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TCAS Functioning and Enhancements

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ABSTRACT
Every year, several aircraft collide with each other, mid-air, leading to loss of precious lives. In this paper we have described the functioning of the traffic collision avoidance system that can be used to avoid collisions between aircraft, thus providing a safe journey for the passengers. We have also discussed further improvements for the system. The drawbacks in the current system of TCAS are studied in this paper along with the changing needs because of rising air traffic. Improving the maneuvering capability by making a new algorithm for calculating the path and also by establishing an exclusive communication link enhances threat handling.

Categories and Subject Descriptors
Electrical, Electronics and Electronics Telecommunication: Radar and Navigation Aids – *Traffic Collision Avoidance Systems*

1.INTRODUCTION
The airline industry is booming and the number of aircraft is exponentially increasing and so are the risks of mid-air collision. This leads to destruction of lives which can't be recovered and a massive loss of property. Wouldn't it be helpful if there was a way to avoid this? Electronics comes to our help here. TCAS or Traffic Collision Avoidance System is an electronic device that can be used aboard aircraft for collision avoidance. All major aviation authorities require commercial aircraft to be equipped with the TCAS system. In this paper we have described the various devices that are used in the collision avoidance system, their working, safety aspects, disadvantages and suggestions that could lead to the improvement of the system.

2.TCAS BASICS
TCAS is a device that uses RADAR Communication as its principle. Each TCAS consists of audio-visual instruments and a transponder. Each TCAS-equipped aircraft interrogates all other aircraft in a determined range about their position (via the 1030 MHz radio frequency), and all other aircraft reply to other interrogations (via 1090 MHz). This interrogation-and-response cycle may occur several times per second. It then uses the received transponder signals to compute distance, bearing and altitude relative to the own aircraft. With the help of the acquired data, the TCAS then calculates if a potential collision threat exists.

When TCAS detects that an aircraft's distance and closure rate are critical, it generates aural and visual annunciations for the pilots. If necessary, it also computes aural and visual pitch commands to resolve a conflict. If the other aircraft uses TCAS as well, these pitch commands are coordinated with the other aircraft's pitch commands so that both aircraft don't maneuver to the same direction. Up to three aircraft can be coordinated simultaneously.

There are two TCAS models. First was the TCAS I, which later evolved into TCAS II with a number of significant changes done to the primary model. The differences will be discussed later.

3.ADVISORIES
There are two kinds of advisories (promulgations). They are the Traffic Advisory or simply TA and the Resolution Advisory or RA. These differentiate TCAS I and TCAS II.

The TA is given to the pilot in form of the word TRAFFIC displayed in yellow on the Navigation Display, and the aural voice annunciation "traffic, traffic". This is not the highest alert level. Its purpose is first to call attention to a possible conflict. The TCAS triggers a TA as soon an aircraft or any other intruder enters the vicinity of the aircraft.

Figure 1. Navigation Display showing TA

The RA is activated if the intruder aircraft continues its approach, without any abatement of conflict. Under normal conditions a TA will precede an RA by 10 to 15 seconds. The RA involves a voice annunciation, telling the pilot to either climb or descend, at different speeds, if necessary.

As seen in the figure 2, the entry of any aircraft into the blue region will initiate a TA, followed by an RA in the red region. Specifically, the blue region is also called the Tau region. The Tau area is a specific "protective area" around the own aircraft. When an intruder aircraft enters the tau area, TCAS triggers an alarm. The threshold of the tau area is defined by time. In other words, tau is the time-to-go to CPA, that is, the "Closest Point of Approach". The time-to-go is distance divided by closure rate -- both combined vertically and horizontally.

Example: Say, a tau value of 30 seconds is used for an alarm threshold. As soon as the intruder's time-to-go to the CPA is dropped to 30 seconds, TCAS triggers an alarm.

In addition to this logic, TCAS uses different tau values at different altitudes. The higher the own altitude, the larger the tau area -- the greater the sensitivity level.

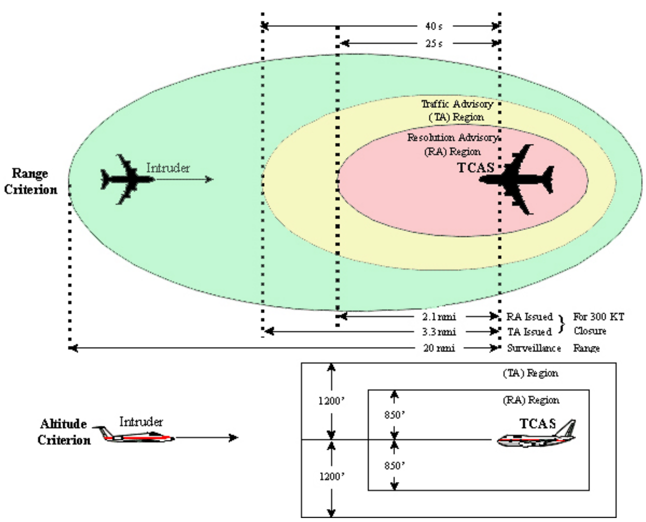

Figure 2. Intruder aircraft in the TAU

For obvious reasons, TCAS will not issue a descent command when the aircraft is at low altitudes. The same goes for high altitudes, to prevent stalling.

The main difference between TCAS I and TCAS II is that the former is capable of providing only TA, whereas the latter provides both TA and RA. This is the main reason for overhauling the TCAS I with II.

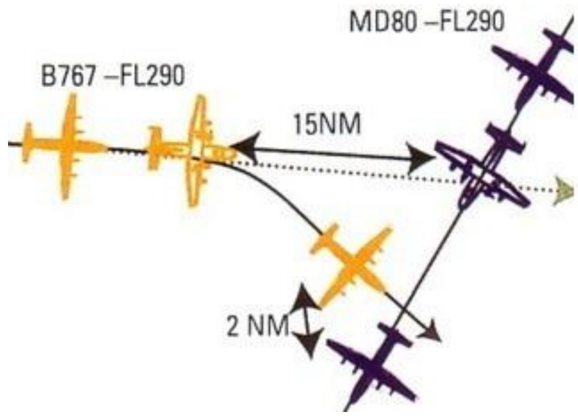

Figure 3. Resolving a mid-air conflict

The above diagram depicts a possible occurrence, wherein two aircraft follow the RA provided, to resolve conflict.

4.TRANSPONDER INTERROGATION MODES:

Several different RF communication protocols have been standardized for aviation transponders:

- Mode 1
- Mode 2
- Mode 3/A
- Mode 4
- Mode A
- Mode C
- Mode S

Of these, the Mode S Transponder is commonly used by TCAS. Mode S (Selective) is designed to help avoiding over interrogation of the transponder (having many radars in busy areas) and to allow automatic collision avoidance. Mode S transponders are compatible with Modes A & C. This is the type of transponder that makes the TCAS and the ADS-B (Automatic dependent surveillance-broadcast) systems function.

Automatic Dependent Surveillance-Broadcast (ADS-B) messages are transmitted from aircraft equipped with suitable transponders, containing information such as identity, location, and velocity. The signals are broadcast on the 1090 MHz radio frequency. ADS-B messages are also carried on a Universal Access Transceiver (UAT) in the 900 MHz band.

TCAS equipment which is capable of processing ADS-B messages may use this information to enhance the performance of TCAS, using techniques known as "hybrid surveillance". As currently implemented, hybrid surveillance uses reception of ADS-B messages from an aircraft to reduce the rate at which the TCAS equipment interrogates that aircraft. This reduction in interrogations reduces the use of the 1030/1090 MHz radio channel, and will over time extend the operationally useful life of TCAS technology. The ADS-B messages will also allow low cost (for aircraft) technology to provide real time traffic in the cockpit for small aircraft.

Hybrid surveillance does not include the use any of the aircraft flight information in the TCAS conflict detection algorithms; ADS-B is used only to identify aircraft that can safely be interrogated at a lower rate.

5.SYSTEM COMPONENTS

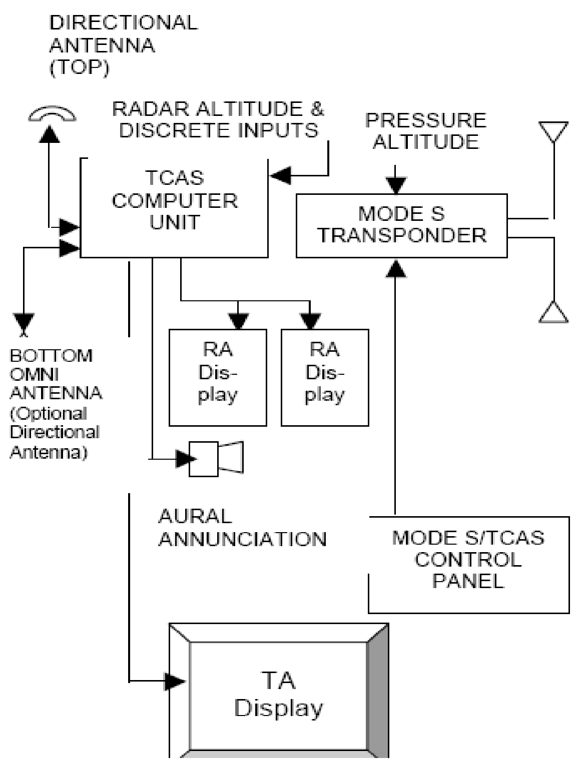

Figure 4. System Components

5.1TCAS Computer Unit

The TCAS Computer Unit, or TCAS Processor, performs airspace surveillance, intruder tracking, its own aircraft altitude tracking, threat detection, RA maneuver determination and selection, and generation of advisories. The TCAS Processor uses pressure altitude, radar altitude, and discrete aircraft status inputs from its own aircraft to control the collision avoidance logic parameters that determine the protection volume around the TCAS aircraft. If a tracked aircraft is a collision threat, the processor selects an avoidance maneuver that will provide adequate vertical miss distance from the intruder while minimizing the perturbations to the existing flight path. If the threat aircraft is also equipped with TCAS II, the avoidance maneuver will be coordinated with the threat aircraft.

5.2Mode S Transponder

A Mode S transponder is required to be installed and operational for TCAS II to be operational. If the Mode S transponder fails, the TCAS Performance Monitor will detect this failure and automatically place TCAS into Standby. The Mode S transponder performs the normal functions to support the ground-based ATC system and can work a Mode S ground sensor. The Mode S transponder is also used to provide air-to-air data exchange between TCAS-equipped aircraft so that coordinated, complementary RAs can be issued when required.

5.3Mode S/TCAS Control Panel

A single control panel is provided to allow the flight crew to select and control all TCAS equipment, including the TCAS Processor, the Mode S transponder, and in some cases, the TCAS displays. A typical control panel provides four basic control positions:

Stand-by: Power is applied to the TCAS Processor and the Mode S transponder, but TCAS does not issue any interrogations

Transponder: The Mode S transponder is fully operational and will reply to all appropriate ground and TCAS interrogations. The TCAS remains in stand-by.

TA only: The mode S transponder is fully operational. The TCAS will operate normally and issue the appropriate interrogations and perform all tracking functions. However, TCAS will only issue TAs, and the RAs will be inhibited.

Automatic or TA/RA: The Mode S transponder is fully operational. TCAS will operate normally and issue the appropriate interrogations and perform all tracking functions. TCAS will issue TAs and RAs, when appropriate.

5.4Antennas

The antennas used by TCAS II include a directional antenna that is mounted on the top of the aircraft and either an unidirectional or a directional antenna mounted on the bottom of the aircraft. Most installations use the optional directional antenna on the bottom of the aircraft.

These antennas transmit interrogations on 1030 MHz at varying power levels in each of four 90˚ azimuth segments. The bottom mounted antenna transmits fewer interrogations and at a lower power than the top-mounted antenna. These antennas also receive transponder replies, at 1090 MHz, and send these replies to the TCAS Processor.

The directional antennas permit the partitioning of replies to reduce synchronous garbling. In addition to the two TCAS antennas, two antennas are also required for the Mode S transponder. One antenna is mounted on the top of the aircraft while the other is mounted on the bottom. These antennas enable the Mode S transponder to receive interrogations at 1030 MHz and reply to the received interrogations at 1090 MHz. The use of the top- or bottom-mounted antenna is automatically selected to optimize signal strength and reduce multipath interference.

TCAS operation is automatically suppressed whenever the Mode S transponder is transmitting to ensure that TCAS does not track its own aircraft.

6.Drawbacks and Potential Remedies

Despite the TCAS II's usefulness, it doesn't come without shortcomings. Most of the important disadvantages are listed below.

1) One of the main drawbacks of the TCAS II is that it can handle only three aircraft at one time. This can be attributed to the fact that the RA provided are either to Climb, Descend or Do Nothing. That is, only vertical movements are provided as conflict resolution. This factor causes problems during conflict at different altitudes.

Horizontal maneuvers come in handy during extremely low or extremely high altitude conflict, or when more than 3 aircraft are within the conflict region.

The software that presently recommends vertical movements can be upgraded to provide horizontal resolutions as well, such as "Turn Left, Bank 30 Degrees". This can help the TCAS handle multiple aircraft at the same instant.

2) When two aircraft are in proximity, it is not only the TCAS that issues warnings and advisories, but so does the Air Traffic Controller (ATC). The ATC may give the exact opposite instructions to an aircraft, as compared to that given by the TCAS. Suppose one aircraft follows the ATC advisory and the other follows the TCAS advisory, then both aircraft may eventually head in the same direction, ultimately leading to collision. It is generally accepted that the TCAS gets priority over ATC, but nevertheless, several mid-air collisions have occurred due to such confusions.

To prevent this, we can incorporate a system, wherein, the RA provided to one aircraft, is also provided to the conflicting aircraft(s), as well as the ATC. This will ensure that the aircraft move in different directions, while the ATC does not provide alternate resolutions.

The transponder can be designed to send the resolutions provided, to the ATC using a down-link system. The ATC can also be equipped with a transponder, which would request information from the conflicting aircrafts, regarding the RA provided.

3) TCAS equipment today is often primarily range-based, as it only displays the traffic situation within a configurable range of miles/feet, and however under certain circumstances a "time-based" representation (i.e. within the next xx minutes) might be more intuitive.

Sometimes the distance between the aircrafts, their relative positions and their altitudes are not enough to avoid the collision. The time taken for the aircrafts to reach other, the speed at which the intruding aircraft is closing in, that is the closure rate would be more significant to the pilot. This will help the TCAS generate quicker and more accurate RAs that will help avoid the impending crash.

This is a simple improvement, as the TCAS calculates the time. TCAS checks the other aircraft's relative distance permanently in short time intervals, it can, therefore, also calculate the other aircraft's closure rate relative to the own aircraft. Hence the TCAS computer unit can be redesigned to simply aurally announce the pre-determined time remaining.

4) Every aircraft is required to file a flight plan before it takes off. The flight plan would involve the path the aircraft would take, to reach its destination. The flight path information is not used in the TCAS and the system is totally dependent on the detection of the intruder when it comes into the vicinity of the host aircraft.

Complex, trigonometric calculations of flight paths and ground speeds can complement to the existing parameters such as altitude information, relative positions, closure rate and other such data. The flight path information will give the timings of the aircrafts, their frequency of travel and their accurate path in the air. There are thousands of aircrafts flying in our atmosphere everyday and data will certainly help the TCAS improve. Although the extrapolations are a little bit unreliable they will ultimately lead to the betterment of the system.

Thus the Flight Plan can be incorporated in the TCAS, by adding a temporary storage memory, if required. Communication of flight plans can be done by the same process, used presently for determining the RA for conflicting aircraft.

7.CONCLUSION

The main changes thus brought about are

1) Maneuvering using a combination of vertical and horizontal movement, which allows a better solution of a threat solution in case of a high air traffic density.

2) Transmitting the aircraft Flight plan along with the other vital information about the aircraft.

3) Establishing a voice link between the two aircraft in the highest threat zone.

Hence, by using an improved TCAS system, the chances of mid-air collision can be greatly reduced. But it will never be able to ensure complete prevention, as human factors are involved here, to a great extent.

8.ACKNOWLEDGEMENTS

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