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Considerations for Implementation and Allocation of Traffic Alerting Functionality

February 9, 2012

DOT/FAA/TC-TN12/4

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16. Abstract

Flight crew response to alerts issued by the Traffic Alert and Collision Avoidance System (TCAS) may be degraded by additional situational awareness alerts from new Next Generation Air Transportation System (NextGen) airborne applications. The intent of this paper is to suggest methods of situational awareness alert integration that maintain the TCAS-required collision avoidance support function while supporting NextGen applications. This paper describes the existing TCAS and Aircraft Surveillance Applications system requirements, and examines expected situational awareness alerts, including TCAS traffic alerts. While the alerts all have a similar function, the parameters of the alerts may vary considerably, both in application and due to operational conditions.

Alternatives for future integration of alerting systems are discussed, including issues surrounding such integration. It is assumed that the collision avoidance function will retain some level of independence from the separation provision. Areas requiring additional study are described.

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LIST OF ACRONYMS

ACAS	Airborne Collision Avoidance System
ADS-B	Automatic Dependent Surveillance - Broadcast
ADS-R	ADS-B rebroadcast
AFM	Aircraft Flight Manual
ASA	Aircraft Surveillance Applications
ASSAP	Airborne Surveillance and Separation Assurance Processing
ATC	Air Traffic Control
ATCRBS	ATC Radar Beacon System
CAS	Collision Avoidance System
CDTI	Cockpit Display of Traffic Information
EFB	Electronic Flight Bag
FAA	Federal Aviation Administration
IL	Interference Limiting
MOPS	Minimum Operational Performance Standards
NAS	National Air Space
NEXTGEN	Next Generation Air Transportation System
QTA	Quasi-TA
RA	Resolution Advisory
RF	Radio Frequency
TA	Traffic Alert
TIS-B	Traffic Information System - Broadcast
TSA	Traffic Situational Awareness alert
TSAA	Traffic Situational Awareness with Alerts (ASA application)
TCAS	Traffic Alert and Collision Avoidance System
VFR	Visual Flight Rules
VSI	Vertical Speed Indicator

Executive Summary

The introduction of new Next Generation Air Transportation System aircraft-based applications to the National Airspace System is expected to generate various types of situational awareness (traffic) alerts on intruder traffic. The addition of these alerts to the existing Traffic Alert and Collision Avoidance System (TCAS) traffic alerts may increase pilot workload and distract the flight crew from the collision avoidance function. This paper seeks to define the Traffic Alerting function, and to investigate alternative ways to efficiently implement this function across the TCAS and ASA systems (including future systems) to minimize overlap, improve performance, and reduce any unnecessary situation awareness alerts.

This paper provides a high-level overview of the TCAS and Aircraft Surveillance Applications (ASA) systems, and expected conflicts between the situational awareness alerts generated by each. Possibilities for improved integration of the two systems (including future systems) are discussed, along with concerns about possible degradation to TCAS effectiveness.

Conclusions for integration of situational awareness alerts in TCAS and ASA are presented, along with suggestions for additional research to address integration concerns.

1 Introduction

Aircraft operating in the National Airspace System (NAS) are protected from mid-air collisions by a multi-layered approach. The layers are relatively independent of one another. Figure 1 shows one depiction of this setup[1]. At the topmost level, the NAS is structured so that aircraft operate in predictable ways following rules that all aircraft must follow. At the next level, in certain airspace[2], Air Traffic Control (ATC) uses radar and Automatic Dependent Surveillance - Broadcast (ADS-B) surveillance systems coupled with voice communications to provide separation assurance to pilots via clearances and tactical direction. And finally, the Traffic Alert and Collision Avoidance System (TCAS) provides the collision avoidance function as a last-ditch effort to direct the pilot to take tactical maneuvers to escape catastrophe[3].

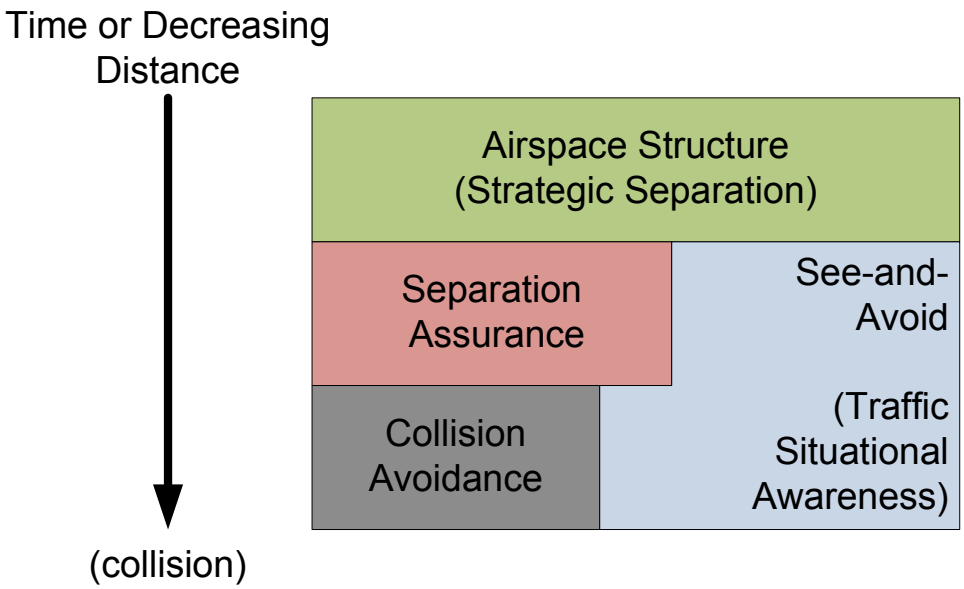

Figure 1 - Depiction of the Layers of Protection from Collision

Parallel to the Separation Assurance and Collision Avoidance functions is "See-and-Avoid". See-and-avoid is the most basic and important function of the pilot in order to maintain safety of flight. It is a requirement in Code of Federal Regulations Title 14 Part 91.113 (b) as follows:

> *When weather conditions permit, regardless of whether an operation is conducted under instrument flight rules or visual flight rules, vigilance shall be maintained by each person operating an aircraft so as to see and avoid other aircraft. When a rule of this section*

[1] Figure 1 is adapted from a nearly identical figure from "Safety Metrics for Future Collision Avoidance Systems", prepared by the RTCA SC-218 Safety Subgroup

[2] The "separation assurance" box in figure 1 has less width than "airspace structure" because it is only applied in certain airspace, whereas airspace structure is true for the whole NAS.

[3] The "collision avoidance" box in figure 1 has less width than the "airspace structure" box for similar reasons – because only certain aircraft are required to be equipped with TCAS. Any comparison of whether "Separation Assurance" and "Collision Avoidance" is more or less prevalent in the NAS is unintentional.

gives another aircraft the right-of-way, the pilot shall give way to that aircraft and may not pass over, under, or ahead of it unless well clear.

Currently, TCAS equipment provides a traffic display that aids the pilot in visual acquisition of other aircraft. The TCAS Minimum Operational Performance Standards (MOPS) defines required symbology to differentiate four intruder threat levels: Resolution Advisory[4] (RA), Traffic Alert (TA), Proximate Traffic, and Other Traffic, as described in Section 2.2.3 of this paper. This traffic awareness function is provided to pilots, although the pilots are told not to maneuver based on information gathered from the traffic display. That data, however, can be informally used to assist in the detection of aircraft in the pilot's visual scanning, thus assisting the see-and-avoid function.

Similarly, Aircraft Surveillance Applications (ASA) systems are being developed to take advantage of ADS-B, as well as Traffic Information Services – Broadcast (TIS-B) and ADS Rebroadcast (ADS-R). These systems will, at a minimum, provide increased traffic situational awareness, although through independent, and possibly more accurate, means than TCAS surveillance. ASA applications may include separation assurance and perhaps even collision avoidance.

ASA systems require a traffic display similar to TCAS displays, and also require integration of TCAS, when present, for a single display from all surveillance sources.

This paper seeks to define the Traffic Alerting function, and to investigate alternative ways to efficiently implement this function across the TCAS and ASA systems (including future systems) to minimize overlap, improve performance, and reduce any unnecessary alerts that distract from the collision avoidance function proper.

2 Background

In the early 1990's, flight crews were first provided with a graphic traffic situational awareness display. This was part of TCAS. The display was provided to assist the flight crew in visually locating and identifying threatening aircraft, and also to assist in clearing the airspace prior to any collision avoidance maneuvers.

The widespread equipage of TCAS, which was mandated, led to the introduction of other concepts that used the traffic display to leverage efficiency and capacity benefits (e.g. In-Trail Climb). Manufacturers also increased the surveillance range to provide enhanced traffic situational awareness. Concerns about lack of aircraft identification generally restricted the implementation of these uses of TCAS.

Later in the decade, ADS-B was introduced as a new surveillance concept. This concept enables traffic displays with longer ranges, greater horizontal accuracy, and significantly more traffic information than available with TCAS. As a separate system, it would also remain independent

[4] TCAS I does not include Resolution Advisory capability.

from TCAS. A number of airborne operational concepts have been developed using ADS-B surveillance information that promise enhanced safety, capacity, and efficiency. The system for these "applications" of ADS-B is the ASA System[5]. It is expected that most large aircraft will eventually be equipped with both TCAS (which is currently mandated) and ASA.

The alerting parameters for TCAS were designed to provide adequate time for traffic identification (out the window) and any collision avoidance maneuvers while being fairly compatible with ATC standard separations. However, some view the number of TCAS alerts to be excessive.

The introduction of some ASA applications will introduce more incompatibility problems with TCAS, as these applications seek to improve efficiency by tightening the separation between aircraft.

2.1 Definitions of traffic situational awareness, separation assurance, traffic alerting, and collision avoidance

As discussed in the introduction, the NAS includes different layers of protection from collision. As applied to airborne systems, such as TCAS and ASA, the terminology is generally defined as such:

Situational Awareness is the perception of elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future.[6] As applied to Traffic Situational Awareness avionics systems, it generally means providing traffic information to the flight crew in a format that increases their ability to perceive, comprehend, and project the location and relative movement of nearby traffic.

Separation Assurance *should* mean assurance that legal separation will be maintained. The term Airborne Separation Assurance has been more generally (mis)applied to airborne surveillance systems that could (in the future) provide Separation Assurance features, or at least aid the flight crew in Separation Assurance. While such features are envisioned, most applications of the surveillance information that are currently under consideration do not provide Separation Assurance. As such, current RTCA/EUROCAE standards documents refer to these applications as Aircraft Surveillance Applications.

Traffic Alerting is generally defined as providing alerts on traffic that are projected to violate some sort of spacing or separation parameters relative to ownship, such as a minimum altitude and range.

All of these functions can contribute to protection from a collision. Collision Avoidance, however, is generally applied to "last minute" collision warning (and guidance) to prevent a mid-

[5] See Minimum Operational Performance Standards for Aircraft Surveillance Applications (ASA) System, RTCA DO-317A (2011).
[6] Endsley, M.R. (1995). Toward a theory of situation awareness in dynamic systems. Human Factors 37(1), 32–64.

air collision or uncomfortably close spacing with another aircraft when other separation provisions have failed.

Two general categories of avionics systems currently provide these capabilities: TCAS and the ASA system. TCAS is primarily focused on collision avoidance, but also provides a graphical display to support traffic situational awareness, and traffic alerting.

The ASA system is focused on providing safety and efficiency improvements through a variety of possible applications. The ASA system is capable of providing additional traffic information (compared to TCAS) to improve situational awareness, such as traffic directionality. ASA could include collision avoidance functionality, replacing the existing TCAS system, although there are concerns such as independence.

Due to their different surveillance sources, the traffic visible to either system may be different, especially prior to a mandate for ADS-B out. When installed on aircraft with TCAS, ASA requires that TCAS data be integrated with ASA to provide a single traffic display.

2.1.1 Description of Acronyms used in This Document

The similar concepts and functions in this document are likely to cause confusion, as legacy, current and future systems are expected to include variations on these concepts and functions. The following acronyms are used throughout the document, and an understanding of their usage within the document may reduce confusion. Several of these terms are unique to this document:

TCAS (Traffic Alert and Collision Avoidance System). The current TCAS system.

CAS (Collision Avoidance System). A current or a future collision avoidance system or function, such as ACAS X (see section 2.2.5).

TSA (Traffic Situational Awareness Alert) – A generic term for any traffic alert used to promote traffic situational awareness, including TCAS TAs, quasi-TAs, and other spacing or separation application alerts.

TA (Traffic Alert). A traffic alert generated by TCAS.

QTA (Quasi-Traffic Alert). A traffic alert function provided by the ASA system, which may attempt to emulate a TCAS-generated traffic alert.

Figure 2 may help visualize the three alerting terms. The sets of traffic generating TCAS TA and quasi-TA are similar, but probably not identical due to differences in surveillance information and processing. The whole set of traffic generating Traffic Situational Awareness Alerts includes TCAS TAs, quasi-TAs, and other application alerts that may include or intersect with the TA and/or quasi-TA sets.

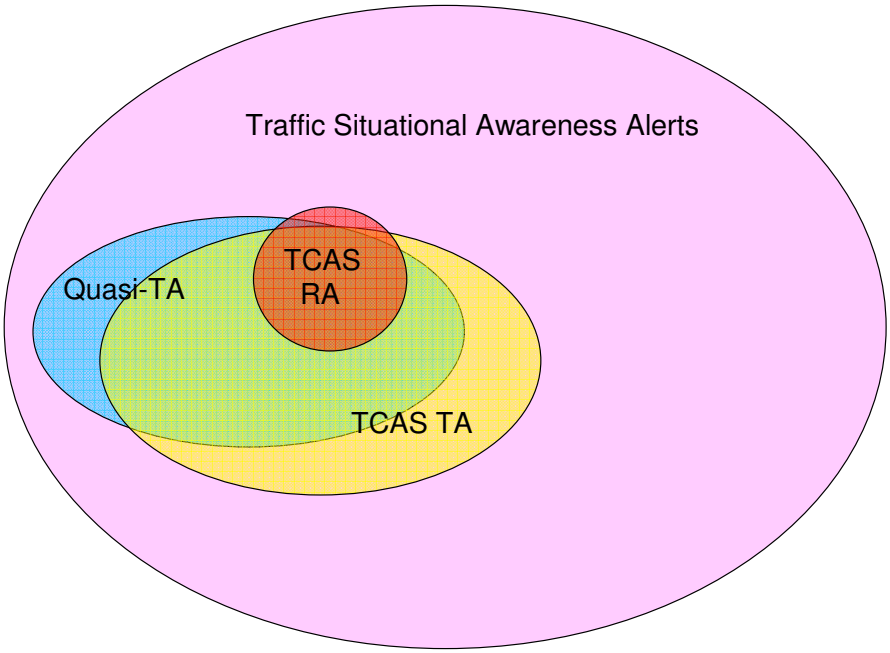

Figure 2 - Relationship of Traffic Alerting Terms Used in This Document

A TCAS RA may also be considered to be a Traffic Situational Awareness Alert that includes guidance. Ideally, all traffic generating TCAS resolution advisories would be a subset of traffic generating TCAS TAs and quasi-TAs.

The following sections provide an overview of TCAS and the ASA system.

2.2 TCAS II Overview

TCAS[7] is an airborne collision avoidance system intended to function as a safety back-up to the ground ATC system. TCAS operates by actively interrogating nearby transponder-equipped aircraft and tracking the received replies. As shown in figure 3 below, TCAS has two types of displays: a traffic display and one or two Resolution Advisory displays. TCAS collision avoidance logic constantly monitors the tracked intruders. If an intruder becomes 'close' (a near threat, see below), TCAS will issue a TA, annunciated 'Traffic, Traffic,' and show the intruder symbol in yellow on the traffic display. If the intruder comes closer still (a threat), TCAS will issue a RA, a vertical maneuver instruction to the pilot. The intruder symbol on the traffic display turns red; the maneuver is shown on the RA display; and the RA is annunciated. TCAS

[7] This section describes TCAS II. TCAS I systems are similar, but do not include Resolution Advisory capability. See Minimum Operational Performance Standards for Traffic Alert and Collision Avoidance System II (TCAS II), RTCA DO-185B (2008).

will issue the least disruptive maneuver that provides adequate vertical separation; this can be in the form of a positive command (e.g., "Climb") or a negative command, (e.g., "Maintain Vertical Speed" or "Level-off").

TCAS provides some degree of protection against all transponder-equipped aircraft. If the intruder is altitude-reporting, TCAS will issue both TAs and RAs against the intruder. If the intruder is non-altitude reporting, TCAS will issue only TAs against that intruder. If the intruder is TCAS-equipped, the two aircraft will coordinate their maneuvers by exchanging Mode S messages.

Both TAs and RAs are based on the concept of tau, or time to closest approach. Tau and other TCAS logic parameters vary depending on the altitude of own aircraft. For example, RA warning times vary from 15 seconds at the lowest altitudes to 35 seconds at altitudes above 42,000 ft. TAs occur 10-13 seconds prior to RAs and are intended to give the pilot time to visually acquire the intruder in preparation for a possible RA.

TCAS determines whether an intruder is a threat by performing tests in both range and altitude. In simplest terms, if the range tau (slant range divided by range rate) is less than a specified value (nominally[8] 25 seconds), the predicted altitude difference at the time of closest approach is computed. If the predicted altitude difference is less than a specified value (nominally 600 ft), then the intruder is declared a threat. In the selection of an RA, TCAS models the intruder as maintaining its current vertical rate and models own aircraft as either climbing or descending at 1500 fpm. TCAS then selects the vertical sense (up or down) that provides the desired vertical separation (nominally 350 ft) at the time of closest approach. The tests for determining a near-threat (TA) are similar but use larger parameter values.

2.2.1 TCAS Architecture

A block diagram showing the major TCAS components is given in figure 3 below. A functional block diagram is given in figure 4.

The 'TCAS computer unit' in figure 3 houses both the surveillance and CAS logic. These two functions are shown in figure 4, with the one block indicating the Surveillance function shown above the dashed line, and all of the blocks that make up the CAS function shown below the dashed line. Surveillance is described in detail in 2.2.2 below and is functionally separate from the CAS logic. As currently implemented, TCAS surveillance handles interactions with the radio frequency (RF) environment and passes established tracks to CAS. As shown in figure 4, CAS performs tracking of own and intruder aircraft, performs range and altitude tests to determine TA and RA status, selects the sense and strength of RAs, and displays this information to the pilot. During the time that an RA is active, TCAS transmits RA reports each scan to nearby ground ATC radars. In the future, this same RA information can be broadcast in ADS-B transmissions.

[8] Nominal values shown in this paper are the values of the logic parameters when own aircraft is between 5,000 ft and 10,000 ft.

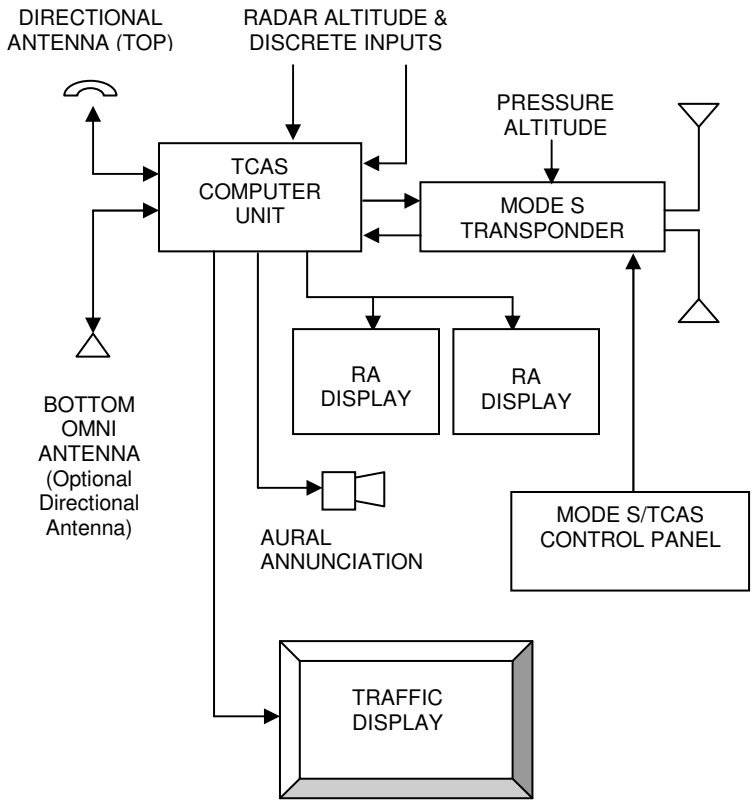

Figure 3 - TCAS Components

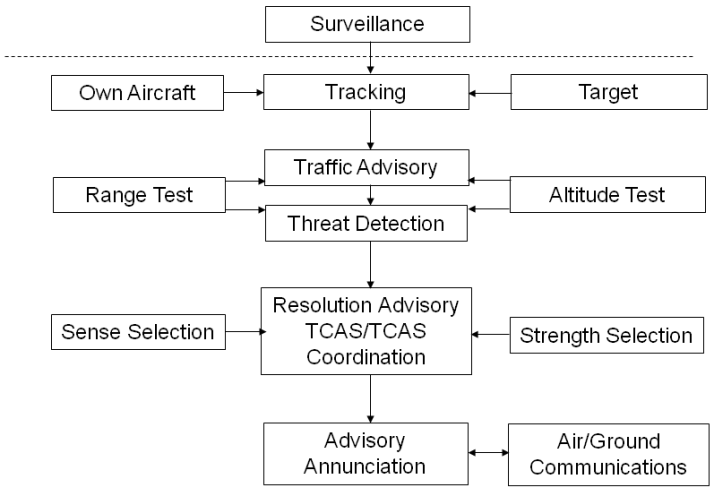

Figure 4 - TCAS Functional Diagram

2.2.2 Means of Surveillance

TCAS and ATC ground systems are forms of Secondary Surveillance Radar; they share the same 1030/1090 MHz frequencies and use similar interrogation/reply formats and protocols for performing surveillance of ATC radar beacon system (ATCRBS) and Mode S transponders. TCAS interrogates intruders at a nominal rate of once per second and tracks the intruder range, pressure altitude, and bearing. TCAS calculates intruder range from the interrogation/reply turn-around time. Intruder pressure altitude is contained in a 13-bit field in the intruder reply and is represented as either 'grey code' with 100 ft resolution or binary with 25 ft resolution, depending on the intruder transponder type. Intruder bearing is estimated using a top-mounted direction-finding antenna on the TCAS aircraft. Bearing error is required to be less than 9 degrees RMS for intruders within +/- 10 degrees elevation relative to TCAS and less than 15 degrees RMS for other elevations. Bearing is not used in the basic collision avoidance algorithms (only range and altitude are used); however, the latest TCAS versions use bearing for horizontal miss distance filtering in order to inhibit RAs on intruders that are well separated from the TCAS aircraft horizontally. TCAS use of intruder bearing is mainly for display purposes.

TCAS performs surveillance of ATCRBS and Mode S aircraft using different techniques. All Mode S transponders 'squitter' once per second, spontaneously emitting a 1090 MHz transmission that contains the aircraft discrete 24-bit Mode S address. Once TCAS receives squitters reliably from an aircraft, it thereafter interrogates that aircraft using its discrete address. In contrast, for ATCRBS transponders (which do not have discrete addresses), TCAS transmits 'Mode C only all-call' interrogations, to which all ATCRBS transponders in the vicinity will reply. TCAS uses a technique called Whisper-Shout to separate the replies into groups based on received power, so that the replies do not overlap one another.

TCAS surveillance has a set of rules for forming 'established tracks.' It is these established tracks that are passed once per second to the CAS logic for processing. Tracks that are well beyond the TA boundary are tracked by surveillance at a 5-second rate; these tracks do not go through the CAS logic; they are simply passed through to the traffic display.

To prevent TCAS from interfering with the ground surveillance function, TCAS, from its earliest designs, has included an 'Interference Limiting' (IL) function by which each TCAS determines the number and distribution of other nearby TCAS units and reduces its interrogation power/range accordingly. The IL design is such that each transponder will be occupied on average no more than 2% of its timeline by ALL of the TCAS within the transponder's reception volume.

There is an optional type of TCAS surveillance called hybrid surveillance, which combines data from active TCAS interrogation/reply sequences with data from ADS-B transmissions. Hybrid surveillance allows use of 1090 megahertz (MHz) extended squitter data (the 1090 MHz implementation of ADS-B) for target surveillance only if that data is validated by comparison with data from an active interrogation. Hybrid surveillance includes algorithms for transitioning from passive to active surveillance before an intruder becomes a near-threat, thereby ensuring that TAs and RAs are based on data from active interrogations. Thus, lower TCAS interrogation rates are possible, but collision avoidance independence is preserved. (Note that while TCAS is

often described as being independent of the ground ATC system, this is not total independence since both ground ATC and TCAS make use of aircraft transponders. TCAS is considered independent in the sense that each TCAS unit contains a fully-functioning airborne radar system.)

2.2.3 Requirements for TCAS Displays

2.2.3.1 Traffic Display

As described in the TCAS Overview above, TCAS has two types of displays, a traffic display and one or two Resolution Advisory displays. The traffic display is intended to aid the flight crew in visually acquiring intruding aircraft; in discriminating between near threats (TAs), threats (RAs), and other traffic; and in determining the horizontal position (range and bearing) of transponder-equipped aircraft. Relative altitude is also shown for those targets reporting pressure altitude. All information is updated once per second.

Targets of interest on the traffic display are shown in various shapes and colors as described below and as shown in figure 5:

1. Own aircraft is shown as an arrow-head or airplane-like symbol colored white or cyan.
2. Non-intruding traffic, defined as other targets within the range of the display, are shown as open diamonds, in white or cyan.
3. Proximate targets, defined as aircraft within 6 nautical miles (NM) in range and 1200 feet vertically, are shown as white or cyan-filled diamonds.
4. TA targets are shown as amber-filled circles.
5. RA targets are shown as red-filled squares.

All targets, with the exception of non-altitude-reporting targets and own aircraft, are accompanied by a data tag that shows the relative altitude of the associated target in hundreds of feet. The number is preceded by a plus or minus sign to indicate whether the target is above or below the altitude of own aircraft. If the target aircraft is climbing or descending at 500 feet or more per minute, the altitude data is followed by a vertical arrow pointing up or down[9].

The output of TCAS each cycle to the traffic display is a list of intruders generally ordered by category (RA, TA, proximate, non-intruding traffic) with smallest range having highest priority within each category. Information for each intruder includes range, altitude, bearing, rate arrow (yes/no), and category.

2.2.3.2 Resolution Advisory Display

The RA display is the primary instrument used by the pilot to determine whether an adjustment in aircraft vertical rate is necessary to comply with the RA determined by TCAS. There are various types of RA displays in use, including round dial Vertical Speed Indicator (VSI), vertical speed tape, pitch cues on the Primary Flight Display (PFD), Flight Director guidance, and Head Up Display (HUD).

[9] 500 feet per minute is a nominal value.

The basic requirement is that the display show a green arc (or delineated area) indicating the vertical speed that the pilot is to achieve and a red arc (or delineated area) indicating the speeds that the pilot is to avoid. For example, a climb RA is depicted on the round dial VSI below. A green arc is shown between 1500 and 2000 fpm, with a red arc between -6000 fpm and +1500 fpm.

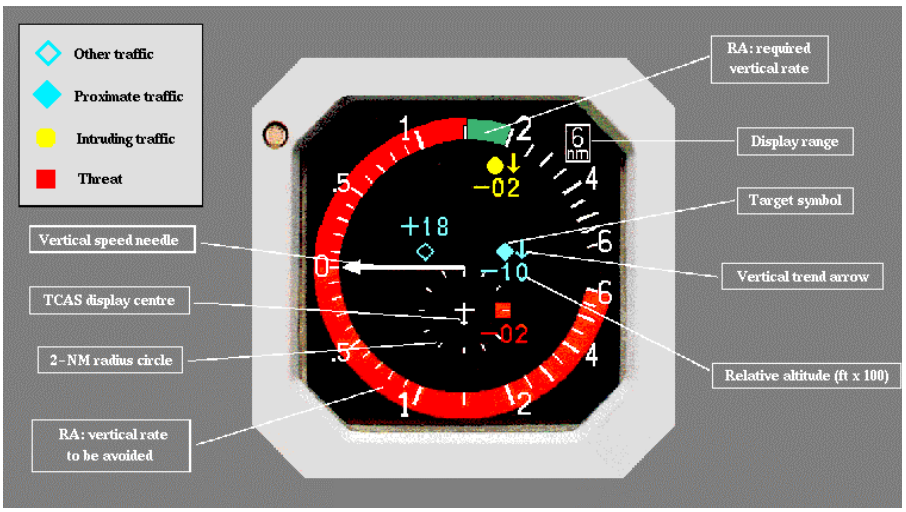

Figure 5 - Combined Traffic Display and RA Display

An aural annunciation accompanies a TA or a RA. TAs are annunciated as "Traffic, Traffic." The annunciation is given once, when the intruder first passes the traffic advisory criteria.

RAs are annunciated once when the intruder first passes the threat criteria; an annunciation is given each time that the RA changes strength or vertical sense. The annunciations used for the latest TCAS version are:

- Basic climb or descend (1500 fpm): "Climb, Climb" or "Descend, Descend"
- Increased strength: (1500 fpm changes to 2500 fpm) "Increase Climb, Increase Climb" or "Increase Descent, Increase Descent"
- Sense reversal (climb changes to descend or descend changes to climb): "Climb, Climb NOW; Climb, Climb NOW" or "Descend, Descend NOW; Descend, Descend NOW"
- Altitude crossing: "Climb, Crossing Climb; Climb, Crossing Climb" or "Descend, Crossing Descend; Descend, Crossing Descend"
- Maintain existing vertical rate: "Maintain Vertical Speed, Maintain"

- Crossing + Maintain: “Maintain Vertical Speed, Crossing Maintain”
- Reduce vertical rate: “Level-Off, Level-Off”
- Preventive RA (no chance in vertical speed required): “Monitor Vertical Speed”
- End of RA: “Clear of Conflict”

The output of TCAS each cycle to the RA display is a set of bits indicating the location of the red and green arcs.

2.2.4 Pilot Use/Response to TAs and TCAS traffic display

FAA Advisory Circular 120-55C describes the use of TAs and the traffic display. Some of the situations likely to cause undesired TCAS alerts are described. ASA applications are expected to be developed to operate more appropriately in these situations.

Note: The following text is from FAA Advisory Circular 120-55C.

12.b.(1) Respond to TAs by attempting to establish visual contact with the intruder aircraft and other aircraft which may be in the vicinity. Coordinate to the degree possible with other crewmembers to assist in searching for traffic. Do not deviate from an assigned clearance based only on TA information. For any traffic acquired visually, continue to maintain safe separation in accordance with current regulations and good operating practices.

12.d.(3) During flight, use TCAS displays to enhance situational awareness. Use displays which have a range selection capability in an appropriate range setting for the phase of flight. For example, use minimum range settings in the terminal and longer ranges for climb/descent and cruise as appropriate.

12.d.(5) It is appropriate to operate TCAS in the TA-only mode in circumstances where unnecessary RAs frequently occur and where such RAs are disruptive to the operation of the aircraft. These circumstances may include:

(a) During takeoff towards known nearby traffic that is in visual contact and which could cause an unwanted RA during initial climb, such as a visually identified helicopter passing near the departure end of the runway. Select the TA/RA mode after the potential for an unwanted RA ceases to exist, such as after climbing above a known VFR [visual flight rules] corridor.

(b) In instrument or visual conditions during approaches to closely spaced parallel runways.

(c) In visual conditions, when flying in close proximity to other aircraft.

(d) At certain airports, during particular procedures, or in circumstances identified by the operator as having a significant potential for unwanted or inappropriate RAs.

(e) In the event of particular in-flight failures, such as engine failure, as specified by the Aircraft Flight Manual (AFM) or operator.

(f) During takeoffs or landings outside of the nominal TCAS reference performance envelope for RAs, as designated by the AFM or operator. TCAS reference performance for RAs is typically attainable during takeoffs and landings at airports within the envelope of international standard atmosphere (ISA) ±50°F, sea level to 5,300 feet mean sea level (MSL). When takeoffs or landings are outside of this envelope, use of a TA only may be appropriate during the limited time period when TCAS reference performance cannot be achieved. This typically occurs when the aircraft is at low speed in specified limiting configurations during takeoff or landing at hot day high altitude airports, such as Mexico City or La Paz.

12.d.(6) When safe, practical, and in accordance with the air carrier's approved operating procedures, pilots should limit VS to 1,500 fpm or less when within 2,000 feet of assigned altitudes. This procedure will reduce the frequency of unnecessary RAs and be in conformance with the Aeronautical Information Manual (AIM) and International Civil Aviation Organization (ICAO) guidance.

2.2.5 Future TCAS

Work is underway to develop a new airborne collision avoidance system, referred to as ACAS X, which will provide more flexibility for aircraft currently equipped with TCAS and provide new capability to general aviation (GA) aircraft not currently covered by a TCAS mandate.

Both of the main modules of the existing TCAS, i.e., surveillance and the collision avoidance logic, will undergo modification. The new surveillance logic is described as 'plug and play,' allowing data from different sources (e.g., active surveillance, ADS-B 1090 extended squitter (1090ES) and ADS-B universal access transceiver (UAT)) to be used separately or fused as appropriate. The new collision avoidance logic is substantially different from that of TCAS and is optimized based on probabilistic models of aircraft behavior in combination with performance metrics (cost functions). A large part of the computations are done offline prior to aircraft installation, and much of the onboard logic is represented as a numerical lookup table that translates aircraft state into optimal action (e.g., no action required, or a specific RA).

Within ACAS X, there are several variants, all of which will utilize the optimized threat logic:

- Xa systems (active surveillance systems) will always have the capability to utilize active 1030/1090 interrogation/reply surveillance techniques. All aircraft currently required to carry TCAS would carry ACAS Xa.

- Xp systems (passive surveillance systems) will not use active interrogation/reply protocols and instead will use ADS-B surveillance to perform collision avoidance. Aircraft not currently included in a collision avoidance mandate would be allowed to equip with ACAS Xp.

- Xo systems (special case operations) are expected to be used in selected Next Generation Air Transportation System (NextGen) operations that, if undertaken with standard ACAS Xa or ACAS Xp logic, would generate an unacceptable rate of nuisance RAs. Closely Spaced Parallel Operations (CSPO) is an example of such an operation. ACAS Xo would seek to provide standard collision avoidance protection against non-participating aircraft (i.e., those not in the parallel approach situation) while removing nuisance alerts for the parallel aircraft on landing approach.

At present, the TA functionality of ACAS X does not differ from that of TCAS, although this functionality has not been addressed with any significant effort.

2.3 Aircraft Surveillance Applications (ASA) System and ADS-B Applications Overview

ASA is an airborne system intended to provide the surveillance, processing, and display capabilities to support a variety of airborne applications of ADS-B (and other surveillance source) data. The minimal application of ASA is enhanced airborne situational awareness (AIRB), which defines the plan-view display of surveilled traffic, similar to a TCAS traffic display. ASA surveillance sources include ADS-B, TIS-B, ADS-R, and, if integrated, TCAS.

In order to present a unified traffic display, the ASA System MOPS requires integration with TCAS if both ASA and TCAS are installed on the same aircraft.

ASA may include additional applications to provide additional capabilities and tools. Most of these applications are enabled by the additional information supplied by ADS-B surveillance. The current applications include:

- AIRB – Enhanced situational awareness for airborne traffic.

- SURF – Enhanced situational awareness for surface (and near-surface) traffic, integrating the display of traffic on airport maps. Ground vehicles may also be displayed.

- VSA – Visual Separation on Approach, which provides speed information on a designated lead aircraft to assist the flight crew with a visual approach.

- ITP – In-trail procedure, which performs application-specific calculations and provides the information, along with aircraft ID, to the flight crew to support requests for closer-than-standard separation altitude changes in procedural airspace.

Additional envisioned applications include:

- TSAA – Traffic Situational Awareness with Alerting, a TCAS-I-like application to provide threat alerting capability onboard non-TCAS equipped aircraft.

- FIM – Flightdeck Interval Management, which provides tools for merging and spacing with other aircraft.

- CD – Conflict Detection, which provides alerts for predicted loss of separation.

- ACM – Airborne Conflict Management, which expands CD functionality to include Conflict Prediction (to examine proposed course changes for conflicts) and Conflict Resolution (to provide suggested resolution maneuvers for conflicts).

- ICSPA – Independent Closely Spaced Parallel Approaches, which provides alerts and blunder protection for parallel approaches in instrument conditions.

ASA provides for the applications with additional data display, processing, and alerts as necessary. Of particular interest (or concern) is the interplay of TCAS and ASA system alerts, especially alerts that, similar to a TCAS TA, are meant to draw attention to intruding traffic.

Some ASA applications apply to all traffic, while others may apply only to specifically designated traffic. ASA includes functionality for designating traffic to a specific application, either automatically or by pilot input.

2.3.1 Functional Architecture

ASA consists of three basic functions: Receive subsystem, Application Processing (ASSAP), and Cockpit Display of Traffic Information (CDTI). These functions can be seen in the Subsystems for ASA Receive Participant box in figure 6.

The Receive Subsystem gathers surveillance information from the available sources. These may include ADS-B, TIS-B and ADS-R. ADS-B is the standard surveillance data source, with TIS-B and ADS-R as available. All ASA data is received passively. The ADS-B/ADS-R/TIS-B Receive Subsystem processes these messages and provides ADS-B, TIS-B, and ADS-R traffic reports to ASSAP.

ASSAP surveillance processing consists of track processing and correlation of ADS-B, TIS-B, ADS-R, and TCAS reports. If multiple sources of surveillance data are used, ASSAP will provide the best source information available.

ASSAP provides reports and tracks, and performs application-specific processing. Surveillance reports, tracks, and any application-specific alerts or guidance are output by ASSAP to the CDTI function.

The CDTI subsystem includes the actual display media and the necessary controls to interface with the flight crew. Thus the CDTI consists of all displays and controls necessary to support the applications. The controls may be a dedicated CDTI control panel or it may be incorporated into other controls, (e.g., multifunction control display unit (MCDU) or Electronic Flight Bag (EFB)). Similarly, the CDTI display may be a stand-alone display or displays (dedicated display(s)) or the CDTI information may be present on an existing display(s) (e.g., multi-function display) or an

EFB. At a minimum, CDTI includes a graphical plan-view (top down) traffic display and the controls for the display and applications (as required).

Note: Figures 6 through 9 are included in the ASA System MOPS (RTCA DO-317A).

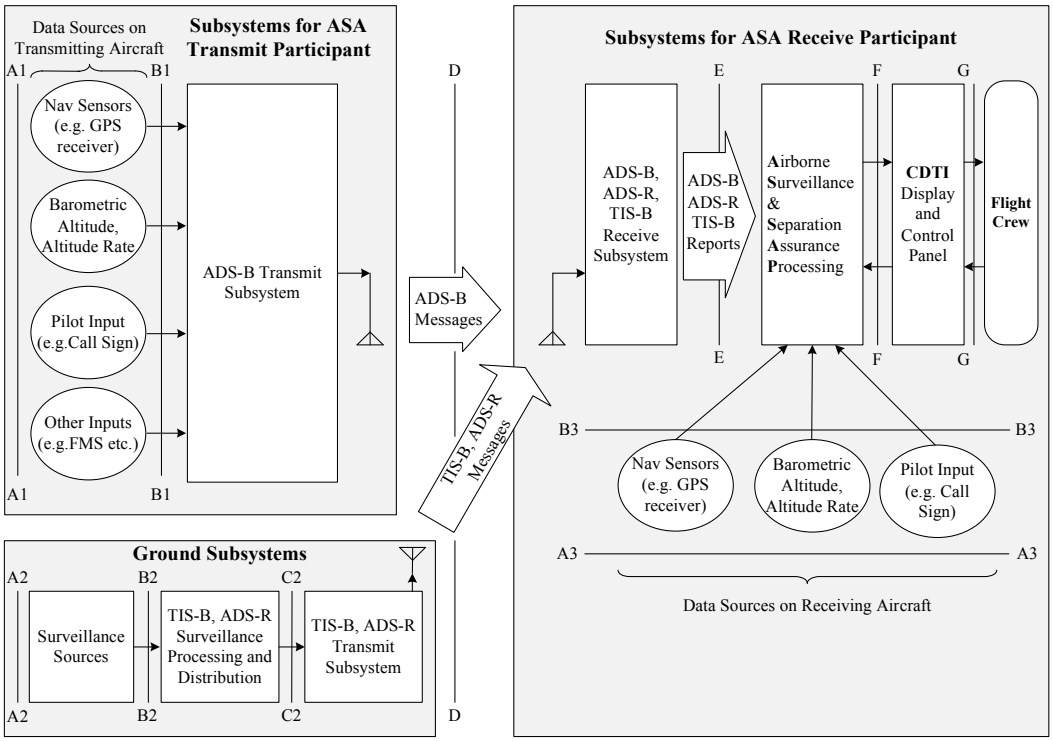

Figure 6 - Overview of ASA System Architecture

2.3.2 Means of Surveillance

The entire ASA Receive System is responsible for the reception and processing of ownship data as well as the reception of ADS-B, ADS-R and TIS-B messages from other aircraft/vehicles and ground systems. This is for the purpose of supporting ASA application processing and providing aural and visual ASA-specific display information to the flight crew.

ASSAP surveillance requirements include track initiation, update, deletion, extrapolation and prediction; track merging and splitting; inter-source correlation (TIS-B & ADS-B/ADS-R; TCAS & others; TIS-B & Ownship) and best selection of data sources. A functional representation of the ASSAP surveillance processing is shown in figure 7. The rationale for this architecture is the need to provide tracks from the best source (if more than one) to application processing, while avoiding the complexity of a fusion tracker as a minimum requirement.

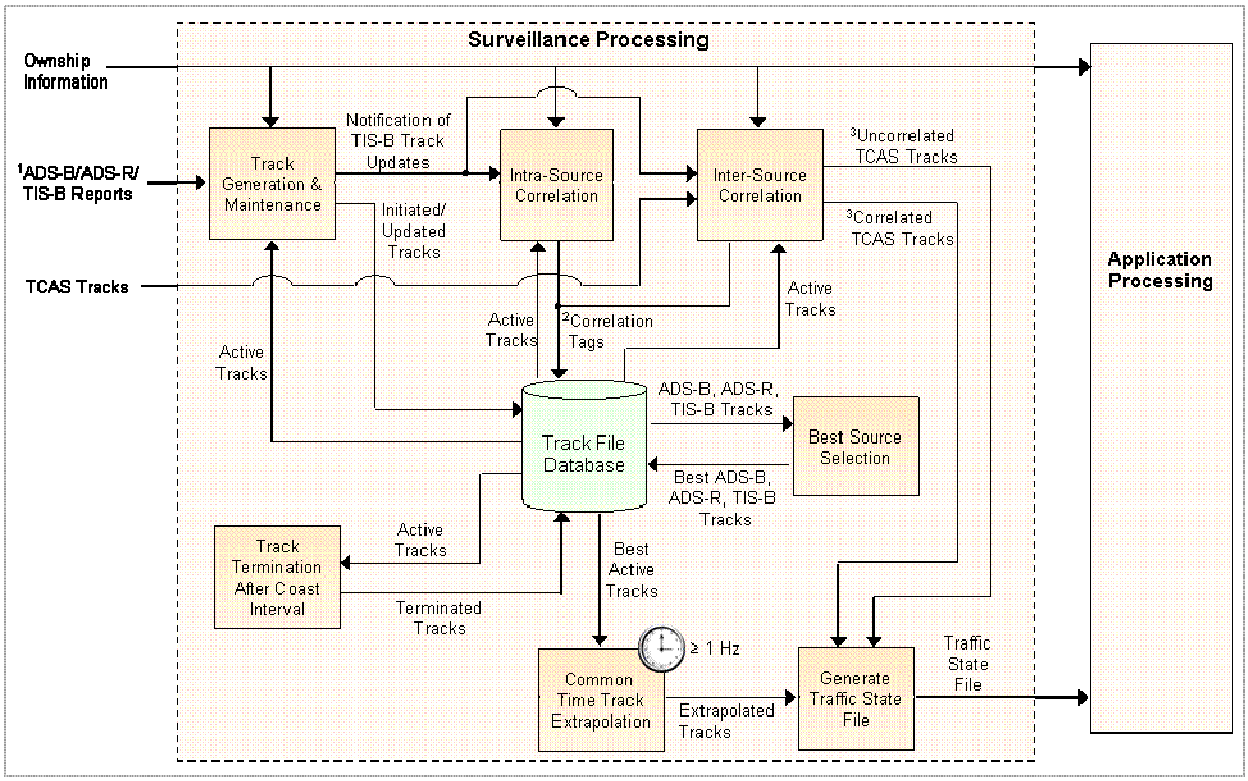

Figure 7 - Example ASA System Surveillance Processing Architecture

Notes:

1. *Depending on the implementation or configuration (1090ES, UAT, or VDL4), ASSAP will receive varying report formats: split state vector and state uncertainty separately, full state vector and state uncertainty, or full state vector and state uncertainty separately. TIS-B processing may be optional, depending on the installation.*

2. *Correlation tags include TCAS correlation tags (e.g., TCAS to ADS). These tags may also pertain to TIS-B to TIS-B correlation, TIS-B to ownship correlation, TCAS to TIS-B correlation, and TIS-B to ADS correlation (if such functionality is implemented).*

3. *TCAS tracks are only merged into the traffic state file when ASSAP determines that TCAS represents the sole surveillance source or best surveillance source for a particular target.*

When multiple source tracks correlate, the best quality source track is chosen based on accuracy and integrity parameters associated with the data. TCAS reports do not contain any of these criteria. When a TCAS track correlates with an existing track, it will only be chosen as the best track when all other source position accuracies drop below the minimum threshold for performing the AIRB application. In all cases, TCAS track flags such as Proximate, TA, or RA

are included with the correlated traffic state file, which is the output of the surveillance processing. The Traffic State File is ordered according to a priority scheme similar to TCAS.

Note: The ASA MOPS does not include specific requirements for TCAS alert data in the correlated traffic state file, but knowledge of this information is required for track prioritization and display symbology.

The Traffic State File serves as the input to Application Processing. (See figure 8)

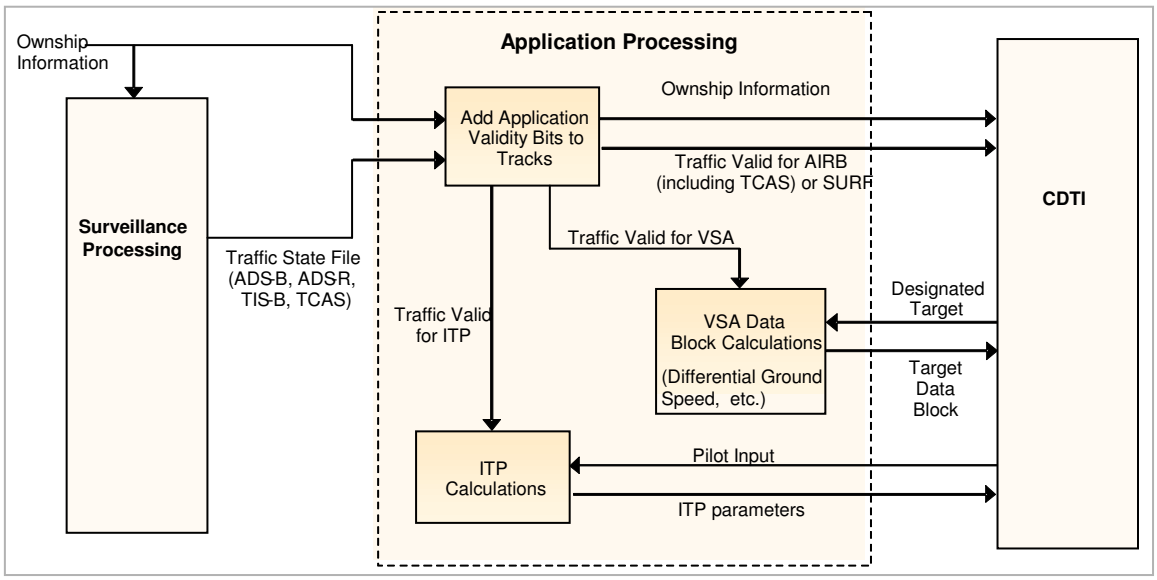

Figure 8 - Example ASA System Processing Architecture

The processor determines whether the data quality of each traffic is sufficient for each installed application, and flags the track as valid or invalid for each. All tracks, except those that are invalid for the minimum application (AIRB) are forwarded to the traffic display. (All TCAS tracks are forwarded to the display.) The processor also provides additional application-specific information to the displays, as required. This can include additional information on specific traffic, additional alerts, etc.

2.3.3 Cockpit Display of Traffic Information

ASA provides a correlated traffic display from all surveillance sources. The traffic position data for correlated TCAS tracks is likely not from the TCAS source. The position source is not affected by changes in the alert level, so that even TCAS TA and RA traffic is still provided with the best available source position data.

Traffic symbology requirements for CDTI were based on TCAS symbology, but must include directionality when available. TCAS-correlated traffic with TAs or RAs use modified symbols which include directionality. Figure 9 shows notional depictions of TA and RA symbols meeting the requirements in RTCA DO-317A.

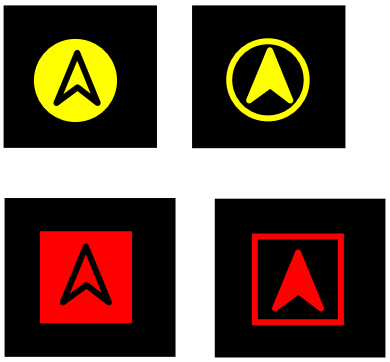

Figure 9 - Examples TA and RA Traffic Symbology Modified With Directionality

Previously published ASA application requirements have included Caution and Warning level alerts for the Conflict Detection and Airborne Conflict Management applications. The alerts were expected to correspond to TCAS TAs and RAs, respectively, for display symbology, as would other applications with similar alerts. The reasoning was that these alert levels are well-defined, and that the display symbology indicates the threat, but other application-specific alerting is also required. Similarly, the TCAS display symbology identifies threatening traffic, but it is the RA display and aural alert that actually provide the resolution advisory.

Note: Because the current version (DO-317A) of the ASA System MOPS does not include any applications that provide alerts, requirements for the use of these symbols for such alerts has been removed from the document. It is expected that it will be restored when such applications are reintroduced in future versions of the document.

All CDTI traffic includes a data tag with altitude information and a climb/descent indication, as in TCAS, but may also include other information, such as Traffic ID. Some applications may require additional data fields.

2.3.4 Use of CDTI Display

The displayed ADS-B information is not currently intended for maneuvering based solely on presence or absence of traffic on the display. As future applications are fielded, we expect that certain maneuvers may be found to be safe and acceptable. The analysis and safety studies to justify such procedures are not yet completed. When those activities are concluded and the maneuvers are shown to be safe and acceptable in the NAS, appropriate maneuvers are expected to be allowed based in part on the displayed ADS-B In information.

2.4 Functional Overlaps between TCAS and ASSAP

Previous sections have introduced the reader to the TCAS processor architecture and the ASSAP processor architecture. These on-board systems assist flight crews with traffic situational

awareness, and can provide guidance and alerting that allow the aircraft to perform collision avoidance maneuvers, spacing maneuvers, and separation assurance maneuvers, independent of air navigation service provider direction, vectoring, or intervention. However, since both systems assist with traffic situational awareness, and provide decision support and guidance to achieve the goals of the flight crew, it is only natural that there would be areas of overlap, where efficiency is best-served by combining functionality or deleting redundant functionality.

Traffic alerts may be provided both by TCAS and various ASA applications, all with different alert triggers based on the application intent. RA triggers may be incompatible with ASA application standard operations. The dilemma for integration is to ensure that TCAS does not inappropriately alert against aircraft that are being monitored by an ASA application. The key to this may lie in the process by which ASA applications are performed, specifically, that applications which allow reduced separation require the flight crew to first designate the target aircraft(s) against which the application will be conducted.

There are several modes of separation possible between aircraft. These include Airborne Collision Avoidance, Airborne Separation, Airborne Spacing, and Ground Separation/Spacing. Only one separation mode can be in effect at a given time, for a given aircraft pair. Thus, if an ASA application providing Airborne Separation or Airborne Spacing is active, it will be necessary to suppress TCAS alerts, or pass information from the ASSAP processor to the TCAS processor informing the TCAS processor to remove the designated aircraft(s) from its Collision Avoidance processing, or to reduce the alerting parameters on the designated aircraft(s) to something compatible with the application. This suppression or desensitization continues until the ASA application has been terminated.

2.4.1 Integration of Traffic Alerts in the ASA System

A number of possibilities exist for integration of traffic alerts in ASA, and additional capabilities for alert integration may be developed for both ASA and CAS.

TCAS alert information is currently provided in the ASA Traffic State File, and may be used to influence ASA application processing. For example, ASA application guidance could be terminated when a TCAS RA is present. Similarly, since all track state information is processed through Application Processing, the TCAS alert outputs to the CDTI could be influenced by specific application processing. Two examples:

1 – If a TSA has been issued on a specific traffic in an ASA application, a subsequent TCAS TA on that same traffic could be suppressed. This would not prevent other TAs from being issued on other traffic.

2 – If an application provides spacings that are incompatible with TCAS while providing alternate collision avoidance protection, the application could suppress TCAS alerts associated with the traffic designated for that application.

Note: Control of the output to the TCAS RA and aural displays is not currently included in the ASA MOPS.

Integration with a future CAS system, such as ACAS Xo (see section 2.2.5), could take advantage of the traffic designation tools in the ASA system. Using the designation tools, one or more specific aircraft is linked to an ASA application. The traffic correlation function should allow determination of the specific TCAS track of the designated aircraft, and then the CAS could use this information to either suppress CAS alerts or alter the alert parameters on the designated traffic. Alert parameters could be tailored to the specific ASA application. The conclusion (or failure) of the ASA application ends the designation, and returned the CAS to normal operation on the traffic.

Note: Current TCAS systems cannot receive input from the ASA system or alter TCAS logic parameters on specifically designated aircraft. The ASA system does not currently output designated traffic information and application information to TCAS.

3 Alternatives for Integration

A number of alternatives may exist for integrating the TA function in an integrated CAS/ASA system. In this section, a number of research questions are discussed that may determine integration constraints.

3.1 Necessity of Traffic Alerting

Question: Can Flight Crews visually acquire or respond promptly and correctly to collision threats without the aid of TAs or similar functionality?

Since its inception, TCAS has issued TAs to flight crews that indicate "the position of another aircraft in the immediate vicinity". However, flight crews are instructed not to maneuver based on this information. As NextGen is implemented, ADS-B is expected to assist with situational awareness similar to the way TAs do in a TCAS system i.e., visual indications on a cockpit display that may or may not be accompanied by an aural annunciation of proximate traffic.

A question naturally arises then, which is, are these two systems performing redundant traffic display and alerting functions? If so, which of them would be the more effective system in which to perform this function? And perhaps more fundamentally – are TAs or TSAs necessary for flight crews to respond to TCAS RAs?

The final question shall be addressed first – we propose that traffic advisories are so ingrained in TCAS, and potentially so critical to its function, that flight crews would not be able to respond to RAs in the manner expected without them. There are three reasons for this:

1. <u>Response Time</u>. In response to a corrective RA, the pilot is expected to respond within 5 seconds. Since it is assumed that there is a TA prior to the RA, the pilot has some time, prior to being required to take the evasive action, to have visually acquired the intruder

(who is soon to become a threat) and verified the situation. If there were no traffic alert function, the pilot would likely look for the threat on the display and then out the cockpit window. The chances of this being done and then commencing the evasive maneuver within 5 seconds are much lower without being prepared by a traffic alert function 10 to 15 seconds earlier. No studies have been conducted on pilot response/reaction times without a traffic alert precursor, and the RA response time assumptions in the TCAS logic were based on studies including TA precursors.

2. TA-only benefits. Safety studies were conducted in Europe that demonstrated the benefit of the TA-only mode (with no RAs) over that of aircraft with no TAs and only a transponder. This benefit was estimated via simulation to be approximately 40% reduction in the frequency of near mid-air collisions (NMACs)10. The study only took into account the TA's ability to prompt the pilot to contact ATC and the value in aiding visual acquisition out of the window. This is a significant benefit without the inclusion of the resolution advisories from TCAS.

3. Familiarity with TCAS. Traffic advisories occur much more frequently than RAs. Data suggests that for every RA issued, there are approximately 35 TAs in the high density terminal areas. Coupling this with more data that suggests pilots only get about 2 or 3 RAs a year (depending on where they fly and many other factors), it would seem that the familiarity with TCAS would be significantly lower without TAs. Flight crews interact with many systems in a complex cockpit environment with varying levels of responsibility. Making sure that the system is familiar to them prior to having to respond in a tactical safety of flight maneuver is critical. TAs are seen to aid that familiarity.

It may be possible to remove the TA functionality from TCAS, but some sort of TA function appears to be a necessary piece of Collision Avoidance. Several sections of RTCA DO-185 include requirements for TAs. Section 2.2.5 defines the Collision Avoidance Subsystem Requirements and item e of this paragraph indicates that as a minimum, the collision avoidance algorithms shall implement the display of TAs and RAs. There are other requirements in Volume I of the document that also require the presence of TAs.

3.2 ADS-B Support for Traffic Alerting Function

Question: Does Global Positioning System (GPS) based (e.g. ADS-B) surveillance provide the necessary accuracy and integrity required to enable visual acquisition and alerts that support prompt and correct collision threat response?

Rule-compliant ADS-B/GPS installations are expected to provide the necessary data quality for accuracy and integrity required to enable visual acquisition and alerts that support a TSA function. In the event of data quality dropping below the thresholds required by the ADS-B Out rule, analysis is being done by the TSAA Working Group to determine the minimum

[10] "WP6 – Final report on post-RVSM ACAS full-system safety study", ACAS Safety Analysis post-RVSM ASARP Project, H. Hutchinson, 3/10/2006, Eurocontrol Mode S & ACAS Programme, pp. 41

requirements on accuracy and integrity for use with the TSA function. CAS developers will also need to do research in this area to decide how to implement the TA function in ACAS X.

3.3 Independence

Several research questions were posed that pertain to the necessity of independence of the TA function from other avionics systems such as Separation Assurance.

Question: Does TA function require complete independence of surveillance source from other aircraft systems for safety purposes?

Question: Does TA function require complete independence of components and software from other aircraft systems for safety purposes. (i.e. Is it insufficient for only RAs to have independence? Is it insufficient for TA function to have partial independence)?

Question: Does the surveillance data for TA functionality have to come from the same source as used for RA to assure TA prior to RA?

Questions about independence are being researched in other venues, with the focus being on determination and resolution of collisions. Regardless of the outcome, we assume that CAS will exist as a separate function from other airborne applications, whether as an independent system or as an independent function.

From section 3.1, we understand that TA functionality is a component of collision avoidance, as an aid to visual acquisition, and a precursor to possible RAs. From section 3.2, we assume that GPS-based surveillance is capable of supporting TA functionality. However, the use of a different surveillance source for the TA function than used for the RA functions may result in variations in the determination of threats, and the issuance of RAs without a TA function precursor.

Standards for a separate (from the RA function) TA functionality could be developed that limit the acceptable rate of RAs without a TA function precursor. (It should be noted that existing TCAS systems do experience pop-up RAs, although these are generally due to late surveillance acquisition, or late determination of the threat, such as due to maneuvering.)

Due to differences in surveillance data, and the complex nature of CAS logic, it may be difficult, or impractical, to reliably provide a TA function precursor to an RA outside of CAS.

One solution to these issues is to maintain the TA function within CAS, while also allowing traffic alert functionality within the ASA system. ASA, integrated with the CAS, would suppress CAS-generated TAs if an ASA-generated TSA is already present on the traffic. Such an approach would allow the benefits of the additional application alerts while avoiding duplication of similar alerts, ensure appropriate TAs or TSAs are provided prior to RAs, and eliminate concerns about the necessity for the independence of TA surveillance and processing (as the function would also remain as part of CAS).

3.4 Traffic Alerting Applications in ASA

Question: Is a TA function included in ASA that will help the Flight Crew visually acquire or maintain minimum airborne separation from aircraft? (No action required for now.)

Currently, none of the ASA applications includes TSA functionality. The TSAA application, currently under development, is expected to provide TSAs for use only in aircraft that are not equipped with TCAS.

3.5 Traffic Alerting Function Parameters

Question: Does TA function require timing parameters similar to TA to be effective for timely collision avoidance response?

- If Yes: Recommend a TA function in ASA to provide alert timing similar to existing TA function, or that CAS maintains the TA function.

The timing of TAs in the existing TCAS logic is generally based on the time to closest point of approach, and the sensitivity level. At higher sensitivity levels (sensitivity level increases with altitude), time to CPA from both TAs and RAs increases. Thus, the time from the issuance of a TA prior to an RA is not fixed, but is nominally within 10 to 15 seconds. However, certain encounter geometries, such as tail chases, may result in TAs that last far longer than the nominal cases without any addition TA notification prior to an RA. As such, it appears that a TA outside of the nominal timing criteria is sufficient.

Assuming that CAS maintains a separate TA function, as suggested above, CAS would continue to generate TAs based on the CAS surveillance source regardless of the presence of ASA QTAs. CAS TAs would only be suppressed in the presence of other QTAs on the same traffic.

Question: If TA functionality includes other traffic situational awareness alerts, are there going to be too many alerts? Does this reduce the preconditioning for an RA?

The number of TAs, and even RAs, issued by the existing TCAS system is of concern to some, although the alerts are appropriate to the design. One concern about reducing the number of TCAS alerts is that, with the alerts being relatively rare events, the flight crew may become too unfamiliar with them and the appropriate response. The existing TCAS system uses wider parameters for TAs than for RAs, resulting in significantly more TAs than RAs.

The question of "too many alerts" appears to be a consideration when designing additional alerting applications. Are the benefits of the application worth the distraction of the alert?

Applications that add traffic situational awareness alerting may not necessarily add to the overall number of alerts, depending upon the integration of the alerts with TA functionality, surveillance

source, alerting parameters, etc. Integration of similar alerts from different applications could limit the overall number of alerts while providing enhanced traffic situational awareness.

For example, a conflict detection application could alert to a loss of separation, followed by a TA. Both alert the flight crew to the traffic of interest. An integrated system could suppress the TA if another TSA (the loss of separation alert) exists on the same traffic.

Question: Does the TA function have to be followable by an RA? That is, what is the effect of having a TA function that cannot lead to necessary collision avoidance guidance (such as TSAs on non-transponder equipped traffic)?

This situation applies only to non-transponder equipped traffic, which are not visible to the current TCAS system, but visible to the ASA system. The addition of these aircraft to the traffic display, and provision for TSAs on them, would be an overall improvement in traffic situational awareness. Future ASA/CAS systems may have additional capabilities/requirements that cover this situation, such as ADS-B input into the CAS function, or some sort of mandated transponder to support CAS.

The existing TCAS system does not currently guarantee that an RA will succeed a TA, even with cooperating aircraft. The altitude thresholds for TAs are larger than for RAs, resulting is significantly more TAs than RAs. TCAS does not provide RAs on non-altitude reporting traffic. TCAS also suppresses RAs below a near-ground altitude threshold. However, non-altitude reporting traffic are obvious on the TCAS display, and the RA suppression altitude is generally well known through training.

One view is that if a TSA cannot be followed by an RA for a particular target (i.e., there is no CAS protection for that target), then display symbology for that target should clearly indicate this limitation. However, during development of the first version of the ASA System MOPS (RTCA DO-317), the working group was unable to determine an operational need for that information, and no indication was required. This topic requires further study, as discussed in section 4.3.

4 Recommendations for CAS / SA Integration

Summarizing the material in previous sections:

- Traffic Alerts are required as part of a collision avoidance function.

- Requirements for independence of CAS from separation, spacing and other applications are under consideration elsewhere. Regardless of the independence requirements, a CAS function will almost assuredly be maintained as a separate function from ASA.

- TSA alerting may take different forms as appropriate for each future application of surveillance data. Such TSAs may not always be sufficient for use as precursors to resolution advisories from CAS.

- Standards for ASA System MOPS require correlation of TCAS data (in integrated systems) for unified display.

With these considerations in mind, the following recommendations are made for integrating CAS and ASA:

4.1 Correlation of Surveillance Sources

An integrated system must correlate all surveillance sources, matching traffic input data as best as possible to provide a single "track" for each aircraft. (This is included in the ASA System MOPS.) A single track is required to prevent duplicate aircraft on the traffic display, and to manage any alerts that may be generated by various applications, including CAS.

The appropriateness of a surveillance source for use in CAS must be determined.

4.2 CAS Function

An integrated system must maintain a separate CAS function, which will provide both TA and RA functions. Other ASA applications, such as a parallel approach monitoring application, may disable or supplant the CAS function on designated traffic. (See section 4.4 below.)

Independence requirements for the CAS function, and appropriate disabling or supplanting of the CAS Function, must be determined.

4.3 Traffic Situational Awareness Alerts

Several applications may include or provide traffic situational awareness alerts in addition to CAS. To avoid duplication of similar alerting functions, it may be desirable to "combine" TSA features from different applications (such as sharing aural alerts and symbol variations) with the TA alerts, or to suppress similar alerts. However, alerts must be appropriately provided.

For example, TA functionality is a necessary component of collision avoidance. TSAs other than those provided by the CAS function may fail to provide a precursor to CAS RAs. Rather than force ASA to precisely emulate CAS parameters to generate QTAs, the suggested methodology is for the applications (and CAS) supplying the TSAs to continue to function independently. Some type of alert processing would monitor for multiple TSAs on the same target, and suppress the additional alerts, as appropriate.

The ASA MOPS does not describe any process for processing and prioritizing multiple alerts. The interplay and priority of aircraft-based applications has not been well-determined, and will require more definition as applications with alerts are added to the system (see section 4.4 below.)

Study is required to determine:

- If other TSA alerts provide the necessary preparation for possible resolution advisories (for traffic capable of generating CAS alerts). In addition to the intended function, do flight crews view the alternate TSAs as a preparation for a possible RA? For example, would a conflict (spacing loss) alert on traffic be sufficient preparation for a collision avoidance maneuver?

- Constraints on TSAs to provide their intended function (such as TSA alert time prior to CAS RA). How similar must the timing of TSAs be to provide collision avoidance maneuver preparation? For example, would a conflict alert issued 1 minute prior to loss of separation be adequate preparation for a collision avoidance maneuver in 2 minutes, or is this too long between the alerts? Some type of alert processing may be required to determine when an additional TSA is appropriate, such as due to a long delay from the start of the last TSA on the same traffic.

- The safety of providing TSAs similar to TAs that cannot result in RAs (for traffic not capable of generating CAS alerts). If the appearance of TSAs is similar or identical to TAs (same traffic symbol on display, same aural alerts), but no RA can result due to surveillance source not being supported by CAS function, is this a safety concern?

  - TCAS-I TAs are not followed by RAs, but this is consistent for the system.

  - Non-altitude reporting TCAS II traffic generates TAs, but not RAs. However, there is no altitude tag associated with the traffic on the display.

  - Future CAS systems may provide RAs on traffic from ADS-B sources, increasingly the likelihood of traffic supporting the CAS function.

  CAS support for all surveillance sources would eliminate this concern, although the appropriateness of the surveillance for CAS must be determined (see section 4.1 above).

4.4 Alert Monitoring and Suppression

The presence of various TSA-generating applications will likely require the development of methodology for reducing the distraction of alerts, while maintaining their required function. The existing ASA System MOPS does not address this problem.

In the current architecture, ASA system processing will have access to the alerts provided by both CAS and the ASA applications, and could modify the track file to suppress alerts as appropriate. Currently, this allows for control only of alerts on the traffic display, such as the traffic symbol shape and color. The ASA system is not currently interfaced to other TCAS displays, such as the aural alerts and RA guidance, and no ASA applications currently provide any alerts.

The ASA System MOPS does not explicitly require the inclusion of TCAS alert information in the track data, but it implicitly requires the information for track prioritization and traffic symbology.

In the event of ASA system failure, TCAS can be linked directly to the cockpit displays and controls.

Future applications will require aural alerts and (perhaps) guidance, so interface to those displays will be required. When such applications are present, the suppression of alert information (alerts and guidance) will likely be required for integration with CAS, and perhaps between the other applications. Future CAS may allow for the application-specific modification of alerting parameters on traffic designated to some ASA applications.

Examples:

1 - During a spacing application that includes guidance, CAS predicts a collision threat on a third aircraft. The CAS alerts would have priority, and the spacing application guidance removed. (Whether the application is terminated or not is to be determined.)

2 – During a parallel approach monitoring application on specifically designated traffic, normal application spacing will likely trigger CAS alerts on the designated traffic. Solutions include:

- The ASA system could suppress the enunciation of the TCAS alerts on the designated traffic.
- The CAS function could suppress alerts on the designated target.
- The CAS function could alter the TA/RA parameters for the designated traffic to something more compatible with the application.

Note: The designation of traffic would cease when the application is complete or fails, reverting CAS systems to normal operation.

5 Conclusions and Suggestions for Further Study

5.1 Conclusions

Airborne traffic situational awareness alerts are expected to be part of a number of future airborne applications. All currently envisioned alerts are expected to be similar to TCAS TAs in that they will alert the flight crew to threatening traffic, due to a predicted loss of separation or spacing. It is sensible to integrate such alerts in a manner that minimizes flight crew distraction while maintaining flight safety.

Requirements for the independence of surveillance sources, processing, and hardware are being investigated elsewhere. The outcome of that work will determine the degree of integration allowed for CAS and other surveillance applications. Regardless, it is expected that CAS will remain as an independent function.

A TA function is a necessary component of CAS, as it does prepare the flight crew for a possible RA. Removing the TA function from CAS may be possible if the number of pop-up RAs is minimal. However, it will likely be difficult to meet such a requirement without using the same surveillance source and similar alerting criteria. As such, it is likely more sensible to maintain the TA function within CAS, where that surveillance source and criteria are already present, while allowing integration with other TSA alerts.

Alert priority schemes must be developed in cases where different alerting systems are expected to operate concurrently.

5.2 Suggestions for Further Study

Several questions remain about the appropriateness of additional and different TSA alerts with respect to collision avoidance, and the use of TAs. The following topics are suggested for further study:

- Determination of timing constraints of TSA alerts prior to RAs. Especially determine if an upward limit exists on the time difference between a TSA alert and an RA.

- Determination of whether TSA alerts must indicate whether CAS guidance (i.e. RAs) is possible. Determine the impact if such indications are not present.

- Determination of whether an RA requires a pre-cursor alert, or if the RA can be modified to eliminate the TA function.

- Determination of whether a pre-RA alert is necessary for CAS systems that include automated pilot response.

6 Participants

This report was prepared by a study team assembled under the Federal Aviation Administration TCAS Program Office. Participants included:

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