground plane. Perspective displays can provide "situation awareness at a glance" by building from a familiar representation. The heading and pitch scales should be consistent with the scene depiction. A perspective display may have an "inside-out" view or an "outside-in" view. The outside-in view is referenced from an outside perspective and may cover the complete field including behind the aircraft; the inside-out view depicts traffic comparable to an actual outside the window visual view. Symbology can be used to represent detailed information such as distance, direction, closure rate, flight ID, and altitude. Because of the amount of information that may be closely located on this display, a means of decluttering the display should be provided. A perspective display may be used in coordination with -- or the flight crew may select between -- a plan view display to provide longer-term information or more precise assessment of the horizontal position of the aircraft.

TABLE 1 - Description of Display Formats With Respect
to Type of Projection and Type of View

VIEW	TYPE OF PROJECTION	
	ISOMETRIC (ENGINEERING DRAWING DEPICTION) • ALL DISPLAYED AND CORRRESPONDING TRUE SEPARATIONS ARE PROPORTIONAL • PICTORIAL 2-D (IMAGE HAS NO PERSPECTIVE DEPTH COMPONENT)	PERSPECTIVE (PHOTOGRAPHIC DEPICTION) • DISPLAYED AND TRUE SEPARATIONS RELATED BY PERSPECTIVE PROJECTION • PICTORIAL 3-D (IMAGE HAS PERSPECTIVE DEPTH COMPONENT)
PLAN VIEW • VERTICAL VIEWING AXIS • BEST DISPLAYS HORIZONTAL (X-Y) POSITION, TRACK, AZIMUTH AND RANGE OF TRAFFIC	• GOOD DISPLAY OF ALL HORIZONTAL SEPARATION • VERTICAL SEPARATION NOT DISPLAYED • NO DISPLAY OF 3-D SEPARATION	• GOOD/FAIR DISPLAY OF ALL HORIZONTAL SEPARATION • MINIMAL VERTICAL SEPARATION PERSPECTIVE • MINIMAL PERSPECTIVE 3-D SEPARATION
SIDE-ON VIEW • HORIZONTAL VIEWING AXIS • BEST DISPLAYS AZIMUTH, ELEVATION, ALTITUDE, AND CLIMB/ DESCENT OF TRAFFIC	• GOOD DISPLAY OF VERTICAL SEPARATION AND LATERAL HORIZONTAL SEPARATION • DEPTH ALIGNED HORIZONTAL SEPARATION NOT DISPLAYED • NO DISPLAY OF 3-D SEPARATION	• GOOD/FAIR DISPLAY OF VERTICAL SEPARATION AND LATERAL HORIZONTAL SEPARATION • MINIMAL DEPTH ALIGNED HORIZONTAL SEPARATION PERSPECTIVE • MINIMAL PERSPECTIVE 3-D SEPARATION
OFF-AXIS VIEW • VIEWING AXIS NEITHER HORIZONTAL NOR VERTICAL • PERSPECTIVE PROJECTION BEST DISPLAYS RELATIVE 3-D (X-Y-Z) POSITION	• PSEUDO-PERSPECTIVE GENERATES MISLEADING HORIZONTAL AND VERTICAL SEPARATION CUES • PSEUDO-PERSPECTIVE GENERATES MISLEADING 3-D SEPARATION CUES	• FAIR PERSPECTIVE DISPLAY OF HORIZONTAL, VERTICAL, AND 3-D SEPARATION

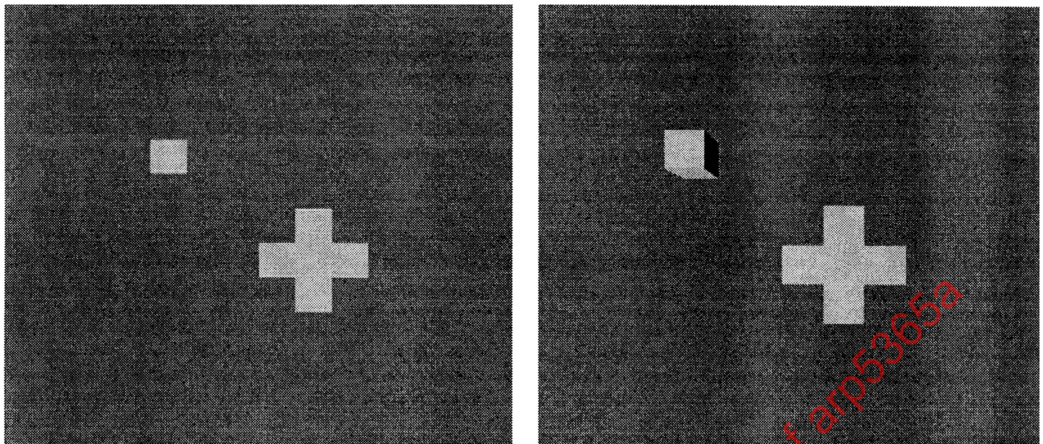

FIGURE 1 - Plan view with isometric projection (left) and perspective projection (right). Note that due to a viewpoint from above the cross shaped building, no depth is indicated for it while depth is shown for the square building.

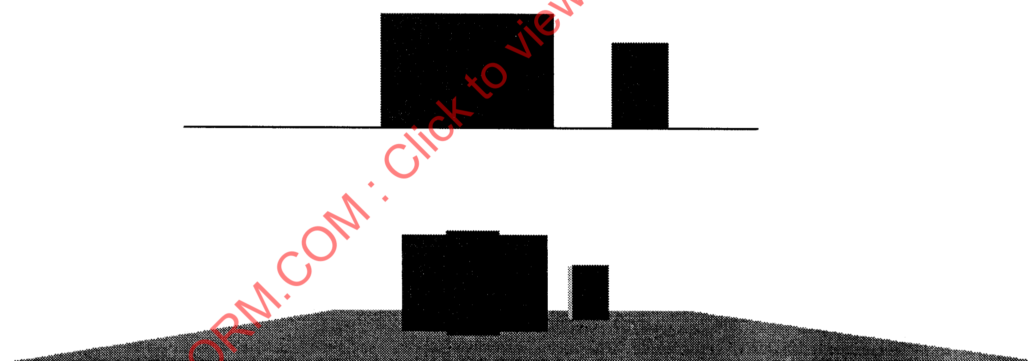

FIGURE 2 - Side view with isometric projection (top) and perspective projection (bottom). Note that relative to depth-less isometric projection, the perspective projection still yields only minimal depth cues to shape of cross shaped building.

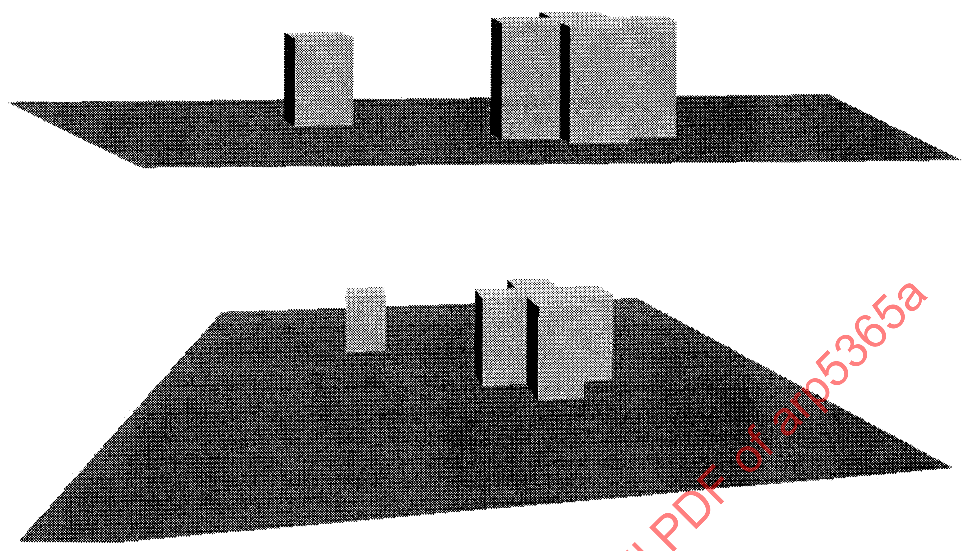

FIGURE 3 - Off-axis view with isometric projection (top) and perspective projection (bottom). Note that apparent depth separations within the isometric projection are attenuated relative to those shown in the perspective projection.

7.1.1.1 (Continued):

Isometric Projection: Isometric projection, or orthonormal mapping, totally ignores depth. As a result, displayed separations are strictly proportional to separations measured parallel to the image plane. This makes isometric projection very valuable for the display of two-dimensional separation, when the two dimensions are particularly significant (e.g., the horizontal dimensions of the ground). On the other hand, when the selected dimensions are unfamiliar or ambiguous, this type of projection can yield ambiguous or illusory interpretations. The most common example of an isometric projection is a map, where the elevation of the depicted terrain does not influence the displayed separation between locations. Another example of this type of projection is found in engineering drawings. Traffic information on an isometric display shows a 3-D view where the same measure is used foreground to background. An isometric display shows relative and absolute and vertical path of own ship and Other aircraft. An isometric display relies on a method to show reference to the ground plane and as a result a method to reduce display clutter should be provided. Reference lines have the potential to be confusing since they would not be depicted in perspective.

Display Point of View: Graphical displays can, of course, present many different points of view, and these may be classified in several manners. The classification into plan views, profile views, and off-axis views is especially relevant to CDTIs.

7.1.1.1 (Continued):

Plan View: Plan views, such as TCAS displays and NAV displays, are top down views (often called God's Eye views), and are the most familiar views to pilots. Plan views are projections of traffic information onto a horizontal slice through the airspace, and may be presented in a track-up, heading-up, or north-up format. Plan views may display traffic flying at all altitudes, or just some subset of altitudes (e.g., TCAS defaults to presenting aircraft within 2900 ft of own ship). Plan views may also be presented as relative to own ship (i.e., moving map, such as used in TCAS), or as fixed. Additionally, relative vertical information should be shown alphanumerically and/or symbolically. Depending on the use for which the format is intended, a method of viewing the range of the display should be shown, and a variety of display ranges may need to be selectable. The isometric rendering in Figure XX illustrates how a plan view format can provide good horizontal (x-y) separation information, but lacks all vertical separation information. On the other hand, the perspective rendering of a plan view does provide some vertical separation information (the vertical development of the smaller building is evident). However, the perspectival transformations shift the rendered x-y locations according to the rules of perspective, and this may make the horizontal separation information less usable.

Side-On View: The Side-On view is a projection of information on a vertical slice through the airspace and have been recommended as a means for giving altitude information to flight crews. Side-On views display traffic flying in some specific region of airspace around own ship. There are many potential Side-On views, but two (Profile and Window) are particularly interesting. The Profile view, is generated by viewing the own ship from the side (an outside-in view). In the Profile view, traffic altitude and distance forward from the own ship are shown relative to the own ship's position and vertical flight path. In the profile view the own ship predicted path may project forward in a straight-line, a curved path following a projected turn, or an FMS flight plan. The forward position of traffic on the display are typically measured in this same plane; however, the distance of traffic to the side of the intended flight is not inherently shown on this display. Issues remain with methods of displaying the relative horizontal position and horizontal closure rate of the traffic. Different scaling will be required for the vertical (altitude) and horizontal (forward distance) axes. Other features may include the display of vertical movement or closure rate of the other aircraft. The Window View, is a Side-On view that does not include the own ship, but displays the window-like view of the airspace in front of the own ship (an inside-out view). The isometric rendering in Figure YY illustrates how a Side-On view format can provide good vertical separation information, as well as information about separation in the vertical plane transecting the viewing direction. However, this view lacks range information (except that provided by known size cues). The perspectival rendering of the profile view in Figure YY illustrates that this view can provide some relative range information (e.g., the wings of the cross shaped building are now visible as being farther away than the front of the building). However, as with the plan view, this comes at the price of perspective transformations that may make the vertical separation information less usable (e.g., the relative height of the two buildings is not as sharply delineated).

7.1.1.1 (Continued):

Off-Axis View: Plan views and Side-On views are typically based upon easily understood, or intuitive, lines of sight, and are selected to highlight vertical or horizontal separation. As such they always tend to collapse out one dimension of separation, i.e., vertical separation in the plan view or one of the two dimensions of horizontal separation information in the Side-On view. An off-axis view results in the representation of horizontal and vertical separation information within the same image. Off-axis perspective views have been recommended as a means for giving flight crews 3-D information. The off-axis view is a projection of information on a slice through the airspace that is neither horizontal nor vertical. In the off-axis view the aircraft's predicted path is not inherently associated with any of the three display axes (left-right, up-down, in-out). The forward position of the Other aircraft on the display are typically measured in this same plane; however, the distance of the Other aircraft to the side of the intended flight is not inherently shown on this display. Issues remain with methods of displaying the relative horizontal position and horizontal closure rate of the Other aircraft. Different scaling will be required for the vertical (altitude) and horizontal (forward distance) axes. Other features may include the display of vertical movement or closure rate of the Other aircraft

7.1.1.2 Mode of Information Coding: Flight Displays can show information using a method depiction ranging from literal to abstract. Functions of the CDTI system should be analyzed to identify the specific information which must pass from the system to the flight crew (display) and that which must flow from the flight crew to the system (control). This analysis should make it possible to decide how to organize and present information to the flight crew (e.g., analog versus digital, literal versus abstract, continuous versus demand driven).

7.1.1.3 Method of Presentation: A CDTI may be implemented on a heads-down display, such as an independent display or an integrated primary flight display. It may also be implemented on a HUD. When combined on a HUD with "look-here" symbology this type of display has the potential to aid visual acquisition for both collision avoidance and procedural purposes. The method of presentation within the cockpit must be appropriate to the pilot's primary scan, CDTI application and flight phase workload. Certain procedures, such as in-trail following on final, may require traffic information to be presented on a HUD. With current HUD systems, features will be typically be limited to green wire frame objects, and the field-of-view is limited. An inherent concern with use of current HUD systems is that the pilot can visually fixate on the HUD and as a result compromise scanning for traffic in the full field of view. However, as technology emerges it is expected that HUD design will employ multi-color, permit shaded objects, and cover a greater section of the pilots' field-of-view.

7.1.2 Alerting and Command Displays: Visual displays may also serve to provide the flight crew with alerts, which serve to direct the crew's attention to some element of the traffic situation, and with commanded avoidance maneuvers or actions to resolve a traffic conflict. These alerts and commanded actions would be generated by an automatic system working in coordination with the CDTI.

The alerting and command displays may be integrated with a spatial presentation of the traffic. For example, with a plan view CDTI format, the specific aircraft involved in generating the alert or commanded actions may be highlighted, the projected point of closest approach may be highlighted on the display, and commanded maneuvers or "non-transgression zones" may be displayed directly on the screen.

The alerting and command displays may also be displayed on a separate section of a CDTI, such as one form of the current TCAS display which combines command information in the outer rim of the display, and spatial traffic presentation in the center of the display.

7.1.3 Aural Displays: Candidate CDTI concepts may use an aural (voice or tonal) display. This display may replace or supplement graphical displays. Both basic state information about other aircraft and warnings/alerts may be provided. It is possible to present aural displays with current aircraft equipment. Displays with fine gradations of tone or modulation to provide a "3-D" effect typically require specialized audio equipment.

7.1.4 Tactile Displays: System designs should be flexible enough to support tactical parameters; however, it is not required to provide the parameters in all implementations.

7.2 Conceptual Near Term Uses of CDTI:

For near-term CDTI design guidance, emphasis is being placed on developing recommendations to facilitate enhancements to visual acquisition, enhanced operations in the oceanic and terminal domains, and increased conflict awareness. A brief description of these applications is provided below (see Mundra, et al. for in-depth discussion of the concepts).

7.2.1 Enhanced Visual Acquisition: A primary task for pilots is to maintain awareness of nearby air traffic by maintaining a constant visual scan. If traffic is sighted, the pilot must first assess the threat posed by the intruder aircraft then, if necessary, maneuver to avoid the other aircraft. This strategy for collision avoidance is termed "see-and-avoid." The effectiveness of see-and-avoid depends on the ability of a pilot to visually acquire the intruder aircraft early enough in the encounter to enable threat assessment and avoidance.

Previous work has found the CDTI could assist pilots in this visual acquisition task by providing a display of nearby traffic (Andrews, 1984; Andrews, 1991). From the pilot's viewpoint this function could be considered an automatic version of the VFR traffic advisory service provided by ATC, but the CDTI would be available in areas outside of radar coverage, where traffic advisories cannot be provided.

7.2.2 Enhanced Oceanic In-Trail Climb/Descent Procedures: The CDTI would enhance the In-Trail Climb (ITC) and In-Trail Descent (ITD) procedures that have been certified on a trial basis for certain portions of U.S. air traffic service provided oceanic airspace (Cieplak et al., 1995). The current procedures authorize the use of the TCAS II traffic display for climbs or descents through the altitude of same direction traffic at separations considerably lower than standard non-radar separations, when certain display adequacy requirements are satisfied and the required training has been accomplished.

The procedures require positive identification of the lead aircraft and an establishment of closure rate by the trailing aircraft. These requirements are currently accomplished in a somewhat cumbersome manner through voice communications and the use of transponder squawk-standby procedures. The CDTI could significantly enhance these procedures by providing the identity of the traffic and the closure rate on the traffic display. A minimum reception and display range of 20 nmi would be required, but longer reception ranges of up to 120 nmi would provide increasing benefit by proportionately increasing the applicability of the procedure. The range readout is currently required to be accurate to within a mile, and therefore the CDTI must also meet that requirement. The procedure is sensitive to the value of the closure rate, allowing a maximum of 20 knots closure between the two aircraft to initiate the climb. Finally, the procedure utilizes traditional separation responsibilities, and incorporates certain distance safety buffers due partly to the inadequate availability characteristics of the current traffic display.

7.2.3 Facilitate Station Keeping in Oceanic, En Route, and Remote Non-Radar Airspace: Station keeping is the monitoring of longitudinal and/or lateral distance once a desired interval has been established. During station keeping in non-radar airspace, ATC could instruct the flight crew to maintain a specific distance from a lead aircraft (say 20 nmi). The flight crew would then use information derived from the CDTI to judge maneuvering of own aircraft to maintain the specified distance. Initial implementations of this concept may be procedurally based, similar to the ITC/ITD, and not require any change in separation responsibility.

7.2.4 Enhanced Visual Approaches: Visual approaches are the backbone of operations at major airports in the U.S. and in certain other parts of the world. During visual approaches, traffic advisories are issued to pilots, and once the pilot confirms visual acquisition of traffic, a visual approach clearance is issued. The process of issuing traffic advisories and waiting for confirmation is more workload intensive than when visual approaches are not conducted; however this increase in workload is accepted because of significant capacity gains (Lebron, 1987). The CDTI could help to enhance visual approach operations in one of several ways including:

a. Improved visual traffic acquisition (Andrews, 1984)
b. Aid to positive identification
c. Enhance pilot judgments of closure and encounter geometries (Olmos, et al., 1998)
d. Reliably conduct visual operations to established weather minima

7.2.5 Facilitate Closely Spaced Parallel Approach in IMC: The Closely Spaced Parallel Approaches (IMC) application is an alternative for providing the safety required to conduct parallel ILS approaches to the current minimum spacing for wake turbulence independence, 2500 ft, or potentially even closer runway spacings. After standard separations are lost during the respective “turn ons” to the final approach courses, separation could be provided procedurally through navigation on the localizers. The CDTI could be used to assist flight crews in maintaining tight stagger position control throughout such approaches (Sorenson, et al., 1991). Conflict resolution logic would be used as a backup to prevent a collision hazard in the event of an error or navigation blunder.

7.2.6 Enhanced Departure Spacing: In today’s environment, successive departures are separated by standard radar criteria during IMC. The distance can be reduced to 1 mile if departure courses diverge by 15° or more. This requirement equates to several minutes delay and can significantly reduce departure capacity causing delays at the departure airport. By observing a previous departure on the CDTI, a pilot could depart behind another aircraft as soon as the departing aircraft’s altitude begin to increase. Upon seeing the altitude readout of the preceding aircraft begin to increase, the pilot would inform the appropriate controlling ATC facility, who then would clear the specified aircraft for takeoff. The pilot would then maintain a specified distance from the preceding aircraft using the CDTI. By using this technique to reduce departure separation in IMC, the departure capacity should increase (Sorenson, et al., 1991).

7.2.7 Increased Conflict Awareness: The inclusion of Traffic Advisories (TAs) within the CDTI builds onto the basic traffic awareness function of the traffic alerting capability. This would give an automated aid (e.g., aural, visual) to the pilot for detection of potential threats.

8. FLIGHT DECK INTEGRATION:

Addition of the flight crew interface (controls and displays) and processing unit components of a cockpit display of traffic information (CDTI) system into the flight deck should consider a number of factors. These include: integrated design versus dedicated design, design consistency, pilot/vehicle integration, information requirements, interaction with other aircraft systems, mission and operational requirements and future growth requirements. Also, the CDTI system interaction with the flight crew-related areas of workload, situation awareness, training and procedures must be addressed to satisfy (existing and potentially new) flight deck certification/FAR requirements. With integrated multifunction or layered displays, issues may arise such as problems with flight crew awareness of the current display mode or status. Testing of these display concepts before implementation is highly recommended. For example, on any particular display space, traffic information may not be the only or primary feature. Several other things can be shown, including: various alerting information, weather, terrain, flight path, nav. data, airspace, and representations of aircraft state. This combining of functions on a single display may be a function of display-space limitations, or it may instead be convenient for the flight crew, allowing simultaneous consideration of related information.

8.1 Design Consistency:

8.1.1 Overall CDTI System Design Consistency: The CDTI system should be consistent with the rest of the flight deck in terms of color, standardization, automation, symbology, interaction techniques and operating philosophy Reference AC 25-11.

8.1.2 Alerting System Design Consistency: The standardization fundamentals recommended in the FAA Aircraft Alerting System Standardization Guidelines (ref: Berson, et al.) should be applied to the CDTI displays and controls to promote a consistent implementation philosophy on the flight deck . For those flight decks that utilize an integrated alerting system, the CDTI should be integrated into that system. For retrofit applications, the guidelines set forth in the above document should be used.

8.2 Display Integration:

8.2.1 Dedicated CDTI Design: The dedicated CDTI concept requires minimal or no integration with the existing avionics system, but instead requires either one or two separate displays. Significant constraints are that available space in the flight deck must be available to accommodate the placement of a dedicated display, and any single display be viewable by both the pilot and co-pilot. This type of approach will typically be used on flight decks with analog avionics or with a federated avionics architecture. The stand-alone approach for these aircraft could use a separate display as shown in Figure 4.

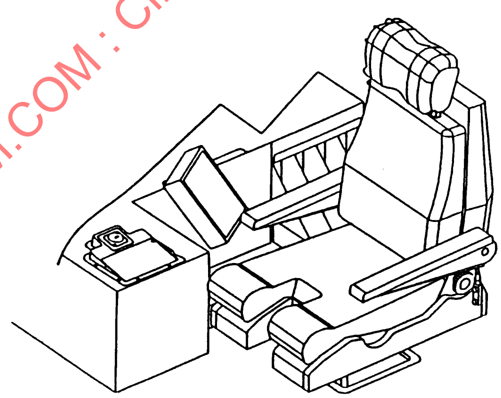

FIGURE 4 - Dedicated System Placement

8.2.2 Shared Displays: As the amount of information available to the flight crew increases, methods of displaying and manipulating that information should be made available. Conventional and hybrid flight decks may require the CDTI display to be shared. Display sharing may be done either by space (e.g., split display) or time. Strategies to allow the flight crew to manipulate the shared display of information should be provided. The use of time-shared displays tend to be useful for independent functions and procedures. Space-shared displays tend to be useful for related or same functions where the need to provide complementary information exists. Display clutter and symbology size can be an issue for shared displays. The use of time-shared displays may require an alerting function to indicate any change of information on the system(s) not currently being displayed.

8.2.3 Integrated Multifunciton CDTI Design: The glass cockpit provides the potential for functional growth. The glass cockpit is capable of displaying multiple images on the same surface by integrating multiple video/sensor input sources. The integrated CDTI approach would require the current avionics system to be equipped with a device that would allow the CDTI graphical, textual and/or aural information to be displayed separately or on the same surface as other existing images. Interface control shall provide the needed selections to the flight crew to manipulate the CDTI system. The glass cockpit permits an integrated design; it does not preclude the possibility of implementing a dedicated system.

8.3 Interaction With Related Flight Deck Systems:

CDTI may often be used in coordination with other systems, driven by closeness of function, mutual benefit, or lack of display space. This section lists some of the systems which may be used in coordination with a CDTI.

8.3.1 Alerting and Separation Assurance Systems: When used in conjunction with a collision avoidance system, the CDTI provides alerts and command information related to maintaining the separation required for the current application. CDTI may be used in coordination with an automatic system for monitoring for conflicts and/or generating suggested or commanded actions to resolve potential traffic conflicts.

Care should be taken that: the alerts appear justified by the presentation of the CDTI; the nuisance alerts be minimized; and that the alerting system attempts to incorporate all the other integrated information.

8.3.2 Autoflight and Flight Management Systems: Current and conceivable future implementations of CDTI may incorporate information concerning the Autoflight and Flight Management Systems. These systems may contribute information to the CDTI to present information about the intentions and future trajectory of the own aircraft directly on the CDTI. Some implementations of CDTI may be integrated with the navigation display, requiring the simultaneous presentation of trajectory selections and traffic information. With such an integration, longer-range implementations can be envisioned in which such a combined display may be used as an input device to the autoflight system; for example, a pointing device may be used to determine and select a deviation around other traffic.

8.3.3 Data Communication Systems: Forms of datalink and/or broadcast data (ex. VDL mode 4, UAT, and Mode S) will most likely become the principal information sources for CDTI implementations which could provide information elements such as the future trajectory of other aircraft. As flight crew involvement in decision making about traffic separation and traffic flow increases, the data communication systems will become increasingly linked with the CDTI. For example, ATC or other flight crews may request or suggest traffic deviations for the own aircraft and for themselves, which could then be presented on the CDTI. Additionally, in future systems, CDTI may serve not just as a display but as input device for specifying trajectories, and for negotiating trajectories with ATC and/or with other aircraft.

Due to the persistence of its presentation of information, CDTI may also serve as a possible compensatory mechanism for "Party Line Information" loss due to a transition to discretely-addressed datalink communications; such a benefit will only be fully acheived, however, if all elements of Party Line Information which require presentation are available on the CDTI.

8.3.4 Existing Collision Avoidance Systems: Any implementation of CDTI must also consider its impact on any collision alerting and avoidance systems presently in the own aircraft, and also in other aircraft which interact with the own aircraft. Such systems would primarily be the Traffic Alert and Collision Avoidance System (TCAS II), updated versions of TCAS, and TCAD; military aircraft installing CDTI for use in civilian airspace may also need to consider current stationkeeping and formation flying systems.

In all cases, CDTI implementation must not interfere with the operation of the collision avoidance systems. To this end, CDTI must not provide conflicting information to the alerting system, should not fundamentally change the presentation of information specified as being required for proper pilot conformance to avoidance maneuver commands, should consider the impact of CDTI symbology and display format changes from those currently used by the system's CDTI components, and must not detract or distract the pilot's attention from the avoidance system when a potential collision is projected to occur.

CDTI has the potential to support the occasional immediate information needs of the collision avoidance system in addition to the possible functions described in 7.2. These benefits should be considered and tested in the design of new CDTI functions for additional applications. Integration of CDTI functions with TCAS collision avoidance functions may require specific information requirements analysis.

8.3.5 Flight Management System (FMS): Flight crew interface with the CDTI System may be different for FMS equipped aircraft. For aircraft equipped with FMS functions in the current avionics, a logical design approach would be the integrated approach. As a result flight crew interaction with the CDTI may be through the FMS. For aircraft that are not equipped with a FMS system, then a separate navigation source and flight crew interface needs to be retrofitted to supply the necessary navigation information and crew control. For CDTI display, own-ship position and velocity data should be consistent, i.e., use the same reference system, as displayed target data.

8.3.6 Aircraft System Integration: When the CDTI is integrated with other aircraft systems, the design should ensure that all data displayed is referenced in the same way and is displayed at the same scale. For example, heading-up oriented data should not be displayed simultaneously with track-up oriented data. One should be converted prior to display. For a second example, if a CDTI display is also displaying weather radar information, the design should not allow the range-scale of the weather data displayed to be different from the range-scale of the traffic data that is simultaneously displayed. If there are separate range controls for different functions such as radar and traffic, one control should affect the range setting for both functions when they are both active.

8.3.7 Caution and Warning System: Priority of warnings, cautions and alerts shall give high priority to safety of flight including collision avoidance, visual acquisition, terrain avoidance, and hazardous weather messages and lower priority to procedural and efficiency of flight messages.

8.3.8 Autopilot/Autothrottle/Flight Director: Hardware and/or software interfaces may be required to provide the flight crew with guidance-based information and control if the CDTI system is integrated with the autoflight system.

8.4 Integration with Mission and Operational Requirements:

8.4.1 Operator Tasks: New or different flight crew tasks associated with the use and/or operation of the CDTI system should not adversely affect performance of existing tasks.

8.4.2 Flight Crew and Controller Coordination: Presentation of traffic information in the flight deck increases the capability of the flight crew to be more actively involved in traffic separation and air traffic management, requires a method for managing the information and procedures new to the flight deck, and changes the role they are willing to accept in relation to the air traffic controllers and other aircraft. Therefore, the addition of increased information content in the flight deck through improved CDTI functions should examine the need for changes in flight crew and controller coordination procedures, and should take into account changes in flight crew and controller communications that may arise in real operations as the air traffic management process becomes more observable by the pilot.

8.4.3 Allocation of Responsibilities and Functions: CDTI has the potential to change the roles and responsibilities of flight crews and controllers as well as their interaction with automated systems. The CDTI implementation should support coordination between the flight deck and ATC. Allocation of responsibilities among flight crew, controllers and automation should not adversely affect performance of existing tasks.

8.5 Information Requirements:

8.5.1 Data Sources for CDTI: Information for presentation on the CDTI system may be from single or multiple sources. These sources include but are not limited to ADS-B, TIS, navigation flight management system, on-board wx/terrain and TCAS. A means should be provided to obtain a figure of merit of the data and to control the data source.

8.5.2 Sensor/Data Fusion: Sensor/data fusion is the integration or merging of data from multiple sensors to enhance sensor viewing resolution and accuracy. Sensor fusion should be used to assist human decision making by integrating large amounts of sensor data into adequate information.

8.5.3 Datalink Fusion: Datalink fusion is the integration or merging of data from multiple datalinks. Fusion of data from multiple datalinks may have temporal as well as identification considerations as datalinks may not all have the same transmission or update rates.

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 flight crew coordination, operational procedures, and 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, traffic 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 flight crew should dictate how the information is presented. Normal traffic information should not use the alerting system to attract the flight crew's attention. Alert urgency should be part of the information contained in the alert information.

9.1 Visual Display Characteristics:

Visual displays can present traffic information in two ways: graphical or textual. While users generally prefer a graphical (i.e., analog) display, cognizance and performance is not always better with graphical representations. That is, performance with either display format appears to be task dependent. In general, a graphical format is favored under the following conditions (Helander, 1987):

a. Rate-of-change information needs to be perceived.
b. Estimations of the variable's magnitude are needed when it is rapidly changing.
c. The deviation of the variable from a prescribed limit needs to be determined at a glance.

In addition, the graphical display of information is favored when the information is inherently spatial and multiple spatial relationships need to be determined at a glance. Both information mediums can be displayed within a stand alone or shared traffic display. Many of the recommendations listed below are applicable to all display types (e.g., location, size, and resolution), however, if a guideline is specific to a display type, it will be so stated.

9.1.1 General Display Recommendations (stand alone and shared):

9.1.1.1 Display Location: CDTIs and their associated controls should be co-located to the maximum extent possible to facilitate parameter adjustment and monitoring function selection. During the normal operation of associated controls, or when the flight crew is engaged in normal cockpit window monitoring, all areas of the CDTI shall be visible to the crew from the design eye positions, assuming binocular vision. If a third crew member is required to monitor the CDTI, it should be visible and legible from the seated position with the (shoulder) harness condition specified for the phase of flight

9.1.1.2 Display Size, Addressability, and Resolution: The CDTI should be of sufficient size, physical resolution, and addressability to provide visual resolution adequate to perform the intended application.

9.1.1.3 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 flight crew 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 usable display brightness appropriate to the display location.

9.1.1.4 Color: Since color does not require focal attention it is highly useful for “at a glance” retrieval of information. In particular, it can be used as a cue that “pops out” (e.g., alerts, highlighting) and can also be used for more global figure-ground segregation and grouping (e.g., distinguishing traffic symbology from surface or terrain symbology). Thus it supports immediate situation assessment on a display (Reynolds & Metcalf, 1992).

General: The following are general observations on the use of color in displays:

a. Color stereopsis causes reds to appear to advance towards the viewer and blues to recede (especially when viewed against a black background).

b. Adjacent colors should not be equal in luminance when discrimination of edges or detail is important. This is because the human eye uses differences in luminance to detect edges, and thus borders between colors of equal luminance appear blurry.

c. The human eye is more sensitive to colors in the middle of the spectrum (greens and yellows) than at the ends (reds and blues). Consequently, greens and yellows appear to be brighter than reds and blues, with lowest subjective brightness for blue.

d. Color choice standardization with the rest of the flight deck should be considered.

9.1.1.4 (Continued):

e. Colors associated with traffic alerts should be consistent with previously adopted standards (see TCAS MOPS and ARP4102/4). In particular, red should be used for situations that require immediate action, and yellow/amber should be used to signal situations that require immediate awareness and possible subsequent action. If the meaning of the color is important it should be redundantly coded with another visual cue (e.g, shape, size).

Backgrounds: High saturation backgrounds should be avoided as they tend to produce color illusions when color is layered onto them and make it difficult to emphasize foreground information. Care should be used because selecting black as a background because it causes colors to appear to “float” at different depths. Mid-luminance background colors are recommended over black as they improve color perception, color discrimination and depth of field. They render the display visible with higher levels of ambient illumination than do displays with black backgrounds. When background detail is being depicted, shape coding is preferable to color coding. This is because details depicted in unsaturated colors may be difficult to discriminate, especially if the background is colored. A range of grays can be used for this purpose.

Alphanumerics: Because of issues with contrast and discriminability of fine detail in color, achromatic colors (black, white, and shades of gray) are especially suitable for text and numerals. In particular, black text offers a high contrast against many colors of backgrounds.

Visual Fatigue: Highly saturated reds and blues are not suitable for text or small symbols because they have a tendency to be seen on different visual planes, and thus result in focusing problems and visual fatigue. Thus highly saturated colors should be reserved for alert purposes only, where information must be relatively intently focused for relatively short periods. Because achromatic colors are also visually restful, and because too many colors on a display can lead to fatigue and confusion, shades of gray are good choices for lines and symbols.

9.1.1.5 Declutter Interface: Methods for alleviating clutter are recommended because of the potential amount of information to be displayed on a CDTI. Two main methods for clutter alleviation are suppression/removal of information and more effective display organization. In addition the following observations on clutter alleviation apply:

a. The effects of clutter may be alleviated by manipulation of conspicuity. Brighter (more luminous) features tend to be more conspicuous (attract attention), and therefore limit search time. In addition, when a number of identical features are coded using two equally conspicuous colors, the features in the color that appears least often will attract the most attention.

b. The effects of clutter may also be alleviated by the grouping of information and symbology. Grouping assists a user to focus attention on subsets of items, and this may limit the number of items examined when searching for a targeted item. Grouping using the color properties mentioned above (hue, value, and saturation) is very effective, as is grouping based upon spatial proximity. However, a large number of colors or brightness levels may actually be counter-productive to organizing information.

c. The potentially large number of surface aircraft in close proximity during take-offs and landings may create substantial display clutter. Therefore, methods, such as allowing removal of all surface traffic, shall be provided to alleviate the display clutter during take-offs and landings.

d. Grouping and separating information is also a function of the context, shape, size, and identity and presentation (in respect to timing) of the colored area.

e. Transparency is helpful for reducing or eliminating the problems of overwriting (e.g., overwriting data tags). For more information on how to achieve transparency see Reynolds and Metcalf (1992) and Birren (1981, pp. 99-103).

f. Critical information must not become unavailable, or become so obscured that the flight crew is unaware of its presence, due to clutter. Therefore, the flight crew must always be provided with a means of selectively removing data or relocating information to a different area on the display (e.g., by moving or dragging an information tag to an uncluttered part of the screen, or by "bringing it up" in a dedicated information box).

g. Decluttering options should not lead to loss of information required for aircraft operation. To this end, "automatic" decluttering (e.g., deleting/relocating information without user input) should be avoided whenever possible, and symbology indicating cautionary or above alert levels should be protected from removal.

9.1.1.6 Mode Annunciation: The system may operate in different “modes” in which the information provided to the crew is dependent on the functions being performed. The mode of the system at any one time may be automatically determined or selected by the crew. The operating mode of the system should be clearly indicated. All mode changes should be highlighted to aid the flight crew in determining that a mode change has occurred.

9.1.1.7 Status Annunciation: Failure, degradation, and level of performance of the CDTI or other component of the system should be clearly indicated.

9.1.2 Graphical Information:

9.1.2.1 Traffic Symbology: The symbology and associated text on a graphical display represents the majority of CDTI specific information. Unless there is a demonstrable improvement, symbology should be consistent with currently utilized symbols. The most important symbols on a graphical CDTI are those which depict traffic and own ship. These symbols have some or all of the following properties: size, shape, hue, saturation, brightness, orientation. For each of these properties, there may or may not be associated meaning. In addition, each symbol may have associated textual tags. Dynamic changes to aircraft symbology should not lead to confusion about aircraft identity.

Symbol Size: Traffic symbols must be large enough to be easily seen and recognized, but not so large as to lead to undue clutter.

a. If symbol size is to be used for discrete coding purposes then it should be limited to two widely different sizes (ICAO, 1993).

b. When possible, brightness contrast rather than size should be used to adjust symbol salience.

c. Smaller sized symbols may need to be solid (filled) in order to be adequately discriminable from background information.

d. There should be an easily perceived location on the symbol that most closely approximates the location of the depicted aircraft (e.g., the center of a circular aircraft symbol or the apex of a wedge symbol).

e. In general, small symbols will need a greater luminance contrast than linear features if they are to be of equal conspicuity. Colors for lines should be relatively unsaturated with just enough luminance difference to ensure good visibility without being intrusive. Luminance varies with line thickness. If lines of different thickness are to be of the same conspicuity, the thinner lines must have added luminance.

Symbol Shape: The complexity of the symbol shape may have an impact on usability.

9.1.2.1 (Continued):

Symbol Orientation: Symbol orientation can be an important characteristic since aircraft have direction, and pilots may intuitively encode this information. Symbols such as chevrons, or circles with predictor lines are potential examples. It takes much longer to visually “read” complexly coded shapes unless these shapes have highly intuitive meaning. In addition, for any fixed symbol size, higher resolution displays are required to adequately render more complexly articulated shapes. Thus more complex shapes must generally be larger, and therefore more cluttering.

Trend Information: Studies of CDTI usage have shown that Graphical trend symbology may be desirable for some functions (Jago and Palmer, 1980; Lester and Palmer, 1983; Palmer, Jago, Baty, and O’Connor, 1980). Graphical predictors may show a predicted path that an aircraft is expected to take, or a position that an aircraft is predicted to occupy at some point in the future. In either case predictors may either be time-based (extended out along the predicted path for the next "X" minutes) or distance-based (extend out along the predicted path for the next "X" miles), although conflict prediction requires time based predictions. Different predictor types have been associated with different functions or usage.

a. Predictor reference frame: Generally, one of two reference frames are used in the depiction of trend vectors: ground referenced, which presents predicted movements over a stable underlying ground plane; and own ship referenced, which presents predicted movements of traffic with respect to own ship. Own ship referenced predictors may also be referred to as relative trend predictors.

b. Ground referenced predictors represent predicted movements over a stable underlying ground plane. These predictors may predict either traffic or own ship path and position, and are useful for monitoring and maintaining spacing intervals between aircraft.

c. Own ship (relative) referenced predictors represent predicted movements of traffic with respect to own ship (e.g., predictors from which own ship motion has been subtracted). These predictors have been shown to reduce reaction times for the task of identifying who will cause a conflict, even in high traffic densities (Lester and Palmer, 1983).

d. If own ship and ground referenced predictors are mixed, care should be taken that it not result in confusion.

e. When the paths of a large number of aircraft are being predicted, methods for reducing the cluttering effects of presenting large number of predicted paths should be instituted.

f. If predictor indicators are to be useful at a variety of ranges, then they must be able to be adjusted to different lengths (e.g., a five mile predictor is too large if the display range is five miles, but may be too small if the display range is 160 miles).

g. If the predictor indicators are designed to aid in extrapolating the 4-D (space and time) path of the aircraft, then they should be based on a time criteria.

9.1.2.1 (Continued):

A significant number of studies have examined various ground referenced predictor concepts (Hart and Wempe, 1979; Palmer, et al. 1980; Sorensen, 1983; Sorensen and Goka, 1983; Sorensen, et al. 1990; Williams, 1983; Williams and Wells, 1986). A summary of the recommendations based on these findings are as follows:

a. Distance spacing criteria are of limited use for decelerating situations, which are typically found in terminal area approach operations. The results of these studies indicate that distance spacing criteria should only be used for constant-speed operations and is not suitable for terminal area station keeping.

   It was also noted that it was difficult for the pilots to detect a change in the spacing interval and that once spacing became too close, it could not be regained. In this regard, a deceleration cue for the leading aircraft was found to be more important than sensor accuracy. Both groundspeed information of the leading aircraft and a relative predictor of the leading aircraft's position have been found to be beneficial in providing this deceleration information.

b. An airborne time-based queue may be used to meet an ATC distance spacing requirement. To support this capability, the desired Final Approach Fix crossing separation, R_{cross}, and the crossing speed, V_{cross}, must be known. Both of these variables may be provided by ATC or may be part of a standardized clearance for use in this type of operation. With both R_{cross} and V_{cross} known, the time constant T_P value to be used for all of the time-based criteria is $T_P = R_{cross} / V_{cross}$. For example, to obtain a 3 nmi separation with a 150 kt FAF crossing speed would require a 72 s separation interval (Williams 1983).

9.1.2.2 Traffic Update Rate: Traffic update rate should be sufficient to support the intended application. In between updates, traffic should be extrapolated in order to maintain smoothness of motion. To the maximal extent possible, all aircraft on the display should show equivalent smoothness of motion.

9.1.2.3 Symbol Persistence: For information or symbology in boundary conditions, cycling between the conditions should be prevented. Three examples of such cycling are

a. Altitude tag fluctuation, such as cycling between +10 and +11 when target is 1050 ft above own ship.

b. Traffic symbol fluctuation, such as cycling between a displayed and a non-displayed state when target is flying right at the limit of the display filter.

c. Alert level fluctuation, such as cycling between higher and lower alerts when at alert level boundaries.

9.1.2.4 Reference Frame: The 2-D Plan View Display can function with a heading-up/track-up or north-updisplay viewpoint. In general, the north-up display has been found to facilitate the formation of a "cognitive map" (Aretz, 1991). However, the costs of mental map rotation associated with the north-up format have been well documented (Aretz & Wickens, 1992; Olmos, Liang, & Wickens, 1997). As a result, whenever possible, a heading-up format should be the default view for the Plan View Display with a north-up option available to the operator. If both formats are available, provisions should be provided to allow the operator to switch from a heading-up to a north-up orientation with a single action.

9.1.3 Textual Information (dedicated and shared graphical displays):

9.1.3.1 Target Flight ID: Target Flight ID's should be available for all cooperating aircraft on the display. To minimize display clutter when presenting Flight ID's, display filters (e.g., altitude filters, range filters, etc.) may be provided and/or provisions may be made to allow the removal of Flight ID's with a single action.

9.1.3.2 Altitude information should be available for all cooperating aircraft on the display and can be encoded textually or graphically.

a. Altitude information should allow the flight crew to discriminate altitude to at least the nearest 100 ft.

b. For textual data, altitude information may be coded in terms of absolute altitude or in altitude relative to own ship or both. Provisions should be made to allow the operator to switch altitude indications.

c. When altitude is displayed solely in textual format, relative and absolute formats should be exclusive options (there will be no mixed presentations with some aircraft using relative format and other aircraft using absolute formats).

d. When altitude filters are being used, a means should be available to ascertain the filter value.

e. Climbs/descents should be indicated when above 500 ft/min (e.g., up and down arrows per TCAS MOPS).

9.1.3.3 Abbreviations: Since display clutter is an important CDTI issue, abbreviation will be an important technique. Moses & Ehrenreich (1981) found that the most important principle is to employ consistent rules of abbreviation. Norman (1981) states that abbreviated terms should be as logical and meaningful to the user as possible. In any case, the operational context must be such as to resolve any ambiguity in an abbreviation. In addition, the following has been found or proposed

a. Word combinations should be abbreviated by using the individual abbreviations separated by a space.

b. Avoid using periods and use hyphens only to improve understanding, (e.g., F-PLN rather than FPLN).

c. Use slashes to indicate dual or alternate functions (e.g., AP/FD = AUTOPILOT and/or FLIGHT DIRECTOR).

d. Upper case letters are used except where lower case letters are standard practice (e.g., Hg for mercury).

e. Norman (1981) suggests that minimum relatively uniform abbreviating principles should be employed (i.e., all abbreviations of common length).

f. Moses & Ehrenreich (1981) found that truncated abbreviations are processed better than contracted abbreviations.

9.1.3.4 Data Tag: A CDTI data tag may be defined as one or more text strings describing attributes of a specific traffic symbol. Data tags are important elements within graphical displays, since they can present information that cannot be depicted graphically. In general, the following applies to the use and formatting of data tags

a. At a minimum, the data tags should include target altitudes (relative or MSL) when presenting traffic on a 2-D Plan View Display. Other information may also be included within the data tag (e.g., flight ID, ground speed, altitude rate).

b. Since data tags are usually much larger than the associated traffic symbology, they can significantly contribute to clutter by overwriting or obscuring the graphical symbology and each other. Therefore, the size of text used in data tags should be the smallest size necessary.

c. To minimize scanning costs, data tags should be located in close proximity to the target symbols with which they are associated. In displays where close proximity is not possible, the user should be provided with an intuitive means of associating the data tag with the traffic symbol (e.g., lines connecting the tag and target symbol, color-coding the data tag and traffic symbol).

9.1.3.4 (Continued):

d. Since reading time and accuracy may degrade with non-canonical text orientations (particularly for longer text strings), any use of rotated text should be tested prior to implementation.

e. Data tags interfere with at-a-glance extraction of information from the CDTI because they must be read individually. Integrated graphic symbology may eliminate or reduce the need for reading data tags. Adding color to graphic symbols can provide an additional means of labeling or attaching information without resorting to alphanumerics. Data tags interfere with "at a glance" extraction of information from a CDTI because they must be read individually. Integrated graphic symbology may eliminate, or reduce, the need for reading data tags. Adding color to graphic symbols can provide an additional means of labeling or attaching information without resorting to alphanumerics.

9.1.3.5 Text Change Indication:

9.1.3.6 Information Storage:

9.1.3.7 Font: Figures and letters should subtend not less than the following vertical angles at the design eye position of the flight crew member who normally uses the instruments:

a. Primary data: 6 milliradians
b. Non-essential and secondary data: 4 milliradians
c. Minor descriptive legends: 3 milliradians

The required resolution (pixel density) for any font needs to be sufficient to avoid distracting staircasing or other aliasing effects. Lower resolutions may be supplemented with anti-aliasing techniques (e.g., font "hinting") in order to achieve this aim.

9.2 Aural Display Characteristics:

a. Aural alerts should be integrated and consistent with the flight deck alerting system and alerting philosophy.

b. Time critical and urgent alert characteristics should be standardized.

c. Alerts should be prioritized.