THEORETICAL CONSIDERATIONS REGARDING THE ACAS (AIRBORNE COLLISION AVOIDANCE SYSTEMS)

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Abstract: *The Airborne Collision Avoidance System (ACAS) represents the latest solution in worldwide aviation with respect to the detection and management of air traffic conflicts between aircraft. The article intends to offer a quick review of the ACAS system in what concerns its components, functioning and operation.*

Keywords: *airborne collision, transponder, ACAS, TCAS.*

Symbols and acronyms

ACAS	Airborne Collision Avoidance System	BCAS	Beacon Collision Avoidance System
TCAS	Traffic Alert and Collision Avoidance System	TA	Traffic Advisory
CPA	Closest Point of Approach	SL	Sensitivity Level
RA	Resolution Advisory	PWI	Proximity Warning Indicator
SSR	Secondary Surveillance Radar	ATM	Airport Terminal Management
ATC	Air Traffic Control	ADS-B	Automatic Dependent Surveillance Broadcast
FMS	Flight Management System		

1. THEORETICAL GUIDELINES

1.1. Introduction

The ACAS represents the latest accepted solution in worldwide aviation regarding the detection and the management of air conflicts between aircraft. The main element of the ACAS system is made of the implementation on board of the TCAS II versions 7 and 7.1 and the pilot procedures regarding the use of these pieces of equipment. It represents the last barrier used to alert the staff on the imminent danger of collision and on the manner of avoiding it, being complementary to the safety systems on the ground implemented in the ATM [1, 2].

TCAS is the commercial brand name for the ACAS. The TCAS is a system based on the communication between two or more aircraft, which are in a traffic conflict, with the help of transponders. We have to mention that the system cannot provide any protection against aircraft which have no integrated transponder. Compared to TCAS I, which only provides warnings when an aircraft is nearby, helping the pilot to reach a better visualization of the danger, TCAS II offers traffic guidance and recommends avoiding vertical maneuvers.

TCAS II monitors the air space around the aircraft, questioning the aircraft transponders situated in its working perimeter.

The data collected from the interrogated aircraft transponders provide the system with the following information: the distance between the two or more aircraft involved, the relative direction, the altitude and the vertical velocity of the interrogated aircraft and the approach speed of the interrogated aircraft. If TCAS II estimates that the space in which the aircraft can consider that its safety has been violated, it will provide traffic advisory TA in order to let the crew know that there is an aircraft nearby. If the aircraft continues the approach, the TCAS II will radiate a RA radiation in order to obtain or maintain a safe distance from the unknown aircraft.

The Airborne Collision Avoidance System (ACAS II) with hybrid surveillance option, certificated by EASA in 2011, supposes the use of an active surveillance combination, meaning the active interrogation (module S) of the aircraft's transponders from the surroundings and passive surveillance, for instance, the use of the ADS-B position and of the altitude data (extended squitter), to the updated monitoring of the ACAS II [1].

The aircrafts equipped with TCAS II will communicate and will solve the traffic problem by using a Mode S transponder. The coordination between them assures the successful avoidance of a collision. The crew must immediately and smoothly follow the resolution advisory (RA). Because of the fact the maneuvers are coordinated by TCAS II, the crew must not execute maneuvers in the opposite direction ~~of~~ to the one indicated by TCAS II. TCAS II can monitor 45 aircraft; it can show up to 30 aircraft and can find resolution advisory (RA) for 3 aircraft at the same time.

1.2. History and evolution

The interest in the developing a collision avoidance system, dates back to 1956 when a collision between two commercial airplanes took place over the Grand Canyon in The United States of America. Both the air companies and the air authorities have realized the importance of implementing such a system which was for the first time initiated and tested by Dr. John S. Morrel. The contemporary collision avoidance system is based on his concept. Before CAS (Collision Avoidance System) systems there was the Proximity Warning Indicator (PWI). For 2 decades a variety of collision avoidance systems were explored, many of them with promising results in testing. Researchers came to the conclusion that the common air operations would have generated a wide range of false alarms, especially in the airdromes areas. Such tests took place until 1974, when the Federal Aeronautic Authority chose to concentrate its efforts and resources on the BCAS System (Beacon Collision Avoidance System) based on the transponder. In 1978 a second collision took place between a light aircraft and an airliner near the city of San Diego, event which led to the expansion of the BCAS System. In 1981 its name was changed into TCAS (Traffic Alert and Collision Avoidance System) [2].

Starting with the 80s, the ICAO (International Civil Aviation Organisation) developed along with the development of the TCAS system the standards for the ACAS (Airborne Collision Avoidance Systems), conceived to function independently and autonomously both in relation to the navigation equipment of the aircraft and to ground systems used to furnish traffic air services. The first mandatory implementation of an collision avoidance system, TCAS II, was required to the flights in the United States air space starting with the 30th of December 1993. In 1955, Eurocontrol approved an implementation politics and a mandatory equipment program regarding the use of the ACAS II in Europe. This latter stipulated that starting with the 1st of January 2000 all civil fixed-wing and turbine engine aircraft having a takeoff mass over 15,000 kg, or a maximum approved passengers places configuration bigger than 30, will be compelled to equip themselves with ACAS II and starting with the 1st of January 2005 all civil fixed-wing and turbine engine aircraft which have a takeoff mass over 5,700 kg or a maximum approved passengers places configuration bigger than 19, will be compelled to be equipped with ACAS II [1, 2, 3, 4].

1.3. Future trends in research

The emergence of UAVs in modern air space has generated the necessity of the use of TCAS in order to reduce the risk of collision between air vectors in different phases of the flight. According to specialist references, UAS capabilities can be multiplied by having on board such a system. Precise information on the airspace in which a UAV will perform can reveal the trajectory characteristics and specifications of any TCAS on all the other aircraft in the area [5, 6, 9].

2. TCAS COMPONENTS

Globally, there are several constructive types of aircraft collision detection and alert systems available on board aircraft. Regardless of the manufacturer, the main components, the operating principle and the generated alerts are the same.

2.1. The computer of the TCAS

Also called the processor of the TCAS unit / computer unit, it provides: airspace surveillance; detecting and tracking the intruder aircraft; tracking the altitude of your own aircraft; detection of threats; determining and selecting the direction of the avoidance maneuver RA; generating traffic alerts. The processor uses barometric altitude data, altimeter radar width, and a discreet spectrum of inputs on the state and controls of its own aircraft to control the logical process for determining the protection zone, see FIG.1.

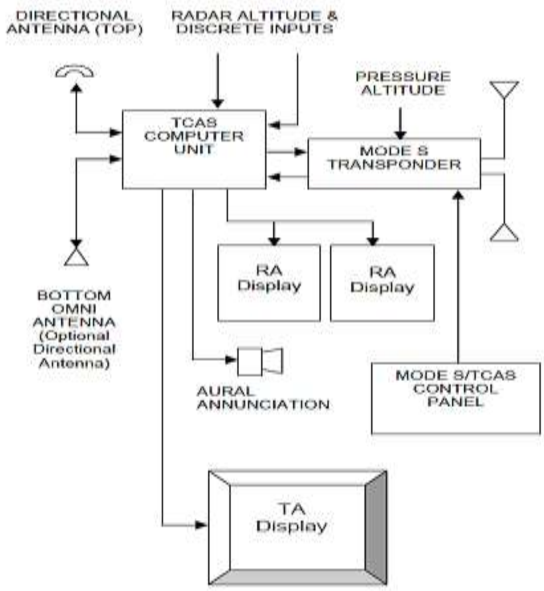

FIG. 1 System block diagram of TCAS, [1].

Position signals, speeds, direction of movement for each aircraft are taken over by process chain: the Antenna - GPS Receiver - Adapter - applied to the adder, where the errors at a given point in relation to the barometric altimeter can be very consistent, depending on the overflown area.

Traffic avoidance actions are taken based on these aircraft input parameters. The generated solution will have the least impact on the aircraft's trajectory. If the intruder aircraft is equipped with TCAS II, the avoidance action will be coordinated with the intruder aircraft.

2.2.Mode S Transponder

This is an essential component for having an operational TCAS II.

If this component fails, the performance monitoring system will detect this and switch the TCAS to "stand-by" mode. The Mode S transponder is especially designed for the use along with the ground Secondary Surveillance Radar (SSR). It was later integrated into the "air to air" data exchange between aircraft equipped with conflict detection and resolution systems, generating together avoidance solutions.

2.3. The Mode S/TCAS Control Panel

A single control unit is provided for the operation of these two types of interdependent equipment. It provides four control positions:

• Stand-by: the TCAS processor and the Mode S transponder are power supply, but there will be no CPC queries and the transponder will only respond to discrete queries;

• Transponder: The Mode S transponder is fully operational and will respond to queries of ground stations and other TCAS systems;

• TA Only: The Mode S transponder is fully operational, the TCAS will operate normally, it will provide interrogations and Traffic Monitoring functions but will only transmit TA alerts, RAs type alerts being restricted;

• TA/RA: Both Mode S transponder and TCAS are fully operational, providing interrogation and monitoring processes. TA and RA alerts will be transmitted. As can be seen from FIG. 2, all TCAS control signals are routed through the Mode S transponder.

FIG. 2 The Mode S/TCAS control panel, [7]

FIG. 3 TCAS system antenna, [8]

2.4. Antennas

The antenna system used by the TCAS includes a directional antenna located above the aircraft and an omnidirectional or directional antenna mounted at the bottom of the fuselage. These antennas transmit queries on the 1030 MHz frequency at different quadrant intensities in the four azimuth segments of 90°. The bottom-mounted antenna emits several interrogations at signal intensities lower than the top of the fuselage antenna, see FIG. 3.

The signals are received through the same antenna array at the 1090 MHz frequency and direct these responses to the TCAS processor. Additionally, the Mode S transponder requires the existence of two similarly disposed antennas in the top and bottom of the fuselage through which it receives signals at the frequency of 1030 MHz and responds to the queries on the frequency of 1090 MHz.

2.5. Cockpit presentation

The TCAS' interface with the crew is provided by the presence of two displays in the cockpit: traffic display and RA display. There may be different presentations including merging both displays in one display. Regardless of the mode of presentation, the functions are the same according to accepted and specified standards in DO-185B and ED-143, see FIG. 4.

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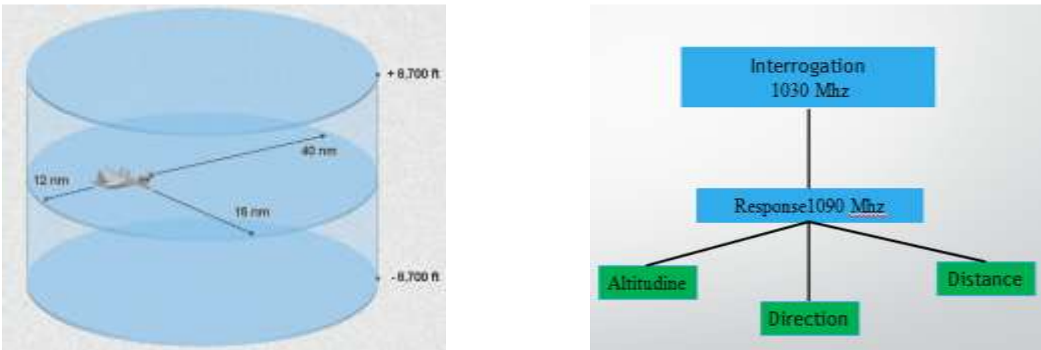
FIG. 4 EFSI and IVSI indicators, [1]

3. TCAS FUNCTIONING PRINCIPLE

The TCAS concept involves the use of radar transponder beacons installed on the board of the aircraft operating with the SSR secondary radar of the ATC units. The level of protection provided depends on the type of transponder installed on the target aircraft. It is essential to note that the system does not provide any protection against aircrafts that are not equipped with a transponder on board and are entering the theoretical protection zone provided by the TCAS, see FIG. 5.

The TCAS II system was designed to operate in traffic with a density of 0.3 aircraft / NM2, which involves approximately 24 aircraft over a 5NM radius, the most intense traffic volume expected for the next 20 years.



a) TCAS surveillance area b) TCAS-transponder information flow chart

FIG. 5 TCAS functioning principle

Designed to work independently of aircraft navigation systems or ground surveillance systems, TCAS interrogates the proximity aircraft transponder system and, based on the received response, it calculates the direct distance, flight altitude (when included in the response message) and head relative flight of the aircraft surveyed. From several successive responses, TCAS calculates the Closest Point of Approach (CPA) with the intrusive aircraft by dividing the distance separating the aircraft at the approach rate. This time value is the main trigger parameter for TA / RA alerts. The TCAS II is designed to ensure protection by avoiding collisions at any rate up to 1200 kt and vertical speed of 10,000 fpm.

In order to determine the distance and the altitude, the aircraft identifies itself into a system of Cartesian coordinates using a 3D positions equations:

$$(p_n)_t=\left[(p_n)_{x,t};\,(p_n)_{y,t};\,(p_n)_{h,t}\right]^T \tag{1}$$

And 3D expression of the velocity/speed of the n aircraft

$$(s_n)_t=\left[(s_n)_{x,t};\,(s_n)_{y,t};\,(s_n)_{h,t}\right]^T \qquad (2)$$

where the x, y indices represent the horizontal axis of the coordinate axes , the h represents the altitude/height and T is the estimated buffer. The determination of the position of the aircraft is also taken from the Global Positioning System (GPS) satellites to eliminate the errors of determination, see FIG. 6. Due to the quicker microprocessors and the precise real-time data provided by GPS, highly accurate navigation is now possible.

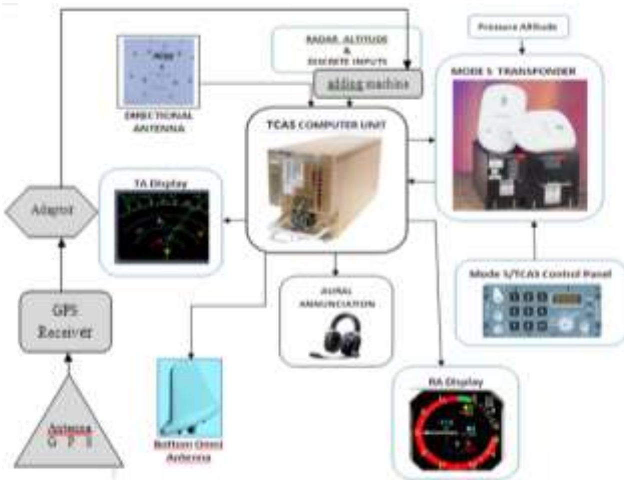


FIG.6 TCAS simplified functional diagram with a GPS module [10].

4. PROPOSED SCENARIO

Most studies on TCAS have considered the analysis of two aircrafts. Thus, TCAS research and development required an expensive cycle of analyses, computational simulations followed by operational tests and evaluations, at an estimated cost of over $ 600 million in 2005. Even if there are scenarios that took into account the interaction of a UAV- aircraft, TCAS development has not occurred for UAVs. We propose a scenario for analyzing several different types of UAVs with TCAS. Several collision avoidance methods by UAVs have been considered, similar to those studied in the hybrid scenarios aircraft-UAV: LIDAR, electro-optical cameras, electronic detection system, radar, IR cameras, visual observation ground or air based, or a combination of such methods.

A number of issues have been identified so: a) in the low-altitude Class G and uncontrolled airspace where many UAVs fly, TCAS would be unable to detect intruders without TCAS; b) in that scenario there is no capability for a UAV operator to visually be aware on these types of threats; c) numerous studies have shown that the level of safety provided by implementation of TCAS increases, but only if there are no system failures and all the information is perfectly accurate and complete; d) the traffic display information cannot be corroborated by the UAV operator, that means the inability of UAV operator to perform visual acquisition of situational awareness.

The combination of three techniques allows safety to be quantified and a collision avoidance system to be thoroughly evaluated. The first technique is an analysis of all possible failures in the entire collision avoidance operating environment. The output of this technique is a logical tree of failure effects. The second method is to use computer simulation to evaluate TCAS performance in the dynamic environment.

And the third technique is the analysis of TCAS performance on an UAV accomplished through flight testing. These three techniques of safety analysis can be conducted in a similar manner for aircrafts and/or UAVs.

In TCAS studies, data were collected from ground-based radar and were analyzed to find encounters between two aircraft where TCAS would alert the pilots of a potential mid-air collision.

Based on statistical radar data traffic models which reflected the statistical characteristics of the airspace were then developed in which these radar data were collected. Then, millions of data are generated based on the proposed statistical model, which constitute the input data into the TCAS logic model implemented in a Matlab Simulink software tool or similar programs.

The simulation begins by generating situations where there are certain UAV conflicts. The initial conditions and the planned trajectory for each UAV are thus established. After obtaining these data and generating the conflict situation, the data of the trajectories' simulation functions with or without TCAS are provided. It is assumed, as a simplifying condition, that there are no other influences on the planned trajectory other than the TCAS. We get a planned trajectory and a trajectory in which the UAV reacts according to TCAS logic. The position of the aircraft is updated at every step of the simulation, and the future states are influenced by TCAS logic, see FIG. 7.

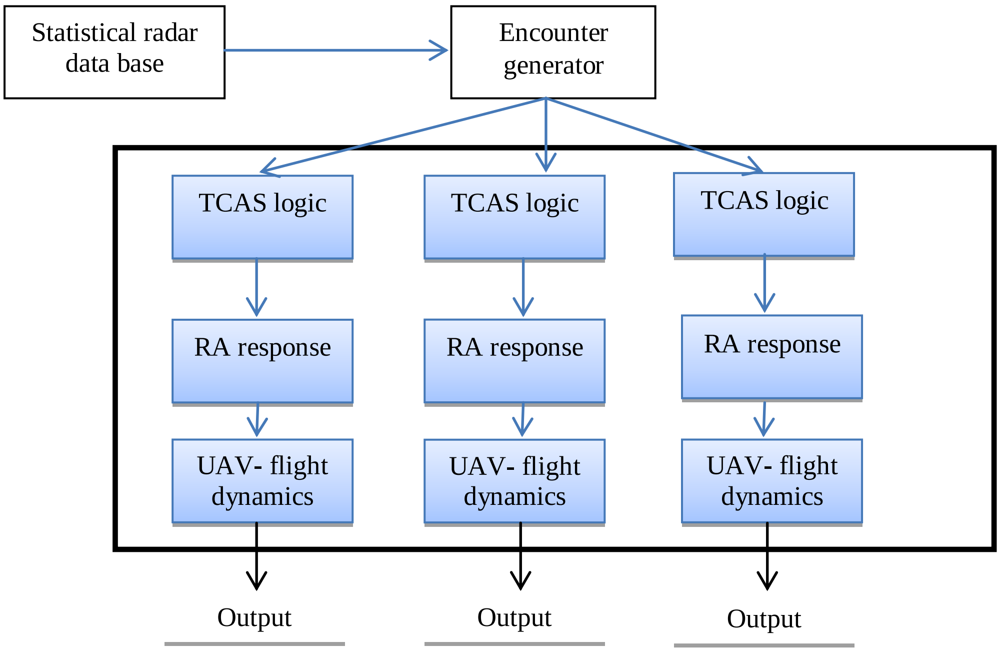


FIG.7 Simulation schematic

CONCLUSIONS

When TCAS II generates an RA, pilots must: follow the RA even in the case of a contradictory instruction given by the ATC and report as soon as possible using the ICAO standard phrase ("TCAS TC"), if the RA requires a deviation from the authorized trajectory. Reporting RA is very important because: the controller does not know the RA until it is reported by the pilot and determines the moment at which the controller (controller) should stop issuing traffic instructions.

Pilots must also inform controllers of the clear conflict situation as soon as possible. The Module for Training Controllers and Pilots is essential to ensure that the procedures are properly applied and to avoid any interference between the ATC and TCAS II RA instructions.

A pilot will not give priority to the ATC instructions, but must prioritize the reporting of an RA when it has occurred and immediately proceed to execute the RA instructions. ATC Horizontal Avoidance Instructions (before an RA report) will not adversely affect the vertical maneuvers required by TCAS II RA; these are mandatory. The information displayed for air traffic controllers may have a delay of several seconds before providing the ATC separation data - appropriate in the old version - but not optimized for collision avoidance purposes. Controllers should pay attention to periodic training, to avoidance techniques, to action and to the specific phraseology.

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