Traffic Alert Collision Avoidance System

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In theory, the traffic alert collision avoidance system (TCAS) has been around since the late 1950s, but from a practical standpoint since the time of the FAA's initial focus in 1981, then its mandate of 1993.

The FAA wanted a new system to help provide conflict resolution in the National Airspace System. Even today, when the airspace capacity still is determined by air traffic control (ATC) workload, TCAS adds one more layer of safety into the system.

The TCAS system actually gave legs to the Mode S transponder, which never got a foothold in the market because of a lack of display options and mandates. The re-introduction of the Mode S transponder as part of this system has given the general aviation market further benefits at little cost.

The emergence of the traffic information service (TIS), which provides even non-mandated-type aircraft with ATC-like traffic information in terminal areas, was a huge safety benefit.

This article provides additional insight into what happens "under the cover" of a typical TCAS II system.

What is TCAS?

TCAS is a predictive warning system that falls in the category of the airborne collision avoidance system (ACAS) and is a proprietary part of that system. TCAS uses the secondary surveillance radar (SSR) transponder returns it receives, along with its own selective interrogations, to determine presence of a possible conflict.

In the beginning, it was a massive undertaking just to come up with a software language and the proper computer modeling to prove out what the system should do and how it would do it.

After several mid-air accidents, there was an industrywide commitment to get a system implemented. One of the core principals to evolve during system development was that time to the threat aircraft (intruder) was more important than distance.

The system processor must constantly evaluate a specific volume of airspace and the geometry around it to solve any possible conflicts that may arise within the airspace. The system must generate its own 1030 Mhz interrogations selectively to provide this level of safety. While the system provides alerting information on any SSR target, the traffic avoidance alerts it provides to the pilot are possible only with other aircraft that provide Mode C and Mode S information.

The Mode S transponder pseudo-randomly radiates (squitter) its unique Mode S address omni-directionally once per second to let its presence be known to other like-equipped aircraft. Following receipt of a squitter, TCAS then sends a Mode S interrogation to that specific Mode S address contained in the message. The replies received by TCAS are used to determine bearing, range and altitude.

When transmitting, the processor has the ability to control the effective radiated power by utilizing a scheme called Whisper-Shout. The Whisper-Shout method helps manage the reach of the system. Intruder range is determined by the time delay between interrogation and the reply sequence, and can be further supplemented by the results of the Whisper-Shout routine.

The aircraft is now an active interrogator in the system and, as a result, has increased 1030/1090 Mhz traffic. In order to limit the 1030/1090 Mhz traffic generated by TCAS, especially in high-density areas, a "TCAS Presence" message is broadcast. The TCAS is designed to limit its own transmissions when a specific traffic threshold is met, thus helping to minimize frequency traffic.

The results of the Whisper-Shout routine also allow certain aircraft to be de-selected as primary threats as the ranging and altitude data is gathered. Once an interrogation is recognized, the receiving aircraft logs in that data and can begin the tracking process. The system is kept quite busy with the constant interrogation, acquisition, tracking and predicting of the crossing geometries for all intruders.

Once established, this bi-directional data link between each TCAS II-equipped aircraft is crucial to a successful resolution. TCAS does handle

Mode A/C transponders differently. TCAS does not interrogate Mode A; however, it does perform a Mode C-only all-call. Remember, target altitude is critical. These replies are tracked, but not all are synchronous; therefore, special algorithms are employed to provide the proper filtering.

The conflict resolution process starts with a traffic advisory (TA), which is informative in nature. It informs the pilot of nearby traffic. This traffic advisory only later becomes a threat if conditions change.

The next step is a preventive resolution advisory (PRA). The PRA basically advises the pilot not to deviate from the present vertical flight profile he is flying. This indicates to the crew the situation is resolving itself as long as the crew maintains its current path.

The corrective resolution advisory (CRA) is the last step in conflict resolution. This command is given to advise the crew to take action vertically to avoid the developing threat. Vertical changes in one's flight path have been deemed the quickest resolution to a possible conflict.

All this action must be done prior to the "closest point of approach" (CPA) as computed by the processor. The CPA is the point ahead that the processor predicts will be an area of conflict with an intruder aircraft. With extremely high closure rates, one can see the element of time is crucial. This is where the Mode S bi-directional data link plays a huge role — the commands issued to the pilot must be transmitted to the intruder aircraft so complementary maneuvers are assured.

The Mode S air-ground link also can be used to verify information such as the proper "N" number versus Mode S address assignment — this was a problem in the early days of the mandate. Reflecting back to earlier times, TCAS reported many false targets or was missing target aircraft altogether.

This created enough concern that, in 1997, the FAA did a random sampling of 548 Mode A/C transponders and found 30 percent failed FAR Part 43 tests and a significant amount reported altitude errors. The terra transponder actually required a modification as a result of these findings. All this data helped resolve some initial problems.

Collision Avoidance Logic

When the goal is to avoid any collision with intruder aircraft, the system must be predictive. This principal has two basic concepts: the system sensitivity level and the warning time available.

The level of sensitivity is a function of altitude and helps define protection levels. The warning time is based on the time to the closest point of approach, which is the point of conflict. TCAS must achieve a good balance between sensitivity and time within that protected volume of airspace to minimize any unnecessary alarms.

In collision avoidance, time-to-go to the CPA — not distance-to-go to the CPA — is the most important concept. With a system designed to ensure collision avoidance between any two aircraft, with closure rates of up to 1200 knots and vertical rates as high as 10,000 fpm, it is obvious how critical time is in these situations.

To de-conflict with any intruder aircraft, the TCAS processor must be constantly aware of the airspace geometry it is transitioning through and the traffic content within the airspace. This volume of airspace and associated trigger thresholds change with altitude. The processor deals in time, not distance, as it tries to de-conflict with any known intruder.

The CPA is the critical spot within the concerned volume of airspace the TCAS must constantly be evaluating for conflicts with intruders crossing geometries. Several actions can be taken: change in course (slow); change in speed; or change in altitude (quickest).

The processor knows some aircraft specifics based on its installation configuration, and it can modify its commands accordingly. While tracking intruder aircraft, the computer evaluates the slant range, bearing and altitude of each, then computes the closure rates of each within the surveilled range. All this is done to determine the time in seconds to the CPA, along with the horizontal miss distance to the CPA.

The intruder's vertical speed is simply obtained by measuring the time to cross successive altitude increments. Altitude increments are based on the encoder/ADC resolution (100ft/25ft). TCAS can simultaneously track up to 30 aircraft in a nominal range of 14 NM for Mode A/C targets and 30 NM for Mode S targets. This information is passed along to the collision-avoidance logic in the computer to determine the requirement for TAs or RAs.

A recent improvement implemented by Change 7.0 includes an adjustment to vertical speed commands so rates of climb and descent are modified for more practical closure rates on assigned altitudes. One benefit of this is, it should minimize vertical profile bumps (overshooting) during a climb or descent profile.

Directional Antenna

The directional antenna, although passive, is a critical component to the system. The system is defined by its accuracy, and here is where the directional antenna plays an important

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role. Important to the pilot is, what quadrant the intruder aircraft is in and what are its bearing and altitude. All of these, of course, are time-critical and serve to aid in the visual acquisition process.

Let's explore the "angle of arrival," as it is termed, and see how it can be determined. The angle could be measured using the typical four-quadrant sine/cosine vector vs. amplitude arrangement, but the monopulse technique employed, as well as trying to resolve bearing ambiguity, present problems. The angle can be measured by comparison between amplitude and phase of the monopulse or, finally, by the "phase interferometer method."

Measuring signal amplitude is somewhat less reliable because of stresses on the antenna, which ultimately could influence received signal strength. The phase interferometer measurement is a process used for measuring very short pulses and their phase relationships.

The size of the antenna, including height, also plays a big part in its accuracy, and yet a low-profile type is employed for obvious reasons.

The antenna radiation pattern is controlled through an electronic beam steering network in the processor in which any one quadrant can be selectively activated and the phase to each element controlled. When using the scheme of direct phase interferometer (also used in optics), the phase matching of the antenna system was found to be critical and, therefore, must be controlled to maintain system accuracy. This could be compensated for by allowing the processor to self-calibrate itself to the antenna after installation, then subsequently while in flight. The calibration must be done from the antenna multiplexer in the processor out to the antenna, as well as inboard of the multiplexer.

Utilization of the electronic beam steering technique allows only one quadrant or sector of the antenna array to transmit interrogations. This selective quadrant transmission results in the transponders in the non-selected quadrants around the aircraft being suppressed because of large side lobes (P2). Thus, the radiation pattern is controlled. The antenna angle of arrival now can be further resolved by concentrating in this one quadrant.

If multiple elements are employed in each quadrant of the antenna, resolution is certainly improved. The angle ambiguity can be resolved further by performing directional interrogations in the remaining quadrants.

The concept employed by TCAS is to control the signal phasing to all elements in the antenna resulting in control of the radiation pattern around the aircraft. This technique allows for directing a great deal of processing power to just a small section of airspace at any one time.

The third generation, or TCAS III, system antenna will consist of a pair (top and bottom) of eight-element, 10.5-inch diameter, electronically steerable circular arrays that continuously scan the space surrounding the aircraft.

The Future of TCAS

TCAS will remain important as we transition into the ADS-B type of National Airspace System. In the future, linking actual GPS position information into the TCAS will enhance the system further. This will result in improved location accuracy, and it will further develop the Free-Flight concept.

In addition, further utilization of the Mode S data link is likely to occur. Currently, we can downlink RA reports to Mode S ground sites and, during an RA, every eight seconds TCAS generates a spontaneous message containing information on the current advisory. This real-time, air-to-ground link will bear more fruit as the ADS-B system takes over in the years to come. ❑