TRAFFIC COLLISION AVOIDANCE SYSTEM

RADAR AND NAVIGATION

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Executive Summary:

Traffic Collision Avoidance System act as the last resort safety mechanism for mid-air collisions. In the first section, Incidents which leads to the development of the TCAS and the initial development of the TCAS is briefly discussed. In next section Functionality of the TCAS system is discussed with the main alert levels of the TCAS system. Currently used TCAS versions are listed in the next section. TCAS II is the most widely used TCAS technology. Components used in TCAS system is discussed in TCAS II component section. In that section how the RA and TA alerts are displayed in the cockpit is discussed with figures. In the final section advantages and disadvantages are listed down.

Development History of TCAS:

The Grand Canyon mid-air collision, which occurred in 1956 caused 128 fatalities. The collision took place in an uncontrolled airspace where pilots should follow the "See and Avoid" procedure to maintain separation. After this deadly incident, development of the last resort collision avoidance system begins. When there is a failure in Air Traffic Control-provided separation services, this kind of an onboard collision system can act as a last resort. Federal Aviation Administration (FAA) tested several early-stage collision avoidance systems during 1960-1970s. These systems functioned properly in normal airline operations; these systems generated high rate of false alarms in dense terminal areas.

Beacon Collision Avoidance System (BCAS) was developed in mid 70's. BCAS used reply data from Air Traffic Control Radar Beacon System (ATCRBS) transponders to determine an intruder aircraft's range and altitude. This design performed well compared to other designs mainly because ATCRBS transponders were installed almost all aircrafts. Therefore, without installing additional equipment BCAS equipped aircraft can be protected. Another Fatal midair collision occurred in 1978 between Cessna light aircraft and PSA flight 182 increases the development effort of an effective collision avoidance system.

In 1981, utilizing the basic BCAS design, TCAS is designed to work independently of the aircraft navigation equipment and Air Traffic Control (ATC) Services. FAA decided to mandate all airliners to equip TCAS soon other countries followed. TCAS II was introduced in 1989 after performing millions of computer simulations and safety studies have shown that TCAS II can handle all the critical near mid-air collisions involved with TCAS equipped aircraft. And the near mid-air collision occurred with TCAS II is less than 10% compared to TCAS.

TCAS Functionality:

TCAS interrogates secondary surveillance radar (SSR) transponder signals of all aircrafts in the determined range and gather slant range, relative bearing, and altitude of surrounding traffic. This interrogation-and-response use 1030MHz to interrogation and 1090MHz to reply other interrogations. TCAS can carried out an interrogation with an aircraft only if it is equipped with correctly operating mode S or mode C transponder.

Time to reach Closet Point of Approach (CPA) is the main parameter for issuing alerts.

Closest Point of Approach (CPA): predicted point in space at which the intruder will be closest to the aircraft.

For that TCAS get the data from several successive results. CPA can be calculated by dividing the range by the closure rate. If the transponder receives altitude data from the nearby aircraft TCAS can calculate the time to reach co-altitude.

A protected 3D volume surrounds each TCAS-equipped aircraft. Size is depending upon altitude, speed and heading of the aircraft. TCAS II can provide a collision avoid protection for two aircrafts which are closing at up to 10,000 feet per minute vertically and 1200 knots horizontally. TCAS system can track 45 aircraft and display 30 of them at once and maximum 21 aircraft in a 5nm radium can provide RAs.

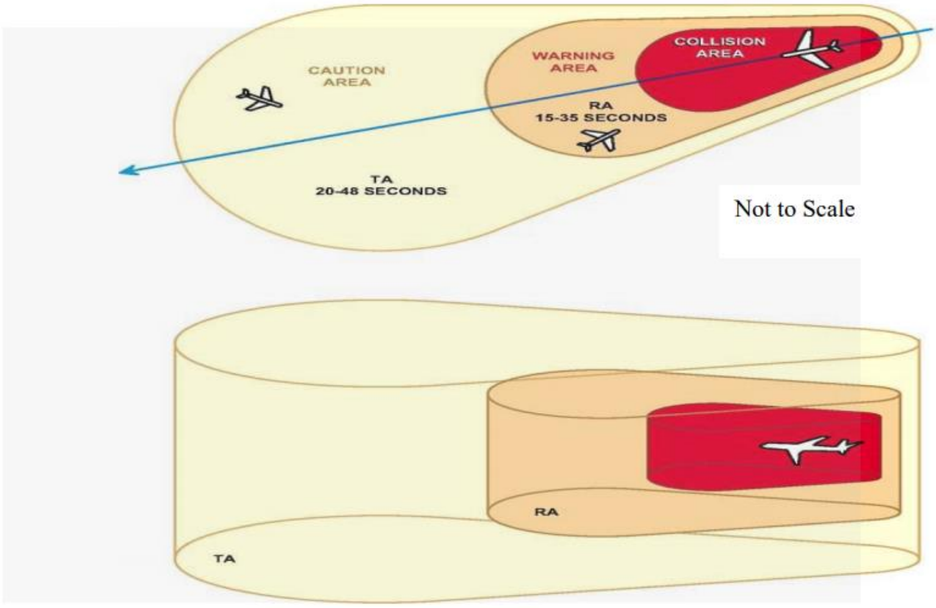


Figure 1: Protected Volume

After analyzing intruding aircraft's information TCAS can issue two types of alerts:

Traffic Advisories (TA): threat advisory which alerts the pilot that another aircraft is close enough to be a potential threat and assist the pilot in the visual search for the intruder. A TA is triggered when intruder is 20-48 seconds away. (actual time is depend on airspeed, maneuvering and altitude)

Resolution Advisory (RA): alerts the pilot that means the other aircraft is a threat (30s to possible collision) and recommend maneuvers that will maintain or increase the current vertical separation from the intruder. If both aircrafts fitted with TCAS II instruments, RAs of both aircrafts are co-ordinates through the mode S data link to ensure a safe passing.

TCAS versions:

Passive: Similar to TCAS with reduced range. These systems rely on transponder signals triggered by third party systems such as ground and other airborne systems.

TCAS I: cheaper and less capable systems compared to commonly used current TCAS II systems.

TCAS II: Most commonly used system which is capable of issuing both TA and RA.

TCAS III: Also known as TCAS II enhanced, includes horizontal advisory capacity.

TCAS IV: Additional information encoded by mode S transponders are used for analysis in this version such as INS and GPS data.

TCAS II Components:

TCAS processor:

Performs following tasks:

- Surveillance
- Intruder tracking
- Own aircraft altitude tracking
- RA maneuver determination and selection
- Advisory generation

Protection volume around the aircraft is determined by pressure altitude, radar altitude, and discrete aircraft status inputs from own aircraft. If the intruder also equipped with TCAS II avoidance maneuvers will be co-ordinated with the intruder.

Mode S Transponder:

Mode S transponder is used to perform normal functions which supports ground ATC system (ATCRBS) and is also used to provide air-to-air data exchange between TCAS-equipped aircraft for co-ordinated RAs. A unique 24-bit identifier is assigned to each aircraft that has a mode S transponder.

Correctly operating Mode S transponder is a mandatory requirement for TCAS II to be functional. Mode S transponder failure put TCAS into Stand by mode.

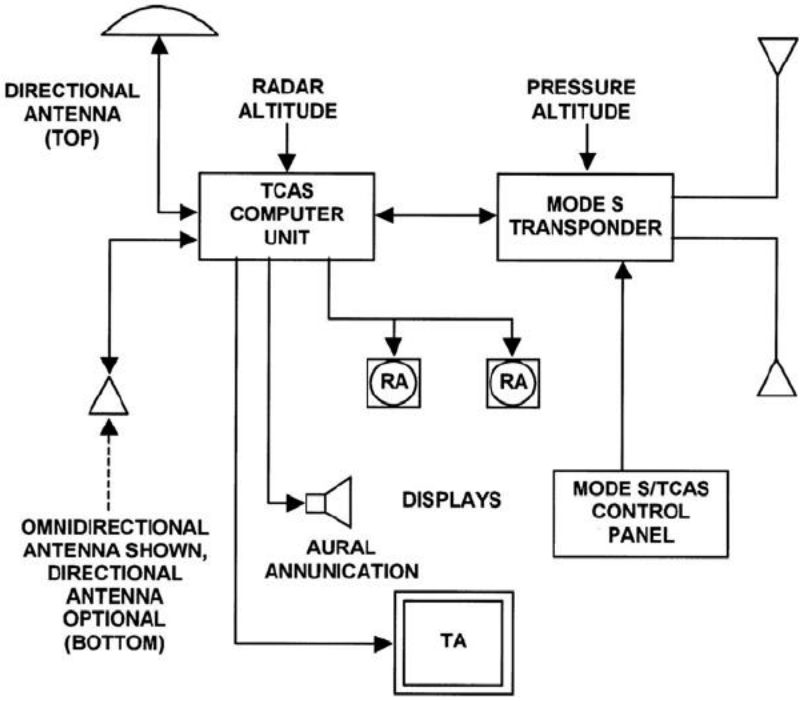


Figure 2: Functional diagram of TCAS system

Mode S/TCAS control panel:

Single control panel is provided to control TCAS processor, Mode S transponder, TCAS displays.

Four basic control positions are available:

- **Stand-by:** Power is applied to the TCAS Processor and the Mode S transponder, but TCAS does not issue any interrogations and the transponder will reply to only discrete interrogations.
- **Transponder:** The Mode S transponder is fully operational and will reply to all appropriate ground and TCAS interrogations. TCAS remains in Stand-by.
- **TA Only:** The Mode S transponder is fully operational. TCAS will operate normally and issue the appropriate interrogations and perform all tracking functions but issues TAs.
- **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.

Antennas:

Commonly used TCAS II system includes directional antenna mounted on the top of the aircraft and omnidirectional or directional antenna mounted on the bottom of the aircraft. Interrogation is done on 1030MHz at varying power levels of 4 90-degree azimuth segments. Bottom antenna transmits fewer interrogations with lower power levels than top-mounted antenna. 1090MHz frequency is used to receive responses from surrounded traffic.

Mode S transponder also requires two antennas mounted on the top and bottom of the aircraft. These antennas receive interrogations at 1030 MHz and reply to the received interrogations at 1090 MHz. Use of the top or bottom antenna is selected automatically to optimize signal strength and reduce multi-path inference. TCAS and model S transponder is connected to the suppression bus of the aircraft which disable one when the other one is transmitting data. But modern transponder-TCAS integrated systems use shared antennas for both TCAS and transponder.

Cockpit Presentation:

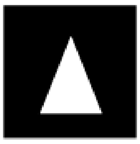
Two interfaces are used to interact with pilots in TCAS systems.

- Traffic Display
- Resolution Advisory Display

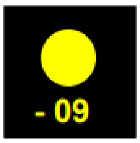
These displays can be implemented in several number of ways, but the information provided in those display implementations are identical and standardized by DO-185B (Traffic display) and ED-143 (RA display) standards.

Traffic Display:

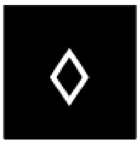
Traffic display shows the position of nearby traffic, relative to the aircraft. It includes vertical speed indications, proximate, TA and RA status. Standardized set of symbols and colors shown below are used to display traffic information



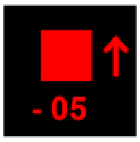
Own-aircraft. Airplane-like symbol, in white or cyan.



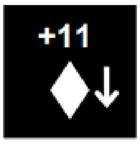
Traffic Advisory (TA), 900 feet below and level. Filled yellow/amber circle.



Other Traffic, altitude unknown. Unfilled diamond in white or cyan



Resolution Advisory (RA), 500 feet below and climbing. Filled red square.



Proximate Traffic, 1100 feet above and descending. Filled diamond in white or cyan

Figure 3: Traffic display of TCAS

Resolution Advisory Display:

RA display provides the pilot with the information to avoid possible threat. Usually this contains required vertical speed or pitch angle to fly. Usually, RA display is typically implemented on:

- Instantaneous vertical speed indicator (IVSI)
- Primary Flight Display (PFD)
    - Pitch Cue Implementation
    - Vertical Speed Tape Implementation

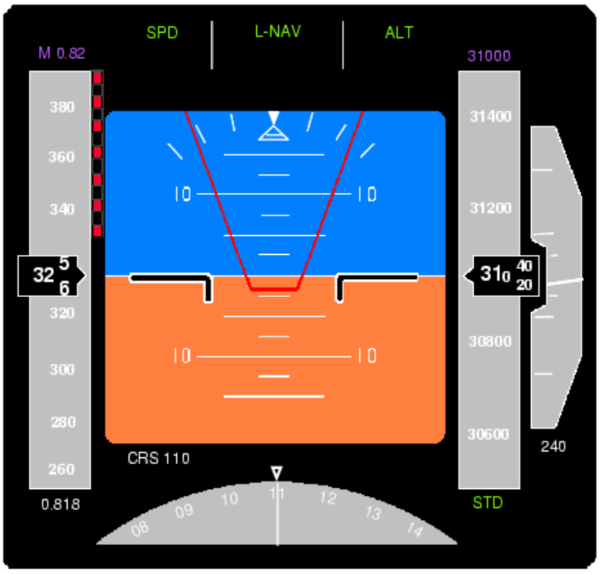


Figure 4: Vertical Speed Tape Implementation

Figure 5: Pitch Cue Implementation

Figure 6: Instantanious Vertical Speed Indicator

TCAS logic algorithm for detect TA and RA can be shown as follows:

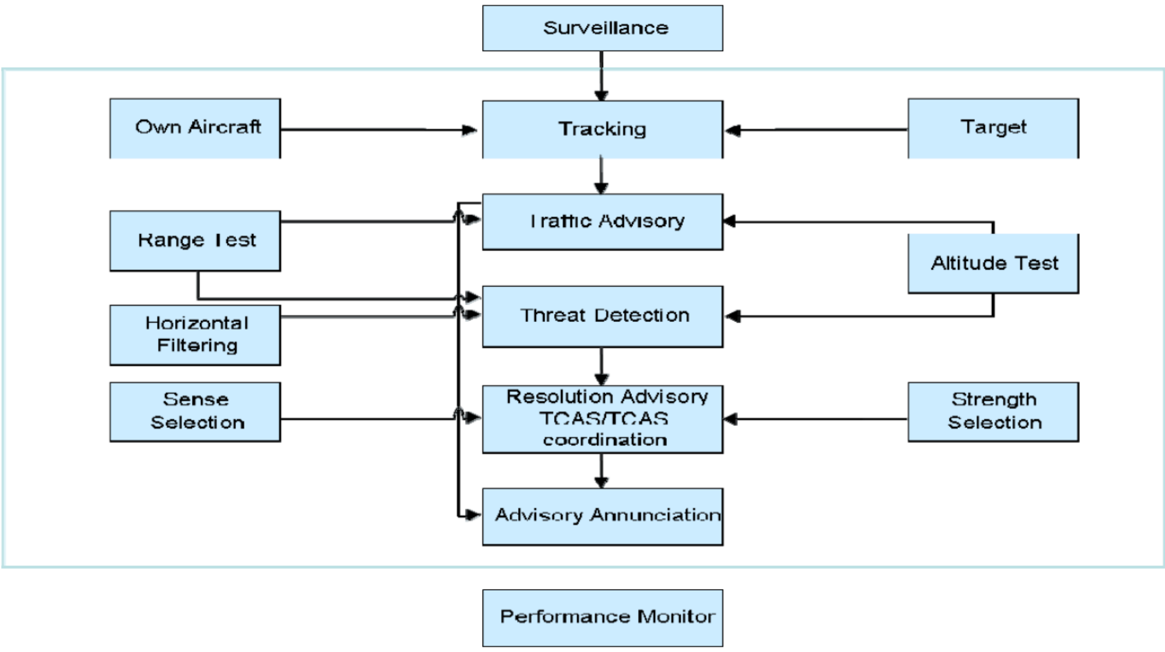


Figure 7: TCAS logic algorithm

Advantages of TCAS can be listed as follows:

- All threats are taken into account.
- Detection of all transponding aircraft aircraft, including those which are not displayed on the air traffic controller's screen.
- Independent system, which acts as the last resort safety measure to avoid mid-air collision when ATC and other ground-based safety measures fails.
- TCAS reduced the risk of mid-air collision

Disadvantages of TCAS system can be shown as follows:

- TCAS cannot detect aircrafts without TCAS antennas. Especially small private aircrafts.
- No detection of aircraft without or not operating transponders.
- No knowledge on pilot's intentions and of the ATC separation minima.
- Basic display: no identification, no past positions, no speed vector
- Unnecessary false alarms.

References:

Traffic collision avoidance system - Wikipedia

TCAS: Preventing Mid-Air Collisions - AeroSavvy

TCAS-II-V7.1-Intro-booklet.pdf (myftpupload.com)

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A Novel Approach towards the Designing of an Antenna for Aircraft Collision Avoidance System - ScienceDirect

Traffic Collision and Avoidance System TCAS - AVIONICS (sciary.com)

13. Typical block diagram of TCAS II. | Download Scientific Diagram (researchgate.net)